8RIVERS

Carbon Capture Utilisation and Storage (CCUS) Innovation Programme

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This final report is a record of the work completed under the Carbon Capture and Storage Innovation programme with regards to the UK deployment of the Allam Fetvedt Cycle. The report also includes work completed on a selected site in the UK so as to fully demonstrate that the commercial scale facility for the technology can be deployed.

The Allam Fetvedt cycle facility will be located at the former TCPP power plant at the Sembcorp owned Wilton International facility on Teesside.

The key knowledge deliverables included in this report are as follows;

- Commercial progress report
- Report on design specification including a description of the site selected, unique characteristics, CO2 market including transport and storage infrastructure, local power and gas market conditions
- Process Flow Diagrams describing process conditions (temperature, pressure, composition, flow rates) and heat and mass balance.
- Class IV project cost estimate
- Optimized site layout plan
- Summary of Project Economics
- Site geotechnical surveys
- Initial permitting strategy including timeline
- Preliminary HAZID write-up
- Final report on site
- Independent Owner's Engineer Report

communication of the Information. Each person to whom the Information is made available must make their own independent assessment of the Information after making such investigation and taking professional technical, engineering, commercial, regulatory, financial, legal or other advice, as they deem necessary

Steve Milward

Director of Engineering and Operations

PROJECT WHITETAIL

NET POWER ALLAM-FETVEDT CYCLE POWER PLANT FOR UK DEPLOYMENT

KKD REPORT

Department for Business, Energy & Industry Strategy

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Executive Summary

In 2017 the Clean Growth Strategy set out the new Government approach to Carbon Capture Utilisation and Storage (**CCUS**) in the UK, highlighting the important role of innovation in supporting cost reduction. To underpin this, the UK Government committed to spend up to £100 million from the BEIS Energy Innovation Programme to support Industry and CCUS innovation to improve business and industry efficiency, and to further reduce the cost of deploying CCUS.

Under the subsequently released Call for CCUS Innovation, 8 Rivers[1] submitted an application for grant funding to progress a Pre-Front End Engineering Design (**Pre-FEED**) study for a commercial scale NET Power Allam-Fetvedt Cycle Power Plant for UK Deployment. The grant application listed McDermott International, WSP and Sembcorp UK Limited as the initial supporters of the 8 Rivers application and in the course of the Pre-FEED study this list expanded to include more than a dozen companies. 8 Rivers has been able to provide a whole chain CCUS solution as a result of over 12 months' work with a total project cost of £2.7m which was supported by a £1.3m grant from UK Government.

The growth in the number of companies supporting the Pre-FEED study can be attributed to the appetite for CCUS in the marketplace as well as the need for new and innovative technology to reach Net Zero by 2050.

Previous work carried out by 8 Rivers, NET Power and their affiliates was leveraged in order to provide a solid basis of design with the following key objectives for the Pre-FEED then identified:

- Ensure that the Allam-Fetvedt Cycle (**AFC**) technology could be deployed in the UK whilst adhering to all relevant and applicable legislation, codes and standards.
- Provide the costs of deployment including development, capital and operational cost for a commercial scale plant that could be located in the UK.
- Progress and optimise the design of a de-integrated solution wherein oxygen could be supplied via pipeline from Air Separation Units (**ASUs**) owned and operated by third parties.
- Identify a site host for the first potential UK deployment and progress a site design whilst capturing any potential issues that require further attention during a subsequent FEED process.

The Pre-FEED study produced a generic or 'cookie-cutter' plant design layout that can be deployed anywhere in the UK – we note that in the course of the study some 26 potential sites in the UK have been identified that meet the criteria set out by 8 Rivers and NET Power for successful deployment of an AFC plant. The EPC cost estimate produced for the generic design establishes a representative market price for a UK deployed AFC project at £359m and this design has been optimised and aligned to UK legislation, codes and standards with no barriers to deployment. The design will use natural gas as fuel and oxygen from a third party de-integrated ASU for reliable production of electricity with almost 100% of the resultant carbon dioxide being available for local pipeline export and carbon sequestration[2].

The design of the AFC is such that it can be operated to generate electricity at baseload to the grid or alternatively operate in 'peaking mode'. The plant can output to the grid from a received instruction to dispatch within 30 minutes from a hot start position, or seconds if operating at Parked Load; with ramp rates of up to 20% per minute[3] the AFC plant can reach full output in less than two hours. Note this is faster than any large utility scale gas to power technology anywhere in the world and is a direct result of

[1] As used in this report, "8 Rivers" refers to either 8 Rivers Capital, LLC, or any of its group companies, including its UK subsidiaries.
[2] There will be negligible emissions from the system seals which prevent fully 100% capture without further capital expenditure. Empirical data gathered through operation of the NET Power test facility by 8 Rivers and NET Power and its suppliers confirms these leakage rates are minimal and that the real life capture rate is circa 99.99%
[3] 20% per minute ramp rate only applicable once thermal equilibrium has been reached for the turbine and recuperative heat exchanger network

the high gross power capability of the AFC turbine generator offset by a near-constant auxiliary power load in the AFC facility. As a result, AFC plants provide the UK with security of supply to back up renewables in variable and seasonal operation, when they are unable to generate at the demanded levels. This operational scheme as both baseload and back-up power is all satisfied with zero carbon emissions, thereby actively supporting the UK Government in meeting its 2050 emissions targets while securing continuous supply of power to the UK grid. The AFC plant design is compliant with UK grid codes and dispatch models that fully support this have been submitted to BEIS and National Grid.

Future benefits to decarbonisation also exist. AFC facilities can potentially run on further decarbonised fuel gasses, allowing for the future implementation of hydrogen or biogas blended natural gas feedstock as well as other sources of decarbonised source fuel, rendering AFC cycles carbon negative and thus further reducing the carbon intensity of the electric grid.

The design of the CO_2 Recuperative Heat Exchangers (**HXR**) and the Combustion Turbine Generator (**CTG**) for use in the commercial scale deployment of the AFC leverages the data generated from years of operation of the 50 MWth Project Demonstration Plant (**Test Facility**) in La Porte, Texas. The rest of the equipment within the AFC plant is proven and readily available from equipment suppliers; 8 Rivers anticipates sourcing most (if not all) of this equipment from suppliers based in the UK wherever commercially viable.

Critical to the overall technical risk of the technology at commercial scale is the proper selection of the turbine inlet condition. To optimise the balance between performance, capital cost and risk to the design, a turbine inlet temperature of 925°C has been selected which has been successfully tested at the La Porte, Texas facility. The resulting turbine outlet temperature also creates a favourable operating regime for the HXR, which can be mostly built using standard stainless materials.

While not expressly reviewed in this study, further equipment developments will allow later plants to reach even higher efficiencies, nearing 60% LHV at competitive economics against existing best in class gas turbine combined cycle facilities while offering inherent full carbon capture. This is predominantly due to expected increases in turbine inlet temperature (to 1155°C and beyond) requiring further optimised blade and rotor cooling approaches, and resulting increases in turbine outlet temperature (to 700°C and beyond) requiring further benchmarking of material limits in the exhaust heat recuperator.

The current design for Project Whitetail is in accordance with the design associated with the Test Facility in La Porte, Texas, and does not include heat integration of the Air Separation Unit (**ASU**). Additional heat is supplied to the HXR by means of the Hot Gas Compressor (**HGC**). Future deployments of the AFC may consider heat integration with the ASU depending on the specific project and process parameters.

The Pre-FEED effort for the generic UK design of the AFC plant has reduced material and manufacturing costs for the $_{S}CO_2$ turbine and heat exchangers, material cost for piping, and identified which pipe routes can be optimised for the most significant CAPEX reductions. The development of the design during the Pre-FEED resulted in a reduction in power island footprint that translated to significant cost savings largely due to an approximate 25% reduction in bulk quantities (i.e. piping).

The Risk Register produced during the Pre-FEED study identified 114 risks which were worked through by the project team. Of the 114 risks identified, only 7 have remained at medium risk which mostly relate to COVID 19. There are no residual high risk items. The final pricing of a location specific deployment would depend on the final design definition, site specific constraints, project schedule, and contractual commercial terms.

WSP and 8 Rivers conducted a site selection assessment to determine the suitability of existing or decommissioned industrial sites in the UK. This assessment identified the Wilton Facility in Teesside as the most suitable location for the Project. Sembcorp identified several potential host sites within the Wilton International facility on Teesside which were reviewed by the project team. The most advantageous site was the former site of the Teesside Power Station (**TCPP**). TCPP was a 1875MW CCGT facility with capability to supply heat and supplementary steam and power to the Wilton development as well as the UK electricity grid. The electrical, water and gas utilities and pipeline service corridors remain available at the site and could easily be repurposed. It was also noted that an existing pipeline from the site to a location north of the River Tees could be repurposed for transport of CO_2 for buffer storage and eventual CO_2 sequestration via ship should the Net Zero Teesside transport and storage system (**NZT**) not be operational. This pipeline will be further investigated during FEED but, given its limited use to date, it is expected to be in good order and more than suitable to transport the quantities of CO_2 required for the project.

The site also benefits from excellent electrical grid infrastructure and already has a grid connection agreement for the former Teesside Power Station. During the Pre-FEED study the grid connection agreement was modified to incorporate the design of the AFC. This modification has been approved by National Grid with expected connection of the AFC is currently expected in 2024.

The Development Consent Order (**DCO**) originally granted in April 2019 by the Secretary of State for the development of a 1748MWe CCGT on the site remains valid. It has been extensively reviewed to assess its suitability for a UK deployment of the AFC.

One key finding of the Pre-FEED effort was that if viable sequestration options for CO_2 could be secured, the first UK commercial scale AFC plant could be operational from early 2025. With an estimated asset life of at least 30 years this would see the first plant operational through to 2055, bridging the point at which the UK is committed to becoming fully 'net zero' in 2050. 8 Rivers has engaged all near- and mid-term CO_2 sequestration projects in the North Sea and beyond to understand timelines for 'first carbon to well' as well as availability and capacity to accommodate 900,000 tonnes per year of CO_2 from Q1 2025[4]. WSP produced a detailed CO_2 optioneering report summarising the options available in the UK. Meanwhile, 8 Rivers has continued discussions with several CO_2 sequestration projects and critical infrastructure organisations who can provide transport and storage solutions. Through this effort, 8 Rivers has secured Letters of Intent (**LOI**) and also agreed Memoranda of Understanding (**MOU**) with several options for CO_2 sequestration supporting deployment of the AFC in the UK from 2025.

The options for oxygen supply, including the use of the existing Wilton Facility oxygen system, were reviewed by Spiritus Consulting which completed a detailed optioneering study and engaged the market to get a fuller understanding of the best solution for UK deployed projects. Given that the project is seeking a Contract for Difference (**CfD**) under a Dispatchable Power Agreement (**DPA**), it is critical that any oxygen supply agreement is commensurate with the term of the CfD, noting that this length of contract for Industrial Gas supply is not normal practice. However, through negotiation and a full Request for Quotation (**RFQ**) process, 8 Rivers has received several tenders for the oxygen supply for a 15 year term. These tenders will be further negotiated during the FEED study

As is critical with large complex engineering projects, and especially so with new or innovative technology, it is key to understand the supply chain (including manufacturing) and skilled labour capability, especially the special experience available to projects in a local jurisdiction, in order to mitigate delay and risk. This allows a project to leverage local expertise and markets to quickly address deficiencies that may occur in the construction, commissioning, and operational efforts of the facility. 8 Rivers commissioned PA Consulting to review (with particular focus on the UK) the supply chain for the AFC from a manufacturing perspective and Vivid Economics to look at how employment in the sector could benefit from this and any future projects. The supply chain report found that AFC projects across the globe can be supported by UK exports of equipment in key areas such as heat exchangers, pumps, valves and turbine components and identified several manufacturers who not only had capacity to supply

[4] With regards to CO2 sequestration 8 Rivers Capital has engaged with the following; Northern Endurance Partnership, Pale Blu Dot, Equinor, Project Greensands, Portos,

these critical components but, in the case of heat exchangers and castings, could lead to expansion of existing manufacturing facilities to support worldwide deployment.

Skilled labour in the sector will be key to the UK reaching Net Zero by 2050 and the Energy Innovation Needs Assessment report commissioned by BEIS in 2019 estimated that 50,000 export jobs could be created in this sector by 2050. The report produced by Vivid Economics for the pre-FEED identified that as much as 10-15% of these export jobs could come from the deployment of the AFC in the UK. Furthermore, a single AFC plant located at the Sembcorp site would create 610 direct jobs and 1600 indirect and induced jobs. Further deployment in line with 8 Rivers and NET Power expectations could see over 1000 direct jobs a year created from 2025 for the following 20 years, whilst indirect and induced jobs could be in the region of 1790 and 1700 respectively a year by 2030.

The commercial project, now known as Project Whitetail, has progressed quickly alongside the Pre-FEED study. At critical points, each workstream has informed the other, adding significant value to the roll out of the first commercial scale project in the UK and instilling significant confidence through the interest expressed from the market and the UK Government.

INTRODUCTION

1.1 PROJECT OVERVIEW

Project Whitetail will be the UK's first NET Power plant and will consist of a single Oxy-Combustion power plant utilising the Allam Fetvedt Cycle (**AFC**). This cycle uses supercritical carbon dioxide (**sCO_2**) as a working fluid and nearly 100% of the CO_2 produced from the process for sequestration.

The proposed site for the pre-FEED study and development of the UK's first NET Power plant will be the former site of the Teesside Power Station (**TCCP**) within the Wilton facility, Teesside. TCCPS was a 1875MW CCGT facility with capability to supply heat and supplementary steam and power to the Wilton site for many years prior to decommissioning. TCCP also exported power to the UK electricity grid and much of the electrical infrastructure for supplying power remains in place and will be reused by the project. The steam, water and gas utilities and pipeline service corridors also remain available at the site and can be repurposed for reuse by the Project Whitetail.

8 Rivers and Sembcorp have been collaborating together on the NET Power technology since 2012 when the proposed 50 MWth demonstration facility for the Allam Fetvedt Cycle was to be sited at Wilton International. An initial pre-FEED study funded by BEIS (then DECC) was undertaken by Parsons Brinckerhoff (now WSP) to determine the suitability of the site and wider Wilton location for a supercritical CO_2 power plant. The study found that there were no 'showstoppers' to the deployment of the technology at the site or in the UK. For commercial reasons the demonstration plant was subsequently constructed in La Porte, Texas and operational in 2018. The plant (which is still to be operated for future R&D) has provided 8 Rivers and NET Power valuable data and insight into the Allam Fetvedt cycle which will be leveraged in future commercial developments. It remains a test centre for continual refinement and improvement of the technology, with future programs in the pipeline such as a publicly announced testing program with the US Department of Energy[5].

This document outlines the status of the Project at the conclusion of the pre-FEED stage of development. The project continues now in its commercial form with various partners, benefitting greatly from the efforts and assistance of the UK Government in this process.

1.2 PURPOSE

The purpose of this report is to detail the status of the Project at the completion of the pre-FEED phase in accordance with Annex 2 of the grant agreement.

[5] https://www.energy.gov/fe/articles/foa-2057-project-selections

UK ENERGY MARKET AND REGULARITY ENVIRONMENT

2.1 INTRODUCTION

Through the 2019 legal obligation for the United Kingdom to achieve net zero emissions of greenhouse gases by 2050, unabated conventional power generation technologies, using fossil fuels such as coal and natural gas, are no longer viable without Direct Air Capture **(DAC)** technology.

In pursuit of these obligations, renewable energy sources, such as wind and solar, could therefore become primary viable technologies. However, these sources suffer from inherent generation intermittency issues which require additional embedded system costs independent of the generating asset to overcome.

This intermittency in generation is often mitigated though the provision of expensive storage which is difficult to provision at scale or back-up generation which would normally utilise a carbon emitting technology. This is in addition to otherwise major reconfiguration of the transmission system to allow for supply and demand relationships to play out over larger transmission areas affected by local weather conditions.

A simple fix would involve capturing carbon from carbon-emitting technologies. However, while commercial scale Carbon Capture and Storage (**CCS**) technology, particularly as post-combustion carbon capture retrofit, has been demonstrated and commercially operated, further deployment will likely require large investments. Furthermore, efficiency penalties in retrofit abatement applications are expected that would act as a barrier to development. Meanwhile, new-build CCS technologies have in the past suffered from complexity and high cost. As such, new innovation in the Carbon Capture space is needed to address all of these concerns and to serve as generation capacity to support a zero-emission future.

As a new, low-cost, full carbon-capture alternative, the 8 Rivers and NET Power Allam-Fetvedt Cycle (**AFC**) technology could play a crucial role in ensuring a reliable and secure low carbon electricity system in the UK as it provides the following features while providing a nearly 100% CO_2 capture rate:

- Operation as a reliable and efficient baseload generator, delivering approximately 300MW of carbon free electricity to the National Grid.
- Operation as a responsive peaking generation facility, providing a ramp rate equivalent to 20% of the installed capacity per minute.
- Provision of spinning reserve capacity through the ability to maintain operation at any load point between 0 and 100% of installed capacity
- The deployment of a single 300 MWe AFC power plant could provide 1 GVA.s of system inertia.

The December 2020 BEIS Energy White paper[6] identified that power Carbon Capture, Utilisation and Storage (**CCUS**) projects with these flexible, low-carbon characteristics will complement the increasing levels of renewables and play a key role in the decarbonisation of the electricity system at low cost.

The following sections provide an overview of how the UK energy market is changing and the unique role which the inherently low carbon, dependable and flexible AFC power plant could play.

2.2 THE EVOLVING UK ELECTRICITY SYSTEM

Over the last 15 years the UK electricity system has been evolving at an increasing pace as it responds to a range of drivers, the biggest of which is the global need to decarbonise. These drivers have helped to increase the volume, and significantly reduce the cost, of renewable generation and battery storage technologies through the replacement of traditional thermal generation assets. This evolution, and the

[6] https://www.gov.uk/government/publications/energy-white-paper-powering-our-net-zero-future

resultant shift away from coal and towards renewables, is illustrated well by Ofgem in the following figure.

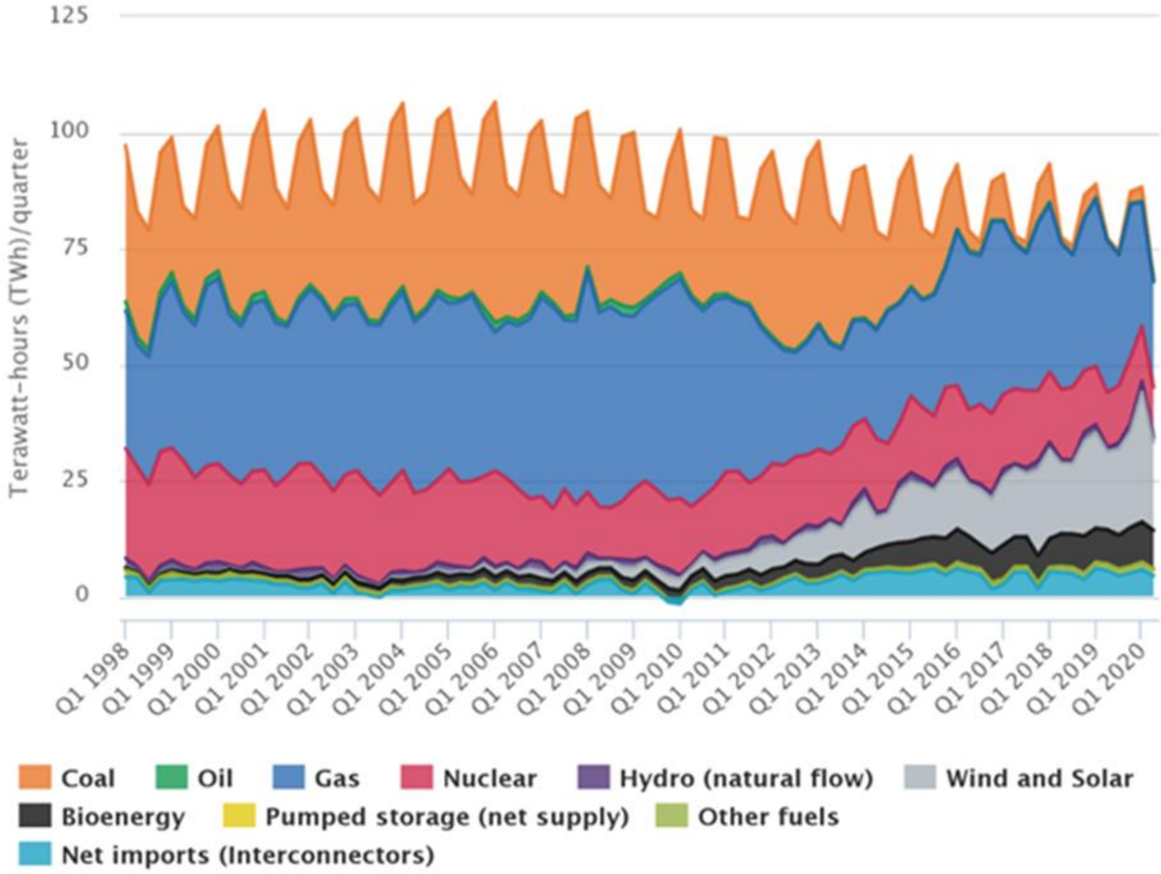

Figure 1 - UK Electricity Generation Mix by Quarter and Fuel Source (GB)[7]

Drivers for change are also being imposed on the electricity demand side through the influence of economy disruptions, climate change, and changes in consumer behaviour (e.g. increasing uptake of domestic solar panels, electric vehicles, and heat pumps). These changing patterns of demand make forecasting future demand more difficult.

National Grid ESO (**ESO**), the system operator, has the role of real-time balancing of the energy demand from consumers with the supply provided by generators. This has become more challenging due to the increasing unpredictability of electricity demand, coupled with the growing proportion of intermittent and non-dispatchable renewable generation within the UK installed capacity. Too much generation and not enough demand results in an increase in system frequency, similarly insufficient generation and too much demand results in a decrease in system frequency. The ESO, through its role as the system operator, has a statutory obligation to maintain the system frequency within defined and acceptable limits.

This means that the ESO has an increasing need for flexible generation which is defined by Ofgem as:

> *"modifying generation and/or consumption patterns in reaction to an external signal (such as a change in price) to provide a service within the energy system.[8]"*

[7] https://www.ofgem.gov.uk/data-portal/electricity-generation-mix-quarter-and-fuel-source-gb
[8] https://www.ofgem.gov.uk/electricity/retail-market/market-review-and-reform/electricity-system-flexibility

This flexible generation can be provided by interconnectors, energy storage, demand side response and generators like the AFC which can respond quickly and flexibly, varying output to suit the network requirements.

A good example of the challenges of balancing the UK electricity system has been provided by the initial coronavirus pandemic lockdown. During this period the UK experienced a sustained period of windy yet sunny weather, boosting the generation provided by renewable technologies, combined with reduced electricity demand due to the closure of large parts of the economy. These two significant influences resulted in the ESO introducing a new balancing service at short notice, paying smaller generators to switch off and consumers to increase demand. Existing baseload generation was also reduced in this period as the ESO also contracted with EDF to reduce output from Sizewell nuclear power station[9].

Coupled with increased unpredictability, the ESO is also facing the challenge of reduced system inertia which increases the speed at which the system frequency changes. Traditionally system inertia was provided by the large thermal power plants operating as baseload generators. Renewable generation does not provide this same level of inertia, so the overall system inertia continues to reduce as the proportion of renewables increases. The AFC is able to help solve this challenge, as it has similar inertia characteristics to the traditional large thermal power plants, whilst being low carbon.

2.3 THE EVOLVING UK ENERGY MARKET.

2.3.1 THE WHOLESALE MARKET

There are wholesale electricity trading and transmission arrangements across the United Kingdom which are collectively known as British Electricity Trading and Transmission Arrangements (**BETTA**). BETTA is based on bilateral trading between generators, suppliers, customers and traders, and participants self-dispatch rather than being dispatched centrally.

Bilateral contracts for electricity are agreed in forwards and futures markets ranging from several years up to 24 hours ahead of a given half hour delivery period. Contract positions can be fine-tuned using short-term power exchanges and energy brokers from 1 to 24 hours before delivery. All the deals are settled at the price registered on the power exchange or agreed bilaterally or through a broker.

Power plant investors must decide to invest based on their expectation of recovering the costs of this investment through selling electricity in the wholesale electricity market. There are, however, other potential sources of revenue, as outlined in the following sections.

[9] *https://www.nationalgrideso.com/news/7-reflections-balancing-grid-spring-and-summer*

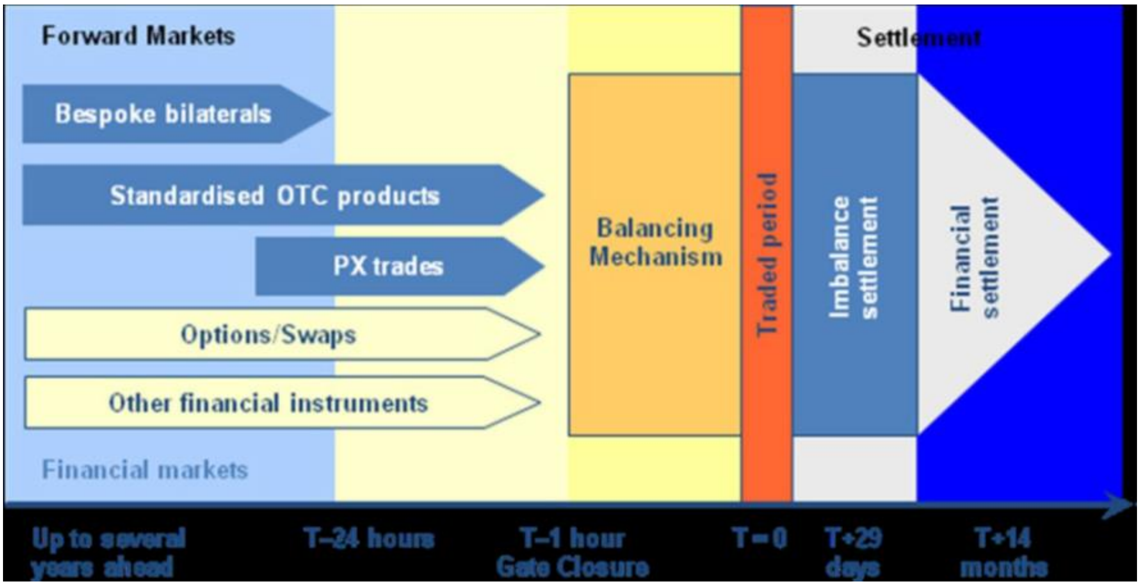

Figure 2 - Graphic Illustration of the UK Energy Market[10]

2.3.2 CAPACITY MARKET

The UK Capacity Market (**CM**) was introduced in 2014 to ensure that there is sufficient generation capacity available, thereby ensuring security of electricity supply. Its establishment had been primarily driven by security concerns arising from the rapid closure of existing baseload thermal generating capacity and the increasing percentage of intermittent renewable generation plants.

As part of the UK CM, two capacity auctions are run to procure capacity for each electricity delivery year. The first auction (**T-4**) is usually held four years ahead of the delivery year to allow enough time to build any new capacity that is needed. The second auction (**T-1**) is held one year before delivery and serves to ‘top-up’ the procured capacity as a more accurate prediction of peak demand can be made.

Companies which are successfully in either auction sign a Capacity Market Agreement committing to provide electricity or reduce electricity consumption when required over a defined period, regularly submitting data to prove capability. In return a monthly payment is made which is dependent on the relevant auction clearing price.

All technologies compete equally within these auctions, including existing and new generation, storage, demand side response and interconnectors. To ensure a level playing field between technologies, de-rating factors are applied that are calculated dependent on a technology’s ability to produce energy when required. For example, a gas fired power station would attract a lower derating factor compared to a solar installation as it can provide energy almost on demand whereas the solar installation would be dependent on the climatic conditions at the time of the request.

It is mandatory for all licensed, eligible capacity to participate in the CM pre-qualification process, however participation in the CM auctions is not compulsory. Capacity that cannot meet the eligibility criteria or is already in receipt of State aid through other measures is ineligible to bid into a CM auction.

2.3.3 BALANCING AND FLEXIBILITY SERVICES

National Grid ESO procures a wide range of services to balance demand and supply, thereby ensuring the security and quality of electricity supply[11]. These include, for example, a fast reserve service, which requires a ramp up or ramp down of power in excess of 25MW/minute within two minutes of the dispatch

[10] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/910153/gb-electricity-market-implementation-plan.pdf
[11] https://www.nationalgrideso.com/industry-information/balancing-services

instruction. This change in power output is then required to be sustained for a minimum of 15 minutes[12]. As the AFC has the capability to ramp rate of up to 20% of nameplate output per minute, equivalent to 60MW for a single unit, it is an ideal solution to provide carbon free fast reserve services.

2.4 WHAT WILL THE FUTURE LOOK LIKE?

The 8 Rivers AFC proposed to be installed at Wilton is likely to be in commercial operation from 2025 through to at least 2055 therefore bridging the point at which the UK is committed to becoming fully 'net zero' in 2050. There are a number of pathways to achieve this objective including the decarbonisation of transport, heat and industry as well as the decarbonisation of the overall UK electricity system. Currently there are uncertainties around policy measures, technology development, extent of societal change, relative costs and system interactions making it unclear exactly how the UK will reach net zero. As a result, a wide range of scenarios have been developed which have common characteristics as follows:

- Electrification of transportation and heat. The level of impact will depend upon the extent and speed at which the national hydrogen economy develops, and how much consumer behaviours change.
- Increased demand for electricity. Electricity demand has the potential to double by 2050 thereby requiring a significant increase in installed electricity generation.[13]
- Continued decrease in renewable generation costs coupled with increasing proportion of intermittent renewable generation with the UK electricity system.
- Greater uptake in new load electrical load type, for example electric vehicle charging and heat pumps, will continue to drive evolution in the UK electricity market.
- Continued need for flexible generation due to increasing prevalence of low inertia renewable generation.

As part of their Energy White Paper, BEIS have modelled *"almost 7,000 different electricity mixes in 2050, for two different levels of demand and flexibility, and 27 different technology cost combinations, resulting in a dataset comprising of over 700,000 unique scenarios"*. This has enabled a better understanding of the types of technologies that have a key role in the system of the future[14], such as the low carbon peaking generation provided by the AFC.

Another good source of insight is the set of Future Energy Scenarios (**FES**), produced annually with extensive stakeholder engagement by National Grid ESO. FES 2020 has two scenarios, 1) 'Consumer Transformation' and 2) 'System Transformation', both of which meet the net zero obligation by 2050, and a third scenario 'Leading the Way' which achieves net zero before 2050[15]. The key insights include the following:

> *"Accommodating high levels of renewable generation and electrification requires a significant increase in flexibility over short and medium timescales from minutes to weeks."*

2.5 FUTURE ENERGY MARKET MECHANISMS

The UK Government assesses annually whether a Capacity Market auction is needed and conducts a full review, including whether it is still needed, every five years[16]. The next review of the Capacity Market is due by December 2024. The Capacity Market is not intended to be a permanent intervention in the

[12] https://www.nationalgrideso.com/industry-information/balancing-services/reserve-services/fast-reserve?technical-requirement
[13] https://www.gov.uk/government/publications/energy-white-paper-powering-our-net-zero-future
[14] https://www.gov.uk/government/publications/energy-white-paper-powering-our-net-zero-future
[15] https://www.nationalgrideso.com/future-energy/future-energy-scenarios/fes-2020-documents
[16] https://www.gov.uk/government/publications/great-britain-electricity-market-implementation-plan

market, and as the market develops and a more cost-reflective electricity price evolves, there may be scope to withdraw the CM.

National Grid ESO is currently making a number of changes to the balancing services that it procures, aiming to standardise, simplify and rationalise the capacity[17]. This will include its future reserve services and its approach to system restoration[18] and as a result a greater volume of flexible generation will be required.

2.6 THE ROLE OF THE ALLAM-FETVEDT CYCLE (AFC) POWER PLANT

The AFC power plant is able to run efficiently and reliably as a low carbon base load plant, providing carbon free peaking and frequency response services, and to increase system inertia though the ability to turn-down to 0% load. There is a new fuel emissions limit for Capacity Market Units which will apply to both new build and existing units from October 2024. It is therefore likely that a significant 'capacity gap' exists by the mid 2020s resulting in a real need for low carbon base load plant like the AFC power plant to bid into the Capacity Market[19].

The AFC is fully dispatchable between 0% and 100% of nameplate output, with a ramp rate of up to 20% of nameplate output per minute, thus offering flexibility and balancing services to the ESO, for example the fast reserve service.

The December 2020 BEIS Energy White paper[20] identified that power CCUS projects with these flexible, low-carbon characteristics will complement the increasing levels of renewables and play a key role in the decarbonisation of the electricity system at low cost.

Future benefits to decarbonisation also exist. AFC facilities can potentially run on further decarbonised fuel gasses, allowing for the future implementation of hydrogen or biogas blended natural gas feedstock as well as other sources of decarbonised source fuel, rendering AFC cycles carbon negative and thus further reducing the carbon intensity of the electric grid.

[17] https://www.nationalgrideso.com/research-publications/system-operability-framework-sof
[18] https://www.nationalgrideso.com/document/159726/download
[19] https://www.gov.uk/government/consultations/capacity-market-proposals-for-future-improvements
[20] https://www.gov.uk/government/publications/energy-white-paper-powering-our-net-zero-future

ALLAM-FETVEDT CYCLE BACKGROUND, DESCRIPTION AND BENEFITS

3.1 OVERVIEW

The Allam-Fetvedt Cycle (**AFC**) is a highly-recuperated, oxy-fuel, semi-closed supercritical CO_2 Brayton cycle that offers significant advantages over traditional power cycles, including high efficiency, low capital costs, low or no water consumption, and the elimination of nearly all air emissions while capturing nearly all generated CO_2. The natural gas-fired cycle, under commercialisation by NET Power, is illustrated in the following figure and described in more detail below.

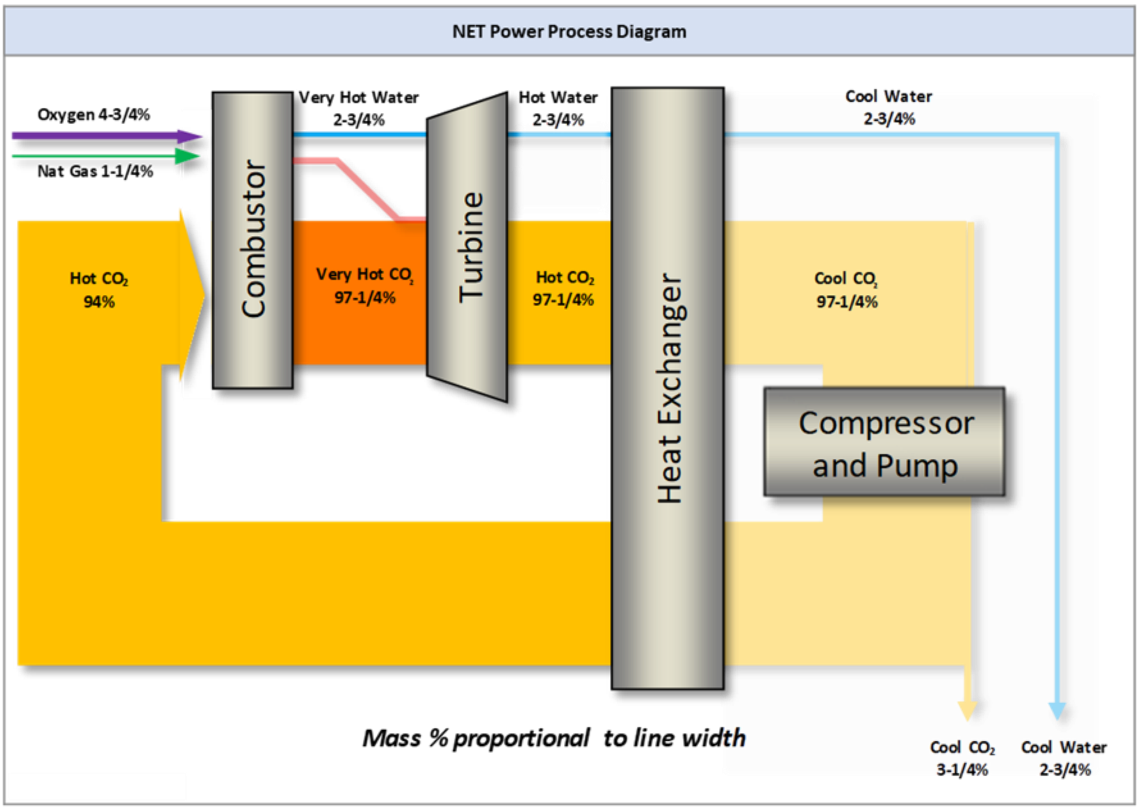

Figure 3 - Overview of the AFC process

Traditional power cycles, such as natural gas combined cycle (**NGCC**), supercritical pulverised coal cycle (**SCPC**), and integrated gasification combined cycle (**IGCC**), require the addition of expensive, efficiency-reducing equipment in order to decrease and capture emissions of CO_2 and other pollutants. The AFC takes a novel approach to reducing emissions from fossil fuel power generation using an oxy-combustion cycle that employs high-pressure supercritical CO_2 as a working fluid in a manner that recuperates and reuses much of the waste heat. In this configuration, the cycle is able to achieve net lower heating value (**LHV**) fuel efficiency from natural gas ranging from 50% to >60% depending on desired CapEx, firing temperatures, and specific project conditions. The only by-products from the process are liquid water and a stream of nominally pure (>97%) CO_2 that is already at pipeline pressure as a result of the operating conditions of the cycle. This allows the carbon exported from the AFC to be directly sequestered without the need for additional and costly pressure booster stations. The inherent operational characteristics of the AFC avoids the necessity of additional capture and compression systems for CO_2 carbon capture and storage (**CCS**) or carbon capture utilisation and storage (**CCUS**). The result is a power cycle with major advantages over conventional systems that do not capture CO_2 and even more so against conventional systems that do.

Even though the AFC process is novel, it utilises well-known concepts and equipment to significantly reduce the overall risk associated with its near-term deployment compared to typical First of a Kind (**FOAK**) projects. The development program led by NET Power achieved start-up and operation of a 50MWt demonstration plant in early 2018 to validate the integrated design and operation of key equipment. This facility is located outside of Houston, Texas and is continuing to operate as an ongoing R&D test site for future improvements of the cycle and technology.

3.2 THE PROCESS

The underlying process behind the AFC captured most clearly when explained thru a plotted pressure-enthalpy (**P-H**) diagram for carbon dioxide as shown in Figure 4. This P-H diagram has pressure (**P**) logarithmically spaced on the y-axis and enthalpy (**H**), a measure of energy, is linearly spaced on the x-axis. Points on this diagram represent the conditions of the CO_2 working fluid at various points within the AFC process.

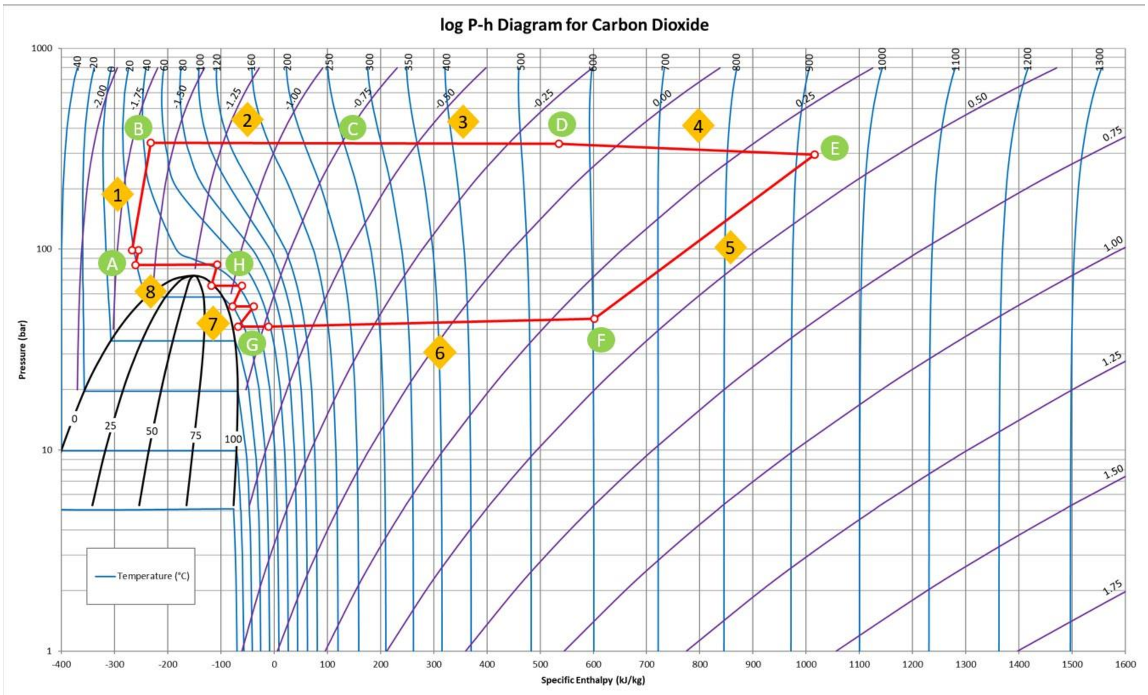

Figure 4 - Pressure-Enthalpy Diagram for the AFC

A detailed stepwise explanation of the AFC thermodynamic process (Figure 4) is as follows:

1. A-B: Pumping recycled CO_2 to approximately high pressure.
2. B-C: Heating of recycled CO_2 (~45% proportion) and oxidant stream in recuperative heat exchanger (stage 1 and 2) recovering low grade heat from turbine exhaust flow.
3. C-D: Heating of recycled CO_2 and oxidant stream in recuperative heat exchanger (stage 3) recovering heat from the turbine exhaust.
4. D-E: Primary combustor heat input from oxy-combustion and sCO_2 recycle flow up to turbine inlet
5. E-F: Turbine expansion work output
6. F-G: Cooling of turbine exhaust (predominantly CO_2/H2O vapor) in recuperative heat exchanger (stages 3, 2 and 1).
7. G-H: Multi-stage compression of recycle CO_2 to required pump inlet pressure.
8. H-A: Aftercooler

Entropy, a measure of a system's thermal energy unavailable for conversion into mechanical work, is represented by the purple lines. These entropy lines should avoid being crossed when moving up and down in pressure. For example, in the turbine this is represented by the line going from the upper right of the diagram down to the lower left (labelled "2" in Figure 4). Moving from right to left along the x-axis represents the energy that is generated, and the right-left distance of line "2" is the amount of power the turbine produces.

The black parabola on the far left represents the bi-phasic "dome" for CO_2. Within this dome CO_2 is a mixture of both gas and liquid. At conditions to the left of the dome, CO_2 is liquid. At conditions to the right, CO_2 is a gas. Above the top of the dome, CO_2 becomes supercritical. In the supercritical realm, CO_2 does not undergo a "phase transition" (changing from liquid to gas, and vice versa); instead, CO_2 is more analogous to a type of gaseous jelly —when it is cold it is more like a liquid, and when it is hot it is more like a gas.

Another important aspect of the AFC can be seen by following the purple entropy lines. Think of these as "rail tracks." Thus, on the right, when the gases are going through the turbine, the drop in pressure follows the rail tracks down, and the turbine produces the amount of energy equal to the difference between the enthalpy value at the upper right of the diagonal line and the enthalpy at the lower left of the same line. By contrast, on the left, these rail tracks are steeper, and those for the pump are steeper (nearly vertical) than those for the compressor. That means the system uses less energy to increase in pressure than the energy it produced in the turbine from the drop in pressure. Further, on the left, note that less energy is required by the pump than to compressor (the entropy lines are steeper for the former than the latter). The AFC exploits this fact to increase its efficiency.

The system design point is where the turbine exhaust stream goes into the heat exchanger (where lines two and three meet at point F). The limitation here is dictated based on commercially available alloys and manufacturing techniques capable of operating under the high pressure and temperature conditions demanded by the AFC.

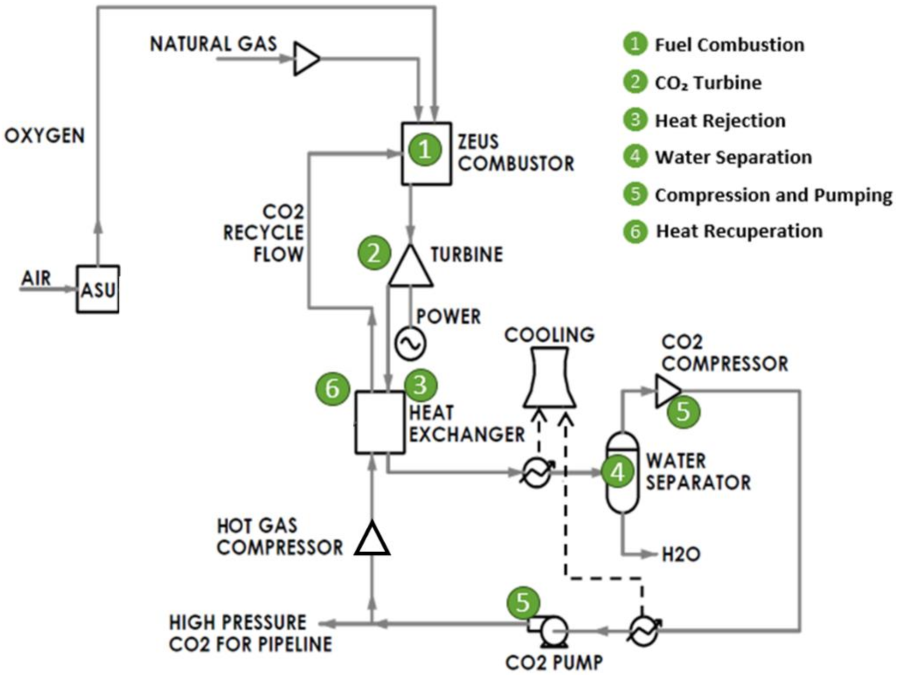

Figure 5 - High-level process flow diagram of the AF Cycle with labelled points

Figure 5 above shows how the key process points are achieved using specific equipment in the AFC. The Combustion Turbine Generator (**CTG**) (points 1 and 2) and CO_2 Recuperative Heat Exchangers (points 3 and 6) are key pieces of equipment for the Plant. Supercritical CO_2 turbines are currently in development with a number of OEMs that are refining their design to provide commercial performance guarantees to customers.

The recuperative heat exchanger design optimises heat recovery for the required temperature and pressure conditions. Notably, NET Power has several alternative heat exchanger configuration options to help drive different customer requirements for efficiency, energy density, and economics.

3.3 CYCLE ADVANTAGES

The following Section provides an overview of the benefits of the AFC compared to conventional technology, such as abated CCGT.

3.3.1 NEAR ZERO EMISSIONS

The AFC is designed to inherently capture CO_2 using Oxy-combustion and a semi-closed loop design. CO_2 capture rates are expected to be nearly 100% after accounting for potential turbo-machinery seal leakage. The oxy-combustion cycle generates near-pure CO_2 that does not require expensive separation from other flue gases.

The only source of nitrogen that enters the process is fuel-derived (in this case, natural gas derived) nitrogen. As a result, NO_X formation is very low. Furthermore, residual NO_X in the process stream is removed automatically in the AFC CO_2 -water separator without additional equipment.

3.3.2 WATER CONSUMPTION

The AFC can provide significant water savings compared to conventional thermal technologies. While the Plant can use conventional evaporative cooling towers, this is purely an equipment selection option and not a requirement. Should dry cooling be utilised (e.g. fin fan cooler), the Plant becomes a net producer of water as there is no requirement for raw water to be supplied since all process wastewater would be of suitable quality to be recycled within the process. If wet cooling is utilised, the Plant only requires approximately 0.016 m^3/min/MWe, which is less than the typical water consumption in the IGCC/CCS systems.

3.3.3 PLANT RAMP RATES AND TURNDOWN

3.3.3.1 RAMP RATE

The ramp rate of the AFC is projected to significantly exceed the performance of conventional thermal technology such as abated CCGT. Once temperature equilibrium has been reached within the major equipment items, the ramp rate of the AFC is expected to be 20% of the nameplate rating per minute. The Plant ramp rate is limited by the performance of the ASU which has a standard ramp rates around 2-3%/min. However, in the case where oxygen supply is de-coupled from the generating portion of the AFC facility, this limitation rests solely on the limits of the turbomachinery and heat exchanger ramp rate. In ASU-integrated designs, this transient performance difference is compensated through the supply of additional oxygen from a local or on-site storage vessel.

LOX storage is used during the ramping of the Plant and has been sized to accommodate twelve (12) hours of oxygen capacity when operating at Baseload. The slight over capacity of the ASU is used to replenish the LOX stored during normal running. All the associated costs of the O_2 storage are accounted for in either the O_2 supply contract (over the fence supply) or CAPEX (Integrated ASU).

3.3.3.2 FACILITY TURNDOWN

As the fundamental process within the AFC is free of nitrogen, the turndown of the Plant is not emissions limited as is the case with traditional technology. The AFC provides the capability to reduce to zero net load to the grid without limitation, enabling rapid dispatch and low-load operation. Turndown of the Plant is limited only by the parasitic load, and through proper design of the switchyard this can be further lowered to the point where balance of plant equipment is powered from the grid with the turbine still synchronised at a low load.

3.3.4 REDUCED DESIGN, CONSTRUCTION AND COMMISSIONING SCHEDULES

The AFC has a land usage that is over 25% less than a conventional thermal power plants as the $_{S}CO_2$ working fluid has a very high density and heat capacity. The smaller material requirements for the equipment reduces construction costs, and most of the equipment in the power cycle can be built in a modular basis to reduce installation time and complexity.

3.3.5 REDUCED MAINTENANCE

Due to the use of $_{S}CO_2$ as the working fluid, the complex equipment required for removal of hazardous emissions is not required. The maintenance costs for the AFC are therefore expected to be low compared to an IGCC and instead on par with GTCC facilities. The heat exchangers are designed to include excess surface area to allow for a given level of fouling before system performance is impacted. In addition, maintenance access is planned and available for inspection and cleaning as needed when the cycle is not operating, and the overall plant footprint is vastly reduced allowing for easier site access for operations staff.

PROJECT WHITETAIL FEASIBILITY STUDY

4.1 INTRODUCTION

The first UK deployment of an AFC power plant will be Project Whitetail, a single natural gas fired, 303MWe oxy-combustion power plant that captures nearly 100% of the CO_2 produced from its process cycle. All emissions are captured at source. Only leakage from low-leakage mechanical seals prevent a full 100% carbon capture rate.

The AFC utilises a trans-critical, semi-closed loop, direct oxy-fired Brayton cycle with supercritical CO_2 (operating between 4.5-34.0 MPa and 30 - 650°C) as not only the working fluid, but also as the oxygen diluent and the turbine coolant. Natural gas is combined with a large recycling CO_2 stream and a mixture of recycled CO_2 and oxygen in the combustor to form a heated, supercritical gas that expands through the turbine and exhausts into a series of recuperative heat exchangers. The combusted gas mixture provides the motive force to drive the turbine-generator set and produce electrical power.

The turbine exhaust passes through the recuperative heat exchanger train for heat recovery prior to subsequent waste heat rejection to atmosphere in the Turbine Exhaust Coalescing Water Separator. This low temperature heat sink further cools the gas mixture, condensing any water produced via combustion and separates it from the cycle to produce saturated CO_2 for recirculation. Intercooled, multi-stage recompression of the CO_2 followed by aftercooling produces a dense supercritical gas mixture suitable for efficient pumping to the targeted pressure conditions of the CTG. The high pressure stream passes through the recuperative heat exchangers, for reheating, prior to entering the CTG combustors.

In order to align with the standard AFC power plant scope that forms the pre-FEED scope provided by McDermott, the project has been split into two sections as illustrated in figure 6 below:

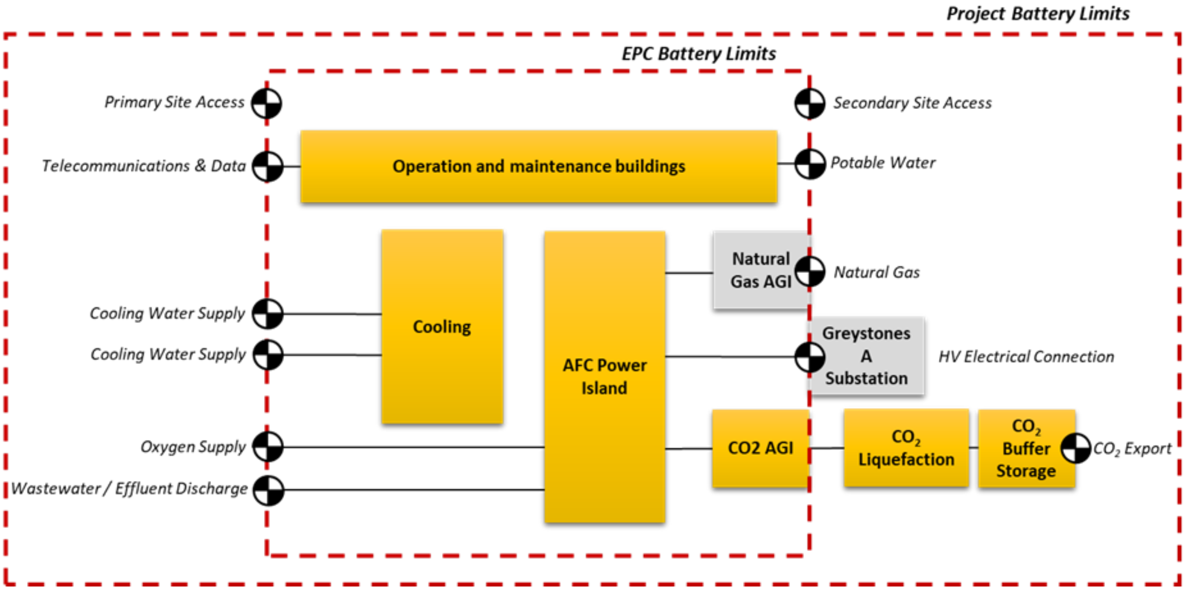

Figure 6 - Diagram of scope boundary for McDermott pre-FEED

4.2 PRE-FEED STUDY

4.2.1 INTRODUCTION

In 2016, NET Power commissioned US engineering firm McDermott (formerly CB&I), and partner 8 Rivers Capital LLC, to develop a Pre-FEED for the first-of-a-kind NET Power Commercial Plant design. The Pre-FEED Phase I was completed in January 2017, culminating in a preliminary design and a design review of in-process work products.

A second iteration of the design (Pre-FEED Phase II) was undertaken to explore other capital configurations. The Pre-FEED Phase II scope included the development of early engineering design deliverables, a Level 2 project schedule, and a Class 4 EPC cost estimate for a NET Power Commercial Plant.

The Commercial Plant Pre-FEED Phase III further developed the NET Power natural gas fired supercritical CO_2 oxy-fuelled power cycle scope, technology, and the project design for the commercial scale. The study assumed a generic site. The goal of Pre-FEED Phase III was to further develop the Commercial Plant design from Pre-FEED Phase II in order to refine capital cost estimate. This design will serve as starting point for the UK Pre-FEED.

An indicative cost for the Commercial Plant utilising the revised Phase III deliverables was developed and significant savings were realised. However, optimisation of the design has continued to meet the flexibility requirements of electricity networks where fast dispatchable support for renewable energy such as wind and solar is a key requirement. Furthermore, the use of energy storage from the ASU has also been developed further to increase the output of the plant when more power is required for short durations. Both of which are included in the latest pre-FEED scope.

These latest developments together with the work from Pre-FEED Phase III will not only reduce the cost and timeframe to deliver a UK-specific NET Power Pre-FEED, but also deliver the most up to date design that meets the UK requirements for clean, dispatchable electricity whilst reducing Commercial Plant capital cost and program risk further.

McDermott were engaged in 2020 to develop an advanced pre-FEED study based on a generic UK site. The overall goal of the latest pre-FEED study is to advance the commercial scale design, cost and business case of a project providing 300 MWe of dispatchable, zero carbon electricity to a nonspecific location in the UK. The feasibility study provides a cost estimate to AACE Class V and advances the project to the point of being ready to proceed with deployment of the full-scale system in the UK.

McDermott's pre-FEED report, 626236060-000-PE-RP-0001, dated February 2021, is included in Appendix A for reference but is summarised in the following subsections for ease of understanding.

4.2.2 CODES AND STANDARDS

The Project will be designed and constructed using Best Available Technique (**BAT**) in compliance with the applicable and current international codes and standards as well as the legally required British codes and standards. For the purpose of this report, international codes and standards are defined as the following:

- American National Standards Institute (**ANSI**)
- American Petroleum Institute (**API**)
- American Society of Mechanical Engineers (**ASME**)
- British Standards (**BS**)
- European Standards (**EN**)
- German Institute for Standardisation (**DIN**)
- International Electrotechnical Commission (**IEC**)
- Japanese Industrial Standards (**JIS**)
- National Fire Protection Agency (**NFPA**)

4.2.3 REFERENCE CLIMATIC CONDITIONS

As the AFC is based on a semi closed $_{S}CO_2$ system, the cycle is not directly influenced by the ambient climatic conditions. The influence of the ambient climatic conditions on the performance of the AFC is expected to be most significant for the operation of the ASU and the cooling system.

The ASU is expected to operate at a slightly higher efficiency during colder winter conditions, however this is not anticipated to have a significant impact on the overall performance.

The AFC requires a cooling load to maintain process parameters and preserve equipment life. For the purpose of this pre-FEED study evaporative induced draft cooling towers have been selected to provide the necessary cooling.

The following reference climatic conditions are considered.

Parameter	ISO	Maximum *(Summer Conditions)*
Ambient Air Temperature (°C)	+15	+25.6
Ambient Barometric Air Pressure (bara)	0.1013	0.1013
Ambient Relative Humidity (%)	60	75

Table 1 - Reference Climatic Conditions

For the purpose of this pre-FEED Study, equipment selection and performance will be modelled based on the design conditions in the above table.

4.2.4 OPERATING REGIME

The operation of the AFC is not constrained by air emission limitations, continuous operation at any load point between 0% and 100% of the rated capacity is possible. The actual operating regime for the Plant will depend on several factors including expected actualised power prices and any agreement for the offtake of export streams such as nitrogen, argon and carbon dioxide. For the purpose of this pre-FEED Study it is assumed that the Plant will be operated continuously at 100% electrical export capacity as follows:

Parameter	Value
Average hours per annum	8,760
Allowance for forced outages (hrs/year)	88
Anticipated operating hours per annum	8,550
Anticipated capacity factor	97.2%

Table 2 - Anticipated Operating Regime

Within this document, the following definitions are used:

- **Full load / Base load:** This is defined to be operation at 100% of the design electrical export capacity
- **Parked Load:** This is defined to be operation at 0% of the design electrical export capacity. In this operating point the generator is synchronised with the local electrical network and power is generated solely to cover the requirements of required balance of plant equipment.
- **Peak Load:** (Applicable only with ASU heat integration) This is defined to be operation at 100% of the design gross electrical output capacity utilising stored oxygen capacity with the ASU turned down thereby minimising parasitic load and maximising net electrical export.

4.2.5 DESIGN LIFE

The Plant is designed for the following minimum design life, with scheduled maintenance:

- Electrical, mechanical and control & instrumentation: 30 years and / or 260,000 operating hours
- Civil works: 50 years
- Cladding system: 30 years
- Painting and coating systems (time to first maintenance): 15 years

This design life assumes the completion of standard maintenance activities and the replacement of parts that are subject to wear and tear during operation as required.

4.2.6 THE SITE

4.2.6.1 SITE SELECTION

WSP and 8 Rivers have conducted a site selection assessment to determine the optimum location to deploy Project Whitetail, the UK's first AFC power plant. To reduce the overall timeframe for project development, this assessment investigated suitable sites for development including existing industrial sites, decommissioned power stations and existing power station developments. In order to determine the suitability of each potential site, an assessment was undertaken using the following key criteria:

- Access to suitable CO_2 export infrastructure
- Access to suitable natural gas supply infrastructure
- Access to suitable power export infrastructure
- Suitability of available land for AFC development
- Planning status
- Availability of cooling water

The WSP report supplemented by separate site identification works provided by 8 Rivers, identified a number of suitable sites. This combined assessment revealed that the following sites had a high suitability for the deployment of Project Whitetail.

- Ince Power Station, Cheshire
- Grain LNG, Isle of Grain
- Phillips66 Oil Refinery
- Total Lindsey Oil Refinery
- British Steel, Sculthorpe
- Salted Chemicals Park, Humberside
- Wilton International, Teesside

Due to the presence and condition of existing infrastructure, the existing DCO planning permission and the proximity to a suitable CO_2 export route, the Wilton International site has been selected as the optimum location for the Deployment of Project Whitetail.

4.2.6.2 LOCATION AND HISTORY

Project Whitetail will be located to the immediate south of the Sembcorp-owned Wilton International facility on Teesside (**Site**). The Site is served by the existing utilities infrastructure that is distributed throughout the Wilton Facility and this makes the location ideal for development of a commercial power plant.

8 Rivers and Sembcorp have been collaborating on the NET Power technology since 2012 when the proposed 50 MWth demonstration facility for the AFC (**Test Facility**) was to be sited at the Wilton Facility. A pre-FEED study funded by BEIS (then DECC) was undertaken by Parsons Brinckerhoff (now WSP) to determine the suitability of the Site and wider Wilton location for a supercritical CO_2 power plant. The study found that there were no 'showstoppers' to the deployment of the technology at the Site or in the UK. For commercial reasons the Test Facility was subsequently constructed in La Porte, Texas and brought into operation in 2018. The Test Facility continues to operate successfully and has provided 8 Rivers and NET Power valuable data and insight on the AFC, which will be leveraged in future commercial development.

The 2000-acre Wilton Facility is owned by Sembcorp Utilities, a leading industrial energy and utilities service provider. Situated in the heart of the Teesside Industrial cluster the Wilton Facility is occupied by well-established process industry businesses such as SABIC, Ensus, Huntsman and Nippon Gases. The site also boasts some 200 MWe of electricity generation from several power plants utilising various fuel sources including natural gas, biomass and household waste. The 39-acre Project Whitetail site (indicated by the yellow boundary on Figure 7) is an ideal location having been the former site of the GDF Suez owned, Teesside Power Station (**TCCP**). TCCP was a 1,875MW CCGT facility that supplied heat and supplementary steam and power to the Wilton Facility for many years prior to decommissioning. TCCP also exported power to the UK electricity grid and much of the electrical infrastructure for supplying power remains in place and will be reused by the Project. The steam, water and gas utilities and pipeline service corridors also remain available at the Site and can be repurposed for reuse by Project Whitetail. The location of the Wilton Facility and Project Whitetail sites is shown in Figure 5 below.

Demineralised, potable and raw water are all supplied in more than sufficient volumes via the network of over ground pipelines that service the Project Site. Furthermore, an effluent pipeline also runs in parallel to the Sembcorp owned effluent treatment facility, again providing more than adequate capacity.

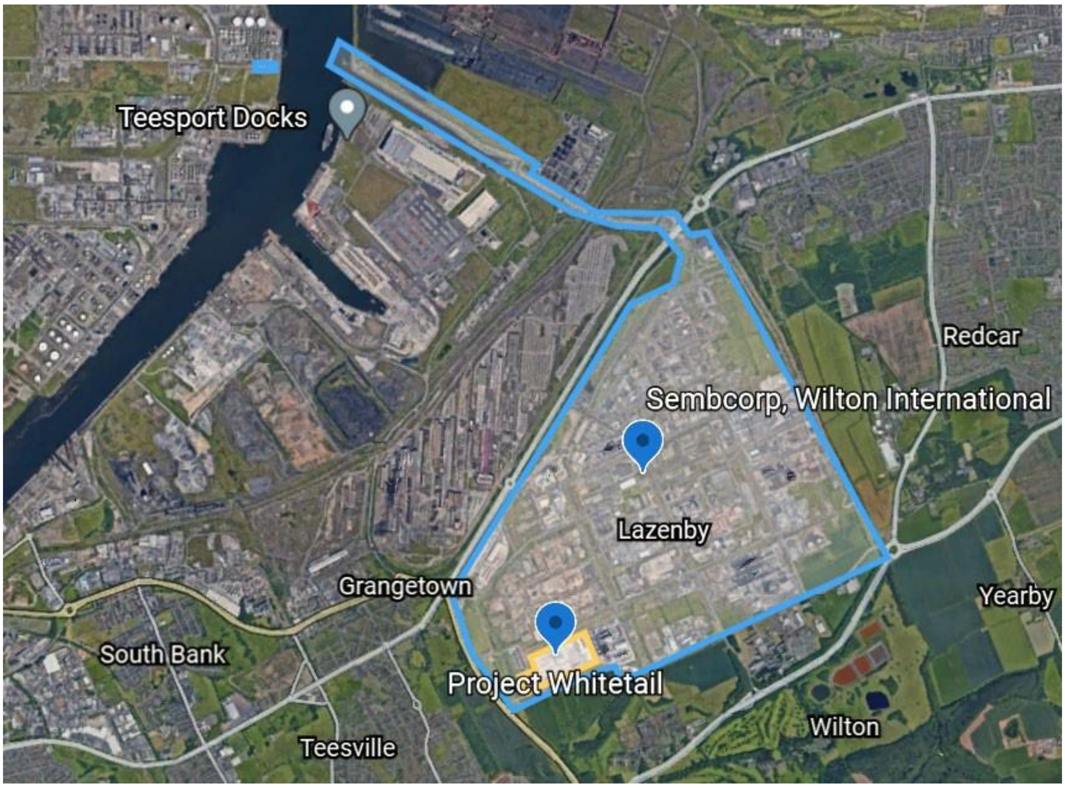

Figure 7 - Sembcorp Wilton Boundary and Location of Project Whitetail

The Project Site has excellent access to the road and highway network with a dedicated access road linking directly from the A1053 to the west whilst the internal rail hub that serves the energy from waste facility to the north enables a direct link into the UK's national rail network. The nearby Teesport, located on the River Tees, is 2.5km to the north and is the home to some of the largest oil, gas and petrochemical companies. This provides excellent infrastructure for potential CO_2 shipping and buffer storage prior to shipping and is linked directly to the project site via existing pipelines which can be repurposed for the Project.

The Wilton Facility is a self-contained Industrial Zone which houses chemical, bio-refining and power facilities as well as other industrial units. From a health and safety perspective the Wilton Facility conforms to the highest level with regards to the UK Control of Major Accident Hazards (**COMAH**) regulations. As such an onsite fire and incident team operated by Flack Fire Services is available to attend any incident and operates a 24-hour, 365-day service to all locations within the Wilton Facility boundary. That said, the location of the Project at the former TCS site does not have any internal road access into the Wilton Facility and is accessed via the external A1053 dual carriageway. With this in mind, the County Fire Brigade stationed at Grangetown would provide the initial emergency response in the event on an incident at the Site and would be backed up by Flack Fire Services. The County Fire Brigade have been consulted for the purpose of the Project and have a response time equivalent to that which could have been provided by Flack Fire Services.

The proposed location at the Wilton Facility has numerous advantages as outlined in this report that make it the ideal location for the Project and the first NET Power plant constructed in the UK. Whilst the existing utilities that serve the Site will provide the necessary gas, water and effluent connections there are other significant benefits to this specific location such as the existing National Grid connection agreement and existing Development Consent Order, both of which can be leveraged to accelerate the development of the Project. Added to that is the excellent transport links and the nearby port of Teesport to the north with good deep-water berths and shipping routes to the North Sea and mainland Europe. The nearby Net Zero Teesside (**NZT**) transport and storage system due to be operational in 2026 will also service the Wilton Facility which gives further optionality for CO_2 sequestration.

4.2.6.3 PROJECT TERMINAL POINTS

4.2.6.3.1 Natural Gas Supply

Natural gas will be provided via underground pipeline to an existing and dedicated Above Ground Installation (**AGI**) on the northern boundary of the Site. The existing AGI only consists of a PIG trap and pipework interface and as such suitable filtering, metering and analysis equipment will be installed by the Project to allow for use within the Plant. In the absence of project specific data standard pipeline specification natural gas has been assumed which conforms to the specification below. Whereas the generic pre-FEED for UK deployment is modelled on pure methane.

Key Parameter	**Value**
Composition	
Methane (%)	89.73
Ethane (%)	4.49
Propane (%)	1.00
i-butane (%)	0.2
n-butane (%)	0.2
i-pentane (%)	0.05
n-pentane (%)	0.05
Neo-pentane (%)	0.00
C6+ (%)	0.1
Carbon Dioxide (%)	0.0
Nitrogen (%)	4.19
Sulphur (%)	0.00
Calorific Value	
Net Calorific Value (LHV, MJ/Sm^3 / MJ/kg)	34.86 / 46.34
Gross Calorific Value (HHV, MJ/Sm^3 / MJ/kg)	38.63 / 51.35
Wobbe Number	49.305
Thermodynamic Conditions	
Supply Pressure (bara)	52
Supply Temperature (°C)	TBA

Table 3 - Natural Gas Specification

The core process within the AFC requires natural gas to be supplied at high pressure to the combustion system (approximately 350-400 bar). As the required gas pressure far exceeds that of the supply at the Project Terminal Point natural gas compression has been included within the scope of supply. In order to protect the compressor from surges in supply pressure, a buffer pipe will also be included to stabilise the pressure at the compressor inlet.

The following table details the natural gas requirements of the AFC when operating on natural gas conforming to the above specification:

Parameter	**Value**
Peak demand (Nm^3/hour)	68,268
Average daily demand (Nm^3/day)	1,424,730
Maximum daily demand (Nm^3/day)	1,638,439

Table 4 - Natural Gas requirements

As stated above, the Project will include the installation of a dedicated AGI to receive natural gas at the terminal point. This AGI will consist of filtration, fiscal metering, heating, control valving and a pipeline inspection gauge (**PIG**) receiving trap. This equipment, with the exception of the PIG receiving trap are expected to be provided with 100% redundancy to ensure security of supply.

4.2.6.3.2 Cooling Water

For an AFC Installation, the main process requires cooling to maintain system parameters and to protect equipment. There are several options available for cooling. The system selection process deserves special consideration as it will have impact on the Project as both efficiency (due to varying parasitic load and water demand) and land requirement will be affected based on the determined solution.

For the purpose of the feasibility study, and to define the extremities of the project requirements, it is assumed that hybrid cooling towers will be utilised. In order to provide surety of supply a storage tank will be included with the capacity to provide the normal cooling water demand for a one (1) day period.

Initial estimates indicate that, in order to maintain a 5x concentration factor in the basin of the hybrid cooling tower, 5,776 tonnes of water per day is required. Considering that Planning Consent was granted for a 1700MW CCGT which would have more than double the cooling water requirement, it is determined that there would be sufficient availability of cooling water to support operation of the AFC. A Best Available Techniques (**BAT**) assessment will be undertaken as part of the FEED process.

4.2.6.3.3 Carbon Dioxide

Under normal operation, the Plant will not emit CO_2 into the atmosphere other than fugitive emissions associated from mechanical seal leakage. Due to the inherent design of the AFC, CO_2 can be extracted from the process for export, either for sequestration or for commercial sale to a Third Party. The exported CO_2 will have a purity of 99.9% and can be provided at pressure between 40 and 120 bar depending on the requirements of the consumer. Higher supply pressures upwards of 320 bar can be attained if special circumstances require so.

Under normal conditions the Plant is anticipated to produce 2,600 tonnes of CO_2 for export per day.

Due to the inherent design of the AFC, any emissions of oxides of nitrogen or sulphur will either be removed by the water separator or exported as a minor contaminant within the CO_2 stream (as permissible). As a result, no additional special provisions are required for these contaminants.

4.2.6.3.4 High Voltage Electrical Export

Under the design conditions considered within this report, the Plant is expected to generate a gross output of [444MWe] measured at the HV terminals of the generator. A portion of the generated energy is expected to be used to provide the required power to the Plant with a nominal net output of 303MWe available for export to the local HV electrical network. As the turbine generator currently is designed with shaft connected loads, the generator gross output may be revised slightly if those are to be removed in the FEED study.

4.2.6.3.5 Aqueous Discharge

Under normal operation the majority of the aqueous effluent that is generated by the Plant relates to the blowdown from the cooling tower which is expected to be 1,450 tonnes per day. This stream is non-hazardous and will be routed to an existing water treatment plant within the Wilton Facility for treatment prior to final discharge.

4.2.7 EQUIPMENT SELECTION

The Project will combust natural gas as fuel with oxygen provided from an un-integrated ASU to reliably produce electricity and high purity carbon dioxide for local pipeline export to downstream consumers such as carbon sequestration. Under normal operation, the Plant will not emit CO_2 into the atmosphere other than fugitive emissions due to mechanical seal leakage. This Project will be configured to generate electricity at a frequency of 50 Hz and will meet all applicable UK codes and standards.

The McDermott Pre-FEED study investigated the following three cases:

- **Base Case:** 900°C turbine inlet temperature with un-integrated ASU
- **Alternative Case:** 925°C turbine inlet temperature with un-integrated ASU
- **Optimised Alternative Case:** 925°C turbine inlet temperature with un-integrated ASU balancing CAPEX/Efficiency

Critical to the operation of the AFC is a reliable supply of nominally pure oxygen that is typically provided via an Air Separation Unit (**ASU**). Due to the possibility of funding via a government provided Contract for Difference (**CfD**), the required oxygen for the Plant will be provided via a dedicated pipeline through an 'over-the-fence' agreement with a Third Party industrial gas supplier. As such the design of the AFC unit does not include any heat integration with the ASU which would provide significant efficiency benefits (refer to section 4.2.11.1 for further information). To compensate the lack of heat supplied by the ASU, the design of the Project includes a Hot Gas Compressor downstream of the Recuperative Heat Exchanger that provides additional heat to the recuperator train described below.

The CO_2 Recuperative Heat Exchangers and the Combustion Turbine Generator (**CTG**) are the most technically novel pieces of equipment for the Project. Multiple suppliers are currently developing the design of the commercial scale CTG utilising lessons learned from the 50 MWth Project Demonstration Plant (**Test Facility**) in La Porte, Texas. The Project will leverage these technical learnings in the deployment of the AFC. Meanwhile, multiple suppliers have been determined for the CO_2 Recuperative Heat Exchangers. Primarily, these exchangers are common in petrochem industry, with the exception being the highest temperature exchanger which requires special consideration based on the required metallurgy. The rest of the equipment with the AFC power plant utilises equipment that is proven and commercially available from international equipment suppliers.

The following items are the major items of equipment within the AFC design.

4.2.7.1 COMBUSTION TURBINE GENERATOR (CTG)

The system consists of a 50Hz single-shaft CTG connected by a reduction gear to an air-cooled generator (4 pole, 1500 rpm) and the Recycle CO_2 Pump.

The combustor produces high temperature, high pressure, CO_2 rich exhaust stream that, in conjunction with the Recycled CO_2, rotates the turbine. The turbine produces nominally 430 MW power to the shaft, which is common to the CTG and the Recycle CO_2 pump. The generator is designed in the base case to produce an estimated 287 MWe (net) of electricity whilst in the alternative case the generator will produce 303 MWe(net). This increase in generation is due to the exclusion of parasitic load from the ASU. However, due to the inclusion of other equipment required for the alternative case, the total parasitic load of the ASU is not directly recovered in the net output.

The turbine conditions selected for the Project, specifically a lower turbine inlet temperature (925°C) have been tested successfully at the Test Facility. Additionally, the lower inlet temperature allows for lower outlet temperature, minimising the risk associated with the recuperative heat exchanger network and eliminating the use of extremely expensive nickel alloys. Similar to other turbines, it is anticipated that there will be continual improvements in the $_{S}CO_2$ turbine design once competitive offerings from suppliers exist.

While the current configuration indicates single-shaft connection of the CTG, reduction gear, generator, and Recycle CO_2 Pump, efforts to reduce rotordynamic risk are exploring the decouple of the Recycle CO_2 Pump from the turbine such that it is motor-driven, as well as synchronous operation of the turbine, removing the need for a reduction gear system. If so, the overall rating of the generator and auxiliaries will be adjusted to reflect the additional gross power provided at the CTG-generator shaft. These studies will be revisited during the FEED stage of the Project.

4.2.7.2 RECUPERATIVE HEAT EXCHANGERS

The Recuperative Heat Exchanger (**HXR**) network cools the high temperature turbine exhaust, transferring heat to the high pressure recycle CO_2, oxidant, and turbine coolant streams, while also recovering heat from the hot gas compressor. The HXR network consists of the following key items:

- Precool section heat exchanger(s)
- Oxidant heating section heat exchanger(s)
- Recycle heating section heat exchanger(s)
- Heat recovery section heat exchanger(s)

The entire turbine exhaust stream leaving the turbine at approximately 600°C is fed to the precool section and is cooled against a process stream before redistribution to two of the three independent parallel sections (oxidant heating and recycle CO_2 heating). A portion of the turbine exhaust gas at an intermediate temperature is fed to the hot gas compressor and returned as a pressurised hot gas stream at an elevated temperature to heat the third parallel train. The hot gas stream is cooled in the heat recovery section before it is returned to the recompression train at an optimal location.

The high operating temperature, pressure, effectiveness, and duty required represents a significant design challenge. The Project utilises a modular network of recuperative heat exchangers. This network uses an optimised combination of diffusion bonded (**DBHE**) and shell and tube (**STHE**) type heat exchangers to achieve the desired outlet temperature for recycle CO_2, oxidant, and turbine coolant streams while collecting condensed water from the low points of the turbine exhaust stream. The system design specifies specific materials to ensure that none of the allowable stresses of any components are defined from time dependent (creep) properties, and the equipment layout minimises thermal stresses experienced during operation, especially in the higher temperature sections.

4.2.7.3 HOT GAS COMPRESSOR

As the Project design does not include integration of the ASU, a Hot Gas Compressor (**HGC**) is included to provide the required input of heat. The HGC is an independent, three stage compressor that is driven by a 60 MWe motor, discharging through the recuperative heat exchanger network and into the recompression train. The HGC adds the requisite high-quality energy (adiabatic heat of compression) into the recuperative heat exchanger network to maximise combustor feed temperatures and plant net output while minimising heat exchanger area and plant heat rate. A suction cooler provides forced convection (air) cooling for transient periods when the suction temperature exceeds target values.

The compressor also serves other operational purposes which have been proven out at the La Porte, Texas test facility, chiefly in commissioning and the acceleration of start-up times within the facility.

The design consists of a single piece of turbomachinery, which although is within the existing capability of equipment suppliers is encroaching on the maximum demonstrated commercial size for both the compressor and the gear. Options for smaller HGCs (i.e. 2 x 50%) shall be considered during the FEED process.

4.2.8 RISK REDUCTION AND OPPORTUNITIES

As part of the ongoing development works, 8 Rivers will continue to manage the risks to the Project by utilising the applicable lessons learned from the construction and on-going operation at the Test Facility. Pre-FEED efforts have reduced material and manufacturing costs for the $_{S}CO_2$ turbine and heat exchangers, material cost for piping, and identified which pipe routes can be optimised for the most significant CAPEX reductions. Continuing engineering design and layout optimisation is critical to minimising the capital cost. Key opportunities are summarised below.

- Continued refinement of engineering to optimise the design and provide a more modularised solution to minimise on-site fabrication, thus limiting the risk of increased capital cost.
- Pipe routing and site layout optimisation has compressed the layout producing a 25% reduction of piping relative to initial (2017) designs created in the first two Pre-FEED phases. The resulting design is significantly more compressed than rival technologies without carbon capture such as Combined Cycle Gas Turbine (**CCGT**).
- Maturity of equipment layout and pipe routing will facilitate further modularisation improvements to minimise project risk and cost of bulks, direct labour, and indirect costs
- Further CTG development/refinement to simplify construction, operation, and maintenance while improving efficiency.
- Optimisation of soft start requirements and variable speed controls.

4.2.9 POSSIBLE COST AND EFFICIENCY IMPROVEMENTS

4.2.9.1 INTEGRATION OF AIR SEPARATION UNIT

The design and configuration of the Project does not include a dedicated ASU to generate the oxygen required by the process, instead it is reliant on oxygen provided via a pipeline from a Third Party. This configuration was selected with the objective of reducing the overall CAPEX of the Project as the inclusion of a dedicated ASU requires a significant investment, although this investment is normally contemplated in financial models of the AFC technology.

Should an ASU be located adjacent to the Project Site it would be possible to integrate the ASU into the process of the AFC unit, increasing the overall efficiency of the Project through the recovery and reuse of heat. NET Power have worked with several ASU suppliers to develop a custom heat recovery system which optimises the compression train of the ASU for heat recovery, transferring heat to the AFC unit via a dedicated heat transfer fluid loop. Thermodynamic modelling has demonstrated that the increase in power consumption at the ASU is minor compared to the increase in electrical output at the AFC unit. The addition of heat from the ASU replaces the heat that would otherwise be added to the AFC process by the HGC as illustrated in the following figure:

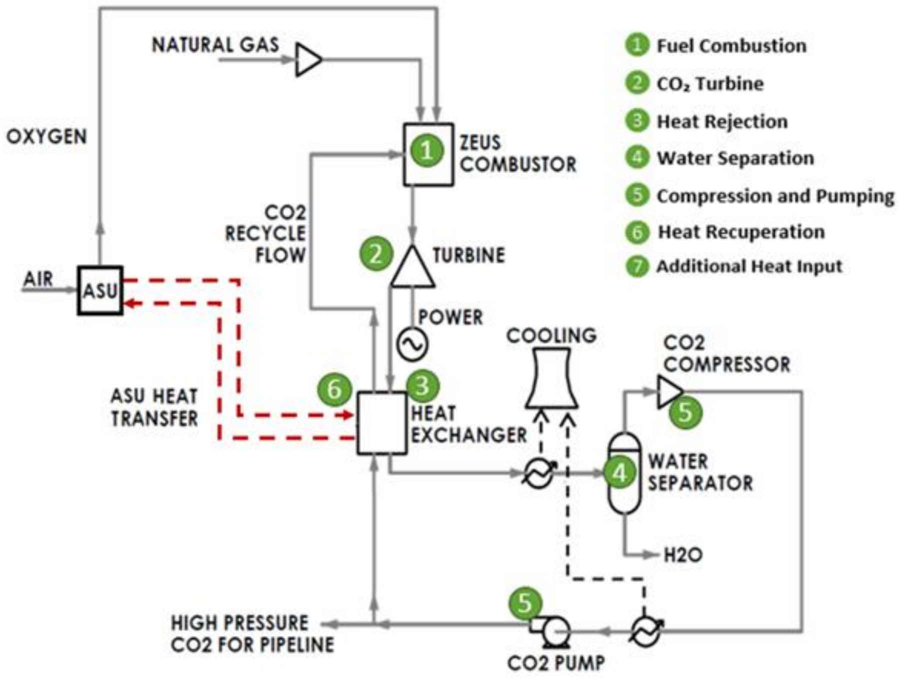

Figure 8 - AFC - ASU Heat Integration

The integration of the ASU would also allow the AFC to provide a short term increase in net power export either to provide rapid response to the demand of the grid or to take advantage of peak power conditions. During low power demand the AFC can be turned down to zero net load while running the ASU at full capacity, storing liquid oxygen for later use. At times of high power demand, the AFC can utilise this stored oxygen to temporarily lower the parasitic load, providing extra power for sale beyond the nameplate rating.

While this integration of the AFC and ASU units increases the CAPEX of the combined overall facility, it also increases the net efficiency of the power cycle. In addition, the inclusion of an ASU within the overall Project design would permit the commercial sale of other gases generated by the ASU (including nitrogen and argon). An evaluation of the local market for those products would be necessary to determine the net present value of an ASU with these optional products.

As described above, in the current configuration contemplated by Project Whitetail, the heat normally provided by the ASU would be provided by a dedicated Hot Gas Compressor.

4.2.9.2 ADVANCED HEAT EXCHANGER DESIGN

The Recuperative Heat Exchanger network is an optimised combination of Printed Circuit type (**PCHE**) Diffusion Bonded (**DBHE**) heat exchangers and Shell and Tube type (**STHE**) heat exchangers. High pressure STHE type heat exchangers are a well-established and commonly used technology that will comply with established Tubular Exchanger Manufacturers Association (**TEMA**) standards. The DBHE sections are fabricated from multiple individual blocks, each comprised from etched plates welded together using a diffusion bonding procedure. The specialised nature of the diffusion bonding process limits the supply chain to a small number of fabricators with specialised furnace operations. Since capacity of an individual supplier may be inadequate to supply all of the blocks in the Recuperative Heat Exchanger system, the design incorporates a modular layout to enable multiple PCHE supply options to be considered when necessary.

The Recuperative Heat Exchanger layout employs a modular top down design to minimise footprint, improve transportability, reduce field construction costs and improve reliability. The entire network can be shipped as a super module with wide load requirements or sub modules for single lane access. This includes the cores as well as the mounting frames for the cores and pipework. Height will vary depending on shipping contents. The system is designed to be assembled at the site from a series of shop-fabricated modules, thereby minimising the number of field connections required. Additionally, the highest temperature services are located on the top of the support structure and the coldest services at the bottom, allowing thermal expansion of the unit upwards rather than in a lateral fashion. This not only compacts the plant layout, but also facilitates collection of condensed water in the Turbine Exhaust stream at the lowest location in the network.

By elevating the high-temperature services at the top of the network there is a reduction of high temperature pipe lengths from the turbine and the provision of easier maintenance access to those exchanger services at the most extreme temperatures. A novel frame support system is employed to allow the high temperature sections to expand freely such that flexibility for thermal expansion resulting from the higher temperatures is accommodated in the lower temperature sections where allowable stresses are higher. Finally, the optimised piping in this network not only reduces costs, but also provides sufficient flexibility to negate potential damage from heat induced stresses.

Modularisation of the recuperative heat exchanger network was essential to ensure the performance of the Plant while minimising the associated cost. Due to the critical nature of the equipment and piping supports, the quantities of instrumentation, and the custom welding required for the unique piping, shop fabrication is essential for quality and cost control. It is also the only way to provide the compactness desired that minimises piping runs and associated pressure drops while providing the proper installation of the insulation as minimising heat loss to atmosphere is critical to the AFC efficiency.

To minimise creep-fatigue related failure potential, the high temperature services utilise materials that are not subject to allowable stresses defined from time dependent properties, thus avoiding a limited life. In addition, the precooling system minimises equipment and piping subject to extreme temperatures and strategically orients them to allow for easy access for inspection or repair.

4.3 RISK MANAGEMENT & MITIGATION

4.3.1 PRELIMINARY HAZID

Refer to the WSP preliminary Project HAZID report, 70053760-WSP-0001-RP-PE-0002-S0_P02 dated August 2020, provided in Appendix O. For ease of understanding this document is summarised below.

The HAZID study for the proposed AFC UK plant was held on 23 / 24 July 2020 involving representatives from 8 Rivers, McDermott and NET Power. The HAZID study comprised a pre-agreed set of guidewords and nodes, focusing AFC in the context of a UK commercially deployed power plant to UK/EU acceptable legislation, codes, standards and practices. The HAZID will form the basis of the HAZOP, which will be completed during the FEED and will then encompass the site-specific aspects of the project when they are fully understood.

In total, 8 HAZID actions were identified and recorded during the study. The HAZID actions were circulated to the action holders and have been subsequently closed out with signed responses received by WSP. Some actions and their requisite responses were not able to be completely closed out at this stage of the project, at least until the FEED phase takes place.

Where this was the case, the actions have been closed (for the purposes of this HAZID report) by appending them to the pre-FEED risk register or including in the pre-FEED report as issues that need to be included in the FEED scope. These items will then be reviewed again at the FEED HAZID/HAZOP study where further design, to a higher level, will be carried out.

4.3.2 RISK REGISTER

Refer to the Risk Register, Project Whitetail Risk Register (Post pre-FEED) dated February 2021, provided in Appendix P and WSP Monte Carlo report, 70053760-WSP-00-XX-RP-PM-0001-S3_P01, dated January 2021, provided in Appendix P. For ease of understanding, these documents are summarised as follows:

At the time of this report 114 risks have been identified by 8 Rivers. Of these 114 Risks, 101 have been determined to have a low residual risk and seven to have a medium residual risk rating following mitigation. No high residual risks have been identified.

For ease of understanding, these seven risk items that have been determined to have a medium residual risk rating are summarised below:

- **Covid-19 Impact on Personnel (Risk ID 17):** Resources within project team or contractors' contract Covid-19 which reduces the availability within project team and/or supply chain potentially impacting whole life cycle. Mitigation - Ensure that other staff can cover anyone who contracts Covid-19.
- **Covid-19 Impact on Program (Risk ID 18):** Resources within supply chain contract Covid-19 which results in potential delays to supply of materials and equipment. Mitigation - To be considered once information on supply chain is available.
- **Covid-19 Impact on Construction (Risk ID 19):** Resources within construction team, contractors and/or suppliers' contract Covid-19 which results in delays to the construction phase if suitably skilled alternative resource cannot be sourced. Mitigation - To be considered once information on construction staffing is available.
- **Covid-19 Impact on Commissioning (Risk ID 20):** Resources within commissioning team and/or Third Party interface teams' contract Covid-19 which results in delays to commissioning phase if suitably skilled alternative resource cannot be sourced. Mitigation - To be considered once information on commissioning staffing is available.
- **Covid-19 Impact on Operations (Risk ID 21):** Resources within operations team contract Covid-19 which result in a risk to plant operation if suitably skilled alternative resource cannot be sourced. Mitigation - To be considered once information on operational staffing is available.
- **Flexible Contract for Difference (Risk ID 29):** Contractual structure, risk allocation of power and carbon pricing and volumes; protection from Force Majeure (beyond insurable risks and quantum), change in law, change in tax - basically all risks which could adversely affect DSCR beyond EPC/LTSA/operational risk. Mitigation - Risk to be negotiated out during contractual negotiations.
- **Unknown Buried Structures and Services (Risk ID 115):** Detection of previously unidentified buried structures and/or services results in a delay to construction. Mitigation - Suitable precautions to be carried out during engineering and construction; ensure all previous engineering drawings and geotechnical drawings have been reviewed.

4.3.3 LAYOUT AND CONFIGURATION

In order to expedite the development process, 8 Rivers preference is to amend the existing DCO rather than starting afresh. As a result, the key consideration in the development of the layout and configuration of the equipment of the Project is to minimise the alternations to the existing consented layout.

The existing planning consent separated the Site into the following areas, limiting the allowable development in each:

- Work Area A
- Work Area 2A
- Work Area B
- Work Area B2

The original configuration consisted of two CCGT units orientated north-south with the main stacks located to the north of the Site. Two banks of cooling towers were located along the northern boundary of the Site in an east-west orientation. The main occupied buildings on the Site are located to the north and west of the Greystones A substation.

A review of the site constraints was undertaken by 8 Rivers determined that adherence to the existing configuration would not result in any material constraints to the deployment of the Project.

The following images provide a comparison of the existing layout and configuration compared to that proposed for Project Whitetail.

Figure 9 - Layout and configuration of existing TCCP DCO

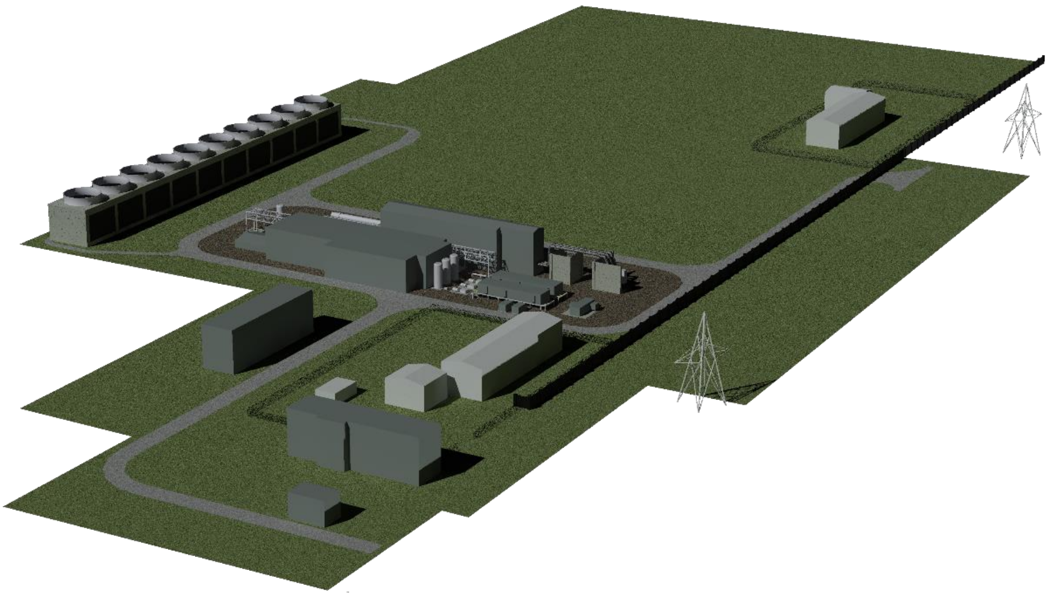

Figure 10 - Proposed AFC Layout and Configuration

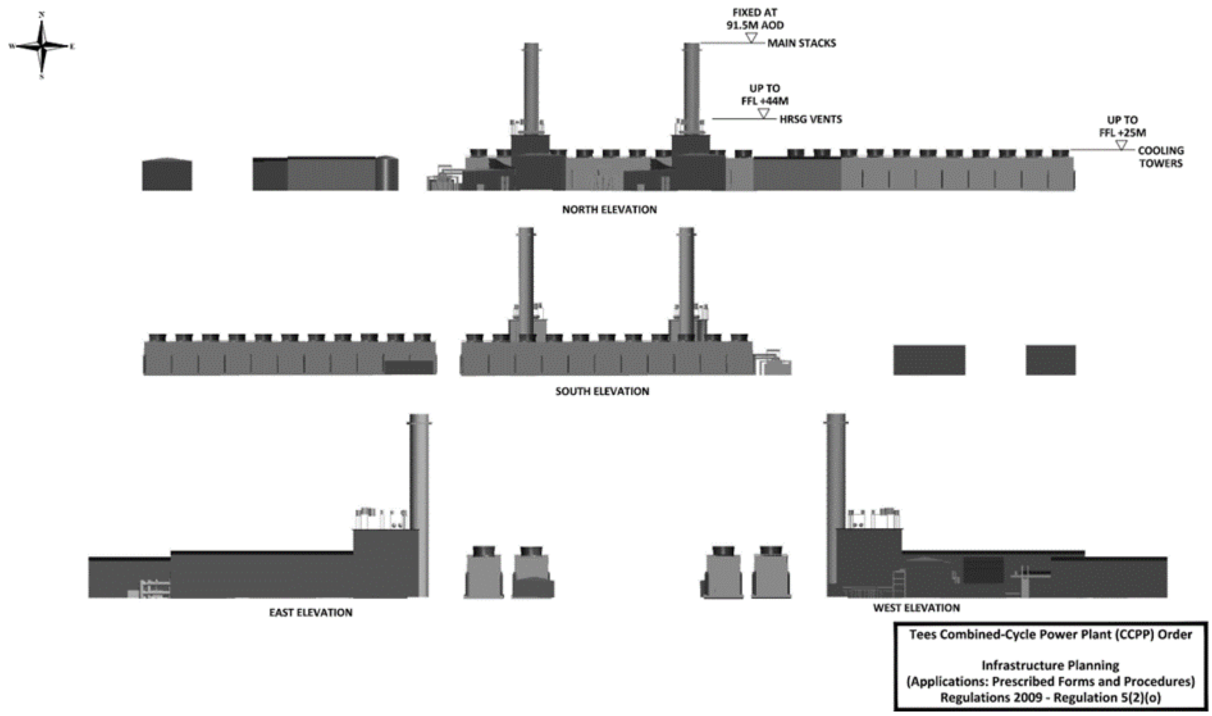

Figure 11 - Elevations of existing TCCP DCO

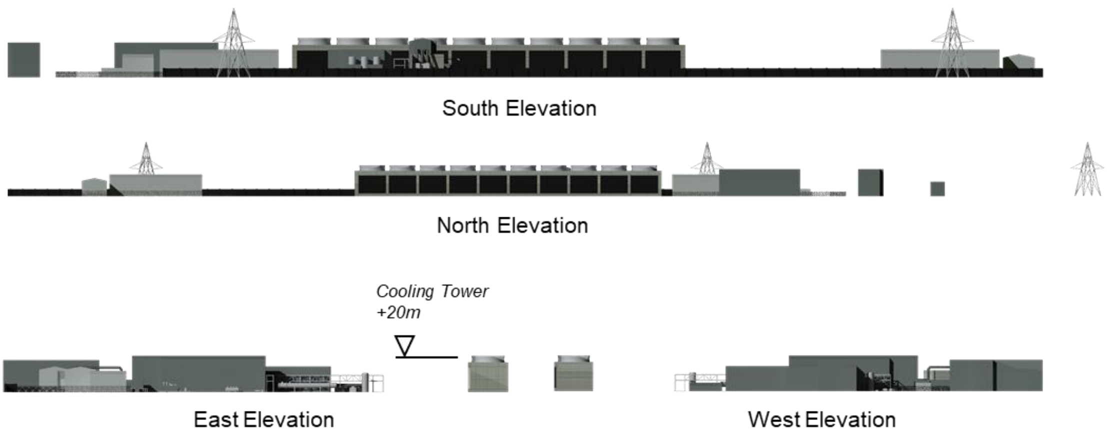

Figure 12 - Elevations of proposed AFC

In conclusion, the adoption of the existing overall layout and configuration does not result in a development constraint and as such will be utilised for the Project to minimise the significance of any amendments to the existing DCO.

Refer to the Site Layout, 10-XXXX-C3-DWG-0007_P4, dated December 2020, provided in Appendix C. Please note that although two units are shown on this layout, only the western unit is proposed for development.

4.3.4 SITE GEOTECHNICAL SURVEY

Refer to the WSP Site Geotechnical Desktop Study, 70053760-WSP-00-XX-RP-GE-0001-S0_P1 dated September 2020, provided in Appendix F. For ease of understanding this document is summarised below

Ground and groundwater conditions: Made Ground with thickness varying between 0.4m and 2.4m. which was proven as reinforced concrete underlain by gravel fill or clay fill with brick, concrete slag and dolomite. Trial pits logs recorded numerous buried concrete obstructions.

The Made Ground is underlain by Glacial Till, generally described as stiff and very stiff sandy becoming slightly gravelly clay. Bedrock of the Redcar Mudstone Formation is shown to underlie the Glacial Till. Rock head was recorded across the site generally between 9.1m bgl and 10.5m bgl.

Perched groundwater in the Made Ground was recorded across the site with local water strikes recorded between at 10.0m bgl and 8.0m bgl. Analysis of the groundwater determined that there was no long-term risk to human health from the samples subject to testing assuming the site is covered in hardstanding.

Ground Risks and Constraints:

- **Hydrology:** The Project Site does not lie within a Source Protection Zone
- **Mining and Quarrying:** The Project Site is not in a coal mining affected area
- **Flood Risk:** The Project Site is not located in a zone at risk of flooding by rivers or sea
- **Sensitive Land Uses**: The Project Site does not lie within 2000m of any form of designated environmentally sensitive site
- **Ground Hazards: I**nformation revealed that there is a moderate risk for potential compressible ground stability hazard
- **Radon:** The Project Site is not within a Radon Affected Area
- **Unexploded Ordnance:** The Project Site is located in an area of low UXO risk and no further UXO mitigation is considered necessary in any future ground investigation works.

Geotechnical Risks:

- **Unknown Ground Conditions (Risk Rating - Medium):** A carefully planned site-specific intrusive ground investigation should be carried out to fill the gaps identified in the existing ground investigation information and targeted to areas of the proposed power plant structures
- **Potential for Compressive Ground Stability Hazards (Risk Rating - Medium):** Targeted intrusive ground investigation to be considered. Consideration to be given to piled foundations end bearing in bedrock for all heavy and settlement sensitive structures.
- **Ground Obstructions (Risk Rating – Medium):** Ground obstructions to be assessed as part of future targeted ground investigation. Consideration to be given to rotary bored piles for the proposed development.
- **Groundwater (Risk Rating – Medium):** Groundwater observations and monitoring to be carried out as part of targeted ground investigation. Design and construction to make appropriate consideration to high groundwater if confirmed.
- **Aggressive Ground Conditions & Contaminated Land (Risk Rating – Medium):** The presence of Made Ground indicates a likelihood for high water-soluble sulphate or low pH conditions. Further chemical testing on soil and water samples to be part of targeted ground investigation.
- **Buried Utilities (Risk Rating – Medium):** Buried services are present at the Project Site. Up to date utility records to be obtained and reviewed prior to any intrusive work on-site.

Potential Contamination Risks: Contaminated Soil (Risk Rating – Moderate): Potential for construction and maintenance workers to encounter contaminated soil. Exposure times likely to be limited and risks would be reduced by wearing appropriate personal protective equipment

Re-use of Existing Piling: The proposed power station complex would lie within the former power block of the demolished Teesside Power Station. Available information shows that the former/demolished power station structures were orientated east-west, but the proposed power station complex structures would be orientated north-south. Some of the pile foundations that supported the former power plant structures would therefore underlie the proposed power plant structures.

It is considered that it may not be prudent to remove the old pile foundations as the cost of removal would be very high as some or all may extend into the underlying rock and would result in significant disturbance and softening of the ground. Re-using the existing pile foundations alone is also not considered feasible as the foundation requirement of the proposed new structures would be different to what could be provided by the old piles in terms of location and capacity. Two potential foundation options are proposed:

- **Option 1** – Install new piles avoiding the old foundations
- **Option 2** – Install new piles to supplement existing piles i.e. re-use existing piles in combination with new piles.

To support consideration of the feasibility of re-use of the existing piled foundations, testing of the old piles would be required. This will include destructive testing of selected piles not proposed for re-use (outside of the footprint of the new structures) prior to construction and further testing of each pile intended for re-use during construction.

4.4 SITE LEASE HEADS OF TERMS

The Heads of Terms (**HoT**) for the lease of the Site are under discussion between 8 Rivers and Sembcorp (as the landlord). This HoT is for a thirty (30) year agreement for the exclusive use of the Site.

4.5 OXYGEN SUPPLY

A permanent Oxygen supply of 3,823 tons per day (tpd) is required for the oxy-combustion process of the Project. The pipeline infrastructure that serves the Wilton Facility provides oxygen which is generated on Teesside by an ASU owned and operated by BOC. An independent market report on the O_2 supply market in the UK was produced for 8 Rivers and identified that substantial O_2 is currently available, though still significantly short of the required amount. Giving consideration to the expected 30 year life of the Plant together with the need for security of supply, the Project is expected to be served by dedicated ASUs operated by an industrial gas company. The expected location of the ASU's will be in close proximity to the Project Site with land on the Wilton Facility has been identified for this.

To accelerate deployment of an AFC power plant at Wilton International in Teesside, 8 Rivers have commissioned an oxygen supply study from Spiritus Group Limited (**Spiritus**) on the oxygen supply options that currently exist in the area, together with the possible options for future development. The current AFC design anticipates a need for approximately 3,823 tpd of oxygen which is anticipated to be supplied from a dedicated ASU located close to the power plant, operated under a long term oxygen supply agreement.

The existing ASUs and oxygen pipeline infrastructure in Teesside are owned by BOC and operates at 40 bar pressure. BOC is one contender for oxygen supply to the Project due to this existing pipeline network and has three ASUs which are not currently used at full capacity. This spare capacity could supply a significant percentage of the oxygen required by the Project. BOC could potentially supply oxygen from existing ASUs, however there would be increased operational expense through the use of older equipment. Installation of new ASU capacity would be required to meet the shortfall and would require capital expenditure.

The Spiritus study summarises the existing capabilities in the region and the ability of industrial gas companies to supply oxygen via new-build ASUs; and details the smaller spare ASU capacity owned by Air Products. Each of the suppliers have the capability to manufacture the ASUs that would have the capacity to serve the Project. Due to the volume of oxygen that is required, it is expected that some would have to build multiple ASUs to meet the Project needs. That said, a multiple ASU configuration would bring other advantages such as system redundancy that would provide increased security of supply.

To ensure an optimal supply solution, 8 Rivers have initiated a competitive process for oxygen supply to the Project with a clear requirement that the successful industrial gas company will supply oxygen via dedicated ASU assets with a long-term supply agreement in line with the lifetime of the Plant.

The interaction to date with the industrial gas companies has been extremely positive and they are engaged at varying levels with LOIs received or entering into negotiation of MoU. Technical and commercial negotiations are continuing with a selection of oxygen suppliers expected in 2021 followed by execution of the long term supply agreement.

4.6 NATURAL GAS SUPPLY

The Wilton Facility hosts a natural gas distribution network fed from Central North Sea gas and this ensures year-round security of supply. It should also be noted that Sembcorp have never experienced a loss of gas supply in their history. Natural Gas for Project Whitetail will be provided via a 24 inch Natural Gas main located on the north side of the Site which provides a more than adequate supply of gas for the Project. A new Above Ground Installation (**AGI**) metering station will be erected on the site close to where the existing 24'' main exists.

4.7 ELECTRICAL EXPORT

As the site is the former location of a large-scale power plant all of the electrical infrastructure for connecting to the grid remains in place in the form of two twin 275kV substations, Greystones A and B. Sembcorp had made a previous grid connection application for the connection of the TCPP Power plant and received approval for the connection of 1700MWe starting in September 2024. A modification to this application was made to National Grid to incorporate Project Whitetail with connection to Greystones 'A' with an expected connection date of September 30th, 2024. Further to this additional connection, future AFC plants were also incorporated into the modification application for a two further plants with connections currently expected in 2027 and 2030, producing nearly 1 GWe in total. At the time of writing National Grid have approved the modifications to the application although the project team are awaiting this in writing.

4.8 CO_2 EXPORT, TRANSPORTATION AND SEQUESTRATION

An eight inch pipeline is located adjacent to the gas connection at the northern boundary of the Site. This directionally drilled pipeline is circa 10km in length and routes through the Wilton Facility before passing underneath the River Tees to a facility on the north side of the river. This pipeline is currently unused and, during its very limited use, did not operate at or near its design parameters. Therefore, this pipeline has been identified as being ideal for the export of CO_2 should the project need to transport via the port for onward shipping to potential sequestration wells in the North Sea. The options for CO_2 transport and storage, including this pipeline, have been studied in detail by WSP. Additionally, an optioneering study (see appendix D) has been produced that will allow the project to better understand the current and future infrastructure in the region for CO_2 export from Project Whitetail. CO_2 offtake plans will continue to be refined with the project plan while keeping an eye to future developments in the sequestration space, both technically, commercially, and politically. Refer to Appendix D.

4.8.1 OVERVIEW OF EXPECTED CO_2 DISTRIBUTION

When operating at the design conditions the Plant is expected to generate 2,580.7 tonnes of CO_2 by-product per day. This generated CO_2 is expected to be transported via large scale carriers to a CO_2 hub terminal for pipeline reinjection into CO_2 storage reservoirs through a pipeline as illustrated in the Figure below.

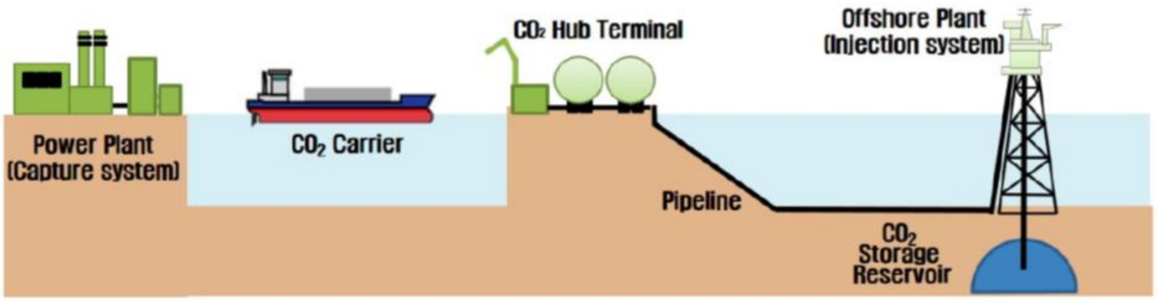

Figure 13 - Expected CO_2 Distribution

For the purpose of this report, the CO_2 distribution chain has been split into the following two stages.

4.8.2 STAGE 01 – PLANT TO INTERMEDIATE STORAGE

Refer to the WSP CO_2 Infrastructure Optioneering report, 70053760-WSP-00-XX-RP-PE-0001-S0_P02 dated September 2020, provided in Appendix D. For ease of understanding this document is summarised below.

WSP reviewed the CO_2 export options available and has presented the following technically viable alternatives for consideration:

- **Pipeline connection to the future NZT system:** A new pipeline connection to the future NZT system is considered feasible but requires further detailed information on both the Wilton Power Plant site and the NZT network before further design stages can be undertaken.
- **New marine export facility on the Tees:** A potential location for a new marine export facility on the Tees, adjacent to the Inter Terminals Seal Sands facility was identified and deemed feasible.
- **Existing marine export facility on the Tees:** The re-use of an existing marine export facility on the Tees, including CO_2 export from the Project Site by road tanker, was deemed feasible. It was not possible to provide a reasonable costing estimate for this option.
- **Transport to remote marine export facility:** Transport to a remote marine export facility, including consideration of possible rail loading, was deemed feasible. It was not possible to provide a reasonable costing estimate for this option.

4.8.3 STAGE 02 – INTERMEDIATE STORAGE TO FINAL SEQUESTRATION

The overall process for transferring CO_2 from the point of export from the Project to the large scale shipping carrier is shown in the following Figure:

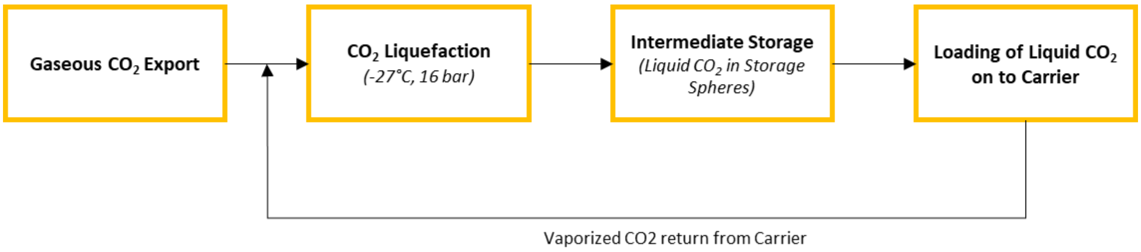

Figure 14 - CO_2 Distribution Block Diagram

The liquefaction process and storage conditions are expected to be finalised during the design stage. However, for the purpose of this report the liquefaction temperature has been selected based on the pressure rating of existing commercially available spherical tanks. In this example, it was assumed that the storage tank will be at 16 bara and -27°C.

Given that the vaporized CO_2 (**$_VCO_2$**) must be captured from the returning carrier as liquid CO_2 (**$_LCO_2$**) is loaded, it is beneficial to collocate CO_2 liquefaction and $_LCO_2$ storage tanks to minimize overall costs. The density of vapor and liquid CO_2 at -27°C and 16 bara is 41.8 and 1063 kg/m3, respectively.

The following Figure is provided to illustrate the expected $_LCO_2$ tank sizing and carrier operations necessary to export the generated CO_2 from the Project to the selected sequestration site.

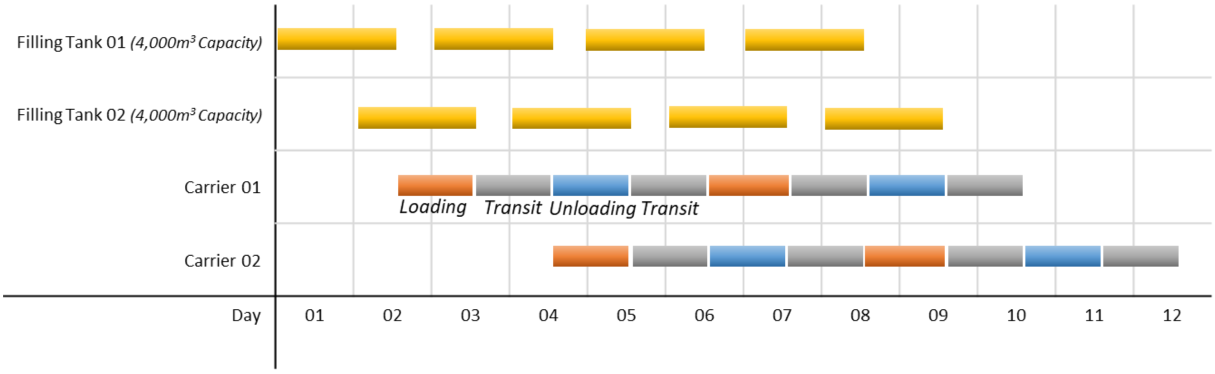

Figure 15 - Anticipated $_LCO_2$ Carrier Operations

4.8.4 PROJECT STATUS

As the export and sequestration is critical to ensuring that the underlying AFC technology can be deployed, significant effort has been expended to ensure a robust Transportation and Storage (**T&S**) system with redundancy and mitigating strategies were developed.

With this in mind, the Project has engaged with all the major CO_2 sequestration projects in the North Sea, both in UK and non-UK waters and in Iceland. The objective of this engagement was to fully understand the individual project timelines and how they fit within the expected Project Commercial Operations Date of Q1 2025. Several options for sequestration that meet with the timeline of the Project have been identified and 8 Rivers is currently in detailed discussions with the relevant counter-parties.

In order to transport CO_2 to other facilities in the North Sea, 8 Rivers have engaged gas storage companies as well as certain UK port operators with regards to CO_2 buffer storage. A key storage option in Teesside is currently being progressed and a letter of intent to buffer store CO_2 on the North Bank of the River Tees has been received during the pre-FEED process. The land identified for this storage facility is close to the pipelines that the Project would utilise and also well located to nearby jetty facilities which could accept the current fleet of CO_2 vessels being developed.

Considerable effort during the pre-FEED Study has progressed the viability of multiple options for sequestering CO_2 and as such 8 Rivers have received several Letters of Intent (**LOI**) for receiving, transporting and sequestering CO_2 as well as progressing Memoranda of Understanding (**MoU**) on the more mature projects that have alignment on the Project timeline. It should also be noted that other potential CO_2 emitters in the Teesside area would also benefit from other routes to sequestering CO_2 and a holistic approach to a more robust solution that provides redundancy may be required. Further detailed assessment of the technical, commercial and economic aspects of each option is still necessary as the Project further develops.

4.9 PROJECT DELIVERY

4.10 SUPPLY CHAIN

Refer to PA Consulting Supply Chain Report, 20210223_8 Rivers_SuplyChainReport_Final dated 23 February 2021, provided in Appendix L. For ease of understanding, this document is summarised as follows:

The proposed construction of the first full scale AFC generation plant in the UK presents significant opportunities for UK companies and supply chains to support this ground-breaking and novel project. This report concludes that the UK engineering and manufacturing sector is well placed from existing energy and aerospace capability to support the project across the value chain through supporting infrastructure, potential OEM support and sub-tier suppliers. The key AFC sub-systems (combustor, compressor, heat exchangers, turbine, and ancillaries) all have elements of uniqueness in specification and design that would require modifications to standard generation or aerospace technologies and processes.

The UK supply chain is strongest for the heat exchanger and turbine systems, a potential supply chain exists but not in depth for the compressor, pumps and valves systems and only with the combustor system is there a concern on current UK capability. The assessment is based on the understanding of the specifications and designs to date and may vary when designs and specifications are finalised. The research and report conclude that there are options to use the UK supply chain (noting the strengths and weaknesses identified) for all sub-systems.

Sub-System	UK Engineering Capability	UK Manufacturing Capability	UK Market Viability
Combustor	A	A	A
Compressor	G	G	A
Heat Exchanger	G	G	G
Pumps & Valves	G	A	G
Turbine	G	G	G

Key:
- R: Red: No significant UK industry presence identified
- A: Amber: There is a UK industry presence that could suit
- G: Green: High level of UK industry presence

Figure 16 - Capability of UK Supply Chain for Key Equipment

8 Rivers and NET Power have several key decisions to make regarding the potential procurement of this plant. The choice between seeking OEM suppliers who could supply finished products or to engage Tier 2 and Tier 3 suppliers with specific engineering capabilities e.g. machining, casting, forging or who can provide specific components e.g. casings and turbine blades.

The following items have been identified as key sub-systems:

- **Combustor:** The UK supply chain for specialised fabricated combustors is not extensive with specialised fabrication being more USA centric. The main UK OEM capability derives from aerospace at Rolls-Royce Hucknall (soon to be moved under Industria de Turbo Propulsores (**ITP**) who were a subsidiary of Rolls-Royce based in Spain, who are now independent and will be owning the Nottingham site going forward), which assembles and manufactures combustion housings and chambers and related complex fabrications. Depending on the specific design, companies who provide housing castings could potentially supply parts or sub-assemblies. For example, Siemens Energy have used companies like Russel Ductile castings (Scunthorpe) for steel castings and William Cook Cast Products Ltd. (Sheffield) for combustion chamber housing and casings. There are a variety of machinists who can machine a cannular casing for industrial gas turbines, such as Bromford Industries in Birmingham and Manthorpe Engineering. There is a proven fabrication capability for the UK aerospace and energy sector that could be employed but this would depend on the level of specialism that the novel combustor would require.
- **Compressor:** There are two main compressor systems required, the first being a hot-gas internally geared compressor, the second is a recycled CO_2 compressor with accompanying

coolers and pumps. Both compressors and accompanying equipment, are commercially available from multiple vendors. The hot gas compressor is more challenging as it requires three stages of compression that would need a high level of engineering capability. Key manufacturers include organisations such as Siemens (within their UK footprint) and Howden who have a global presence across energy manufacturing but compressor specific sites across UK. Note that if hot gas compression system was broken down into some of the sub-components such as the compressor blades, this is a large supply chain that exists in the UK to support aero requirements.

- **Heat Exchanger:** The heat exchangers associated with this project are much smaller and cheaper to build than massive boilers for conventional thermal power generation plants. This means that the constraint of 'machine size' is less critical, which favours the UK market where large-scale manufacture has moved towards being off-shored. Heatric, a well-regarded global heat exchanger manufacturer, is based out of Poole. They are a provider to both the oil and gas and the nuclear markets, providing field service engineering of the 'compact' type heat exchangers which may be required by this project.
- **Pumps & Valves:** Flowserve is a global supplier of pumps and valves who have a centre for manufacturing in Sussex. Doosan Babcock in Renfrew is a specialist energy company across thermal, nuclear, and petrochemical markets. Whilst they are primarily boiler specialists, they have experience across steam generation and in particular pipework and pressure valves which could be utilised by this project. Mersen are conveniently located on Teesside and have a division dedicated to anti-corrosion/graphite solutions. The company also have maintenance and service-based offerings. There are of course sub-components around precision machining and general fabrication and supporting infrastructure that the UK industry would be able to provide across a variety of manufacturers and engineering firms.
- **Turbine:** It is established that the 8 Rivers and NET Power engineers agree that most established and capable gas turbine manufacturers could manufacture this component but that they would need a degree of engineering collaboration and support from 8 Rivers and NET Power. Broken down into its main components, the turbine is a series of blades and vanes through several stages, with the fixed blades attached to the turbine casing. In part due to UK gas turbine industry, the UK has full value chains for this type of engineering. The novelty of this specific turbine is the higher temperature required which pushes the engineering and manufacturing closer to aero-derivative turbines which the UK supply chain is equipped to provide. Rolls-Royce has significant experience in ensuring that turbine blades can reach extreme temperatures and has the Advanced Turbine Blades Facility in Rotherham which produces turbine blades through growing single-form crystal. Rolls-Royce also has a Turbine Disc facility in Tyne so depending if they were engaged on this project, they might see an opportunity from an engineering or manufacturing perspective. Considering the casing on its own, there are a number of capable machinists in the UK, for example Goodwin International based out of Stoke-on-Trent.

  A significant number of UK-based companies have experience in the supply of high integrity components such as castings and forgings (e.g. Doncasters, Howmet Aerospace). There is a mature supply chain for machinists with vertical turret lathes or CNC capability versed in high-grade materials and working with these suppliers.

4.11 ECONOMIC IMPACT

Refer to Vivid Economics Report, 'The catalytic potential of the Allam Fetvedt cycle technology within the UK CCS sector' dated February 2021, provided in Appendix M. For ease of understanding, this document is summarised as follows:

The Allam Fetvedt Cycle technology will lower the costs of reaching the UK's net zero target. Under the CCC's 6th Carbon Budget, the UK will require 15GW of gas-fired generation with carbon capture and storage (gas CCS) generation capacity by 2050 to meet its net zero target. The AFC promises higher efficiency than other existing gas CCS technologies while providing a near 100% carbon capture rate. Its ability to generate clean electricity at a reasonable cost was recognised by the MIT Technology Review as one of the 10 Breakthrough Technologies in 2018, with a significant potential to be deployed widely across the globe.

The Vivid Economics report quantifies the direct, indirect and induced jobs that can be brought by deploying AFC technology in the UK. The estimates focus on domestic jobs supported by (a) the planned deployment of a 300MW unit at the Wilton International industrial site in Teesside, and (b) wider UK deployment of the AFC technology assuming it reaches half of the UK's gas CCS capacity, i.e. 7.5GW by 2050. The key results are presented in Table 4 below. It should be noted that these estimates do not distinguish jobs that are additional to what would otherwise occur in the economy.

The deployment of a single AFC unit at Wilton could support 610 direct jobs during the peak of the construction phase. This contains a mix of manufacturing and services jobs required for construction and installation, some of which represent key technologies such as advanced heat exchangers. Besides, the project supports another 1,620 indirect and induced jobs. During its operation, the project could support 30 direct jobs alongside 560 indirect and induced jobs per year.

UK wide deployment of AFC technology could support 1,050 direct jobs in 2030, in addition to 1,790 indirect and 1,700 induced jobs. Indirect jobs are spread across UK firms in all major sectors, with a higher concentration along the supply chain for necessary goods and services. These sectors include fabricated metal products, gas distribution, electricity, and construction. Induced jobs are supported by extra spending in the economy, concentrated in retail trade and the hospitality sector. The estimated number of direct jobs represent 15-20% of long-run estimates of domestic CCUS direct jobs in the EINAs report published by BEIS.

Early deployment of the AFC technology could act as a much-needed catalyst to increase skilled labour in the CCUS sector, which will help the UK reach Net Zero and support up to 50,000 export jobs by 2050. While the deployment of CCUS promises some high-quality jobs, it also demands a large number of skilled workers that will be key to the green economy. Labour market statistics indicate a widening shortage of skilled workers in the manufacturing and construction sectors. This may hinder the development of CCUS infrastructure in key industrial regions. Expanding and upskilling the existing workforce will be important to realise the PM's Ten Point Plan for a green industrial revolution.

AFC Deployment Scope	Direct Jobs	Indirect Jobs	Induced Jobs	Annual Total
Single Unit at Wilton – Construction peak	610	640	780	2,230
Single unit at Wilton – Operation Phase	30	90	90	210
UK wide deployment – 2030	1,050	1,790	1,700	4,540
UK wide deployment - 2040	1,180	2,340	2,280	5,800

Table 5 - Job estimates of the annual number of jobs supported by deploying AFC technology

4.12 PLANNING AND PERMITTING

4.12.1 PLANNING HISTORY

In April 2019 Sembcorp Utilities was granted a Development Consent Order (**DCO**) by the UK Secretary of State for the construction of the 1748MWe CCGT Tees Combined Cycle Power Plant (**TCPP**). The plant, which was due to be constructed at the Site, never moved forward, however the DCO remains valid as it is owned by Sembcorp.

Within the DCO it was envisaged that the TCPP development would comprise:

- **Work No.1A:** Up to two separate Combined Cycle Gas Turbine (**CCGT**) units of up to 850 MWe net electrical output each, with each generating unit including a gas turbine, steam turbine and

electricity generator, heat recovery steam generators (**HRSG**); condensers; emission stacks; and main and auxiliary transformers
- **Work No.1B:** Cooling infrastructure including up to two banks of hybrid cooling towers; pumps; and sampling and dosing plant
- **Work No. 2A:** Associated development in connection with the project including a permanent laydown area, vehicle parking area, internal roadways and footpaths, lighting and signage
- **Work No. 2B:** Associated development including an area reserved for carbon capture, compression and storage, to be laid out as vehicle parking and used for open and covered storage and laydown during construction

Construction of the project was planned to proceed under either one of the two following scenarios:

- Two CCGT trains of up to 850 MWe net electrical output are built in a single phase of construction to give a total net capacity of up to 1700 MWe.
- One CCGT train of up to 850MW net electrical output is built and commissioned and within an estimated 5 years of its commercial operation the construction of a further CCGT train of up to 850 MWe net electrical output commences.

Sembcorp, together with 8 Rivers, plan to the ‘re-use’ the DCO for the purposes of deploying Project Whitetail.

With regards to the environmental permit, the Secretary of State noted that the proposed TCPP Development would be subject to the Environmental Permitting regime under the Environmental Permitting Regulations 2010 covering operational emissions from the generating station. The Environment Agency would have to examine information on air quality (including air dispersion modelling), noise and other emissions to the environment which would be submitted as part of the Environmental Permit application.

It was noted in the DCO that Sembcorp has yet to submit an Environmental Permit application, although the Environment Agency has stated in the DCO that based on the information submitted to date there is no indication to suggest a Permit would not be issued. In the circumstances, the Secretary of State considers there is also no reason to believe the Environmental Permit will not be granted in due course. Given that the emissions from the Project are significantly less than the proposed TCPP development it is assumed that the same statement would apply.

INDEPENDENT OWNER'S ENGINEER REPORT

Refer to the Independent Owner's Engineer Report produced by WSP, 70053760-WSP-00-XX-RP-PM-0002-S3_P03 dated February 2021, provided in Appendix Q. For ease of understanding this document is summarised below:

WSP were engaged to provide an Independent Owner's Engineering report on the current status of Project Whitetail. This report constitutes the professional opinion of WSP as to whether the project objectives have been achieved and comments on further development of the Project.

The Feasibility study included a Pre-FEED, which developed a Proposed AFC plant design based on a generic UK site. This design represents a true 'base case' design and is suitable for deployment in the UK. Technical review highlighted five design comments that should be implemented at the next design stage; however, these do not prevent the project from moving to the FEED stage. The design of site-sensitive elements such as cooling towers and geotechnical structures as well as the opportunities and alternatives to enhance the Proposed AFC plant design to fine-tune the performance characteristics of the plant, are expected to be investigated during the FEED stage.

Initial data indicates that the Proposed AFC plant has competitive performance characteristics to similar scale natural gas plants, but with a clear zero-emissions benefit that is in alignment with established net-zero and CCUS government policy. There is a clear need for long-duration dispatchable energy to supplement renewable energy in the future of the UK electricity system.

While a site has not yet been formally selected, the Wilton International site in Teesside has been examined as a provisional site. The geography and the existing and planned infrastructure indicate the Wilton site it is highly suitable to accommodate the AFC plant. It also located within the Teesside Industrial Cluster, close to the proposed Net Zero Teesside project which could provide an economical long-term CO_2 offtake.

Realistic strategies have been developed to gain planning permission and environmental permits for the Proposed AFC plant at the Wilton site. If this site is selected, it is entirely feasible that the Proposed AFC plant can be consented as a Material Change to the Tees CCPP DCO and this would be a more realistic and efficient consenting strategy route than undertaking a new DCO procedure.

The Proposed AFC plant requires a number of commercial interfaces to operate, such as oxygen supply and CO_2 export. Those negotiations are critically important to the project and 8 Rivers are already in discussions with associated stakeholders.

McDermott's EPC CAPEX estimate of £359.62 million for the Base Case plant appears reasonable for deployment at a generic UK site. WSP's cost assessment estimated a total CAPEX 3.2% lower than the McDermott estimate, using comparable assumptions and exclusions. Notwithstanding, the low variance gives confidence that the costing is within the accuracy ranges expected at this early stage, and that the costs are reasonable.

McDermott's CAPEX estimate represents a standard design for deployment at a generic UK site. The McDermott assumptions and exclusions from the EPC CAPEX estimate have been indicatively quantified at an additional £20.95 million. This would take the total Base Case EPC CAPEX cost to £380.57 million. It is also important to recognise the other Owner and EPC CAPEX costs which remain unquantified at this stage.

Risk studies were conducted throughout the project and analysed technical and project risks to a level of detail beyond that normally seen at Feasibility Stage. The commitment of a detailed suite of mitigation actions, including many which are already complete or in progress, is deemed to reduce project risk to low levels, which is reflected in the Monte Carlo Analysis.

This Feasibility Study presents a compelling case for the Proposed AFC plant to be deployed in the UK. The Pre-FEED appears feasible for a generic UK site and there are no technical blockers which should prevent this project from moving to the FEED stage.

PROJECT DEFINITION FINALISATION RESULTS

6.1 CLASS IV CAPEX ESTIMATE

Refer to the McDermott Pre-FEED report, 626236060-000-PE-RP-0001, dated February 2021, is included in Appendix A. For ease of understanding this document is summarised below.

The EPC cost estimate produced as part of the Project pre-FEED established a representative market price for the Project. Final pricing will depend on the final design definition, site specific constraints, project schedule, and contractual commercial terms. The estimate provided represented the cost to construct a single AFC unit under an EPC contract with evaporative cooling and oxygen supplied via a Third Party pipeline on a generic green field site. The pre-FEED provided by McDermott estimated that the total EPC cost on this basis would be £372.1M.

The development of the design during the Pre-FEED resulted in reduction in power island footprint that translated to cost savings due to approximately 25% reduction in bulk quantities (i.e. Piping). The reduction in turbine inlet temperature led to savings not only due to the lower cost of the turbine, but also to less expensive, more available piping materials.

McDermott, on behalf of 8 Rivers, developed a Pre-FEED study for the design of a standard commercial scale NET Power plant for at a generic site within the UK deployment (UK Reference Plant). This Pre-FEED optimised and aligned the design of the AFC unit to the electrical requirements, climate conditions, and other features specific to a UK region project.

The following estimated CapEx was determined for a single AFC unit with a turbine inlet temperature of 925°C without ASU:

Parameter	Value
Gross Unit Power Output (MW)	436.4
Net Unit Power Output (MW)	296.0
Net Unit Heat Rate (LHV) (kJ/kWh)	6,689
Net Unit Efficiency (%)	53.8
CO_2 Capture Rate (%)	near 100%
Total EPC Unit Cost (£M)	372.1
Unit Cost per kW	1,257

Table 6 - Estimated Single Unit CAPEX

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6.2 OPEX ESTIMATE

The following table provides an estimate of the Operating Costs of the Project over a notional 40 year period. Refer to Appendix E for a detailed breakdown of the estimated OPEX.

	Annual Average (£M)	**40 Year Total (£M)**
Sub-Total	£116,030.809	£4,757,263.158

Table 7 - Estimated Single Unit OPEX

ABBREVIATIONS AND ACRONYMS

The Following abbreviations and acronyms are used throughout this report:

AFC	Allam- Fetvedt Cycle
AGI	Above Ground Installation
ASU	Air Separation Unit
BEIS	Department for Business, Energy & Industry Strategy
BCA	Bilateral Connection Agreement
CapEx	Capital Expenditure
CCGT	Combined Cycle Gas Turbine
CCS	Carbon Capture and Storage
CCUS	Carbone Capture Utilisation and Storage
CO_2	Carbon Dioxide
COMAH	Control of Major Accident Hazards
CTG	Combustion Turbine Generator
DBHE	Diffusion Bonded
DCO	Development Consent Order
DECC	Department for Energy & Climate Change
FEED	Front End Engineering Design
H	Enthalpy
H_2O	Water
HGC	Hot Gas Compressor
HRSG	Heat Recovery Steam Generator
HXR	Recuperative Heat Exchanger
IGCC	Integrated Gasification Combined Cycle
LHV	Lower Heating Value
NGCC	Natural Gas Combined Cycle
O_2	Oxygen
P	Pressure
P-H	Pressure - Enthalpy
$_SCO_2$	Supercritical Carbon Dioxide
SCPC	Supercritical Pulverized Coal
STHE	Shell and Tube
TCPP	Tees Combined Cycle Power Plant
TPD	Tons per day
TPS	Teesside Power Station

Appendices

A. **McDermott Pre-FEED report**
B. **Not Used - Confidential**
C. **Site Layout**
D. **CO_2 Distribution and Storage Evaluation**
E. **OPEX Estimation**
F. **Site Geotechnical Survey**
G. **Not Used - Confidential**
H. **Not Used - Confidential**
I. **Not Used - Confidential**
J. **Not Used - Confidential**
K. **Not Used - Confidential**
L. **Supply Chain Report**
M. **Economic Impact Report**
N. **Not Used - Confidential**
O. **Preliminary HAZID**
P. **Risk Register**
Q. **Independent Owner’s Engineer Report**
R. **Heat and Mass Balance and Process Flow Diagram**

Table of Contents

1 EXECUTIVE SUMMARY

This report presents the Pre-FEED (Pre-Front End Engineering Design) work performed by McDermott on behalf of 8Rivers LLC for the design of a standard commercial scale NET Power plant for UK deployment (the UK Standard Plant), at an as yet undefined location.

The NET Power plant is able to achieve highly efficient and low cost electricity generation with zero emissions. NET Power uses the proprietary Allam-Fetvedt Cycle (AFC) to combust natural gas and oxygen to generate electricity. The resulting carbon dioxide from combustion is captured in a semi-closed loop and recycled through the cycle, allowing power to be generated without releasing the carbon dioxide to atmosphere. A portion of the recycled carbon dioxide is sent for utilization or sequestration.

NET Power has undergone nearly 10 years of commercial development, beginning with the 25 MW_e/50 MW_t Small Scale Project Test Plant (Test Plant) design in 2010. The Test Plant was successfully constructed and commissioned in 2018, which validated the feasibility of the technology. Since then, the commercial scale design utilised in development of the UK Standard Plant has been further enhanced and optimized from three prior Pre-FEED phases that created the preliminary design (January 2017), minimized high-nickel alloys (December 2018), and lowered turbine inlet temperature to allow selection of more standard materials to reduce project technology risk and cost (Early 2020). The UK Standard Plant Pre-FEED customizes the design work performed to date for the electrical requirements, climate conditions, and other features specific for the northern UK region and provides an updated AACE Class IV EPC estimate, a Level 1 EPC project schedule, and basic engineering deliverables.

McDermott has developed a design for a Base Case at 900°C turbine inlet temperature and an Alternative Case at 925°C for the UK Standard Plant. Table 1.1 presents the estimated performance and CAPEX for both.

Table 1-1 UK Standard Plant Case Performance

Plant Performance	Units	Base Case	Alt Case (3)
Turbine Inlet Temperature	°C	900	925
Net Output	MW_e	279.4	296.0
Net Heat Rate (LHV (1))	kJ/kWh	7,078	6,689
Net Efficiency	%	50.9	53.8
Purified CO_2 Capture Rate	MTPA	0.926	0.935
CO_2 Allowances Avoided (Approximate)	M£/year	21.0	21.0
Total EPC Cost per Unit (2)	M£	359.6	372.1
Cost per kW	£/kW_e	1,287	1,257

(1) Lower Heating Value
(2) Does not include Air Separation Unit (if necessary)
(3) Data presented is for the Optimized Alternate Case as described in Section 9.1.

The Base Case design demonstrates the feasibility of deployment of the NET Power technology within the UK, a preliminary Hazard Identification (HAZID) study on the design was facilitated by an independent team. The engineering work formed the basis of the cost estimate with engagement of equipment suppliers in the European Market for a number of the most complex mechanical equipment items. A high level construction execution approach was developed based on the major subcontracts envisaged and preliminary engagement with several UK subcontractors was incorporated into the final estimate.

The Alternative Case represents a scope of work added to this project midway through completion due to improved turbine conditions provided to McDermott by NET Power with increased net output. The less rigorous technical definition available for the alternative case limits this estimate to AACE Class V. For this analysis, both the Base Case and the Alternative cases utilize identical thermal input (550 MW) and demonstrate the efficiency improvement achievable via higher turbine inlet temperature. However, the thermal input is scalable for both to achieve a desired net output.

For both cases the report identifies some options to lower the £/kWe for incremental increases in CAPEX via premium efficiency or higher performance equipment. Optimizing these parameters for owner's levelized cost of electricity (LCOE) and net present value (NPV) targets remains to be completed outside this pre- FEED evaluation.

The CO_2 Recuperative Heat Exchangers and the Combustion Turbine Generator (CTG) are the most technically novel pieces of equipment for the plant. Potential turbine suppliers are currently developing the design of the commercial scale CTG. The historical NET Power supercritical CO_2 (sCO_2) turbine design operates at 60 Hz. The basis for this pre-FEED considers a 50Hz machine is commercially available. The recuperative heat exchanger design, developed by Lummus Heat Transfer for this study, optimizes heat recovery for the extreme temperature and pressure conditions required by the cycle. The rest of the equipment specified for the NET Power plant utilizes equipment that is proven and commercially available from international equipment suppliers, coordination with whom is essential to programme success.

As the UK's energy mix changes due to decarbonisation, the mix of renewable generation will increase. However, as this transition occurs, there is still a need for fossil fuelled, cost effective, reliable, dispatchable power with a rapid start-up response to manage the intermittency of renewable energy. NET Power is a well suited technology to achieve this goal, with the key benefit of carbon capture. A benchmarking exercise was conducted as part of the Pre-FEED cost estimate development to compare the cost of an nth of a kind (NOAK) NET Power Plant against other carbon capture technologies for the UK market. LCOE calculations are outside the McDermott scope of work, so, it is recommended these are developed to further compare the NET Power technology to other net zero options.

2 PROJECT BACKGROUND

8 Rivers is undertaking the 'Allam-Fetvedt Cycle (AFC) Power Plant for UK Deployment Project', a Project under the Carbon Capture, Utilisation and Storage (CCUS) Innovation Programme supported by BEIS. The Project is a feasibility study that considers the deployment of this revolutionary power cycle to bring the technology to the UK. The AFC is a technology that achieves highly efficient and low cost electricity generation with zero emissions through the novel use of supercritical carbon dioxide as the primary process fluid.

Alternative renewable energy options, such as wind and solar cannot reliably, economically, or technically meet global energy needs without considerable technical advancements. Thus, alternative technologies, such as NET Power, are necessary to augment renewable power generation for the coming decades.

The overall project is being led by 8 Rivers, with McDermott (MDR) providing the 'NET Power UK Standard Plant BEIS Pre-FEED' engineering and cost input to the overall feasibility study scope. This report summarises the work that has been performed in the MDR executed Pre-FEED.

The overall goal of this feasibility study is to advance the commercial scale design, cost and business case of a project providing 300 MWe of dispatchable, zero carbon electricity to a nonspecific location in the UK. The feasibility study provides a cost estimate to AACE Class IV for the Base Case and one to AACE Class V for the Alternative Case, advancing the project to the point of being ready to proceed with deployment of the full-scale system in the UK.

2.1 NET Power Partners

8 Rivers, MDR, Exelon and Occidental Petroleum are partners in the NET Power programme. This unique collection of companies combines expertise in research and development, patent protection, engineering, procurement, construction, power generation, along with commercial experience with CO_2 in enhanced oil recovery (EOR) processing.

Additionally, NET Power continually contracts numerous consultants to ensure that the equipment, industries, and markets are completely understood to reduce the risk from first-of-a-kind equipment/facility.

2.2 Project Deliverables

The UK Standard Plant Pre-FEED deliverables included in this report are as follows:

- Project description
- Export capacities and plant performance including auxiliary loads

- Preliminary engineering deliverables (HMB, PFD, P&IDs, equipment lists, load lists, single line diagram, plot plans, control system and telecommunication block diagrams.)
- Preliminary subcontracting plan utilizing local vendors in the UK
- Class IV Cost Estimate per AACE-18R-97 and Level 1 EPC Schedule
- Identification of modularization opportunities with current equipment and layout
- Support of a HAZID on the design

2.3 NET Power Cycle Description and Comparison to Alternative Power Cycles

2.3.1 NET Power Technology Description

The UK Standard Plant utilizes NET Power's proprietary AFC, which reacts natural gas with oxygen in a series of parallel, direct fired oxy-combustors feeding the turbine-generator to reliably produce electricity and carbon dioxide (CO_2) at pipeline conditions ready for sequestration or other commercial applications. The plant also captures approximately 98% of CO_2 emissions economically and efficiently with an order of magnitude lower NO_x emissions that are not dependent upon traditional components (ammonia and catalyst) typically required to control it.

The AFC utilizes a transcritical, semi-closed loop, direct oxy-fired Brayton cycle with supercritical CO_2 (approximately 34.0 MPa and 200 - 600°C) as not only the working fluid, but also as the oxygen diluent and the turbine coolant. CO_2 combines with natural gas and oxygen in the combustor to form a heated, supercritical gas that expands through the turbine and exhausts to a series of recuperative heat exchangers. The combusted gas mixture provides the motive force to drive the turbine-generator set and produce electrical power.

The high-temperature turbine exhaust stream (approximately 4.0 MPa and 600°C) contains a carbon dioxide concentration that is > 90%. Evaluation of site specific fuel gas composition remains for FEED studies, as the current modelling assumes pure methane. The turbine exhaust passes through the recuperative heat exchanger train for heat recovery prior to subsequent waste heat rejection to atmosphere in the Turbine Exhaust Coalescing Water Separator. This low temperature heat sink further cools the gas mixture, condenses water produced via combustion, and separates the water from the cycle to produce saturated CO_2 for recirculation. Intercooled, multi-stage recompression of the CO_2 followed by aftercooling produces a dense supercritical gas mixture suitable for efficient pumping to the targeted pressure conditions of the CTG. The high pressure stream passes through the recuperative heat exchangers, for reheating, prior to entering the CTG combustors.

In conjunction with the recuperative heat exchangers, a portion of the turbine exhaust stream passes through the Hot Gas Compressor where the adiabatic heat of compression raises the fluid temperature. This stream returns to the recuperative heat exchanger network to transfer that heat to the recycle CO_2, oxidant, and turbine coolant streams flowing through the exchanger(s) to the CTG. The hot gas rejoins the recycle CO_2 stream at an optimal location in the compression train.

A slip stream of the high pressure CO_2 stream is exported via a pipeline or other method to maintain the inventory of CO_2 in the cycleThe inherent low levels of nitrogen in the feed streams virtually eliminates the production of NO_x relative to traditional combustion processes and simplifies the purification process.

Pure oxygen, from a pipeline or local air separation unit (ASU), mixes with a portion of the recirculating CO_2. This diluted stream, known as oxidant, reduces flammable inventory and explosion risks associated with high-pressure pure oxygen by reducing the overall stream oxygen concentration to levels comparable to that of air. A dedicated Oxidant Pump compresses and discharges the oxidant through the recuperative heat exchangers for preheating prior to injection into the combustor.

The UK Standard Plant generic site layout encompasses an area of approximately 3.0 hectares (including approximately 1.1 hectares for the cooling tower and associated equipment), as depicted in Appendix A.3. The refined layout minimizes the electrical raceway and piping runs, especially the more expensive high-energy piping, while optimizing operations and maintenance features. An open-loop evaporative cooling tower, which provides heat rejection from the process via its lube oil coolers, generator coolers, and process coolers, occupies much of the footprint.

2.3.2 Comparison to Brayton Cycle

The efficiency advantage of the AFC over conventional Brayton cycles is due to the fact that carbon dioxide is superior to air (predominantly nitrogen and oxygen) as a working fluid with respect to heat capacity and density, resulting in it containing more energy per unit volume.

An analysis of the combustion processes (air versus oxy-fired) illustrates the basic benefits of the AFC. Combustion of methane (CH_4) with oxygen (O_2) occurs per the following formula:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

For every molecule of methane, two molecules of oxygen must be supplied. Typically, combustion processes require excess oxygen to ensure complete combustion of the methane. The composition of air is approximately 4 molecules of nitrogen for every molecule of oxygen. This means that traditional combustion processes contain mostly nitrogen. This results in a fuel efficiency of approximately 40%, primarily due to the concentration of nitrogen and partially due to the unfavorable physical properties of nitrogen (relative to CO_2). The injection temperature of the working fluid in a traditional combustion gas turbine (aka air-fired) is approximately 425°C after the heat of compression has been added. The AFC differs significantly in the total amount of energy entering its gas turbine. The ratio of oxygen to methane is still essentially 2:1, with only minor amounts of excess oxygen required to ensure complete combustion, but there is no nitrogen. Oxygen is supplied essentially free from nitrogen, which virtually eliminates nitrogen from the system along with its less favorable physical properties and NO_x potential. This results in approximately 30 mass units of carbon dioxide for every 1 unit of oxygen (i.e. a very high concentration of CO_2 with its favorable physical properties). CO_2 is approximately 1.5 times the density of nitrogen at combustion conditions, where the heat capacity of CO_2 is approximately 10% higher as well. This minimizes circulating fluid mass and volume requirements, and leads to very high gross turbine efficiency. This allows the net efficiency of the UK Standard Plant to be competitive with a combined cycle system without carbon capture as capital estimates, heat rates, and efficiencies presented in Section 5.1, 8.1, and 9.1 demonstrate.

2.3.3 Comparison to Rankine Cycle or Other Cycles

Despite the fact that the Rankine cycle is an established mature technology with nearly a century of continual improvement, the NET Power AFC actually offers higher efficiency with integrated carbon capture compared to a single reheat Rankine cycle power plant. For comparison, the NET Power AFC offers approximately 5% efficiency improvement with carbon capture included over Rankine Cycle and USC at comparable turbine inlet temperatures (both cycles offer higher Carnot efficiencies with higher temperatures).This does not include the subsequent efficiency penalties required to add post combustion carbon capture and sequestration (CCS) to Rankine cycles. State of the art Natural Gas Combined Cycle (NGCC) plants offer efficiencies approaching 60%, but do so at the cost and complexity of two cycles without carbon capture. CCS penalties are currently estimated at 6-12% of the total power output for commercial scale operations and require the additional capital costs for the CCS systems, which approximately double the plant CAPEX, as shown in Table 8-2. Additionally, while the CCS captures over 90% of the CO_2, it cannot capture all of it economically, which means NET Power offers the highest potential economical carbon capture as demonstrated in Table 8-2. While retrofitting NGCC plants with CCS systems is the only choice for existing facilities, the comparison for new installations comes down to an economic analysis. With less and smaller equipment, a UK Standard Plant provides competitive CAPEX with best in class carbon capture. An exhaustive comparison of current power generation cycles is available in Fundamentals and Applications of Supercritical Carbon Dioxide (sCO_2) Based Power Cycles by Brun, Friedman, and Dennis.

2.4 Technical Focus Areas/Challenges

The Pre-FEED development programme has found the following four systems to be the most technically challenging in the design and development of the UK Standard Plant, and believes these to be focus areas for continued evolvement, likely through the first decade of commercialization as the technologies further mature. The Pre-FEED efforts have successfully developed these systems for commercialization, and future improvements, as the technology matures, offer even higher plant efficiencies and lower heat rates than current projections in this report.

2.4.1 Combustor Turbine Generator (CTG)

The design of the supercritical CO_2 (sCO_2) CTG began with the initial design at the onset of the commercial scale turbine development in 2013. The continued evolution of turbine conditions includes updates based on experiences during the Test Plant design, construction, and commissioning. The current turbine conditions, specifically a lower turbine inlet temperature selected by NET Power in 2019, minimize risk associated with the recuperative heat exchanger network, and eliminate the use of extremely expensive nickel alloys with limited commercial experience and supply.

2.4.2 Recuperative Heat Exchangers

The recuperative heat exchanger network cools the high temperature exhaust and heats the high pressure Recycle CO_2, Oxidant, and turbine coolant streams, while also recovering heat from the Hot Gas Compressor. The high operating temperature, pressure, effectiveness, and duty required represent a significant design challenge. NET Power has commissioned an independently developed packaged modular system for the recuperative heat exchanger network. This proprietary network uses an optimized combination of diffusion bonded (DBHE) and shell and tube (STHE) type heat exchangers to achieve the desired outlet temperature for Recycle CO_2, Oxidant, and turbine coolant streams while collecting condensed water from the turbine exhaust stream at low points. The system design specifies specific materials to ensure that none of the allowable stresses of any components are defined from time dependent (creep) properties, and the equipment layout minimizes thermal stresses experienced during operation, especially in the higher temperature sections, where a proprietary support system forces thermal expansion to occur in piping sections experiencing the lowest temperatures in the recuperative heat exchanger network. The system employs a modular design to minimize shipping (reduced modules sizes and counts) and field construction costs, with a significantly reduced equipment footprint and reduced piping in the balance of plant.

2.4.3 Hot Gas Compressor (HGC)

Installations without ASU heat integration require maximum HGC compressor sizing. The HGC in this design is an independent, motor-driven multi-stage machine without intercooling (to maximize outlet temperature) that discharges through the recuperative heat exchanger network and into the recompression train. The HGC adds the requisite high-quality energy (adiabatic heat of compression) into the recuperative heat exchanger network to maximize combustor feed temperatures and plant net output while minimizing heat exchanger area and plant heat rate.

The design development of the HGC has overcome a number of technical challenges. First the discharge temperatures necessary for quality heat input challenge the lubrication, bearing, and sealing systems. Each of these has required coordinated development with suppliers, and was complicated by the CO_2 environment since it is an excellent solvent and aggressively corrosive at compression conditions. High temperatures also impact compression density, Mach numbers, impeller tip velocities, and numerous other compressor design parameters. The current HGC design is the result of more than 5 years of previous collaborative development with potential suppliers.

The current design consists of a single piece of turbomachinery, which is within the existing capability of equipment suppliers, but it is encroaching on demonstrated commercial sizing limits for both the compressor and the gear. Options for smaller HGCs (i.e. 2 x 50%) should be considered during FEED, as this may operational benefits at the penalty of cost (i.e. startup, turndown, etc.). Coordinated refinement of the equipment design, process conditions, and control systems is ongoing and crucial for continuation through FEED.

2.4.4 Potential for ASU Heat Integration

The UK Standard Plant Pre-FEED project does not include an ASU; however, if an ASU is being considered near to the selected project site, there are options for integration between the two plants. The NET Power team has worked with several ASU suppliers to obtain commitment from them to provide a custom heat recovery system should this option be selected by a future owner. This requires optimizing the compression train for heat recovery and transferring that heat to the power cycle via a heat transfer fluid loop with provisions that allow the power cycle and the ASU to operate independently. However, when integrated with the UK Standard Plant, the increase in power consumption at the ASU is minor compared to the increase in electrical output at the power block. While this is somewhat contrary to the typical ASU operation, NET Power successfully negotiated incorporation of this arrangement with several of the major global industrial gas suppliers in 2019. This represents one of the largest commercial hurdles that the project team targeted to resolve during the commercial plant development work to date. While this option increases the CAPEX of the combined overall facility, it also increases the net efficiency of the power cycle and is a consideration for owner ROI and LCOE evaluations in FEED studies.

3 Basis Of Design

3.1 Standard Plant Design

In 2016, NET Power commissioned MDR to develop a Pre-FEED (Front End Engineering Design) for the first-of-a-kind NET Power Commercial Plant design. The Pre-FEED Phase I was completed in January 2017, culminating in a preliminary design and a design review of in-process work products. At that time, NET Power determined that a second iteration of the design (Pre-FEED Phase II) was necessary in order to reduce the capital cost of high energy pipe and heat exchangers. The Pre-FEED Phase II scope included the development of early engineering design deliverables, a preliminary project schedule, and a Class IV EPC cost estimate for a NET Power Commercial Plant. In July of 2019, NET Power further decided to reduce project cost and risk by modifying the design to a 900°C turbine inlet temperature, which allowed more commercially proven and available materials of construction in the piping and components around the sCO_2 turbine. The Pre-FEED Phase III completed the current NET Power natural gas fired supercritical CO_2 oxy-fuelled power cycle scope, technology, and the project design for the commercial scale.

3.1.1 UK Standard Plant Design

The BEIS programme does not specify a particular net output target for the design basis for this study. As such, the NET Power Commercial Plant Pre-FEED Phase III design was selected and modified for the specific conditions of a generic site location in the North East of England in the United Kingdom to create the design basis for the UK Standard Plant design presented in this report. Henceforth, this Standard Design is referred to as the Base Case (900°C Turbine Inlet) and is the basis for developing the overall plant performance (Section 0) and indicative Class IV cost estimate (Section 0). Section 9 presents several investigated alternative configurations that demonstrate design basis options that optimize performance to specific owner needs and preferences.

The UK Standard Plant design considered in this report uses an assumed lean natural gas as fuel and oxygen from a third party to reliably produce electricity and CO_2 for local pipeline export to downstream consumers such as EOR operations. Under normal operation, the plant does not emit CO_2 into the atmosphere other than fugitive emissions (i.e. unintentional emissions typically associated with normal operation of industrial processes such as equipment leaks, valve stem leaks, and flange leaks).

The UK Standard Plant incorporates applicable lessons learned from the engineering and construction of the Test Plant as well as findings from the Hazard and Operability Study (HAZOP) conducted during the Test Plant engineering phase.

3.2 Design Codes & Standards

The plant, systems, and equipment will comply with Recommended and Generally Accepted Good Engineering Practices (RAGAGEP), and will be designed to comply with all UK laws and regulations as applicable to the project. Applicable international codes and standards, such as API, ASME, British Standards, CGA, EN, ISO, NACE, NFPA, etc., will be applied to the design and fabrication of all components of the project, with project specifications developed during FEED to include any additional contractual or specific regulatory requirements applicable to the UK, such as PED, ATEX, and CE markings. The estimate has been developed based on globally sourcing equipment to international codes and standards, and the applicable codes applied are identified here-in. None of the Pre-FEED work performed to date has identified any equipment that could not be supplied to the UK market according to these international standards.

3.3 Site Considerations

For the UK Standard Plant Pre-FEED project, the final specific site is unknown. A generic design has been produced, suitable for implementation at a selected UK site. Once a specific site is selected, the design will be further developed to consider the specific aspects inherent to the site (such as roads access, interface point locations, topography, etc.).

3.3.1 Ambient Condition Design

The design basis for the plant includes two sets of ambient conditions. The first are generic UK summer conditions, which are 25.6°C (dry bulb) at 75% relative humidity and 0.1 MPa at sea level. Summer design conditions derive from ASHRAE published data for Albemarle Ouston, Dishforth, Fylingdales, Leeming, Linton on Ouse, Loftus, Newcastle, and Tynemouth – all of which are located in the North East of the United Kingdom. These locations are the closest ASHRAE (American Society of Heating, Refrigeration & Air Conditioning Engineers) data available for this area. The maximum summer wet bulb temperatures (exceeded 2% of the time) for those stations (18.7°C) agree within approximately one degree. With low variation, selection of the maximum value for the group ensures a conservative summer design basis with room for future increases due to global warming between the time of this study and the final commissioning of the plant. The second set of ambient conditions are standard conditions per ISO Standard 3977-2, which are 15°C, 60% relative humidity, and 0.1 MPa at sea level.

4 PROJECT DESCRIPTION

The following sections provide additional details for the configuration, operation, and control of the individual systems or pieces of operating equipment within the Base Case (900°C Turbine Inlet) Standard Plant Design. It is recommended this section is read with reference to The Simplified Process Flow Diagram in Appendix A.1.

4.1 Combustion Turbine Generator System (CTG)

4.1.1 Function

The combustor produces high temperature, high pressure CO_2 and H_2O that, in conjunction with the Recycle CO_2, rotates the turbine. The turbine produces nominally 430 MW power to the shaft, which spins the generator to produce an estimated 387 MW_e (gross) of electricity. Approximately 37 MW of the shaft power goes to drive the shaft-driven Recycle CO_2 Pump.

4.1.2 Configuration (Scope by Turbine Supplier)

- One (1) Turbine Generator with reduction gear and starting system[1]
- Turbine combustors and associated headers and connection design to the turbine (one fuel mixture terminal point for EPC firm)
- Lube and Control Oil System
- Flame Detection System
- One (1) Turbine Instrument and Control Package
- One (1) Generator Instrument Package
- VFD and Excitation System
- Torsional analysis of turbine/pump powertrain

4.1.3 System Operation & Controls

The system consists of a CTG, that is a 50Hz, single-shaft machine connected by a reduction gear to a generator (4 pole, 1500 rpm) and the Recycle CO_2 Pump. The design is in accordance with IEEE 50.13.

The combustor feeds are Oxidant, Recycle CO_2, nozzle coolant, and fuel gas.

[1] In the event the final turbine generator system is available at 50Hz, a reduction gear is no longer necessary

4.2 Recompression System (RCS)

4.2.1 Function

Produces supercritical fluid conditions for the Recycle CO_2 stream to return it through the HXR to the CTG.

4.2.2 Configuration

- One (1) Recycle CO_2 Compressor (1C-2500), Motor Driven
- One (1) Recycle CO_2 Compressor Aftercooler (1E-2510)
- One (1) Recycle CO_2 Pump (1P-2520), w/ 2 Stages
- One (1) Recycle CO_2 Pump Variable Speed Coupling (1VS-2520)
- Two (2) CO_2 recirculation loops with control valves
- One (1) CO_2 bypass loop around the Recycle CO_2 Pump with control valve
- One (1) Recycle CO_2 Pump Intercooler (1E-2520)

4.2.3 System Operation & Controls

A coalescing filter, the Turbine Exhaust Coalescing Water Separator, separates the water from the cooled Turbine Exhaust. From there, the compression of the Recycle CO_2 stream begins. The motor driven Recycle CO_2 Compressor, along with stage 1 of the Recycle CO_2 Pump, pressurizes the stream. The specified compressor complies with API 617 and includes a separate API 614 lube oil and dry gas seal system. Inlet guide vanes are the primary capacity control mechanism for the compressor. Following the compression of the CO_2 gas, the Recycle CO_2 Compressor Aftercooler chills the gas sufficiently to allow the stage 1 of the Recycle CO_2 Pump to further compress the fluid.

The Recycle CO_2 Pump Intercooler cools the CO_2 to approximately ambient temperature before entering stage 2 of the Recycle CO_2 Pump, which produces supercritical conditions and sends the CO_2 stream through the recuperative heat exchangers to the CTG. The CTG drives the Recycle CO_2 Pump via a Variable Speed Coupling.[2] The Recycle CO_2 Pump specification is an API 610 BB5, radially-split, multi-stage, between-bearing pump with API 682 dual contacting mechanical seals.

During startup, CO_2 partially circulates back to the suction side of the Recycle CO_2 Compressor until system inventory and pressure are sufficient to start the Recycle CO_2 Pump. The CO_2 Aftercooler maintains the circulating CO_2 stream's temperature, and a bypass around the

[2] Following this pre-FEED, it was determined the pump should be motor driven rather than connected via a Variable Speed Coupling to the turbine.

Recycle CO_2 Pump allows the compressed CO_2 to fill the entire loop. This bypass closes when the pump achieves normal operation.

The current Recycle CO_2 quality requires some remediation of H_2O and O_2. The expected maximum permissible export pipeline temperature is approximately 65°C. The final technologies selected during the FEED depend upon the residual water and oxygen concentrations in the Recycle CO_2, which have been and will continue to be validated in the Test Plant trials.

4.3 Recuperative Heat Exchanger (HXR)

4.3.1 Function

The recuperative heat exchanger (HXR) is a network of high pressure heat exchangers used to cool Turbine Exhaust and preheat Recycle CO_2 and Oxidant.

4.3.2 Configuration

- Precool Section Heat Exchanger(s)
- Oxidant Heating Section Heat Exchanger(s)
- Recycle Heating Section Heat Exchanger(s)
- Heat Recovery Section Heat Exchanger(s)

4.3.3 System Operation & Controls

The Recuperative Heat Exchanger network for the UK Standard Plant is an optimized combination of Printed Circuit type (PCHE) Diffusion Bonded (DBHE) heat exchangers and Shell and Tube type (STHE) heat exchangers. High pressure STHE are a well-established and commonly used technology that will comply with established Tubular Exchanger Manufacturers Association (TEMA) standards. The DBHE sections are fabricated from multiple individual blocks, each comprised from etched plates welded together using a diffusion bonding procedure. The specialized nature of the diffusion bonding process limits the supply chain to a small number of fabricators with specialized furnace operations. Since capacity of an individual supplier may be inadequate to supply all of the blocks in the Recuperative Heat Exchanger system, the design incorporates a modular layout to enable multiple PCHE supply options to be considered when necessary.

HXR transfers heat from the Turbine Exhaust stream and Hot Gas stream in order to heat the Recycle CO_2 and Oxidant streams to the required inlet temperature for the combustor. For the current 900°C turbine design, a “Hot Gas” path is integrated with the recuperative heat exchanger network for the purpose of recovering the adiabatic heat of compression.

The Recuperative Heat Exchanger layout employs a modular top down design to minimize footprint, reduce field construction costs and improve reliability. The system is designed to be assembled at the site from a series of shop-fabricated modules, thereby minimizing the number of field connections required. Additionally, the highest temperature services are located on the top of the support structure and the coldest services at the bottom. This not only compacts the plant layout, but also facilitates collection of condensed water in the Turbine Exhaust stream at the lowest location in the network. By elevating the high-temperature services at the top of the network there is a reduction of high temperature pipe lengths from the turbine and the provision of easier maintenance access to those exchanger services at the most extreme temperatures. A novel frame support system is employed to allow the high temperature sections to expand freely such that flexibility for thermal expansion resulting from the higher temperatures is accommodated in the lower temperature sections where allowable stresses are higher. Finally, the optimized piping in this network not only reduces costs, but also provides sufficient flexibility to negate potential damage from heat induced stresses.

4.4 Hot Gas Compression System (HGC)

4.4.1 Function

The HGC adds adiabatic heat of compression to the cycle to maximize cycle net efficiency and minimize overall CAPEX.

4.4.2 Configuration

- One (1) Hot Gas Compressor (1C-2100), Motor Driven
- One (1) Hot Gas Compressor Suction Cooler (1E-2110)
- One (1) Hot Gas Discharge Water Separator (1S-2100)
- One (1) Hot Gas recirculation loops with control valves
- One (1) Hot Gas bypass loop around the Hot Gas Compressor Suction Cooler with control valve
- Two (2) Water drains with control valves

4.4.3 System Operation & Controls

A portion of the Exhaust gas enters the HGC system. The HGC Suction Cooler reduces temperature when necessary (only during excursions or transient conditions). The HGC incorporates several stages of adiabatic compression and is deliberately designed to maximize the temperature of the outlet stream. The compressor discharge passes through the HXR to provide necessary thermal input to Recycle CO_2 stream en route to the CTG. The cooled Hot Gas then passes through the coalescing filter, the Hot Gas Discharge Water Separator, which separates the water from the cooled Hot Gas. From there, the Hot Gas rejoins the balance of

Recycle CO_2 at the inlet of the Recycle CO_2 Pump Intercooler. The specified compressor complies with API 617 and includes a separate API 614 lube oil and dry gas seal system. Inlet guide vanes are the primary capacity control mechanism and provide surge control for the compressor.

4.5 Water Separation System (WSS)

4.5.1 Function

The WSS cools and removes water from the Turbine Exhaust stream prior to sending it to the RCS system.

4.5.2 Configuration

- One (1) Condensate Recirculation Cooler (1E-1500)
- One (1) Water Separation Venturi Mixer (1MXR-1500)
- Two (2) Condensate Recirculation Pump (1P-1500A/B), each 100%
- One (1) Turbine Exhaust Coalescing Water Separator (1S-1500)

4.5.3 System Operation & Controls

This system consists of a Water Separation Venturi Mixer for cooling the Turbine Exhaust upstream of the Turbine Exhaust Coalescing Water Separator. The condensed water circulation loop consists of 2 x 100% Condensate Recirculation pumps which draw water (condensed and separated from the Turbine Exhaust stream) from the Turbine Exhaust Coalescing Water Separator. This condensate water is sent through the Condensate Recirculation Cooler where it is cooled before entering and mixing with the Turbine Exhaust stream in the Venturi Mixer. The water spray within the mixer cools the Turbine Exhaust and condenses water vapour prior to the combined stream's entry into the Turbine Exhaust Coalescing Water Separator. The Coalescing Water Separator removes the liquids from the Turbine Exhaust stream. The condensed and separated water gravity settles to the bottom of the Water Separator vessel while the dried gas exits the top of the vessel towards the suction of the Recycle CO_2 Compressor.

The Condensate Recirculation Cooler is cooled by water from the Cooling Water System (CWS), which has the plant's Cooling Tower as its heat sink. In order to maintain water (condensate) level in the Water Separator, portion of the recirculation pump's discharge is sent to the Cooling Tower Basin through a level control valve. Redundant level control instruments, as depicted in the P&IDs in Appendix A.4, ensure a liquid seal in the sump of the Turbine Exhaust Coalescing Separator to prevent errant loss of CO_2 vapour and to ensure safe operation. This water offsets water lost from the cooling tower due to evaporation, blowdown, and/or drift, thereby reducing the amount of makeup water required by the cooling tower.

4.6 Oxidant System (OXS)

4.6.1 Function

This system mixes Recycle CO_2 with oxygen to produce Oxidant and then compresses the Oxidant stream to supercritical conditions and returns it through the HXR to the CTG.

4.6.2 Configuration

- One (1) Oxidant Pump (1P-2700)
- One (1) Oxidant Pump Inlet Cooler (1E-2700)

4.6.3 System Operation & Controls

Oxygen from outside the battery limit of the AFC enters the system. Recycle CO_2, from the first stage of the Recycle CO_2 Pump, dilutes the oxygen, creating the Oxidant stream at a location that minimizes pure oxygen piping. This stream is approximately 80% CO_2 and 20% O_2 (by mass) during ISO operation. A flow controller from the Fuel Gas Compressor regulates the flow of the pure oxygen to ratio it to the fuel gas supplied to the combustor. An analyser in the suction of the Oxidant Pump determines the amount of diluent CO_2 required to produce the Oxidant mixture. The Oxidant Pump compresses the stream and delivers it to the Oxidant sections of the recuperative heat exchanger train for pre-heating prior to entering the combustor.

The Oxidant Pump specification calls for an API 610 BB5, radially-split, multi-stage, between-bearing pump with API 682 dual contacting mechanical seals. To minimize starting torque and to allow for operation at variable process conditions, a variable speed hydraulic coupling is recommended. During the FEED phase, a motor starting analysis, potentially reducing CAPEX and providing simpler operation, is recommended to evaluate the feasibility of utilizing fixed speed API 613 gears in lieu of variable speed hydraulic couplings. Utilizing fixed speed gears will require a more detailed evaluation of pump performance at ISO and summer conditions.

4.7 Fuel Gas System (FGS)

4.7.1 Function

The fuel gas system receives natural gas and provides fuel gas to the combustion turbine. Plans for FEED stage include detailed analysis of location specific fuel gas composition to determine necessary purification steps and impacts to the AFC.

4.7.2 Configuration

- One (1) Fuel Gas Compressor Package (1C-4000)
- One (1) Custody transfer metering station (provided by gas supplier)

4.7.3 System Operation & Controls

The Fuel Gas System supplies natural gas to the combustor. Fuel Gas enters the Fuel Gas Compressor suction coalescing filter to remove liquids to protect the fuel gas compressor and the combustor from particulate and liquid carryover. Filtered fuel gas enters the Fuel Gas Compressors where it is pressurized. The compressor has water-cooled inter-stage heat exchangers to optimize the compression efficiency and produce higher density fuel gas output from the compressor. The compressor discharge includes a high efficiency coalescer, included in the vendor's scope of supply, to remove oil vapour and aerosols from the fuel gas prior to entering the combustor(s). A fuel gas meter provides a fuel gas flow rate signal for use in turbine controls.

Any captured or condensed liquids from the filter or compressor drain to the Oily Water Separator.

One (1) x 100% API 618 reciprocating compressor package is specified for this service. The compressor, completely skid mounted, includes the following:

- Suction and inter-stage knock-out drums
- Suction and discharge pulsation suppression devices on each cylinder
- TEMA R (Refinery Service) shell-and-tube intercoolers
- Forced feed API 618 lubrication system with main and stand-by lube oil pumps, shell-and-tube lube oil cooler, and duplex 10-micron oil filters
- Lubricated, double-acting two (2) stage reciprocating compressor with direct drive motor.
- High efficiency coalescer at compressor discharge to remove oil vapour and aerosols from the discharge gas to less than 1 ppmw or less with absolute liquid removal of 0.3 micron @ 99.99% efficiency and absolute solid removal of 0.3 micron @ 99.5% efficiency.
- A shell-and-tube recycle cooler with recycle valve.
- A common API 618 closed loop compressor jacket water and packing water cooling system with circulation pumps, filters, and coolers (if required).

4.8 Cooling Water System (CWS)

4.8.1 Function

The Cooling Water System supplies cooling water to equipment for heat load removal.

4.8.2 Configuration

- One (1) Evaporative Cooling Tower (1ET-5000) – Wet Type, Multi-cell, Induced Draft, Counter Flow
- Three (3) 50% Cooling Water Pumps (1P-5050A/B/C)
- Three (3) Cooling Water Pump Strainers (1STN-5050A/B/C)

4.8.3 System Operation & Controls

The system supplies cooling water to equipment for heat rejection. The cooling water circulates through heat exchangers and oil coolers to maintain safe and efficient operation of plant equipment. The heated cooling water then returns to the cooling tower for heat removal.

The Cooling Tower specification calls for a conventional induced draft open circuit design installed on a concrete basin with three (3) x 50% Circulating Water Pumps. Each pump discharge includes a basket type strainer to remove particles 250 micron and larger in order to protect heat exchangers from potential blockage.

For a typical site/makeup water quality, Sodium Hypochlorite and Non-Oxidizing Biocide addition control biological growth. An added dispersant enhances removal of scale forming compounds. Sulphuric Acid injection (potentially not needed due to carbonic acid from produced water) provides pH control in order to minimize scale formation. Once a site is chosen and makeup water quality is known, chemical treatment can be finalized.

The CWS System provides cooling water to the following equipment (not all inclusive):

- Fuel Gas Compressor Intercooler, Recycle Cooler, and Lube Oil Cooler
- Turbine-Generator Lube Oil/Control Oil Coolers
- Turbine-Generator Seal Oil Coolers (if required)
- CTG Generator Coolers
- Recycle CO_2 Pump/Oxidant Pump Lube Oil Coolers
- Recycle CO_2 Compressor Intercooler, Aftercooler, and Lube Oil Cooler
- Recycle CO_2 Pump Intercooler
- Turbine Gland Intercoolers, Oil Cooler, and Turbine Gland Exhaust Cooler
- Miscellaneous Equipment

4.9 CO_2 (Carbon Dioxide) Storage System (CDS)

4.9.1 Function

The Carbon Dioxide Storage System supplies CO_2 for the initial fill and subsequent refills of the system.

4.9.2 Configuration

- Three (3) Liquid Carbon Dioxide Storage Vessels (1V-3500A/B/C)
- Three (3) CO_2 Electric Vaporizers (1VAP-3500A/B/C)

4.9.3 System Operation & Controls

Tank trucks supply pure CO_2 to the Carbon Dioxide Storage System Vessels. The Liquid Storage Vessels supply CO_2 for startup, operational changes, and re-charging the system. The vaporizers gasify the CO_2 and feed it to the Turbine Gland Seal Compressors. From there, it enters the balance of the plant. In order to meet a sufficient flow rate to support initial fill/startup of the plant, the vessels, skids, and vaporizers allow liquid draw from the vessels

4.10 Plant Water System (PWS) and Raw Water System (RWS)

4.10.1 Function

The specific site location and/or available sources of water available will determine the scope of the PWS and the RWS. The purpose of these systems is to take Raw Water from local supply and distribute it to various other water systems.

4.10.2 Configuration

- Valves, Piping, and Instrumentation
- Plant Water hook-ups
- Raw Water pump (1P-7200A/B)
- Plant Water pump (1P-7000A/B)

4.10.3 System Operation & Controls

An existing municipal water supply or supplementary Raw Water system provides water to the PWS and the cooling tower. These system(s) supply water to the fire protection system and the combustor turbine generator utility station and other plant utilities as required. Water provided to the battery limit of the plant from a local water company via a water main is the design basis for this work, and that water does not require water treatment. It is also assumed that the Raw Water does not need water treatment before addition to the cooling tower.

4.11 Turbine Gland Seal System (TGS)

4.11.1 Function

The TGS recovers leakage from the turbine glands for reinjection into the Recompression System of the main cycle.

4.11.2 Configuration

- Three (3) Turbine Gland Exhaust Coolers (1E-3000A/B/C)
- Three (3) 50% capacity Turbine Gland Seal Compressors (1C-3000A/B/C)

4.11.3 System Operation & Controls

The TGS recovers turbine seal leakage gas. The Turbine Gland Exhaust Cooler cools the stream upstream of the compressor via heat rejection to the circulating cooling water. The Turbine Gland Seal Compressor discharges for injection into the cycle upstream of the Turbine Exhaust Coalescing Water Separator. Control options include sliding vanes and recirculation. An oil-injected API 619 rotary-type positive displacement compressor driven by a TEFC squirrel cage induction motor is preferable for this service due to capacity. An API 619 bulk and 2-stage secondary oil separation system designed for a guaranteed/maximum oil carryover of 50 ppb is necessary.

4.12 Instrument System (IAS)

4.12.1 Function

This system receives compressed air, dries it, and distributes instrument air.

4.12.2 Configuration

- One (1) Instrument Air Receiver Tank (1V-8000)
- One (1) Desiccant Air Dryer Skid (1SKD-8010)
- Piping, valves, pressure regulators, pressure sustaining valves
- Service air hook-ups

4.12.3 System Operation & Controls

The IAS receives compressed air from an off-site source. A heatless desiccant air dryer and a receiver provide a reliable source of dry compressed air for use by instruments, equipment, systems, and facilities as required. Pressure sustaining valves allows for "service air" users to connect to the IAS and use compressed air while preventing those users from drawing too much air and lowering the main IAS headers below the minimum required pressure.

5 PLANT PERFORMANCE AND EXPORT CAPACITIES

5.1 Plant Performance

Design of the UK Standard Plant is an optimization focusing on balancing the relationship between capital cost and efficiency. Higher system efficiencies are readily achievable with minor design changes (presented subsequently in this section), typically with increased cost, and can be tailored to individual owner needs and preferences.

At ISO conditions, the gross plant electrical output of the Base Case (900°C Turbine Inlet) is 387.0 MW_e considering generator efficiency and the shaft-driven CO_2 pump (~37 MW). Estimates for the auxiliary power requirements for the selected equipment are expected to be approximately 107.6 MW, for ISO conditions (15°C and 0.1 MPa). Plant performance is summarized in Table 5-1.

Table 5-1 UK Standard Plant Performance (900°C Turbine Inlet) per Unit

Plant Performance Parameter	Units	Base Case
Gross Output	MW_e	387.0
Net Output	MW_e	279.4
Net Heat Rate (LHV (1))	kJ/kWh	7,078
Net Efficiency	%	50.9
CO_2 Capture Rate	MTPA	0.926

(1) Lower Heating Value is 50.03 MJ/kg

In addition to the parasitic loads of the major plant equipment, many detailed electrical loads, such as motor inefficiencies, variable speed drive/coupling losses, oil heaters/pumps, jockey pumps, PDC cooling, plant lighting, control room air conditioning, transformer and distribution losses, and generator excitation losses have been considered in the determination of overall plant performance. Optimizing these items for power savings remains for the FEED phase. Additionally, minimizing variations between summer and ISO cases is part of the design, which facilitates reliable operation and competitive vendor options and reduces the use of variable speed motors or hydraulic couplings with their associated inefficiencies.

Current efforts have optimized various plant attributes based on minimizing CAPEX as outlined in Section 8.11.1. Customer funded FEED studies can target specific net efficiency ranges (within reason) and optimize CAPEX versus OPEX based on plant dispatch models. The following are net efficiency improvement opportunities for evaluation in future FEED efforts (not necessarily cumulative):

- Optimize summer/ISO performances via equipment configuration

- Reduced turbine-cooling flow
- Use of dry gas seals
- Approach isothermal compression with additional stages
- Intercool fuel gas compressor and preheat fuel
- Increase combustion temperature to 1200 °C
- Add a second stage intermediate pressure turbine with reheat

Inclusion of some of the improvements requires assumptions at the time of the report, as specifications and agreements are currently in development for some of the equipment. A higher inlet temperature turbine with lower coolant flows and dry gas seals is an example of this. While these improvements are technically viable, the major uncertainties associated are the time frame and capital costs required to commercialize. Anticipated performance for an optimized 925°C turbine inlet temperature configuration are presented in Section 9.

5.2 Partial Load (Turndown) Operation

Although optimized for baseload operation, the emerging prevalence of renewable energy sources in power generation requires load share for fossil-based power plants during normal operation. The NET Power design is capable of this, as demonstrated by partial load simulations of system performance using equipment data obtained from vendor quotations. This provides an estimation of net efficiency over a range of expected output cycling for the standard plant. Not only can the system turn down efficiently, but it also does so without the concerns of high NO_X production or ammonia slip that plagues other technologies at low loads due to their NO_x abatement systems being tuned for normal load operation.

A summary of the relative net efficiency of full speed full load (FSFL) as a function of the percentage of net output (net power) for the original turbine inlet conditions (1150°C) is in Figure 5.1. Replication of this evaluation for the 900°C turbine design is pending at the time of this report and remains for the FEED phase of the project with specific equipment parameters. Similar relative net efficiency performance is anticipated for the 900°C turbine as a function of net output to that presented for the 1150°C turbine configuration.

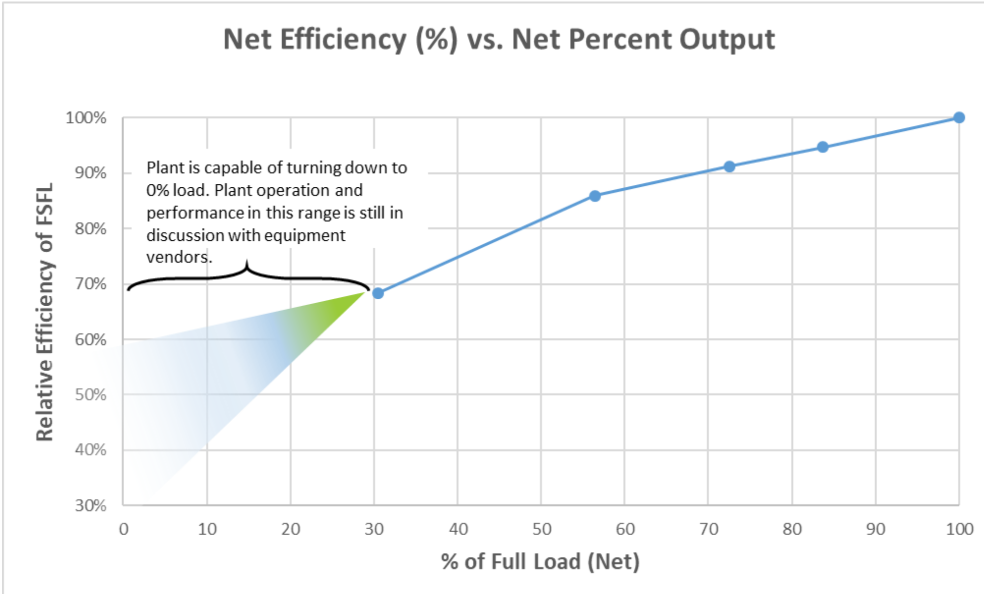


Figure 5-1 Relative Efficiency as a Function of Net Full Load Preliminary Projections

Figure 5-1 presents a preliminary part-load performance curve for the UK Standard Plant design. The slope of this curve is subject to future equipment and system design and optimization. Additional equipment and/or variations in equipment selections may provide the opportunity to flatten the slope of the performance curve producing higher plant efficiencies at partial load operations. Examples of such modifications may include the use of 2x50% Recycle CO_2 Pump (and/or 2x50% Oxidant pump configurations, integration of inter-stage inlet guide vanes at the Recycle CO_2 Compressor, and use of stored liquid oxygen, etc. Each individual NET Power Standard Plant must evaluate the benefit of higher part-load performance given the potential trade-offs that exist between CAPEX and OPEX considerations and the specific targets for LCOE.

Figure 5-1 also demonstrates that the efficiency of the UK Standard Plant does not significantly decrease throughout the anticipated operational range (load shedding). Relatively minor reductions in flows and pressures significantly decrease power output at the CTG, allowing the turbomachinery to continually operate near optimum efficiency points, which results in efficient plant operation from 55% to 100% FSFL net output. On the low end of that range, the plant can produce 55% of the FSFL net output and maintain 85% of the FSFL efficiency. For operation above 70% FSFL net output, greater than 90% of FSFL efficiency is anticipated.

5.3 Plant Boundary Limit Import/Export Rates

5.3.1 NET Power – Interface/Terminal Points

The following is a list of interface or terminal points for the plant:

- Natural gas supply at the project boundary
- Oxygen supply at the project boundary
- Raw water supply at the project boundary
- Potable water supply at the project boundary
- Wastewater to effluent outfall at the project boundary
- Sanitary waste to municipal sewer at the project boundary
- Carbon dioxide for pipeline export (Nitrogen and Argon, not in Standard Plant design, are potential additional customer options if ASU is owner-furnished)
- Storm water run-off to the project boundary
- Export electric power at high side bushings of generator step-up transformer
- Roads connection from inside project area to interface at project boundary

5.3.2 NET Power – Utility & Raw Material Interfaces

The following is a list of assumed utilities and interfaces available at the generic UK site Base Case. The interfaces for the Alternate case are identical to the base case. These preliminary interfaces are:

- Potable Water
- Raw Water for makeup to Plant Water and Fire Protection (water-cooled plant configuration)
- Natural Gas
- Oxygen import
- Wastewater Discharge
- Electrical Interface

5.3.3 NET Power - Export Capacities

The following is a list of interface or export products for the Base Case plant configuration based on minimizing CAPEX:

- Electrical Power
- Carbon Dioxide

6 PLANT DESIGN

The following sections outline major completed work, including information supporting decisions to use certain types of equipment and piping.

6.1 Regulatory Compliance, Permits and Consents

UK laws and regulations are applicable to the project. During FEED, a Regulatory Compliance, Permits and Consents Plan will be developed to assure no incidents of non-compliance or schedule impacts associated with failure to identify and obtain approvals, permits and consents occur. The following summarises the main aspects specific to the UK.

6.1.1 Permitting

The Planning Act 2008 (PA2008) and Environmental Permitting (England and Wales) Regulations 2016 (EPR2016) are key legislations that require early attention in FEED, as they will govern final site selection, project design and schedule.

The PA2008 introduced a system for consenting major infrastructure, known as Nationally Significant Infrastructure Projects (NSIPs), in England and in Wales. The PA2008 has created Development Consent Orders (DCOs) to authorize NSIPS and the Planning Inspectorate (PINS) as the agency responsible for operating the planning process for NSIPs. The DCO threshold for onshore energy generating stations are those with capacity more than 50MW. The EPR 2016 require operators of regulated facilities, which could harm the environment or human health, to obtain permits from the Environment Agency in addition to the DCO. Regulated facilities include thermal power stations and other combustion installations with a heat output of 300 megawatts or more.

Figure 6-1 shows the relationship between DCO and EPR regimes, taken from the Planning Inspectorate advice note. The advice also recommended for NSIP that involve novel technology and there is only limited or no understanding of the best available techniques, early engagement and submission of the permit application will be key to align the permit decision with the DCO examination. In such cases, and/or if a proposed development has the potential to affect a Habitats Regulations designated site, it is recommended that permit application(s) are submitted at least 6 months prior to DCO submission.

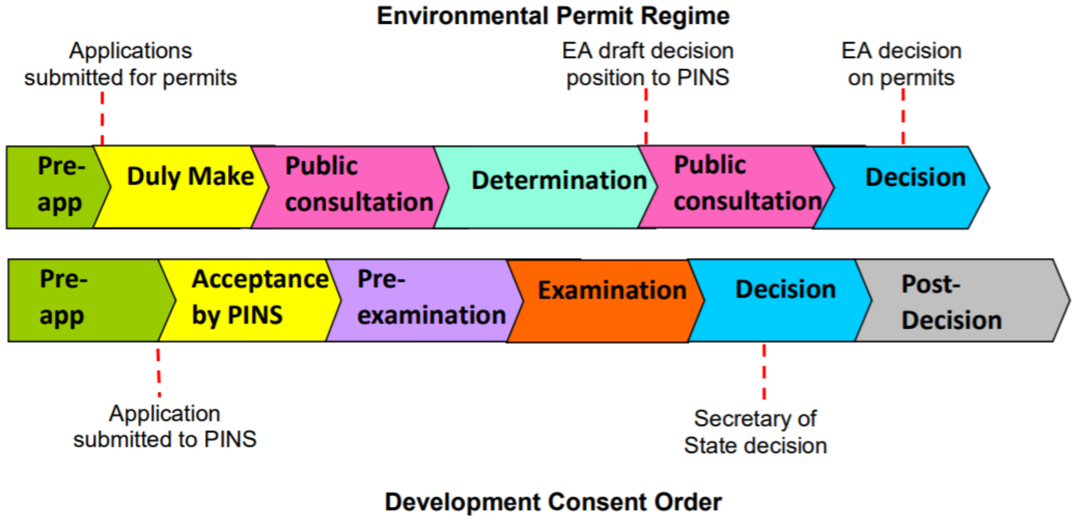


Figure 6-1. Relationship Between DCO & EPR Regimes

6.1.2 CDM Regulations

European Council Directive 92/57/EEC specifies safety and health requirements at construction sites. In the UK, its management requirements have been transposed by the Construction (Design and Management) Regulations 2015, (CDM). Any UK Standard Plant project is statutorily required to follow these regulations. Duty holders should be appointed as early as possible in the project, and must be appointed in the pre-construction phase. Different duty holders have different responsibilities under the regulations.

The primary responsibility for ensuring compliance with the Regulations resides with Project Engineering and Construction Manager and those undertaking the primary work of design or construction activities. A Project CDM procedure will be developed during FEED to ensure a plan is in place to develop the key documentation required by CDM:

- Pre-Construction Information
- Construction Phase Plan
- Health and Safety File

6.1.3 European Directives

CE Marking Directive 93/68/EEC, the Pressure Equipment Directive (PED) 2014/68/EU and the Equipment and Protective Systems Intended for Use in Potentially Explosive Atmospheres (ATEX) 2014/34/EU Directive have specific requirements that must be addressed, or the UK equivalents after the UK leaves the European Union. Compliance will be required for any UK Standard Plant project.

For PED, it will be necessary to engage the services of a Notified Body for conformity assessment in line with the directive. It is envisaged that this NoBo will be Lloyds Register.

6.2 Process Engineering

6.2.1 Process Flow Diagram (PFD)

The Simplified PFD is in Appendix A.1.

6.2.2 Preliminary Equipment List

A key focus of the Pre-FEED has been optimizing and minimizing the equipment comprising the Standard Plant. While each specific owner can customize equipment for efficiency and operability targets in FEED, the base list of equipment for the Standard Plant is in Appendix A.7.

6.2.3 HAZID

A Preliminary Hazard Identification (HAZID) workshop has been performed for this UK Standard Plant Pre-FEED, and the results are documented under separate cover in the WSP document "NETPOWER CCUS OWNERS ENGINEER – HAZID Report," 70053760-WSP-0001-RP-PE-0002-S0_P02, dated August 2020. A summary of the HAZID actions are in provided in Appendix B.

6.2.4 Process Pipe Design

The Standard Plant Pre-FEED development effort includes optimisations to minimise capital cost of piping by implementing process conditions that allow lower cost materials of construction to be selected (compared to early iterations of the AFC design), as well as by implementing the highest practical fluid velocities in order to minimize pipe diameters. Fluid velocities adhere to RAGAGEP and MDR's Hydraulic Guidelines procedures. Typically, higher velocities are in the vapour or supercritical vapour regions. The designs specifically avoid high velocity in two-phase flow locations.

6.2.4.1 O_2 Within Process Piping

Pure oxygen presents a safety concern due to its extreme reactivity. The Standard Plant minimizes this safety concern by diluting pure oxygen with CO_2 to produce an Oxidant stream with an oxygen concentration similar to that of air. This dilution occurs at the battery limit near the plant boundary in order to minimize the length of piping containing pure oxygen within the plot. Quantum cascade laser analysers monitor the oxygen concentration in the oxidant stream and provide feedback to the controls system in order to maintain the concentration below the safety limit set forth by the European Industrial Gases Association (EIGA Doc 13/20, Oxygen Pipeline and Piping Systems) requirements. The implementation of the construction, cleaning, and commissioning procedures required per EIGA Doc 13/20 for pure oxygen piping to all

Oxidant piping provides an additional and redundant level of safety despite the use of engineering controls that prevent higher Oxidant oxygen concentrations during operation.

6.3 Preliminary Plot Plan

The Conceptual Overall Plot Planas well as the turbine vendor's preliminary equipment outline for the CTG have been developed. In cases where vendor equipment outline drawings are not currently available, 3D modelling and overall arrangements utilize similar prior project equipment and experience in order to facilitate plant arrangement development.

A key focus of the UK Standard Plant design development has been optimization of the physical layout, which has successfully eliminated approximately 4 hectares from the original (2017) arrangement. The layout considers the process and equipment drawings from bids to optimize equipment locations and to minimize the length of high energy piping runs, while maximizing opportunities for pre-fabricated module implementation. This results in compacted site footprint, reducing overall materials and construction labour costs and therefore overall total-installed-cost. Minimizing expensive, long-lead piping and cable quantities is a key accomplishment.

The power block layout follows the logical flow path of the AFC, which optimizes the relative locations of the major components and reduces pipe runs and line losses. This routing minimizes the overall cost of expensive bulk commodities and maximizes the use of prefabricated assemblies (modularization). The layout also provides adequate space for construction and maintenance activities while including space for portable maintenance equipment such as mobile cranes. A loop road at the perimeter of the plant provides convenient access to the equipment and structures.

The area bounded by the perimeter loop road is approximately 3.0 hectares for the UK Standard Plant site, of with 1.1 hectares dedicated to the cooling tower and related components and 1.9 hectares dedicated to the power block. The fence and the storm water runoff basin are outside of the loop road. The cooling tower area layout and acreage will vary from site-to-site due to local site conditions.

Select areas identified as opportunities for pre-fabricated modules and have been preliminarily designed as such. See Section 7.3 for additional information on Plant Modularization.

6.4 Civil/Structural/Architectural

6.4.1 Site Selection

As the Pre-FEED considers a generic site location for the UK Standard Plant, key parameters which should be considered for the selection and evaluation of potential sites include:

- Potential for local utilization or captured CO2 export infrastructure

- Availability of natural gas and oxygen
- Existing electrical transmission systems nearby
- Available site area with adequate space for construction laydown and parking
- Proximity to existing water supply and wastewater disposal system
- Proximity to adequate transportation – roads, railroads, and shipping ports
- Permit likelihood
- Political climate and support
- Captured CO_2 tax credits/Carbon allowance reductions
- Groundwater quality
- Lack of flood zone concerns
- Topography – slightly elevated above adjacent area, gentle slopes
- Soil conditions – good suitable soils (no karst, minimal clays, etc.)
- Land planning and zoning – suitable for industrial plants
- Environmental sensitivity – no endangered or threatened species nor adverse impact to wildlife
- Cultural sensitivity – no significant archaeological or historical impacts
- Buried Ordinance – no significant removal necessary
- Noise – no sensitive noise requirements due to adjacent neighbours

Assumptions for developing the estimate include many factors related to the potential site. Because of the generic project location, assumptions have been made when developing the project cost estimate. See Section 8.4 for Basis of Estimate and Major Assumptions for assumptions related to the site. Differing site conditions may result in changes to the project cost.

6.4.2 Civil

As above, for the generic site, some broad assumptions have been made regarding the project site, and other location specific civil aspects, these are summarized below.

6.4.2.1 Clearing, Grading, and Site Preparation Assumptions

The site clearing process removes trees, brush, and debris as required to construct the facility. This includes removal and disposal of said items within the limits of construction. The initially cleared area only includes the approximate construction limits so as to minimally disturb existing vegetation. Temporary laydown, sedimentation controls, and areas disturbed by planned construction are in the limited scope of site preparation.

Erosion control measures comply with the guidelines of applicable national, and local regulations in effect during construction.

Established grades minimize the amount of earthwork required during construction to best balance cut/fill quantities of earthwork. The estimate assumes a level site, which reduces costs by requiring minimal grading work and no off-site borrow or wasting of material. Once a site location is selected, a geotechnical study to determine soil quality and groundwater evaluation are necessary prior to site excavation, and foundation design.

The design of embankments, channels, ditches, ponds, and erosion protection, as needed for specific sites, comply with the recommendations of the Final Geotechnical Investigation and Report.

6.4.2.2 Demolition

It is assumed that there is no demolition work for the power facility.

Hazardous materials such as lead paint, asbestos, and contaminated soil are assumed not to be present. Confirmation of these assumptions is pending final selection of a plant site. Brownfield or other eco-sensitive sites may have significant cost impacts.

6.4.2.3 Storm Water Drainage

The grading and drainage system will comply with all applicable national, and local regulations.

Uncontaminated Storm Water runoff and potential firewater flows will be directed to an existing third party drainage system at the site boundary via a permanently installed storm water drainage system. The permanent storm water drainage system for the project will primarily consist of grass or rip-rap lined drainage ditches and sheet flow. The design includes catch basins to collect surface runoff, and underground piping with manholes at all junction points and turns where necessary. Underground piping materials are typically high density polyethylene (HDPE). Roads that cross over open channels have reinforced concrete or HDPE culverts to pass the required flow.

Potentially contaminated water is routed to the oily water separator.

6.4.2.4 Roads and Surfaced Areas

A looping road, with an asphalt paved surface provides access throughout the power facility. Crushed rock covers all other areas that are not curbed concrete under process equipment within the plant loop road.

The road surfaces and sub-grades comply with appropriate standards. All designs will be required to adhere to the recommendations of the Final Geotechnical Investigation and Report and consider the appropriate use of trucks and anticipated traffic volume.

Pipe racks, conveyors, electrical lines, etc. that cross over roadways maintain a minimum of 6.0 meters of clearance. This excludes the overhead (or buried) line from the step-up transformer which will be governed by IEC code requirements.

6.4.2.5 Landscaping

As required for erosion protection, areas disturbed by grading and not covered with surfacing are seeded with native vegetation or grasses, and/or crushed stone.

Trees and shrubs and other landscaping, if desired, are assumed to be the responsibility of the owner.

6.4.2.6 Fencing and Gates/Security

A permanent security fence borders the perimeter of the loop road. This fence is 2.4 meters in total height and consists of 2.1-meter-high chain link fabric fence plus three strands of barbed wire on 45-degree angle support arms.

Automated vehicle gates permit entrance at two locations. Pedestrian gates are swing-type. Operations can monitor and control gates from the control room. An allowance is made for plant lighting.

6.4.3 Structural

6.4.3.1 General

Structural designs will be in accordance with the European Standards (Eurocodes). A project Civil/Structural/Architectural (CSA) Design Criteria document, developed in FEED, will further define the design criteria and applicable code revisions (years) that the project follows.

6.4.3.2 Foundations

The following are the major foundation assumptions (the parameters apply to a generic UK location with favourable geotechnical conditions providing a low cost design):

- Foundations are shallow type (e.g., mat, slab-on-grade, and footing). No deep foundations (e.g., piles) are necessary. The geotechnical investigation effort for each site will confirm this during FEED and prior to the beginning of detailed design.
- The allowable soil bearing capacity (q_{all}) is 190 kPa.
- The modulus of subgrade reaction (k) is 40700 kN/m^3.

- Blow counts (N-Value) are 30 blows mm, as derived from Standard Penetration Testing (SPT) at the bearing surface, assuming no soft underlying layers.
- Silty-sand material comprises the soil. The previous values assume this soil composition and will be confirmed by the geotechnical investigation or accordingly updated in the next phase of the project.
- No hazardous materials, no karst formations, no liquefaction potential, no expansive clays, and no loose rocks or boulders are within soil layers.
- Deep groundwater, and no artesian aquifers that allow groundwater to migrate to the surface or the bottom of excavations.
- Minimal plastic fines [Plasticity Index (PI) < 15].
- Relatively flat site requiring minimal cut and fill.
- Site elevation is above 100-year flood inundation elevation.
- Site is not in the downstream floodplain of a dam.
- Eurocode EN1998-1 shall be adopted as the seismic design code. The project assumes a Soil class B for the site location. A site-specific probabilistic seismic hazard analysis (PSHA) study should be conducted to estimate the earthquake ground motions at the plant location and identify the Soil Class once the site is selected. No faults in the existing subsurface.

6.4.3.3 Combustion Turbine Generator (CTG)/Recycle CO_2 Pump Area Foundations

Elevated concrete pedestals on a mat foundation support the turbine-generator. This structure houses the turbine, generator and Recycle CO_2 pump. An open elevated steel structure with a concrete slab on metal deck surrounds the pedestals. This elevated structure serves two purposes: 1) To provide a deck with stair access to facilitate access and maintenance for the CTG/Pump equipment; 2) To provide cover from the weather for CTG area equipment and skids located below.

Concrete pads doweled into the mat foundations support the elevated structures for CTG area equipment and skids. The CTG lube oil skid includes a concrete basin that is adequate to retain the maximum contained volume of oil.

NET Power continues to investigate the feasibility of utilizing a modularized, stay-in-place formwork for pedestal foundation construction. MDR, a partner in NET Power, has a proprietary system comprised of plate steel, internal stiffeners, and reinforcement for construction of a 350 MW class steam turbine/generator set that is adaptable for the NET Power combustion turbine and pump table top. A modularized approach increases site safety, minimizes construction risk via off-site fabrication, and lowers schedule risk of critical items. MDR maintains a competitive advantage of using modular fabrication for concrete mega structures as used on previous nuclear projects, and this method continues to evolve into practice into non-nuclear applications.

6.4.3.3.1 Transformer Foundations

Transformer foundations are concrete pedestals and mats. The transformers have a common concrete basin sized to contain the oil volume of the largest transformer's main tank plus an allowance for rainfall and fire-fighting water. Firewalls protect the Generator Step-Up, Unit Auxiliary, VFD, and Excitation Transformers. Cost comparison determines whether firewalls or distancing to meet equipment separation criteria is preferable to provide protection for the isolated phase bus and other surrounding equipment.

6.4.3.3.2 Power Distribution Centre (PDC) Building Foundation

PDC building foundation is a mat with piers to provide the required ground clearance to allow for bottom feed of tray/cable.

6.4.3.3.3 Heat Exchanger/Cooler Equipment Support Structures Foundations

Structural steel frames supported on mat foundations elevate heat exchangers and coolers that are vertically stacked to minimize the overall footprint of the plant.

6.4.3.3.4 Pipe Racks and Pipe Support Foundation

Pipe racks are structural steel with braced towers and bents. Foundations are mats or isolated footings. Miscellaneous pipe supports are T-posts supported on footings or shallow piers.

6.4.3.3.5 Cooling Tower and Pump Structure Foundation

The Cooling Tower structure support is a slab-on-grade foundation with perimeter concrete walls doweled into the slab at its external edges creating a basin that contains the working volume of cooling water required for operation. A pump bay/well, centred on the plant side of the tower's longest dimension, provides support for the Circulating Water Pumps and houses required flow straighteners, trash screens, etc. Ancillary equipment such as Chemical Totes and Feed skids are on separate mat foundations next to the basin.

6.4.3.3.6 Yard Structures/Equipment Foundations

All yard structures and equipment sit on mat foundations or spread footings with the top of foundation extending a minimum of 200mm above finished grade.

6.4.3.3.7 Cranes and Hoists Foundations

No permanent cranes or hoists exist other than the gantry crane at the turbine pedestal. All operations and maintenance activities outside of this area utilize mobile equipment provided by owner when needed.

6.4.3.3.8 Control Building Foundation

The Control Building sits on a slab-on-grade foundation.

6.4.4 Architectural

6.4.4.1 Buildings and Enclosures

Buildings, or enclosures, include the Control Building, Main PDC, and Cooling Water PDC. The buildings have environmental controls necessary for the facility use. The exteriors consist of suitable weather resistant materials.

The Control Building contains minimal office space, conference room, restrooms, and a control room. Windows are provided in the control room. Interior architectural walls consist of metal liner panels or gypsum drywall. Owners can opt for additional pre-engineered buildings, including an Administration Building, to be separate or a part of the Control Building and a Warehouse for maintenance or storage. The current estimate includes only the Control Building.

6.4.4.2 Maintenance Access

Permanent stairs or ladders provide access to routinely maintained locations that will be formally identified in the next phase of the project. Stairways access the turbine-generator maintenance deck and the PDC platform. Installed ladders provide all other accesses.

6.4.4.3 Coatings

Preparation of metal surfaces for coating systems follows ISO standards, National Association for Corrosion Engineers (NACE), along with the specific instructions of the coatings manufacturer. Coating of steelwork may be painting or hot-dip galvanizing (HDG). The difference in cost between the two systems is minimal; the HDG provides longer service life, whereas painting may require replacing or field touch-up. The selection of the coating system will be investigated in more details and confirmed in the next of the project.

Vendor-supplied equipment has the manufacturer's standard coatings that are suitable for the project environment.

6.5 Electrical

6.5.1 Interconnection

The interconnection to the existing 275 kV transmission grid is the responsibility of the owner, as are the 275 kV Switchyard and transmission systems. 275kV is a typical UK Grid distribution voltage suitable for connection to this type of plant. The Scope of Work point of common coupling is at the high voltage bushing of the Generator Step-up Transformer.

6.5.2 Main Power Generation System

The basis for the UK Standard Plant design is a supercritical CO_2 (sCO_2) turbine UK grid compliant machine generating at 50 Hz.

6.5.2.1 Isolated Phase Bus (IPB)

22 kV Isolated Phase Bus connects the Generator, the Generator Circuit Breaker (GCB), the Generator Step-Up Transformer (GSUT), and the Unit Auxiliary Transformers (UAT). 22kV is as typical BS/IEC rating for bus duct and switchgear. The bus shall be self-cooled (no fans), without pressurization system or space heaters. The IPB main bus short circuit (SC) current rating shall be greater than the maximum available SC current from either the generator or the switchyard system, whichever is greater. The IPB taps SC Current shall be greater than the combined SC currents available from the generator and the switchyard systems. This is typical design for an IPB system. The IPB shall comply to BS 159, IEC 66271-200 and IEC 60071.

6.5.2.2 Generator Circuit Breaker (GCB)

The GCB current rating will be equal or greater than the maximum generator MW output at 0.85 power factor and 0.95 pu generator voltage in order to ensure GCB is fully rated under worst case operating conditions. The GCB will include voltage transformers, surge protection equipment, disconnect switch, grounding switches and current transformers as required to support the protective relaying system.

6.5.2.3 Generator Step-Up Transformer (GSUT)

The GSUT consists of an oil-filled three-phase, two winding power transformer. The GSU rating will be based on ONAN/ONAF/ONAF cooling at a 65°C temperature rise. The high voltage winding will be wye connected, with two 2.5% no-load taps above and below the normal rating, and with the neutral solidly grounded. This transformer has an oil containment system and fire rated wall designed to applicable standards. Applicable codes do not mandate blast walls, and the layout includes adequate safe spacing. Further analysis could be taken during a Quantitative Risk Assessment (QRA), but currently a blast wall is not considered necessary or beneficial due to the lack of redundant transformers. Firewall shall be EL60 as recommended in IEC 61936-1.

6.5.3 Unit Auxiliary Transformer (UAT)

The facility includes two UATs that are the primary source of power to plant auxiliary loads. Each UAT will be oil-immersed type, two winding and three winding, rated based on ONAN/ONAF/ONAF cooling at a 65°C temperature rise. The delta connected high voltage windings will have two 2.5% no-load taps above and below the normal rating.

The transformers shall have firewalls between them to limit a fire in one transformer from spreading to adjacent transformers.

Each UAT low voltage winding shall be wye connected with the neutral grounded thru a 400 A neutral grounding resistor.

6.5.4 Power Distribution Centre (PDC).

Three PDCs will be provided to house the plant electrical distribution system:

- Main PDC houses the medium voltage switchgears, low voltage (LV) MCCs, distribution panels and transformers, DC/UPS System, DCS I/O cabinets, Turbine Control Panel and Generator Control/Relay panel, the Hot Gas Compressor/Recycle CO_2 Compressor starting system, and other miscellaneous equipment.
- Cooling Tower PDC houses LV motor control centres, DCS I/O cabinets, distribution panels and transformers, and other miscellaneous equipment.
- Auxiliary PDC houses LV motor control centres, DCS I/O cabinets, distribution panels and transformers, and other miscellaneous equipment.

6.5.5 Medium Voltage Switchgear and Motor Starters

The medium voltage system consists of medium voltage switchgear rated at 11 kV and 6.6 kV nominal, IP41, internal arc classification AFLR enclosure for indoor installation. The switchgear uses drawout vacuum circuit breakers and medium voltage fused contactors.

The plant electrical control system remotely controls and monitors all breakers and contactors via protective relaying using IEC 61850 Ethernet TCP/IP protocol.

Motor contactors and auxiliary contacts allow remote control and monitoring by the Process Control System (PCS) or Unit Control Panel (UCP), as applicable.

The medium voltage switchgear connects to the UAT secondary windings by cables appropriately rated to carry the auxiliary load on each winding.

6.5.6 Hot Gas & Recycle CO_2 Compressors – Synchronous Motor Starting System

One Variable Frequency Drive (VFD) starting system sequentially starts and synchronizes each motor.

The task of the VFD is to accelerate each synchronous motor from zero up to nominal speed and synchronize it to the power supply network by closing the running circuit breaker (RCB) and tripping the starting circuit breaker (SCB). Its main function is to control the energy exchange between the power system and the motor, which during acceleration operates at variable frequency and voltage.

The main components of the soft starting system are:

- The input circuit breaker (ICB) and the starting circuit breaker (SCB)
- The input and output isolation transformers, which match the supply voltage and the machine terminal voltage to the Static Frequency Converter (SFC) design voltage.
- The VFD comprises the following main units: line converter, dc-link reactor, inverter and control unit with auxiliaries that is responsible for the control, monitoring and protection.

6.5.7 Distribution Transformers

Station Service transformers are fed from the medium voltage distribution system. These are dry type, IEC IP54 located outdoors.

6.5.8 Excitation and VFD Transformers

These transformers, designed and provided by the turbine vendor, receive power from the 6.6 kV switchgear.

6.5.9 Low Voltage Switchgear and Motor Control Centres

The Motor control centres (MCC) are metal clad type, IP 41 for indoor installation. The low voltage switchgear arc classification will be in accordance with IEC TR 61641, Criteria 1 to 7.

The plant electrical control system remotely controls and monitors the low voltage switchgear breakers using Profibus DP protocol.

Motor contactors and auxiliary contacts allow remote control and monitoring by the Process Control System (PCS) or Unit Control Panel (UCP), as applicable, using Profibus DP protocol.

6.5.10 Motors

Motors for the Hot Gas Compressor and Recycle CO_2 Compressor are IEC 60034 Synchronous type, and all other motors are squirrel-cage induction type per IEC 60034.

Fractional horsepower motors below 0.75 kW are rated 230 V, 50 Hz, single-phase for operation, except for motor operated valves, which are rated 400 V, 50 Hz, three-phase.

Motors from 0.75 kW through 250 kW are rated 400 V and are fed from MCCs using combination starters. LV motors above 180 kW shall have soft starting methods. Motors above 250 kW through 4500 kW are rated 6.6 kV. Motors above 4500 kW are rated 11 kV.

All 6.6 kV and 11 kV motors shall be furnished with RTDs. All motors rated 750kW and above will have surge protection and vibration probes. All motors 2000kW and above are provided with differential protection.

DC motors are rated for 110 VDC ungrounded service.

Space heaters are provided on all 400 V motors rated 5 kW or larger located outdoors, and 20 kW or larger located indoors.

6.5.11 Essential AC and DC Power Supply System

The Essential AC and DC Power Supply Systems each provide power for important plant systems and components through dedicated distribution panels.

Each Essential AC System consists of an inverter, static switch, maintenance bypass switch, isolation transformer and main AC power panel board. An alternate 400 VAC source provides power via the isolation transformer through the static switch if the inverter fails. The Essential AC system serves critical loads such as the Plant Control System, communication system, control room emergency lighting, and other miscellaneous systems.

Each Essential DC Power Supply System consists of (1) 110 VDC station battery bank with a main DC panel board. The battery bank includes one battery charger. The 110 VDC systems are the primary power source for the Essential AC Power Supply System and Essential DC Motors. The station battery supplies emergency loads in order to safely shut down the unit.

Inverter, charger and batteries shall be dual-redundant for all essential/safety critical systems.

6.5.12 Electrical Protection System

The plant electrical protection system isolates faults selectively to minimize impact to plant operations in accordance with industry practice. The plant, switchyard, and transmission protection systems are coordinated to maximize plant availability.

Primary and backup discrete or multifunction digital relays protect the Generator Step-Up Transformer and the generator. The unit auxiliary transformer utilizes primary and backup discrete or multifunction digital relays for electrical protection.

6.5.13 Wire and Cable

Medium Voltage (MV) power cable insulation is cross-linked polyethylene (XLPE). The multi-core MV cables shall be galvanized steel armoured with metallic screen. The single core MV cables shall be aluminium wire armoured type with metallic screen.

Low Voltage (LV) Power, control and signal cable insulation (including cable furnished with equipment) is cross-linked polyethylene (XLPE)) with galvanized steel wire or aluminium wire armouring. Cable jacket is low smoke zero halogen type (LSZH).

6.5.14 Telephone and LAN System

The plant telephone system provides off-site communications. Telephone raceway, wiring within the Control Building and telephone/LAN jacks exists in the Control Room for wall telephone/LAN jacks. The owner provides telephone line to site, Telephone/LAN cabinets, LAN routers/servers and site PBX.

6.5.15 Site Notification System

Site paging/notification is out of scope. On-site communications include hand-held radios, supplied by the owner.

6.5.16 Site Security System

A motorized main gate controls access to the site. Additional security system components are the responsibility of the owner. Security cameras and/or building access control is the responsibility of the owner.

6.5.17 Fire Alarm System

A fire alarm system is in the Control Room and all PDCs. Administrative/Office areas of the Control Building have smoke alarms only.

6.5.18 Plant Lighting and Convenience Outlets

The Lighting system design is in accordance with the recommended practices of the Illuminating Engineering Society (IES), BS, and the site permitting requirements.

All outdoor areas use light emitting diode (LED) fixtures. Photocells control outdoor lighting. Perimeter lighting locations are on direct buried fiberglass lighting poles or on nearby structures.

Indoor lighting is LED type. Dimmers adjust control room lighting near the operator control stations.

Individual lamps of strategically located LED fixtures are fed from the Vital AC panelboard for emergency lighting in the control room.

Emergency egress lighting and LED exit signs contain backup battery packs, activated on loss of normal AC power.

230 VAC duplex receptacles are in administration offices, control room and other occupied areas in accordance with BS 7671. 110 V duplex receptacles and up to ten (10) 400 V, 60 A welding receptacle shall be installed within the plant areas where maintenance activities occur. 110 VAC Receptacles shall be located so that no more than a 30-meter extension is required. Outdoor receptacles shall be weatherproof RCD protected.

Low voltage distribution panelboards, for lighting and receptacles, shall be sized for the supply transformer and near the panel loads.

6.5.19 Plant Earthing System

Earthing will comply with relevant applicable UK standards. Station earthing design is based on analysis of soil resistivity data. The earthing system shall be designed to:

- Establish a minimum resistance to earth at all locations in accordance with IEEE 80.
- Protect personnel from dangerous potentials such as transferred, step, and touch potentials during normal operating and maximum earth faults.
- Provide connection to earth for power equipment neutrals.
- Dissipate lightning charges.

Electrical equipment and metallic structures, including building steel and tanks, are effectively earthed in accordance with IEC 60364-5-54 and IEEE Standard 665 "Guide for Generating Station Grounding." An earthing grid to be established shall be subsurface throughout the plant and be interconnected by use of compression connectors.

Lightning protection of plant structures is in accordance with IEC 62305 standards.

6.5.20 Cathodic Protection System

Cathodic protection, coating, and wrapping techniques protect buried metallic piping and structures in the plant area. Galvanic anodes provide cathodic protection. Cathodic protection designs meet the criteria of the latest recommendations of NACE and ISO.

6.5.21 Raceway

The raceway system includes cable ladder rack, cable tray, cable trench, and duct bank, as required. Cable ladder rack and trays are aluminium ladder type with IEC 61537 classification ratings.

Outdoor cable routes shall mainly be on cable ladder rack or direct buried in areas without available structural support. EMT conduit is permissible for indoor receptacle, communication, and lighting circuit conduits.

Underground conduit is PVC encased in concrete (steel reinforced under roadways). Elbows used for risers are rigid galvanized steel or fiberglass to prevent the pulling rope from cutting through the bend during cable installation.

6.6 Instrumentation & Control

6.6.1 General Design Criteria

A plant wide Integrated Control and Safety System (ICSS) will be provided. The ICSS will ensure safe, reliable and efficient control, monitoring and shutdown. The ICSS will be made up of the Process Control System (PCS), Emergency Shutdown System (ESD) and Fire and Gas System (FGS).There will also be individual package controls. They will communicate with the ICSS via hardwired signals and Modbus, Profibus or similar communication protocols. The ICSS and package control systems will generally be of a failsafe design.

Instruments will be provided to ensure safe operation of the plant. They will be designed to be safe, simple and robust ensuring independence between monitoring/control and safety functions.

6.6.1.1 PCS

The PCS will have a distributed structure with a centralized Human Machine Interface (HMI) located in the Control Room. Redundancy will be required for critical equipment such as controllers, power supplies and the main control network. Controllers will be partitioned based upon process systems and redundant inputs will be connected to different I/O modules.

The HMI installed on the Operator Work Stations (OWS) will provide the facility for the Operator to control and monitor the plant via mimic displays, alarms, trends and commands.

Reviews will be undertaken in order to avoid unnecessary and nuisance alarms. Pre-alarms will be implemented to give Operators sufficient time to intervene and avoid a trip. Automatic overrides of certain trips will be permitted in order to automate the startup and shutdown of equipment.

6.6.1.2 Safety Instrumented System

Emergency Shutdown System (ESD)

The Emergency Shutdown System forms part of the facility's safety systems. Its prime function is to shutdown the facilities to a safe state in case of an emergency situation, thus protecting personnel, the environment and the asset. It shall carry out the emergency shutdown functions of the facility according to the defined safety philosophies.

The ESD system shall be based on a fail-safe design built using high reliability and high availability equipment. Depending on the size of the system, multiple nodes connected to the dedicated safety network may be required.

An ESD matrix panel shall be incorporated in the Control Room Operator Control Desk. This panel shall be hardwired directly to the ESD system.

Fire and Gas System (FGS)

The F&G detection and protection system forms part of the facility's safety systems. Its function is to mitigate against the effects of any fire and/or gas releases in order to protect personnel, the environment and the asset. The FGS will continuously monitor the facilities and initiate the protective actions as defined in the safety philosophies.

The FGS system shall generally be of a non-failsafe design, with outputs utilising "energise to trip" principles. The system shall use high reliability and high availability equipment. Depending on the size of the system, multiple nodes connected to the dedicated safety network may be required.

A FGS matrix panel shall be incorporated in the Control Room Operator Control Desk. This panel shall be hardwired directly to the FGS system.

6.6.1.3 Package Control Systems

In general, there will be 3 types of package and control:

1. The package will be delivered with its instruments but without cables and cable trays. These packages will be fully controlled by the PCS. Systems shipped in individual components, such as the water separator and its associated pumps/heat exchangers are an example of this type.

2. The package is equipped with instruments, cables and cable trays. Instruments are wired and connected up to skid edge junction boxes. These packages will be fully controlled by the PCS

3. Control and shutdown functions will be implemented in a dedicated control panel as part of the package scope of supply e.g. turbine generator, compressors etc. These packages will generally be supervised and controlled by higher level logic configured in the PCS.

6.6.1.4 Interfaces

Electrical driven equipment that interfaces with the PCS will utilize a redundant communications interface wherever practical. Shutdown trip signals will be hardwired.

PCS signal interfaces with packaged control systems will generally be a communications interface for monitoring, hardwired for control.

Remote I/O may be utilised subject to the outcome of a cost benefit analysis in FEED.

Subject to owner approval, wireless instrumentation is permissible for monitoring. However, wireless technology will not form part of any closed control loop.

PCS communication cables between buildings will be redundant fibre optic.

All systems will be designed, built and configured to ensure that mitigation measures are implemented to protect against cybersecurity risks.

6.6.1.5 Vibration and Temperature Monitoring System

The turbine generator, compressors and some pumps will include vibration and temperature monitoring. These monitoring system will interface with the package control system or PCS as required in order to shut down in the event of excessive temperature or vibration. Protective functions based on supplier recommendations will be implemented if interfaced to the PCS.

6.6.1.6 Control Room

The Control Room will allow Operators to fully monitor and control the plant via the PCS and associated equipment. The Control Room Operators will have control over all areas of the plant and have all necessary information to allow for the start/stop and control of the machinery and essential services.

The Control Room will comprise control desks housing Operator Work Stations, pushbutton panels, radio and other communications equipment.

The Control Room design will be based on ergonomic considerations taking into account normal day- to-day operations as well as the requirement to respond to emergencies.

6.6.1.7 Plant Simulator

NET Power provides a dedicated plant simulator to train operators on start-up, shut-down, normal operation, and upset conditions. The simulator delivers a “reduced scope, high realism” level of simulation as defined in ISA S77.20.01.

The simulator operates in real time, allowing the instructor to load various operating scenarios, and be pre-programmed with multiple operation malfunctions.

The simulator includes a trainee station that mimics an actual operator workstation and a separate instructor station.

6.6.2 Instrumentation

6.6.2.1 General

The standard instrument loop architecture will consist of field instruments connected to junction boxes or remote I/O, which are in turn connected to marshalling cabinets by means of multipair cables or redundant fibre respectively. Signals will then be routed to the appropriate control system.

In general, marshalling and system cabinets will be installed indoors, whereas junction boxes and remote I/O will be installed outdoors in the field.

Redundant instrumentation will be provided as necessary to minimize the likelihood of plant load reduction or shutdown.

Field instrumentation and control valve interfaces will be based upon a hardwired 4-20mA, 24VDC signal. HART® protocol will be provided wherever possible for feedback and diagnostic purposes. Dedicated hardwired 4-20mA feedback will be provided for combustor or turbine protection. For other applications HART® feedback is acceptable.

Where possible instruments that require remote mounting will be functionally grouped on local panels or transmitter racks.

All instrument equipment will be tagged.

6.6.2.2 Environmental Conditions for Instruments

Instrumentation will be chosen to ensure it is suitable for both the process conditions monitored and the environmental conditions in which it resides.

All indoor instrument equipment will be minimum IP21 rated, IP65 if water mist is present. All outdoor instrument equipment will be IP65 rated, IP66 if located where water spray exists e.g. wash down.

6.6.2.3 Tubing and Fittings

All instrument tubing, fittings, valves and manifolds will be 316 stainless steel minimum. Higher specification alloys will be used when exposure to process components or conditions warrant. Such details will be captured on the instrument installation details and hook up drawings.

6.6.2.4 Earthing

All instruments, junction boxes and equipment rooms will be interconnected as part of a plant wide earthing and bonding system.

6.6.2.5 Utilities

All systems and their cabinets will be powered from redundant AC UPS supplies.

Instrument air will be used for pneumatic instrumentation and pneumatic operated actuators (e.g. control valves, on/off valves).

6.6.2.6 Packaged Equipment

Packaged equipment suppliers will supply and install all instruments within the skid boundary. Interfaces to the ICSS will generally be at skid edge junction boxes.

6.6.2.7 Emissions Monitoring

A gas analyser will monitor turbine exhaust emissions exiting the plant vent during startup, shutdown, or other process upset conditions and communicate them to the PCS. The analyser will be based upon laser technology in order to eliminate the need for calibration gases. Care will be taken to correctly specify the calibration ranges for each constituent gas to ensure the appropriate lasers are selected.

7 PLANT CONSTRUCTION

The Class IV cost estimate for this Pre-FEED study assumes a preliminary construction strategy based on McDermott experience executing other large energy infrastructure projects in the UK, including the Isle of Grain LNG facility and the South Hook LNG facility. This overall strategy forms the basis of the construction aspects of the Class IV estimate. Other EPC contractors would be anticipated to develop strategies pertinent to their experiences, which could impact project cost.

A detailed Project Execution Plan (PEP), developed during FEED as part of the project planning stage, will establish project execution steps and will provide all project team members with a reference for understanding the project objectives and plans for execution. These plans cover engineering, procurement, fabrication, construction, and commissioning requirements for engineering, procurement, and construction (EPC). It also includes subcontracts, project coordination and communication methods, budgets and scheduling, milestones and progress measurement, monthly reporting requirements, QHSSE (quality, health, safety, security, and environment) rules and regulations, and all other essential factors for project success.

During the PEP development, one key early FEED activity is the creation of a construction strategy that considers the site specific issues that can affect schedule, price and execution risk in order to generate an optimized approach for the UK Standard Plant project. The considerations include an early assessment of whether modularization of any components on the project offers a beneficial reduction in project risk. This must be done early in the project so that the findings can be included in the design before construction begins. Section 7.3 provides an overview of potential modularization opportunities.

7.1 Construction Strategy

During the execution of the FEED phase of the project the construction group provides critical information and feedback to engineering to ensure that lessons learned and best construction techniques & practices are inherent in the engineering design. This process continues through FEED and into EPC detailed design through an active Constructability programme, regular discussion with Engineering, and participation in the model reviews at all stages.

Early in the FEED phase on the project, Construction engages with Engineering, Procurement and Subcontracts to ensure that all disciplines adopt the Advance Work Planning (AWP) concept and that information requirements to assist in the construction phase are incorporated early. This includes layout of construction path, segregation of site work areas, development of construction areas and work planning breakdown, embedding AWP in 3D model, and establishes the critical path of the project. This critical process identifies the sequence of work to be completed by engineering and procurement to support the sequence construction work on site.

Construction supports the Subcontract group in developing scopes of work by providing technical and commercial input into the proposal and ensures the AWP is built into the subcontractor scopes. The Construction group assists in the Technical and commercial assessment of subcontractor proposals and evaluations. During EPC project execution, Construction coordinates with the subcontractors to implement AWP for work scopes and to develop the individual work packs.

A basic sequence of works for the project is as follows;

- Complete site prep and establish temporary roads and drainage
- Commence piling and/or ground improvement
- Installation of underground utilities – pipe, cable, etc.
- Installation of concrete foundations
- Lay paving around foundations and structures
- Set Large Equipment
- Erect structural Steel
- Installation of pipe
- Set electrical buildings
- Set smaller equipment
- E&I installation
- Painting and insulation
- Final site dressing

It is critical to finish undergrounds and paving works where possible prior to the commencement of above ground works. This reduces interface and access issues during the construction phase.

Any heavy lifts on the project would be identified in the FEED. The design considers the ability to successfully and economically complete these lifts without creating unnecessary safety hazards. All heavy lifts greater than 50 tons and lifts requiring two cranes, will require detailed lift procedures that are developed and approved by engineering and the construction corporate rigging staff. This includes the heavy haul access and heavy crane movement plan during the major critical lifts.

During the FEED Phase of the project, the construction group reviews individual areas and establishes detailed execution strategies in coordination with engineering. The Construction Execution Plan (CEP) describes these specific approaches.

7.2 Construction Contracting Strategy

The construction of the UK Standard Plant requires specialized construction capabilities. MDR will subcontract a large portion of the work to experienced and capable subcontractors with MDR supplying a small self-perform team to execute or assist in critical work and provide support services where required.

As for all large MDR projects, an established onsite project team manages and executes the project. The onsite team oversees all work carried out by MDR and subcontractors. The team is comprised of experienced MDR personnel to ensure there is team integration and ownership from all parties. Some of the project team members are responsible for planning, managing and overseeing the subcontract work.

7.2.1 Preliminary Subcontracting Plan Utilizing UK Region-Specific Vendors

The project will utilise qualified subcontractors for all subcontract packages. Subcontractors execute the majority of the permanent installation work and site support services. The project will be split into work scopes with a civil contractor completing all underground works and a single (or multiple) Mechanical, Structural, Piping, E&I Contractor(s) implementing all aboveground works. The exact scopes and split will be determined during FEED execution. The subcontract scopes of work for permanent works may include:

- Concrete, civil, site preparation and earthworks contractor
- Piling/ground improvement contractor
- Main subcontractors based on geographical areas responsible for:
    - Pipe installation
    - Structural steel erection
    - Electrical and Instrumentation (E&I) installation
    - Mechanical equipment installation
    - Painting & Insulation
    - Scaffolding
    - Post Weld Heat Treatment (PWHT)
    - Non Destructive Examination (NDE)
    - Notified Body Services
    - Pipe cleaning, testing and drying
    - Fuel supply for subcontractor scope
    - Site offices
    - Crane supply
    - Construction Equipment, Tools and Consumables
- Permanent building installation including control room

- Permanent fencing installation
- Telecommunications – Including the integration of systems
- Logistics

Table 7-1 presents a preliminary Work Breakdown Structure (WBS) to be used for construction subcontracts:

Table 7-1: Main EPC Subcontracting Packages for Permanent Works

Package Description		SC No.
Site Preparation		SC 1
Piling (if required)		SC 2
Buildings – Design + Procurement + Installation		SC 3
Civil Works	Concrete and Foundations	SC 4
	UG Works (Piping & E&I)	
Mechanical, Piping, Insulation, Painting and E&I works	Structural Steel Erection	SC 5
	Equipment Erection (including internals/platform)	
	Piping Erection	
	Scaffolding Works	
	Painting Works	
	Fireproofing Works	
	Insulation Works for Piping & Equipment	
	Electrical Works	
	Instrumentation Works	
Cooling Tower Design & Erection		SC 6

The contracting strategy reduces interfaces requiring management and coordination between on-site subcontractors. MDR may opt for nominated Lower Tier Subcontractors (LTSCs) for items services such as waste management and fuel supply. This ensures that the Main Subcontractors (MSCs) utilise LTSCs that have sufficient capacity and meet main contractor requirements. This strategy also reduces the number of companies operating on site.

All MSCs and LTSC must conform to all project safety systems, material handling requirements, quality requirements, AWP requirements, project plans, and procedures. In addition to the MSCs and nominated LTSCs, MDR also requires subcontractors to manage the following:

- Survey Control
- Fuel supply
- Temporary power for offices

- Temporary Building installation
- Medical services
- Security services
- Catering
- Material Handling and management

7.3 Modularization

7.3.1 Introduction

In the majority of onshore projects, a stick build execution approach has been the industry norm. This is the most cost effective approach unless there are significant identified risks that impact the costs due to site conditions, labour productivity, labour availability, and labour rate. Inclusion of a modular construction approach is preferable when assessment indicates high risks to the project for potential reasons including labour source (Union), labour availability, expected poor productivity, complex weather, extensive site development activities, risk of flooding, lack of infrastructure to support the activity, transportation facilities, housing, etc.

While stick build execution does offer some degree of flexibility in the Engineering / Procurement activities and actual site execution, it cannot eliminate risks that are purely site-based. The construction management workforce on site is also typically larger (dependent on the extent of subcontracted work activities and suitability of subcontractor to control their workforce in an appropriate manner) for stick build execution, with peak labour workforce on site higher as well. Reductions in construction management and labour are clear benefits of modular construction approaches.

Regardless of the application of a stick build or modular approach, the required civil work scope falls under a stick build classification. This effort includes, but is not limited to, the following:

- Site preparation
- Site elevation adjustment (Cut and/or Fill)
- Soils improvement
- Foundation installation
- Roads and drainage
- Underground piping installation
- Underground electrical and/or instrument cabling duct banks
- Temporary construction facilities (office, warehouse, laydown, parking, canteen, etc.)

- Buildings and landscaping.

In addition to the work activities indicated above, the following activities can occur on site or in a fabrication yard:

- Structural Steel erection
- Mechanical equipment installation
- Piping installation (may also include piping fabrication if site based fabrication is applied versus pipe spooling/fabrication in an offsite facility)
- Electrical and instrument component and cabling installation
- Pipe testing (hydrostatic and/or pneumatic, X-ray)
- Insulation and paint installation
- Pre-commissioning
- Commissioning

Overall completion of the site requires sequential execution of these activities. As such, delays in the early activities (site prep, soils improvement, cut/fill) as a result of weather delays, flooding, and difficulty accessing the site represent risks to the project schedule. Increasing overtime efforts and the labour workforce on site for subsequent work packages are the only viable options to maintain schedule if delays in these items occur. Labour agreements and workforce availability in the project vicinity may limit these, and extensive overtime may not be cost effective due to reduced productivity.

The best construction methodology that minimizes the need for overtime or high labour concentrations during field construction is modularization. This project execution method conducts a significant amount of fabrication away from the construction site to minimize the time and resources required to erect the plant. This requires fabrication and assembly of the plant in transportable units, or modules. Modules may take the form of:

- Vendor fully packaged and skidded equipment and related systems (typical weight in the range of 200 to 2,000 tonnes)
- Pre-assembled pipe racks or sleeper ways – PAR (typical weights in the range of 200 to 800 tonnes)
- Pre-assembled Units (integrated process and/or utility systems) – PAU (typical weights varying from 150/200 tonnes to 10,000 tonnes)

Benefits of modularization are primarily reduction of project risk associated with site work and schedule due to:

- Decreased risk of cost escalation; based on the use of established fabrication facilities with known and experienced workforce resulting in better control of labour rates and productivity
- Reduced schedule risk as a result of controlled work environment (module fabrication yard) allowing execution of the structural, mechanical and electrical/instrument work effort, along with pre-commissioning to be done regardless of the progress being made on site (site prep, civil works, underground works, foundation works)
- Pre-commissioning to the maximum extent possible at the fabrication yards in a controlled environment reduces site-based risk
- Increase safety due to less work at height and in controlled environments (e.g., fabrication and assembly of sub-modules at ground level, indoor fabrication utilizing pancake stacking approach)
- Reduces site overall workforce congestion and improves QHSSE by moving structural/mechanical/piping/electrical/instrumentation/pre-commissioning work efforts to established fabrication yards with better controlled environments
- Reduction in on-site heavy construction equipment required to erect structural steel, mechanical equipment, and piping along with reduction in related scaffolding requirements.
- Change from heavy cranage to set equipment to self-propelled mobile transport (SPMT) for onsite movement and setting of modules
- Reduced environmental impact at the site by minimizing local construction activities
- Reduced social impact at site and to local community infrastructure
- Minimizes laydown space, which reduces the area disturbed during construction
- Foundation requirements are often simplified
- Reduced fitting errors and re-work, as components are pre-fit prior to shipment
- Allows for simplified and competitive procurement, especially when the installation site is located in an area where raw materials, equipment, and labour are expensive or difficult to obtain
- Shorten schedules by allowing for concurrent processes, such as fabrication, permitting, and logistical arrangements

As noted previously, a modularization study that is conducted early in FEED once a specific site is selected, reviews the specific site constraints and risks and determines the final extent of modularization to be included in the design. It is anticipated, due to relatively high labour costs in the UK, the weather, and the unionized workforce, that some level of modularization is anticipated to reduce construction risk and costs on the project.

7.3.2 Modularization Opportunities with Current Equipment and Plant Arrangement

A primary goal of the UK Standard Plant Pre-FEED programme is the development of a standard plant design with targeted modularization to mitigate project risk. Certain elements of the technology are inherently suited to this goal due to compact sizing of complex mechanical equipment and parallel heat exchanger design. Currently, planned portions of the design for modular implementation included in the cost estimates are:

- Recuperative Heat Exchanger Network
- Modular Table Top (MDR has a proprietary modular construction method)
- Pipe Racks
- Packaged Equipment on Skids

Modularization of the recuperative heat exchanger network is essential to ensure performance and minimize cost. Due to the critical nature of the equipment and piping supports, the quantities of instrumentation, and the custom welding required for the unique piping, shop fabrication is essential for quality and cost control. It is also the only way to provide the compactness desired that minimizes piping runs and associated pressure drops while providing the proper installation of the insulation. Minimizing heat loss to atmosphere is critical to the AFC efficiency. Finally, with several components in the network being proprietary, shop fabrication and shipment of modularized assemblies is the only way to protect intellectual property.

Modularizing the pipe racks throughout the plant reduces the quantities of elevated work onsite during the construction phase. It also considerably reduces construction congestion by converting field labour task to shop fabrication assemblies, where lifts, elevated structures, and hoists exist to facilitate construction. It reduces the amount of field welding, which frees up surrounding areas for other tasks, as well. Receipt of complete assemblies with pipe supports and installed cable trays further reduces onsite labour and minimizes the opportunities for injuries and mistakes.

7.4 Level 1 Project Schedule

A Level 1 schedule for the UK Standard Plant is provided in Appendix C. There are two main critical paths, CTG design, delivery, and install and the design, fabrication and delivery of the ASU (by Others if necessary). Critical Activities and Assumptions include the following:

- The schedule commences with a full Class 2 FEED study for approximately 12-months duration, with the primary goal of fully designing the plant's systems to allow major equipment procurement to start as early as possible. Many problems with large EPC project executions can traced back to this early phase in the project where construction needs to start before engineering is complete with the design and procurement phase.

- All key subcontracts are bid, evaluated and negotiated during the FEED phase, such that Awards can be placed at LNTP
- There is a 4-month period anticipated between Limited Notice to Proceed (LNTP) and Full Notice to Proceed (FNTP) to allow for the finalization of the Project financing, whilst also allowing the earlier order placement of Long Lead Items.
- The purchase orders for the CTG and other major Long-Lead equipment (CO_2 Compressor and Aftercooler, Recuperative Heat Exchanger, CO_2 Pumps and Recuperative Heat Exchanger Network) are placed at LNTP to reduce the overall construction schedule.
- Site design inputs shall be provided prior to start of FEED study. The future site is assumed to be greenfield/brownfield with no remediation, demolition, or other environmental concerns that require time or effort to correct prior to start of the project.
- Supporting services and plant tie-ins shall be available prior to FNTP.

The owner is assumed to have all necessary permits already in place at LNTP such that early construction activities are not impacted.

8 Cost Estimate and Value Proposition

8.1 Class IV Budget Cost Estimate

The estimate is an indicative Class IV estimate per AACE 18R-97 and establishes a representative market price for the UK Standard Plant. The estimate does not represent an offer to perform the work. Final pricing depends on the ultimate design definition, site selection, project schedule, and contractual commercial terms. This estimate represents the cost to construct the power facility on an EPC basis. In accordance with MDR estimate classifications, this is a Class IV estimate, factored or parametric, with an end usage for study screening and project viability.

The estimated EPC Project Cost is as shown in Table 8-1.

Table 8-1 Estimated Project Cost (Class IV)

Cost Parameter	Units	Base Case
Total EPC Cost (per Unit)	**M£**	**359.6**
Cost per kW	£/kW_e	1,287

This estimate assumes that all phases of the project follow MDR standard specifications, work processes and procedures. Any owner required deviation from those may affect cost and/or schedule.

8.2 NET Power Value Proposition

The aforementioned capital cost estimate provides the industry standard metric of cost per kW_e, but that does not fully represent the true value proposition of a UK Standard Plant. A complete analysis of the net present value (NPV) must include the income resulting from CO_2 sales or use along with the favourable elimination of carbon dioxide allowances that CCS negates. While the cost for those allowances varies with market conditions, those for the EU have averaged £10/tonne CO_2 for the past decade and have trended higher by several fold in recent years. The UK Standard Plant captures approximately 942,600 tonnes of CO_2, which are currently worth over £21M for the carbon dioxide allowances, a cost that NET Power enables owners to forego annually. The impact of Brexit on this evaluation is not final at the time of this report. The proposed UK Emission Trading System (ETS) includes a similar carbon dioxide allowance structure and pricing with a minimum currently proposed at £15/tonne. Clearly, the reduction in emission fees and the addition of revenue from the CO_2 sales positively impact the levelized cost of electricity (LCOE) and the NPV of a UK Standard Plant.

For owners that elect to own and operate an ASU, there are also other options to include nitrogen and argon production for sales as well. An evaluation of the local market for those products is necessary for the owner to determine the net present value of an ASU with these optional products.

8.3 Comparison with Alternative Power Cycle Costs

Table 8-2 provides a comparison of the NET Power Cost/kW_e compared to alternative technologies with CCS. A basic 2x2 NGCC provides baseline costs for combined cycles without CCS as well. Cost estimates for this table are from the BEIS report Assessing the Cost Reduction Potential and Competitiveness of Novel (Next Generation) UK Carbon Capture Technology.

Table 8-2 Capital Cost (2017 Prices)	
Cycle/Technology	**£/kWe[(1)]**
NET Power AFC with CCS @ 98% Capture	950-1000[(2)]
Natural Gas Combined Cycle (2x2) - No CCS	500-600
Natural Gas Combined Cycle (2x2) with CCS @ 90% Capture	900-1000
Natural Gas Integrated Reforming Combined Cycle (2x2) with CCS @ 90% Capture	1500-1600
Supercritical Pulverised Coal with CCS @ 90% Capture	2100-2200
Supercritical Pulverised Coal with Oxy-Combustion CCS	2200-2300
Coal Integrated Gasification Combined Cycle with Pre-Combustion CCS @ 90% Capture	2900-3000
Natural Gas Combined Cycle with Molten Carbonate Fuel Cells with CCS @ 90% Capture	1000-1100
Biomass Fired Circulating Fluidised Bed Boiler with Post-Combustion CCS @ 90% Capture	3100-3200
Biomass Fired Circulating Fluidised Bed Boiler with Oxy-Combustion CCS @ 90% Capture	3600-3700
Biomass Integrated Gasification Combined Cycle with Pre-Combustion CCS @ 90% Capture	4100-4200

(1) Assessing the Cost Reduction Potential and Competitiveness of Novel (Next Generation) UK Carbon Capture Technology.

(2) Range shown considers a FOAK to NOAK adjustment of the EPC Price for UK deployed AFC. This adjustment is based on a method developed by the US department of energy and assumptions similar to those in the report referenced in table note (1). The NOAK turbine cost is sourced from reputable original equipment manufacturers (OEMs). The calculation assumes the N=16th unit. This cost data should be used for comparison purposes only.

Generating power without carbon dioxide emissions is only economically comparable to current combined cycle (without CCS) capital costs if environmental regulations or tax credits (carbon allowances) incentivize emission controls. While the ultimate mature price for NET Power, and possibly wind and solar with improved energy storage, is certain to decrease below current predicted levels, it is very unlikely that any emission free power generation can ever match the £/kW$_e$ for combined cycles without CCS. Thus, there is a price for eliminating carbon emissions. However, there are downstream benefits, such as completely eliminating emissions from transportation, that likely make the value of eliminating carbon emissions worth the price.

8.4 Basis of Estimate

The Class IV estimating model is a roll-up of the detailed indirect and direct costs.

Typically, Class IV direct estimates are based on scaling or parametric factoring of estimates from similar facilities. In this case, the only similar facility is the NET Power Test Plant. While the Test Plant is useful for factoring smaller components or systems, predominantly the generated bulk quantities come from a bottom-up approach. Material take-offs for large systems derive from the site layout and design presented in this report.

A significant portion of the direct cost relates to the equipment. Equipment costs are based on competitively bid and internationally sourced equipment and materials.

The estimate reflects a fully subcontracted construction execution approach, specific to the UK market based on budgetary quotes from reputable UK contractors.

The referenced scope, materials of design, and plant layout given in this document are the basis for bulk material quantities estimated by the engineering team. Equipment foundations, concrete, structural steel, electrical tray/cable, and balance of plant piping estimates use the plot plan and equipment sizes from supplier bids. Similarly, instrumentation and control wiring estimates assume locations for inline instruments and equipment locations in the plot plan. The high-energy piping, primarily in the recuperative heat exchanger network and turbine areas, requires atypical pipe wall thicknesses and some specialty materials. These critical lines estimates derive from a preliminary 3D model to ensure accuracy.

Estimated home office work hours assume standard deliverables from Power Projects. Estimated hours use the standard corporate templates, and unit rates consider the estimated construction quantities for the Civil/Structural, Electrical, Instrumentation/Controls, and Piping disciplines. The process discipline estimate reflects system complexity, assumed deliverables (for example, heat balances, water balances, AIV/FIV analysis, relief valve sizing, etc.), and standard rates or experience. The Mechanical discipline estimated hours considers availability of existing standard specifications for the equipment and the complexity and quantity of document review. All disciplines budgets include provisions for lessons learned from the Test Plant.

Quantities for construction oversight staffing levels and indirect project costs are based on experience in the United Kingdom and across the European Union and the quantities provided by Engineering.

8.4.1 Technical Assumptions/Clarifications

1. The estimate applies all previously stated site, mechanical, civil, and electrical design basis assumptions.

2. Initial estimate pricing covers the first UK Standard Plant.
3. Labour:
    - Direct Construction – Subcontracted
    - Construction Management Team – EPC Contractor Employed
    - Engineering & Design – EPC Contractor including high value operating centres
4. Assumption for site development work includes site preparation, roads, walkways, fences, and storm drainage.
5. Assume a relatively flat (no major dirt work or fill), balanced (any dirt from excavation repurposed on site) Greenfield/Brownfield site with no existing buildings, undergrounds, foundations, etc.
6. Assume that required geotechnical studies verify presumed soil stiffness and spread footing thickness, validate that 1.2m deep foundations are adequate, and confirm assumed design bases that piles, dewatering plans, and soil improvement are unnecessary.
7. Assume major dewatering is not necessary during construction.
8. Assume good, well-draining soil – no hazardous soils, no unsuitable soil disposal, no expansive clays, no liquefaction potential, no rock, no wetlands, no endangered species, no historical artefacts, no buried ordinance, etc.
9. Assumes no handling or disposal of contaminated soil, waste products, asbestos, or any other hazardous materials.
10. Assume paved roadway loop system inside the plant fence. Plant entrance road to perimeter fence is by others.
11. Assume adequate construction laydown, including craft parking space, is available adjacent to the permanent plant on the existing property.
12. Initial site surveying cost to be by third-party firm with subsequent surveying in field to be by EPC Contractor.
13. Assume third-party firm performs geotechnical work and provides a full report, with oversight/review by EPC Primary Contractor.
14. Storm water discharges primarily into a perimeter ditch just outside the loop road and then into a storm water basin.
15. Included plant control building with facilities consists of metal roofing and siding. No administration, warehouse, and maintenance buildings are in the estimate.
16. Wastewater discharges to the plant boundary without wastewater treatment, other than oil/water separation.

17. The CTG foundation preliminary design is a pedestal type structure that supports the turbine along with the maintenance deck. The commercial scale turbine conceptual design provided by a potential vendor is the assumed turbine.
18. It is expected that a number of components in the facility operate at noise levels above 85dBA and, depending on operational exposure, some areas of the facility may require to be designated as requiring hearing protection. Sound attenuation measures for the turbomachinery is unlikely to be cost effective and require this designation. The cooling towers and the turbine include sound attenuation measures in their design, and these help to also mitigate environmental noise emissions.
19. The UK Standard Plant includes a cooling tower without plume abatement. If necessary, plume abatement measures can be added to the cooling tower design, or dry cooling can be implemented at an additional capital expense with impacts to plant net efficiency.
20. The turbine ships complete and ready for installation/coupling to gear box and Recycle CO_2 Pump. In addition, all auxiliary equipment (lube oil system, etc.) is on skids or in modularized assemblies. Equipment is shop assembled to the maximum extent possible, including fully assembled/piped/wired skids. Enclosure and combustors ship separately for field assembly.
21. A VFD (in lieu of a start-up compressor) initiates operation of the CTG and the shaft-driven Recycle CO_2 Pump.
22. The development schedule for a 50Hz turbine design will support the overall project schedule.
23. The turbine supplier sizes and provides the VFD Transformer, Excitation Transformer, Lubrication Oil equipment, Seal Oil equipment, EHC Oil equipment, an air-conditioned VFD/Excitation Compartment [LEC] housing LCI & Excitation Control cabinets, the fuel/Oxidant/cooling lead piping and all ring headers connecting the inlet to the combustors and into the turbine. EPC Contractor provides two (or fewer) terminal points each for fuel/oxidant/recycle/coolant flows) and other typical turbine generator accessories.
24. The turbine supplier is responsible for control configuration, instrumentation, instrument list, I/O list, interface list, graphics, and technical advisors for commissioning of their supplied equipment.
25. The turbine supplier provides generator relay protection settings including AVR, LCI, PSS, and all relaying and metering.
26. The turbine supplier provides any required fuel gas leakage analysers.
27. Assumes hydrogen gas supply is via trailers, and nitrogen gas supply is via portable bottles (lease arrangements by owner) with appropriate infrastructure and safety measures.
28. Heavy haul requirements are uncertain, as they depend on final location and equipment/module sourcing and delivery routing.

29. Assume that locally available power at the site boundary is of sufficient capacity to provide site construction power, and that a connection to grid is available. MDR furnishes only site distribution equipment for the power plant.
30. Assume service and potable water required for construction are available at the site boundary. The flow will be sufficient to support construction.
31. The estimate does not include utility costs for water or power usage during construction. It assumes these are owner-supplied.
32. All concrete and steel quantities are from initial model take-offs located on the plot plan within the site boundaries.
33. Assume no as-built drawings are necessary.
34. Assume pre-engineered building subcontracts include foundations design/supply.
35. Vendors provide all platform/ladder/stair access needed for equipment and tanks. The equipment pricing does not include platform/ladder/stair access needed for the PDCs, Isolated Phase Bus duct, Generator Circuit Breakers. The CSA estimate contains these items in miscellaneous steel.
36. Cost for off-site CO_2 pipeline inter-connect, including installation, is by others. No costs for scrubbing/cleaning CO_2 are included. CO_2 export pipeline scope ends at plant boundary.
37. The estimate does not include spare parts.
38. Assume no Vendor Technical Field Assistance (TFA) other than turbine.
39. All compressors include vendor supplied instrumentation and controls, and these skid mounted instruments do not require field installation.
40. Simulator or man-hours to support simulator development are currently not included in the estimate. NET Power provides supporting simulator support for the UK Standard Plants as part of the license agreement.
41. Assume the heat tracing system is a turnkey subcontract based on 900 meters of pipe size of less than 75mm diameter.
42. The estimate excludes transmission lines from the plant. The owner provides the main switchyard, switchyard protection, metering panels and control house, and connection to the transmission lines. The Terminal Point is at the GSU HV bushings.
43. The estimated cost for turbine generator includes generator and ancillary equipment as well as required Technical Advisor time for construction and startup and operator training.
44. Assume the owner leases required CO_2 storage tanks and vaporizers.
45. The estimate does not include equipment necessary for black starts (without relying on external power network to back feed for start-up).

46. All owner scope and owner-provided information (ex. leased equipment) required by contractor is available prior to kick-off of detailed engineering.

8.4.2 Commercial Terms & Assumptions

1. Owner to provide Builders All-Risk Insurance.
2. This estimate is considered present day/overnight (date of the report) and excludes forward escalation.
3. The estimate excludes taxes, bonds, warranties, and letters of credit.
4. The estimate excludes custom duties, value added taxes, and offload fees.
5. No overseas taxes or duties are included.

8.5 Engineered Equipment Quotes & Estimates

The cost basis in the estimate for the major equipment items are previously obtained vendor budgetary equipment estimates, specific to a U.S. commercial scale NET Power Plant, which were selected on a best cost and best athlete basis. These quotes were adjusted for the UK markets and conditions along with updated vendor budgetary quotes specific for the UK Standard Plant for 61% of equipment on a cost basis (excluding the combustion turbine generator). The updated budgetary quotes were from major suppliers in the European Union and were specifically for supply to the United Kingdom. Equipment budgetary quotes are preliminary pending further refinement during FEED phase. The Combustion Turbine Generator cost is a verbal estimate between NET Power and turbine supplier.

8.6 Piping Estimate Overview

Global Sourcing is included to provide a competitive estimate. The project compares pipe spool fabrication unit rates from recent quotes received from the global competitive market pricing from Asian and Middle Eastern fabrication yards. In each Pre-FEED phase, the project validates the previous fabrication cost as being accurate for current quantity estimates and confirms fabrication quotes are current-day for those quantities with average fitting and weld counts per spool.

Design experience and rules of thumb on the flexibility of piping are used in lieu of stress analysis to estimate the high-energy piping material take-off (MTO).

The goal of the designers has been to limit the cost of the most expensive piping (high temperature and pressure applications), which is influenced by the overall plant layout. The piping material estimate contributes to approximately 60% of the plant bulk materials on a cost basis. The high-energy piping estimate uses preliminary 3D modelling or centreline routing. The balance of plant piping MTO (predominantly non-CO_2 containing/interfacing systems) uses the plot plan and equipment location as a guide, which is standard practice for Class IV estimates. The estimate considers these MTOs and subsequent material inquiry bids (on unit rate basis) to determine competitive, global pricing. The small-bore piping estimate is a scaled estimate based on previous chemical and power plant experience. Freight to the UK is also estimated.

8.7 Construction Estimate Development

For this Pre-FEED, the Construction execution strategy for a UK site location will be to engage Subcontractors to perform full Construction activities. The project team has engaged the UK market and sought budget quotes from UK Contractors who hold good reputations in the industry and those who we have worked with in the past. The Direct Construction estimate was then brought together utilising the market data received plus benchmarking against other significant energy projects previously undertaken by MDR in the UK (e.g. Isle of Grain LNG and South Hook LNG), and across the European Union.

8.8 Construction Indirects Estimate

The construction indirects consider the project schedule and factor against subcontractor cost. An allowance for craft support during start-up is included.

8.9 Pre-Commissioning, Commissioning & Start-Up

The estimate includes Pre-Commissioning activities, but excludes the commissioning and start-up of the plant as the responsibility of the owner. Before turnover to the owner, completed pre-commissioning activities include piping blowing, flushing and cleaning, electrical checkouts, motor runs, switchgear checkouts, and relay testing. Specialty subcontractors complete some activities such as relay setting, iso-phase bus testing, and generator breaker testing.

8.10 Home Office Services (HOS)

The Home Office estimate forecasts the project hours for the various engineering disciplines. Each discipline’s estimate considers the hours by task for a firm price proposal. The Home Office Services support hours (PM/Doc Control/Procurement/Subcontracts/Project Controls) are a ratio of the engineering hours, based on recent projects of similar scale.

8.11 Cost Reduction Opportunities

8.11.1 Cost Reduction Initiatives Explored & Incorporated

The following optimization/cost reduction initiatives, identified during the Pre-FEED efforts, are part of the current design:

1. Modular Tabletop to reduce construction schedule and costs
2. Site Compaction/Pipe Minimization
    - Consolidation of the plant layout to reduce the overall site footprint and required piping, installation costs, and interconnecting bulk quantities

- Vertical designs reduce site development and foundations
- Optimal equipment locations organized per process flows to minimize high cost piping quantities and electrical cable

3. Optimization of plant layout to facilitate modularization
   - Vertical designs facilitate partitioning equipment within conceptual shippable envelopes
   - Pipe rack preliminarily designs enable modular design and shop construction
   - Grouping select heat exchangers into bays such that framing, piping, and all other components support shop fabrication into module(s)
4. Evaluation of metallurgy options for savings
   - Ongoing corrosion studies are currently investigating alternative materials of construction for compact heat exchangers, piping, and turbine components to confirm current material selections and pursue potential future cost effective options
5. Optimization of combustor-related piping via coordination with turbine supplier to minimize pipe runs and simplify installation and maintenance

8.11.2 Potential Cost Savings for FEED Consideration

The following items as potential cost reductions for evaluation during FEED:

1. Investigate all vendor suggestions, including code allowance for changing design conditions throughout heat exchangers.
2. Review heat exchanger materials with metallurgist and corrosion study results.
3. Increase pressure drops through various exchangers to reduce size and costs (net efficiency trade-off).
4. Evaluate further relaxation of temperature approaches in exchangers versus the net efficiency impact.
5. Evaluate equipment efficiency versus capital cost.
6. Develop firm price specifications and narrow focus to key equipment suppliers. Iterate and optimize design and layout with suppliers. Receive firm, best and final offerings.
7. Fully develop modular solutions to incorporate maximum number of design elements into the pipe racks and equipment modules, including piping, controls, and electrical trays. Finalize selections of vendor modularizing, off-site modularizing, or on-site pre-assembly of piping and auxiliary heat exchangers.
8. Evaluate use of cantilevered cable tray in order to pull cable with manlift.
9. Combine material procurement with equipment suppliers.

10. Investigate using a double-redundant wireless network for transmitting instrument data instead of hardwiring all instruments.
11. Conduct motor starting study and possibly eliminate the need for the Voith variable speed hydraulic coupling.
12. Incorporate future applicable commissioning and testing lessons learned from the Test Plant within P&ID and piping design (cost avoidance).
13. Eliminate the use of independent vibration monitoring systems for a common machine monitor system coordinated with the DCS.
14. Combine the lube oil systems for rotating equipment.
15. Optimize physical interface(s) of the turbine by coordination with turbine supplier on piping and controls design. Minimize coolant and sealing flows and connection points.

9 ALTERNATIVES

9.1 Alternate Case (925°C Turbine Inlet)

The Base Case (900°C Turbine Inlet) design basis targets minimizing the CAPEX of the UK Standard Plant by operating at a turbine inlet temperature that allows for increased implementation of common stainless steels and other readily available alloys. However, it does not maximize potential net efficiency. Historical turbine and recuperator development efforts have pushed the turbine inlet temperature to nearly 1150°C (near maximum temperatures allowed for ASME certified materials). At those temperatures, the maturity of the high-alloy nickel market imposes additional risk to both CAPEX and schedule.

To demonstrate the improved performance as a function of increased turbine inlet temperature, this pre-FEED presents the performance and CAPEX estimates for an Alternate Case utilizing a 925°C turbine inlet temperature configuration. This minimal increase in turbine inlet temperature, along with lower turbine outlet pressure, allows for similar temperature profiles to the Base Case, which maintains the simplified materials of construction. While 25°C seems like a trivial temperature increase, the results demonstrate that even minor increases in this temperature are economical. Similar trends are well known in advanced ultra-supercritical steam turbine configurations.

The Alternate Case (925°C Turbine Inlet) includes many of the net efficiency improvement opportunities listed in Section 5.1, such as reduced blade-cooling flow, dry gas seals, and a higher turbine inlet temperature. Inclusion of some of the improvements requires assumptions at the time of the report, as specifications and agreements are currently in development for alternative turbine configurations that are first-of-a-kind for sCO_2 turbines at this scale. However, these improvements are technically viable and have been commercially demonstrated for gas or steam turbines as well as small demonstration size (10 – 25 MW) sCO_2 turbines.

There are several plant-wide configuration changes in the Alternative Case (925°C Turbine Inlet) that bear clarification. The following describe the main changes as compared to the Base Case design:

- A closed-loop cooling water system is implemented that minimizes potential for exchanger fouling from the open-loop cooling system. This reduces net efficiency due to the increased pumping duty of two circulating systems and temperature approach limits between them, but it improves overall plant availability.
- By implementing dry gas seals on the turbine, the Turbine Gland Seal System (TGS) and associated equipment is eliminated entirely. This does require alternative provisions for filling the plant from the CO2 Storage System (CDS), such as a pump/vaporizer combination. This configuration change reduces both parasitic load and capital costs.

- The Recycle CO2 pump is uncoupled from the turbine, and is instead motor-driven. Current turbine vendor proposals suggest that the overspeed provisions will not require the pump as a brake.
- An additional stage is added to the Recycle CO2 Compressor to improve efficiency. Accordingly, an additional intercooler is required between the final compressor stages.

The Alternate Case (925°C Turbine Inlet) was developed with a focus on maintaining high net output and efficiency and represents a more expensive CAPEX 925°C plant configuration. To ensure that the full range from high to low cost configurations are presented in this report, an extensive optimization analysis was undertaken to find the lowest CAPEX 925°C plant configuration, which is the Optimized Alternate Case (925°C Turbine Inlet). An example of the optimisation efforts is relaxing temperature approaches in heat exchanger to reduce required areas and lower cost. While this lowers the capital cost, it does so at increased compression duties due to lower suction densities resulting from the warmer temperatures.

For this optimization, individual sensitivity analyses were performed and the results input into a capital cost scaling calculation to determine the impact of each parameter on the Total Plant CAPEX (£/kW). Then the individual parameters that had the greatest impact on Total Plant CAPEX were selected to be included in multifactorial optimization runs. Using the optimal ranges of the following selected parameters, the models were run through a final series of multifactorial optimization cases and the results fed into the capital cost scaling calculations to find the one case, the Optimized Alternate Case (925°C Turbine Inlet), that minimized Total Plant CAPEX (£/kW).:

- Hot Gas Compressor Inlet Flow
- HXR Oxidant Outlet Temperature
- HXR Recycle CO2 Outlet Temperature
- Recycle CO2 Pump Intercooler Outlet Temperature
- Recycle CO2 Pump Intercooler Approach
- Recycle CO2 Compressor Aftercooler Approach

Although not explored in this study, the potential does exist to increase the net efficiency beyond the Alternate Case by increasing equipment performance albeit with higher cost per kW. These optimizations facilitate owner's evaluations of LCOE and NPV for the specific operations of their facilities.

Anticipated performance and CAPEX for the Alternate Case (925°C Turbine Inlet) and the Optimized Alternate Case (925°C Turbine Inlet) configurations are presented in Table 9-1 alongside that of the Base Case (900°C Turbine Inlet). Due to the late inclusion of this work in the scope of this project and the need for further equipment development, this estimate is limited to AACE Class V.

Table 9-1 UK Standard Plant Summary Performance & EPC Cost				
Performance/CAPEX Parameter	**Units**	**Base Case**	**Alternate Case**	**Optimized Alternate Case**
Turbine Inlet Temperature	°C	900	925	925
Gross Output	MW_e	387.0	443.8	436.4
Net Output	MW_e	279.4	303.3	296.0
Net Heat Rate (LHV (1))	kJ/kWh	7,078	6,533	6,689
Net Efficiency	%	50.9	55.1	53.8
CO_2 Capture Rate (2)	MTPA	0.926	0.934	0.935
AACE 18R-97 Estimate Class		Class IV	Class V	Class V
Total EPC Cost (per Unit) (3)	**M£**	**359.6**	**385.8**	**372.1**
Cost per kW	£/kW_e	1,287	1,272	1,257

(1) Lower Heating Value
(2) Purified CO2 Rate
(3) Does not include Air Separation Unit (if necessary)

While Table 9-1 presents reasonable targets for plant performance, it is important to realize that there are potential design requirements that can negatively impact virtually all of these values. One example is dry cooling, which increases CAPEX and decreases net output. It is essential that site specific requirements and their impacts are known prior to economic evaluations.

9.2 60 Hz to 50 Hz Frequency Converter Alternative

The historical supercritical CO_2 (sCO_2) turbine design for the UK Standard Plant operates at 60 Hz. This Base Case and Alternative Case designs presented here presumes that the turbine supplier can design a similar performing turbine/generator set that operates at 50 Hz. Since confirmation of that possibility requires a longer time frame than this project, the project team proposes, as an alternative approach, the addition of a group of frequency converter modules that adjust the produced 60 Hz power to 50 Hz.

A high level design for the frequency converter option was developed with a specific leading electrical technology company applicable to this project.

The work found that a provisional additional space allowance of approximately 1.4 hectares for 60 Hz to 50 Hz converters would be required on the plot, should they be necessary. The overall site development footprint including power block, cooling tower, and frequency converter area would then be approximately 4.4 hectares.

With input from the frequency converter vendor an estimate was developed for this alternative that utilises the same basis, assumptions and cost factors as have been developed for the Base Case cost estimate. The estimate represents the cost to construct the additional Frequency Converter facilities on an EPC basis assuming this is an additional scope in conjunction with the Base scope. In accordance with MDR estimate classifications, this is a Class IV estimate, factored or parametric, with an end usage for study screening and project viability.

9.3 Conclusions

The combination of Base and Alternate Cases brackets with reasonable confidence the achievable performance range for these configurations of a UK Standard Plant. Customizing the configuration to the target owner goals (net efficiency vs. CAPEX) remains for specific FEED studies.

The Net Output for this case can be adjusted to individual owner's targets. This case, as presented, maintains the same thermal heat input (natural gas feed rate) as the Base Case (900°C Turbine Inlet). Altering that value to meet specific target output rates is anticipated to have minimal impact to the £/kWe CAPEX value. With constant fuel input, the export CO_2 produced remains nominally constant as compared to that of the Base Case (900°C Turbine Inlet) presented previously.

10 Further Work

10.1 Discipline Specific Design Status

The following sections describe the status of the engineering design in the context of the overall scope of engineering expected to be completed prior to the commencement of construction activities. All engineering and design work will be executed in accordance with designer's ISO 9001 programme. The engineering and design processes begin with the requirements of regulatory agencies, codes and standards, and best practices.

10.1.1 Mechanical and Process Engineering

Mechanical and Process design deliverables are shown in Table 10-1, including the current status of the design:

Table 10-1 Mechanical/Process Engineering Deliverables

Deliverable	Status	Notes
Basis of Design and Design Philosophies	Preliminary	To be developed further once Project Site is selected and to cover specific owner requirements
Design Criteria	Advanced	Cycle economic optimization and vendor requirements have had significant development (7+ years)
Heat Balance/Thermal cycle	Advanced	Cycle completed and vendor data from indicative pricing incorporated. Need to optimize after "Plant Attributes" study finalized and verify with thermophysical property study, corrosion/materials study, and final Test Plant testing
Water Balance	Started	Water usage conceptual
Piping and Instrument Diagrams (P&IDs)	Preliminary	Detailed and updated to reflect preferred bidders' designs
Heat & Mass Balance Development and Management	Started	Evaluation of location specific fuel gas composition to be modelled in FEED. Specific evaluation of nitrogen and other impurities and impacts to combustion and corrosion. Incorporation of Test Plant data to be included.

Table 10-1 Mechanical/Process Engineering Deliverables		
Deliverable	**Status**	**Notes**
Review of Vendor P&IDs	Not started	
Pressure and Thermal Relief System	Not started	
Scope Boundaries and Terminal Points	Preliminary	Started and shown on P&IDs, will change with optimization as well as specific site criteria
Line and Valve Lists	Preliminary	
Partial Load Studies	Started	Discussed in Section 5.2
HAZOP Review	Not started	Performed on the Test Plant
Control Valve and Instrument Data Interface	Started	Narratives and DCS interface were worked out for the Test Plant.
Equipment Sizing Calculations	Started	HTRI and other analysis run on all heat exchangers. Significant modelling of other components in Aspen Plus
Equipment Lists	Advanced	
Equipment Specifications/Requisitions	Preliminary	Datasheets complete for current cycle runs for key equipment
Subcontract scopes	Not started	General interest and ROM all-in rates have been provided for creation of the estimate
Contacts and Meetings with Vendors	Not started	Meetings with suppliers providing indicative pricing to utilize in optimization planning
Review of Vendor Documents	Not started	Complete review, comments and optimization of preliminary submittals for indicative pricing only
Shop Testing and Inspection	Not started	
Construction and Commissioning support	Not started	Incorporating applicable lessons learned from the Test Plant

Finalizing all the process design information (heat and mass balances) and issuing P&IDs for design is a key early activity.

Standard practice is to annotate and cross-reference P&IDs for vendor interfaces, and this Pre-FEED assumes that practice (not replicating vendor P&IDs).

10.1.2 Piping Engineering

Piping design deliverables are shown in Table 10-2, including the current status of the design:

Table 10-2 Piping Engineering Deliverables

Deliverable	Status	Notes
Design Criteria	Preliminary	The material selection and wall thicknesses have been developed per current Heat & Mass Balance design basis and available process stream information with available related corrosion studies. However, material specialist and corrosion testing programmes are currently reviewing material specifications considering a 30-year life of the plant. These may alter current material selections. Detailed pipe specifications need to be developed where they do not exist currently.
General Arrangement Drawings	Preliminary	The Power Block Plan drawing is included in Pre-FEED report. General Arrangement Area (GA) drawings will be developed as more detailed and enlarged versions of information contained on Plot Plan drawings. GA Area drawings will reflect specific equipment locations, spacing, and layout context. Specific details on equipment size is needed to inform modelling for optimization. Better and more complete information on turbine vendor scope is required.
Equipment Modelling	Started	Equipment modelling has begun based on available equipment bid information.

Table 10-2 Piping Engineering Deliverables		
Deliverable	**Status**	**Notes**
Piping Specifications	Started	Material specifications have been started. Finalization is required pending topics discussed in Design Criteria notes. Technical specifications such as required for supporting procurement, fabrication, and construction will be developed during detailed engineering.
Piping Design and Modelling	Started	Piping design and modelling has begun for the larger piping in process-critical systems. The remainder will be designed in further stages of detailed engineering.
Piping Isometrics	Not started	Piping has been modelled to support quantity estimates and equipment layout. Isometrics will be developed in detailed engineering if required for stress analysis validation.
Stress Analysis and Support Systems	Not started	Stress engineers have reviewed preliminary piping layouts to ensure quantities allow for good-practice stress and flexibility loops.
Specialty Items Specifications and Datasheets	Not started	Selection on the Test Plant was time intensive, but is a good place to start. Specialty Items will be specified during further detailed engineering.

The project schedule is based on early piping design after critical system P&IDs are submitted and approved by the owner. One of the key deliverables is the alloy and stainless piping design interfacing with vendor equipment. Due to the long manufacturing lead-time of the large bore alloy piping, our schedule assumes an early mill order release (pre-buy) once the routing is in the model and preliminary stress is run for flexibility and nozzle loads.

10.1.3 Civil/Structural Engineering

Civil/Structural design deliverables are shown in Table 10-3, including the current status of the design:

Table 10-3 Civil/Structural Engineering Deliverables		
Deliverable	**Status**	**Notes**
Design Criteria	Preliminary	C/S/A design criteria is consistent on most projects. The work that needs to be performed is on the modularization concepts and plan.
Specifications	Preliminary	Concrete, grout, steel fabrication and installation per standard specifications
Geotechnical Studies	Not started	This requires an owner and a specific site
Site Preparation and Rough Grading Drawings	Not started	This requires an owner and a specific site
Foundation Design and Drawings	Started	Foundations sized based on good soil and equipment weights from indicative bids
Structural Analysis and Design Calculations	Not started	
Structural Steel and Concrete Drawings	Not started	
Final Grading and Drainage Design	Not started	This requires an owner and a specific site
Architectural Design	Not started	
Subcontract Scope	Preliminary	Input to cooling tower design data, including a flow-study for the cooling tower basin

10.1.4 Instrumentation and Control Engineering

Instrumentation and Controls design deliverables and current status from are shown in Table 10-4.

Table 10-4 Instrumentation & Controls Engineering Deliverables		
Deliverable	**Status**	**Notes**
Design Criteria	Preliminary	I&C design criteria is well developed for NET Power for the Test Plant; however, there are several cost savings ideas to be implemented.
Control Systems Input to Other Disciplines (Specifications & Datasheets)	Started	Cycle completed and vendor data from indicative pricing incorporated. Need to optimize after "Plant Attributes" study and double-check versus extensive instrument measurements from Test Plant after first-fire
P&ID Support	Started	Input to the Mechanical team during the Pre-FEED
Instrument Specifications	Preliminary	
DCS Segment Drawings	Not started	
DCS Cabinet Drawings	Not started	
DCS Graphic Display Drawings	Not started	
DCS Simulator Support	Preliminary	NET Power has performed substantial work for the Test Plant that will be useful for the Commercial scale plant
Field Mounted Instrument Datasheets and BEA	Not started	
Instrument and I/O Database	Not started	
Alarm, Shutdown and Controller Set points	Not started	
Instrument Heat Tracing Requirements	Not started	
Instrument Installation Details	Not started	
Instrument Location Drawings	Not started	

10.1.5 Electrical Engineering

Electrical design deliverables are shown in Table 10-5, along with their current status.

Table 10-5 Electrical Engineering Deliverables

Deliverable	Status	Notes
Design Criteria	Not started	Standard design criteria available; to be developed in FEED phase.
Electrical Specifications	Not started	Existing robust electrical specifications will be used along with the owner's criteria and the site conditions. Will be developed in FEED phase.
Electrical Load List	Preliminary	The equipment list provided has load information from supplier indicative bids
Single-Line Diagrams	Preliminary	The first basic single-line diagram is provided as Appendix A.5. Additional diagrams for the medium voltage systems will also need to be provided
Earthing, Lightning Protection, and Cathodic Protection Drawings	Not started	Will be developed in FEED phase.
Underground Electrical Drawings	Not started	Will be developed in FEED phase.
Aboveground Electrical Drawings	Not started	Will be developed in FEED phase.
Lighting Drawings	Not started	Will be developed in FEED phase.
Cable and Raceway Schedule	Not started	Will be developed in FEED phase.
Schematic Diagrams	Not started	Will be developed in FEED phase.

Table 10-5 Electrical Engineering Deliverables		
Deliverable	**Status**	**Notes**
Electrical Power System Studies	Not started	Will be developed in FEED phase.
Bulk Material Take-Off	Preliminary	
Vendor Document Review	Preliminary	Preliminary electrical review of turbine documents

10.2 Risk Reduction and Future Opportunities

NET Power continues to minimize risks to the UK Standard Plant design and CAPEX by engaging industry experts and contractors, collaborating with equipment suppliers, and incorporating the proprietary technology discovered during the engineering, construction, commissioning, and operation of the Test Plant. Future Test Plant trials include custom startup evaluations, emergency shutdown trips, equipment benchmarking and extreme condition testing, data analysis to vet operating models and simulations, and continual corrosion and equipment monitoring to develop predictive maintenance cycles and optimize materials of construction. Increasing the certainty of the capital cost estimate requires detailed engineering to optimize the equipment configurations and system controls, along with further development of modularized solutions to reduce field construction hours. These steps maximize the equipment reliability and efficiency while minimizing capital costs, construction schedules, and layout spacing.

Pre-FEED efforts have reduced material and manufacturing costs for the sCO_2 turbine and heat exchangers, material cost for piping, and identified which pipe routes can be optimized for the most significant CAPEX reductions. Continuing engineering design and layout optimization is critical to minimizing the capital cost. Key opportunities are summarized below.

- Pipe routing and site layout optimization has compressed the layout producing a 25% reduction of piping relative to initial (2017) designs created in the first two Pre-FEED phases.
- Maturity of equipment layout and pipe routing facilitates further modularization improvements in FEED to minimize project risk and cost of bulks, direct labour, and indirects.
- Further CTG development/refinement to simplify construction, operation, and maintenance while improving efficiency.
- Optimization of soft start requirements and variable speed controls.

10.3 EPC Cost Estimate Risk and Limitation

The estimates in Section 8 and 9 are indicative Class IV and V estimates, respectively, per AACE 18R-97 and they establish a representative market price for this type of facility specific to UK execution. The final pricing is dependent upon the selection to pursue some of the cost reduction opportunities and the success those opportunities produce along with net efficiency improvement opportunities. Additionally, final design definition, site selection, project schedule, and contractual commercial terms may impact the final costs.

Appendix A.1 – Process Flow Diagram

Appendix A.2 – Heat & Mass Balances

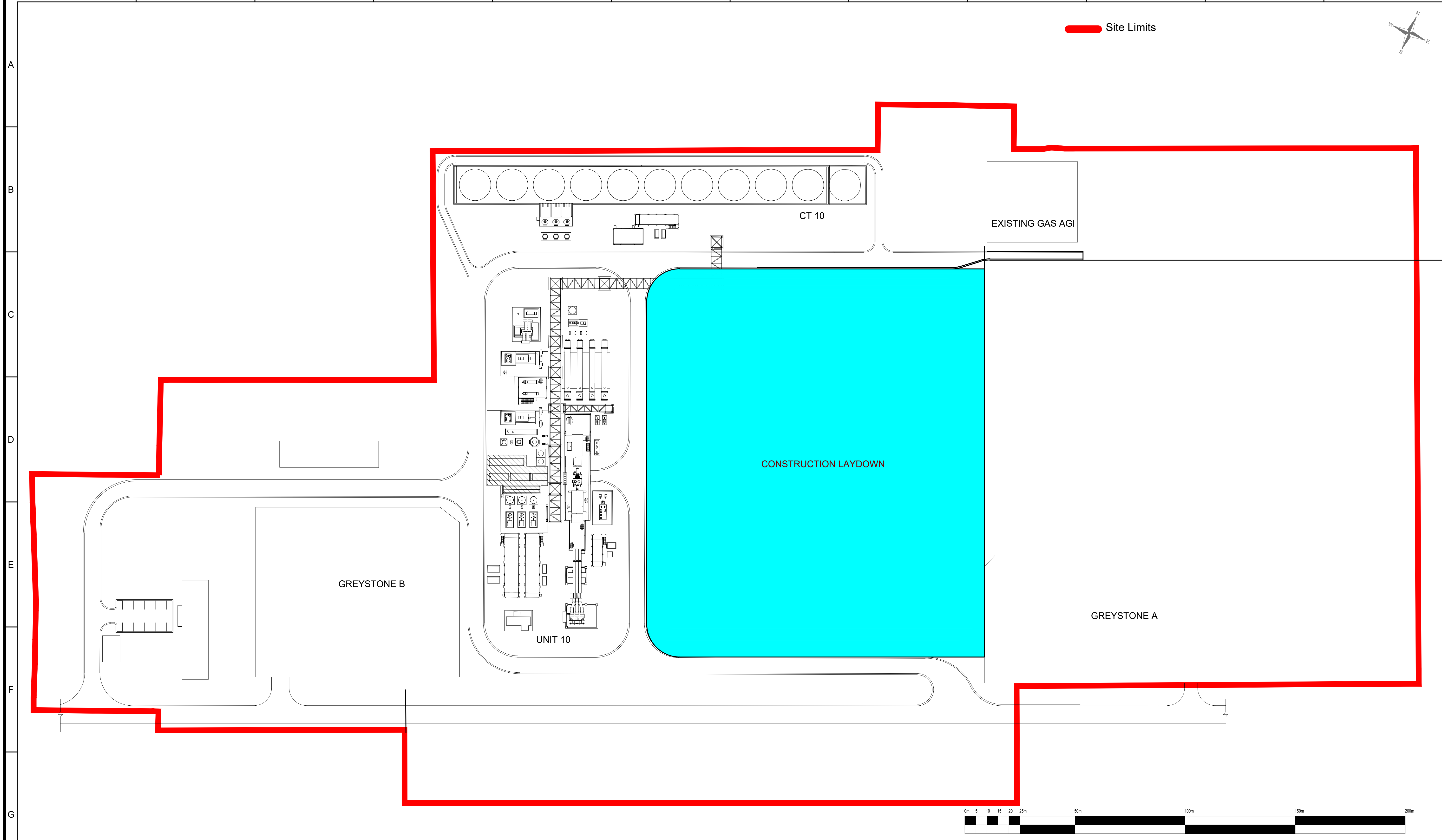
Appendix A.3 - Conceptual Overall Plot Plan

Appendix A.4 – Piping & Instrument Diagrams

Appendix A.5 – Key Single Line Diagram

Appendix A.6 – Control System & Telecommunication Block Diagrams

Appendix A.7 – Equipment List/Load List



PRELIMINARY ISSUE

REV	DATE	DRAWN	REV'D	APP'D	REVISION
P1	16/03/2021	IH			PRELIMINARY ISSUE

DRAWING NUMBER	REFERENCE DRAWING TITLE

8RIVERS
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APPROVED
DESIGNED
DESIGN REVIEW
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DATE

TITLE: ONE UNIT AFC CONFIGURATION
SCALE: AS SHOWN
DRAWING No: 10-1000-C3-DWG-EN 0008
REV: P1
A1

8 Rivers Capital LLC

ALLAM CYCLE UK PRE-FEED

CO2 Infrastructure - Optioneering Report

70053760-WSP-00-XX-RP-PE-0001-S0_P02
SEPTEMBER 2020

CONFIDENTIAL

8 Rivers Capital LLC

ALLAM CYCLE UK PRE-FEED

CO2 Infrastructure - Optioneering Report

REPORT (VERSION P02) CONFIDENTIAL

PROJECT NO. 70053760

OUR REF. NO. 70053760-WSP-00-XX-RP-PE-0001-S0_P02

DATE: SEPTEMBER 2020

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QUALITY CONTROL

Issue/revision	First issue	Revision 1	Revision 2	Revision 3
Remarks	Issued for Client Comment	Client comments incorporated		
Date	August 2020	September 2020		
Prepared by	Tony Alderson Andy Jackson	Tony Alderson		
Signature		Alderson, Tony (Tony.Alderson) Digitally signed by Alderson, Tony (Tony.Alderson) DN: cn=Alderson, Tony (Tony.Alderson), ou=Leeds (3 White Rose Office Park), email=Tony.Alderson@wsp.com Date: 2020.09.08 12:54:02 +01'00'		
Checked by	Andy Mustoe	Andy Jackson		
Signature				
Authorised by	Ben Platt	Ben Platt		
Signature		Digitally signed by Ben Platt DN: cn=Ben Platt, c=GB, o=WSP, ou=Energy, email=benjamin.platt@wsp.com Reason: I am approving this document Date: 2020.09.08 13:31:37 +01'00'		
Project number	70053760	70053760		
Report number	70053760-WSP-00-XX-RP-PE-0001-S0_P01	70053760-WSP-00-XX-RP-PE-0001-S0_P02		
File reference				

CONTENTS

TABLES

FIGURES

1

INTRODUCTION

1 INTRODUCTION

1.1 INTRODUCTION

8 Rivers Capital LLC has been awarded funding under the BEIS Feasibility Study strand of the CCUS Innovation Competition.

"Feasibility Study" is defined by BEIS as "the evaluation and analysis of the potential of a project, which aims at supporting the process of decision-making by objectively and rationally uncovering its strengths and weaknesses, opportunities and threats, as well as identifying the resources required to carry it through and ultimately its prospects for success".

The goal of the Feasibility Study is to advance both the technology and business case to the point of being ready to proceed with the FEED design for a commercially operated facility located in the UK.

In parallel with the UK Pre-FEED study being undertaken by McDermott, a Site-Specific Study is being performed to complete a set of engineering deliverables and reports to enable the development of the site to continue to Front End Engineering Design with confidence and cost certainty.

This Site-Specific Study is based on the former Combined Cycle Power Plant site at the Wilton International site at Teesside. This site has been identified by both 8 Rivers and Sembcorp and is deemed to be suitable for an Allam Fetvedt cycle power plant.

This CO_2 Infrastructure Optioneering Study represents one element of the Site-Specific Study.

1.2 BACKGROUND

The Net Zero Teesside (NZT) project formerly OGCI, proposes to develop a CO_2 pipeline network around the Tees Valley to transport captured CO_2 from multiple sources to offshore storage sites in the Southern North Sea. One arm of this network is anticipated to terminate on the Wilton site, and therefore will provide a suitable export route for CO_2 captured at the power plant.

However, it is anticipated that the NZT pipeline may not be available until 2027 or later. To meet project timelines. it is therefore necessary to consider alternative options that could facilitate CO_2 export to commence in 2024, before the NZT pipeline is available, and to provide an alternative export option in the longer term.

1.3 SCOPE

The scope for this study was divided into two parts.

i) For export via the NZT pipeline:

- Determine a most probable tie-in / interface location between the plant and the third-party CO_2 transportation infrastructure.
- Taking cognisance of existing pipe corridors across the Wilton site, propose a routing for on-site pipework to interconnect between the plant and the interface location.
- Determine requirements for an Above Ground Installation (AGI) upstream of the interface.

- For the new pipework and equipment within the site battery limits, use in-house data and costing methodologies to determine a Class IV capital cost estimate for these facilities.

ii) For alternative export options:

- Identify viable alternative CO_2 export options from the Wilton site
- Options should include transportation by pipeline, road, rail and ship
- Identify existing infrastructure that could be utilised as part of the CO_2 export system
- Determine the requirements for new facilities, equipment and transport hardware associated with each option

2

OPTIONEERING

CONFIDENTIAL

2 OPTIONEERING

2.1 INTRODUCTION

This section discusses the various options available for each element of the CO_2 export facility. The following options are discussed herein:

- Pipeline connection to the future NZT system
- New marine export facility on the Tees
- Existing marine export facility on the Tees
- Transport to remote marine export facility

2.2 PIPELINE CONNECTION TO FUTURE OGCI CO_2 PIPELINE

The NZT connection option provides a link to the 3rd Party network that will allow 8 Rivers Capital the most physically convenient way to export CO_2. The NZT pipeline network is understood to be planned in close proximity to the Wilton site, therefore it provides an economic alternative for exporting CO_2. The NZT plans are understood to route a pipeline very close to the northerly edge of the power plant plot area on the Wilton site. The plans are not presented within this document but the connection to this asset would constitute a very small length of pipeline to create the link and tie-in.

The sizing of the NZT pipeline is not yet confirmed and this would present a risk in attempting to ensure that adequate capacity in the NZT pipeline is available.

The NZT connection would constitute the following parts:

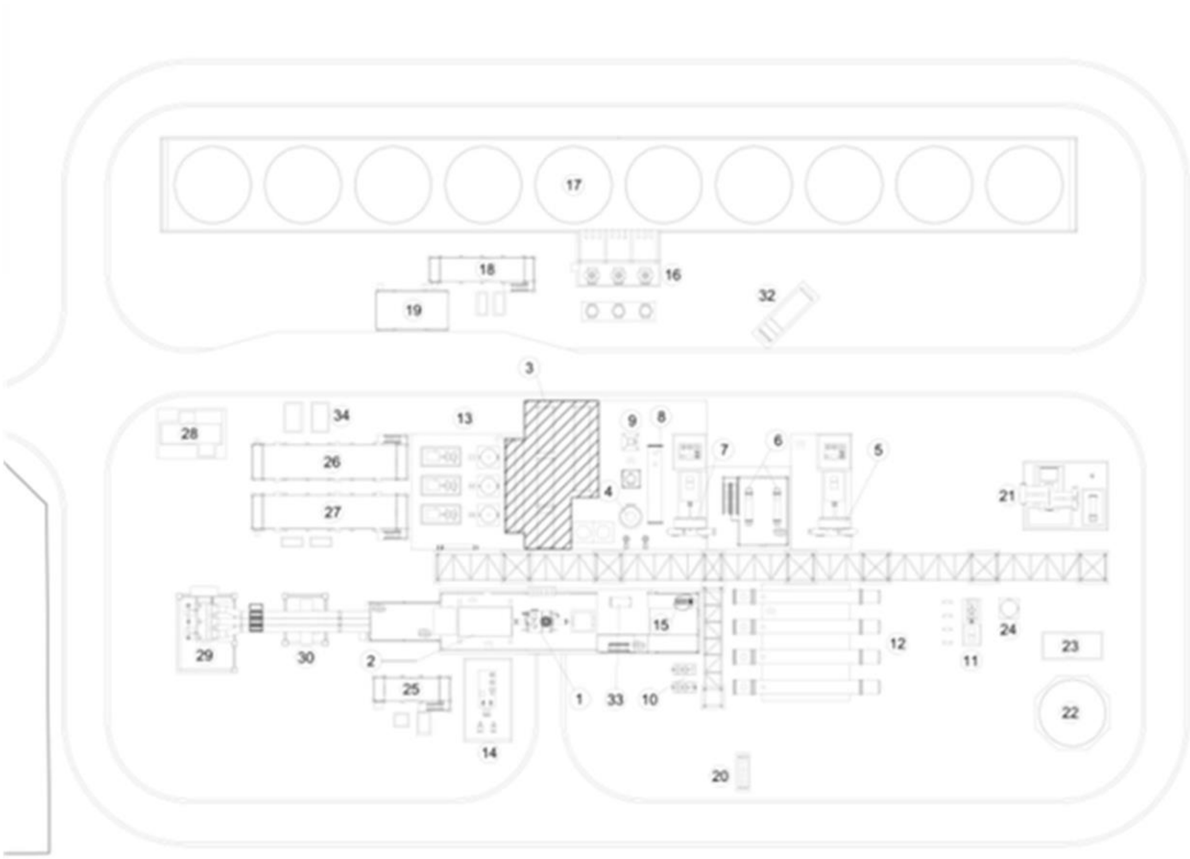
- Link pipeline and tie-in to the CO_2 outlet at the Wilton site
- On-site pipework
- On-site CO_2 treatment AGI (if required)
- Off-site pipework
- NZT tie-in

Link pipeline and Tie-in to the CO_2 exhaust at the Wilton site

Within the power plant plot area on the Wilton site, the CO_2 pipework routing would be governed by the specific plant layout, it is understood this is yet to be confirmed so the start point cannot be definitively named at this time. WSP has considered the layout provided in the document titled “Conceptual Overall Plot Plan” with Drawing No. 626236060-000PI-01-000001, Rev A. It is assumed the CO_2 export stream would originate from the region of the “Recycle CO_2 Pump” or the “CO_2 Turbine and Combustors”, based on this plot plan. See Figure 2-1 overleaf.

The design of this connection is not considered here, it is assumed an export process stream will be available as part of the overall plant design.

Figure 2-1 - Preliminary site layout, extract from 626236060-000PI-01-000001 Conceptual Overall Plot Plan, Rev A



Depending on how this start point is accommodated in the plant design and the required CO_2 quality characteristics from NZT, there may be a need for some process stream treatment at this point. WSP has assumed, for the purpose of this report, that space near to the start point will be at a premium such that any treatment of the CO_2 stream will be performed at or near to the power plant site boundary.

On-site pipework

From the start point mentioned above, the pipeline will need to navigate the power plant site.

The following internal routing options are available:

- Direct lay below ground into a verge which then follows the road around the site to head towards an exit of the site on the north boundary; or
- Mount onto the existing utility racks (assuming enough space is available), follow these east and then either extend the racks north to accommodate the pipeline path to the northern boundary or exit the racks at the eastern most point and then enter a verge below ground by the road to then head north and leave the site via the north boundary; or
- Flip the site such that the CO_2 export point is to the north of the site, thus the connection could be much shorter and be a brief length of either buried pipeline, or mounted on new piperacks.

This would constitute circa 300 metres of pipework to be routed on the Wilton project site.

On-site CO_2 treatment AGI

It should be noted that the NZT connection will likely have a specific CO_2 quality entry criteria that will need to be met by 8 Rivers. This will require that at some location on the 8 Rivers site, an export facility with a CO_2 conditioning skid might be needed. This could necessitate a need for:

- Compression / regulation;
- Dehydration (likely controlled upstream);
- Metering; or
- Heating.

This would be achieved via a small Above Ground Installation (AGI) at the Wilton site boundary, though this could be situated closer to the CO_2 exhaust connection. Should the CO_2 need to be heated or compressed it may be possible to use on-site process streams to decrease the parasitic load of this system.

No matter the conditioning required, metering is highly likely to be necessary for the purposes of billing between NZT and 8 Rivers for volumes of CO_2 exported.

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Off-site Pipework

This would constitute circa 20 metres to 50 metres of pipework depending on the specific NZT network location and the requirements of that connection. This section of pipeline could be designed to *BS PD 8010: 2004 Part 1 - Steel pipelines on land* if it is to be gaseous phase CO_2.

NZT tie-in

The physical connection to the NZT pipeline is likely to be in the form of a tee off the main OGCI pipeline inside an AGI with minimal telemetry. This can be done many ways but will at least involve a physical tee piece, a construction valve and a Remotely Operable Valve (ROV) to provide safe isolation. If the NZT main is not live at the time then this connection should be simple to perform, however if the main is live with CO_2 then a more complicated process will be required.

2.3 NEW MARINE EXPORT FACILITY ON THE TEES

It is considered that CO_2 could be exported via ship for storage either in the UK or Norwegian sector of the North Sea or potentially for use for Enhanced Oil Recovery (EOR) in the USA. One potential option is to link to the Northern Lights CCS project in Norway (https://northernlightsccs.eu/). This project includes marine transportation of CO_2 from two proposed capture plants in eastern Norway to a marine terminal in the Bergen area, from which the CO_2 will be routed to an offshore storage site by pipeline. It is therefore considered that CO_2 could be exported from Teesside to the proposed CO_2 terminal at Bergen in Norway.

There is a potential location for a dedicated ship loading facility on the north bank of the River Tees, adjacent to the Inter Terminals Seal Sands facility. This location is beside the north portal of the pipeline tunnel under the river, which would facilitate the installation and routing of a new CO_2

pipeline to the facility. An existing, mothballed pipeline that could potentially be utilised for CO_2 transport also passes close to this site. Figure 2-2 (from Google Earth) shows the potential location (outlined in red).

Figure 2-2 - Google Earth view of Potential Location for New CO_2 Marine Export Facility

PIPELINE REQUIREMENTS

CO_2 would need to be transported from the power plant at Wilton to the marine loading facility via pipeline. Two options exist:

- Gas-phase pipeline with CO_2 liquefaction at the terminal.
- Liquefaction at the power plant and a refrigerated liquid-phase pipeline to the terminal.

The pipeline size requirements have been determined for each of these scenarios. 8 Rivers have advised that the maximum CO_2 export rate from the power plant will be 239,600 lb/h (109 tonnes/hr), produced at a pressure of 405 psig (27.9 barg). For a gas-phase line, industry norms suggest a nominal gas velocity of 20 m/s would be appropriate for CO_2. On this basis, an 8" line size would be required.

For a liquid-phase line, based on typical marine transport conditions of 15 barg and -30°C and a nominal velocity of 2 m/s (typical for liquid pipelines), a line size of 6" would be required. It should be noted that this line would need to be insulated, so the overall diameter including insulation would increase to circa 12".

Wilton and Seal Sands Pipeline Re-use

WSP has been informed that there is an existing redundant 8” pipeline from Wilton and Seal Sands that could be used for the export of CO_2. This pipeline is routed from the proposed Wilton site past the new Marine Export Facility on the Tees. In order for this pipeline to be used theremaining asset life should be determined. WSP understand that this pipeline did not experience regular full pressure range cycling which would reduce fatigue life, therefore there is a likelihood thatthis asset can be reused. It would be prudent however to complete a full fatigue assessment to verify the condition of this asset and its remaining design life.

The above indicates that this existing pipeline is appropriately sized for transporting gaseous phase CO_2 from the power plant to the marine terminal. This pipeline is unsuitable for liquid CO_2 as it is uninsulated, and in particular the HDD section of the line under the river could not be retrofitted with insulation.

New Pipeline

WSP was provided with a new pipeline corridor route to review by the client (see Figure 2-4~~Figure 2-4~~). This route would connect the Wilton site to the new Marine Export Facility on the Tees and thereby facilitate marine export of CO_2.

This corridor constitutes a new route within which it would be possible to install either of the pipeline options described above, gas or liquid phase. The route starts at the Wilton site and would be at an on-site AGI that would either liquefy the CO_2 for transport as a liquid or compress gaseous CO_2 for transport as a gas.

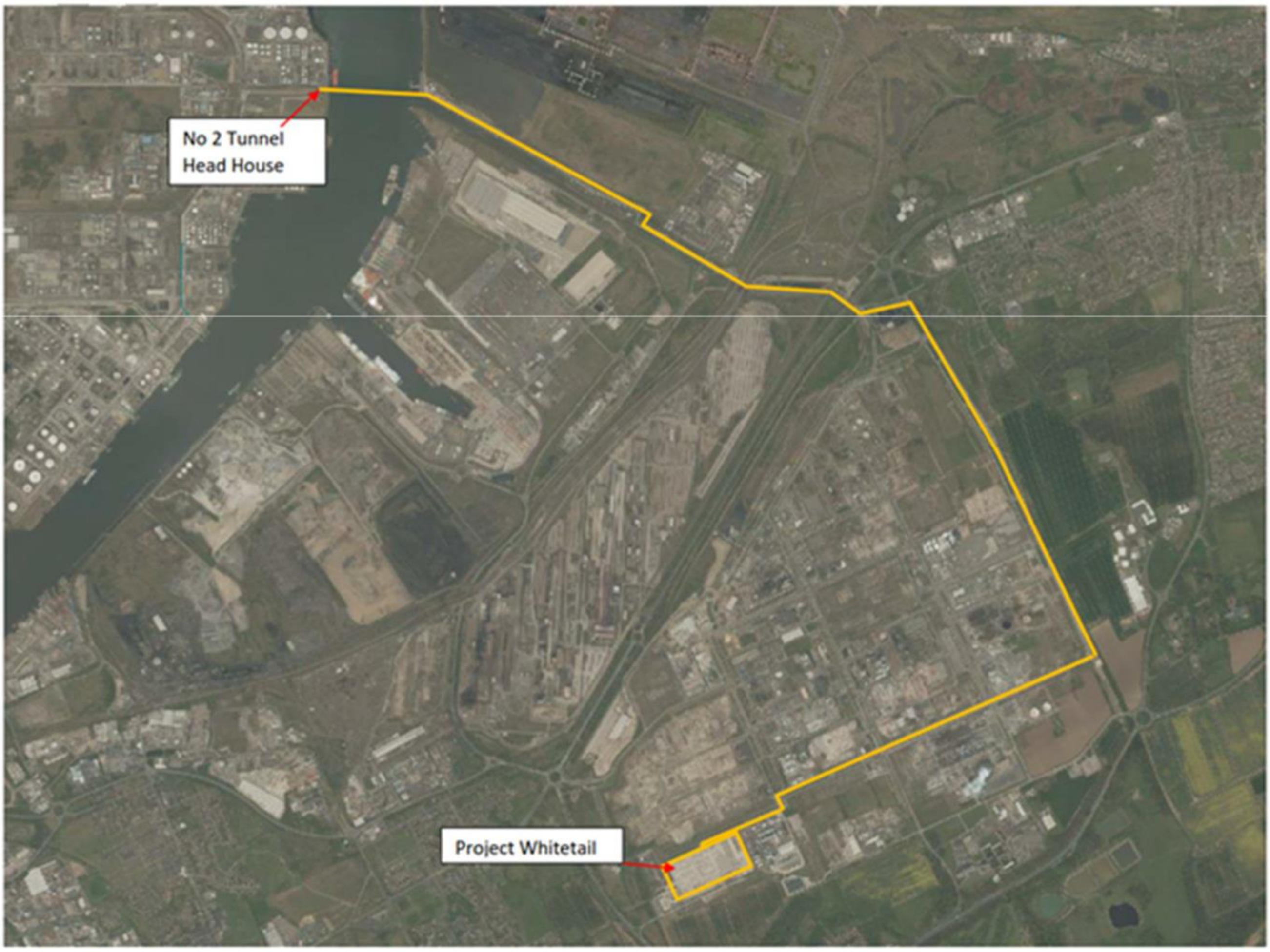
The route then continues into a utility corridor to head east; it will remain in this corridor either on pipe bridges or in the existing trench up to the point where the pipeline would enter the tunnel under the river. At the point of emerging from the tunnel the pipeline will then need to turn back on itself and enter the Marine Export Facility.

WSP has performed a brief desktop review and there are no major concerns from this route.

WSP would however note, that there has not been opportunity to verify capacity in this corridor or in the existing tunnel for the new CO_2 pipeline. However, it is understood from client investigations that space is available. Further to this, due attention to the extra size afforded by the lagging of a liquid line option, should be considered.

WSP would estimate from past experience that a new gaseous phase pipeline as described above (that utilises existing corridors and crossings) should cost in the order of £15m.

Figure 2-4 - Route corridor from Wilton site to the new CO_2 Marine Export Facility



LIQUEFACTION AND STORAGE

As stated above, CO_2 is transported by ship as a pressurised, refrigerated liquid. Therefore, the facilities required for CO_2 export include a liquefaction plant. The location of the liquefaction plant is dependent upon the operating regime of the pipeline. Assuming the existing pipeline is to be reused, then the liquefaction plant would be located adjacent to the marine loading facility.

From cost data presented in Reference 1 (Appendix A), an indicative cost for the liquefaction plant is £13 million.

Intermediate storage of liquid CO_2 prior to ship loading is required at the ship loading facility. Reference 1 recommends a storage capacity of 120% of the total cargo capacity of the shipping fleet. The Northern Lights project is proposing the use of a 7,500 m^3 capacity CO_2 carrier. Assuming this size of ship, a ship would need to be loaded approximately every 3 days. Based on typical ship speeds and 12-hour loading/unloading durations, a round trip of around 4 days is anticipated. Therefore, a fleet of 2 ships would be required. Applying the above guidance, then a CO_2 storage volume of 18,000 m^3 would be required.

Rather than construct new storage capacity, it may be possible to reuse existing storage tanks at Seal Sands. It is understood that 2-off redundant LPG spheres may be available. However, the capacity, physical condition and suitability of these storage spheres still needs to be determined.

MARINE LOADING FACILITIES

At the ship loading terminal, facilities to transfer the CO_2 from storage to the vessels will be required. This will include transfer pumps, pipework, marine loading arms, etc.

It should be noted that if new jetty civils infrastructure is required, then this would represent an additional cost.

It is anticipated that custody transfer of the CO_2 would transfer to the Transport & Storage (T&S) organisation at the marine loading facility. Therefore, it would be the responsibility of the T&S organisation to procure the ships to transport the CO_2 to the storage location.

OVERALL SHIPPING COSTS

Reference 1 (Appendix A) provides indicative data for the overall cost of CO_2 shipping, including the impact of a range of parameters and sensitivities. From this data, and the predicted shipping parameters described above, it may be determined that the overall cost of exporting CO_2 from Teesside to Norway would be around £15 per tonne of CO_2. For export to the US Gulf Coast (for EOR), the overall cost is projected to be around £50 per tonne of CO_2.

2.4 EXISTING MARINE EXPORT FACILITY ON THE TEES

Nippon Gases currently operate a CO_2 ship loading/offloading facility, located within the PD Ports Teesport Commerce Park on the south bank of the River Tees. The facility is around 2.5 miles from the Wilton site and was formerly operated by Yara.

Figure 2-5 - CO_2 carriers "Froya" and "Gerda" berthed at Nippon Gases terminal on the Tees (Terminal and vessels were operated by Yara at this time)

This facility currently handles a fleet of CO_2 carriers operated by Praxair Ship AS, each with a cargo capacity of 1,800 tonnes (1,940 m^3). The terminal incorporates on-site CO_2 storage and road tanker loading/offloading facilities. Figure 2-5 illustrates two of the fleet berthed at this jetty on the Tees, while Figure 2-6 (from Google Earth) shows the jetty, CO_2 storage tanks and road tanker loading bays.

Figure 2-6 - Google Earth view of Nippon Gases CO_2 terminal on the Tees

ROAD TRANSPORTATION

It may be possible to utilise this facility for CO_2 export from the power plant. In this scenario, it would be necessary to install CO_2 liquefaction at the power plant together with a road tanker loading facility; road transport is considered to be the most viable option in this case, as there are no existing pipeline corridors between Wilton and Teesport Commerce Park.

Typical CO_2 road tanker trailer units have a capacity of 25 m^3 (see Figure 2-7~~Figure 2-7~~). On this basis, for round-the-clock operation, 4 to 5 tankers would need to be loaded per hour. On a 2-shift basis this would increase to 6 to 7 per hour. Assuming a 2-hour round trip, and allowing for spare vehicles, these two cases would require fleet sizes of 10 or 14 road tankers, respectively.

Figure 2-7 – CO_2 road tanker trailer manufactured by Karbonsan

ROAD TRANSPORT LOADING FACILITIES

Multiple road tanker loading bays would have to be provided at the power plant, comparable to those located at the Nippon Gases facility.

While it may be possible to utilise the existing CO_2 storage capacity at the loading terminal, it will be necessary to provide additional CO_2 storage at the power plant to provide a buffer between CO_2 liquefaction and road tanker loading. The volume of additional storage required would be dependent upon the capacity and availability of the existing storage. However, as a worst case it could match the 18,000 m^3 stated above for a new-build marine loading facility.

2.5 TRANSPORT TO REMOTE MARINE EXPORT FACILITY

There are multiple CCUS projects under development in the UK. Several of these are likely to include CO_2 marine terminal facilities for ship-borne transportation of captured CO_2 to designated storage sites. Examples include the South Wales cluster and ‘Project Cavendish’ at Isle of Grain, Kent.

As an alternative to ship loading on the River Tees, it would be possible to transport captured CO_2 from the Wilton site to such a third-party marine terminal.

RAIL TRANSPORTATION

Rail transportation of CO_2 from Wilton to the marine facility is anticipated to be most viable option for long distance overland transport. There is existing rail infrastructure at Wilton and, for example, at Isle of Grain. Therefore, it is likely that there would be no requirement for new rail lines or sidings to facilitate rail transport.

Existing CO_2 railcars have a capacity of around 60m^3 (see Figure 2-8). Capacity appears to be limited by maximum axle load, since larger capacity rail cars are utilised for other liquefied gases with lower density. Companies including VTG AG (https://www.vtg.com/wagon-hire/our-fleet/g97062d) and GATX Rail Europe (https://www.gatx.eu/fleet/tank-cars/pressure-gas-cars) operate and lease such wagons.

Figure 2-8 - CO_2 railcar, operated by VTG AG

Two block trains per day, each consisting of 22 wagons, would be required to accommodate the CO_2 to be exported from the power plant. Assuming a 36-hour round trip between Wilton and Isle of Grain, three trains would be required; making an allowance for spares this equates to a fleet of around 73 railcars. It is not known what the size of the existing CO_2 railcar fleet is, or whether they are available for use. It may be necessary for a new dedicated fleet of wagons to be constructed and leased.

Whether custody transfer of the CO_2 would take place at Wilton or at (for example) Isle of Grain is unclear; if the former, then 8 Rivers would have responsibility for arranging rail transport. While the railcars could be leased from one of the companies identified above, a contract for the operation of the trains would have to be placed with one of the rail freight operating companies such as DB, Freightliner, GBRf or DRS. In addition, factors such as securing freight paths on the network would have to be considered.

RAIL LOADING FACILITIES

Sembcorp have identified a potentially suitable location for a rail loading facility on the Wilton site, where a new loading gantry could be installed. This is the former coal unloading facility adjacent to the northern boundary of the Wilton site. The existing redundant 8” pipeline discussed above is routed past this location, and could therefore be utilised to transport gaseous CO_2 from the power plant to the rail loading facility, by installing a new tie-in to this line. In this scenario, the CO_2 liquefaction plant and buffer storage would be located adjacent to the rail loading facility.

Applying the same “120% of the fleet size” metric as applied to marine transportation for the CO_2 storage associated with rail transport results in a required storage volume of 4,750m^3.

The required capacity of the CO_2 liquefaction plant would be unchanged from the marine export options, as this is based on the CO_2 production rate from the power plant.

3

CONCLUSIONS

3 CONCLUSIONS

3.1 SUMMARY

WSP has reviewed the CO_2 export options available and has presented several technically viable alternatives for consideration by 8 Rivers. The following options were discussed:

- Pipeline connection to the future NZT system;
- New marine export facility on the Tees;
- Existing marine export facility on the Tees; and
- Transport to remote marine export facility

The following conclusions were reached.

A new *pipeline connection to the future NZT system* is feasible but will require further detailed information on both the Wilton Power Plant site and the NZT network before further design stages could be undertaken, a preliminary CAPEX cost estimate, which included onsite pipework, CO_2 conditioning and compression and tie-in to NZT pipework, was estimated to be £1.56m.

A potential location for a *new marine export facility on the Tees*, adjacent to the Inter Terminals Seal Sands facility was discussed and deemed feasible. The various facilities required for this option were discussed, these being:

- A connecting pipeline (between the Wilton Power Plant site and the export facility shore-side location);
- Liquefaction and Storage; and
- Marine Loading Facilities.

The re-use of *existing marine export facility on the Tees* was discussed, this included the CO_2 export from the Wilton Power Plant site by road tanker, this option was deemed feasible. It was not possible to provide a reasonable costing estimate for this option.

An option for transport to a *remote marine export facility* was proposed, this included consideration of a rail loading option. This option was deemed feasible but it was not possible to provide a reasonable costing estimate for this option.

Whichever of these options are to be pursued, more detailed assessment of the technical, commercial and economic aspects of the option is necessary, including engagement with necessary third parties.

Appendix A

REFERENCES

1. Element Energy “Shipping CO_2 – UK Cost Estimation Study” Final report for Business, Energy & Industrial Strategy Department, November 2018.

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PROJECT WHITETAIL

ESTIMATE OF PROJECT OPERATIONAL EXPENDITURE (KKD)

DATE: 12 MARCH, 2021

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Zero Degrees Whitetail 1 Limited

Quality management

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Project number			

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1 Introduction

1.1 The Project

Zero Degrees Whitetail 1 Limited (**ZDW1**) is developing an Allam-Fetvedt Cycle (**AFC**) power plant at Wilton International Industrial Estate, Teesside, United Kingdom (**Project Whitetail/Project**) which will be a global marquee carbon capture project. The AFC technology (licensed by NET Power, LLC, (**NET Power**)) achieves highly efficient and low-cost electricity generation with zero emissions through the use of supercritical CO_2 as the primary process fluid. This technology has been successfully demonstrated at 50 MWth scale on NET Power's pilot plant in La Porte, Texas, and is now being commercialized. Utilizing AFC technology (under license from NET Power), Project Whitetail will provide around 300MW of clean power to the Wilton International facility and the UK National Grid. CO_2 captured from the process will be exported from the facility, via pipeline, for sequestration outside of the site battery limits.

Project Whitetail will be developed, owned and operated by ZDW1 and its consortium partner(s). The Project utilizes oxi-combustion technology at its core and as such requires a secure supply of gaseous oxygen for operation.

1.2 Purpose of this Document

This Estimate of Project Operational Expenditure provides an overview of the operational costs over the 30 year operational design life of the Plant. This estimate of operational expenditure is intended to be a high-level estimate, and as such this estimate does not account for any seasonal variation performance, annual inflation of costs or degradation of performance with accrued operational hours.

2 Operational Assumptions

2.1 Operational Hours

The following table details the key operational parameters for the Plant:

Parameter	
Anticipated Commencement of Commercial Operation	2023
Anticipated Termination of Commercial Operation	2053
Annual Capacity Factor	92.5%
Average Operating Hours per Annum	8,103

Table 1 - Plant Operational Assumptions

2.2 Plant Outages

As the Project is currently at the pre-FEED stage of development, a detailed schedule of planned outages for maintenance of major equipment items is yet to be developed. To include an allowance within this estimation of Project Operational Expenditure for both scheduled and forced outages, an allowance of 27.4 days non-generation per annum has been included.

3 Variable Costs

The following items summarize the assumptions for the estimation of variable operating costs:

1. **Fuel:** Natural gas consumption is assumed to be charged at a fixed rate based on the BEIS 2019 Fossil Fuel report.

2. **Maintenance:** It is anticipated that the $_SCO_2$ turbine will be maintained under a separate agreement with a specialist company. This Commercial Service Agreement (CSA) is assumed to be charged based on operating hours accrued.

3. **Potable Water:** Potable water consumption is assumed to be charged at a fixed rate per m^3.

4. **Raw water:** Raw water consumption is assumed to be charged at a fixed rate per km^3.

5. **Wastewater Discharge:** Discharge of wastewater from the Plant is assumed to be charged at a fixed rate per km^3.

6. **Oxygen:** Oxygen consumption is assumed to be charged at fixed rate per ton consumbed.

7. **Bleach:** The consumption of bleach i is assumed to be an annual fee based on usage.

8. **Corrosion Inhibitor:** The consumption of corrosion inhibitor is assumed to be an annual fee based on usage

9. **Caustic:** The consumption of caustic is assumed to be an annual fee based on usage

4 Fixed Costs

4.1 Fixed Operations Costs

The following table summarizes the assumptions for the estimation of fixed operations costs:

Item	Assumptions
Onsite Labor	29 full time site staff. Costs include salary, overtime, pensions, other employment benefits, and taxes.
HVAC	Maintenance and repair cost for building HVAC, benchmarked cost (from similar plants).
Building Costs	Janitorial/Cleaning benchmarked cost
	Roof replacement. 10-year frequency.
Fire Protection System	Maintenance and repair costs, benchmarked cost including detection system and all extinguishing systems.
Bulk Materials Costs	General piping inspection cost
	Annual foundation inspection / repair costs, 1-year frequency starting year 11
	General lighting replacement cost
Laboratory Services	Benchmarked cost for oil sampling and analysis
Site Services and Maintenance	Landscaping and roads including gravel touch-up.
	Security services
Chemical Feed System	Bleach
	Corrosion inhibitor
	Caustic
Lockout Tagout	Labelling, tags, ink
Trash Services	Trash removal/recycling costs
Software	Maintenance software license
	Document control software license
	Learning management software license
CO2 Monitors	One replacement CO_2 monitor per year
	Calibration gases
Site Radios	Radio rental/replacement agreement
Filters	Benchmark cost based on 5% filters replaced per year.
EHX Oil Replacement	Benchmarked oil replacement cost.
Turbine Oil Purification	Benchmarked cost for 7-day purification. 3-year purification frequency
Replacement Servos	Benchmarked cost assuming six servo replacements per year.
Safety Valves	Benchmarked cost for high energy safety valve inspection and repair
	Benchmarked cost for low energy safety valve inspection and repair. 3-year intervention frequency
Replacement Insulation	Miscellaneous insulation repair and replacement
Scaffolding Rental	Miscellaneous scaffolding rental

Technology Provider License Fee	NET Power license fee
SG&A	0.25%

Table 2 - Fixed Operating Costs Assumptions

4.2 Fixed Maintenance Costs

The following table summarizes the assumptions for the estimation of fixed maintenance costs:

Equipment Item	Assumptions
Heat Exchanger Network	1-year inspection frequency
CO_2 Compressor	Initial capital spares
	2-year inspection frequency
	5-year inspection frequency
	15-year overhaul frequency
	15-year frequency
Natural Gas Compressor	Initial capital spares
	1-year inspection frequency
	15-year frequency
CO_2 Pump	Initial capital spares
	3-year inspection frequency
	6-year inspection frequency
PCO Pump	Initial capital spares
	3-year inspection frequency
	6-year inspection frequency
	15-year frequency
TGS Compressor	Initial capital spares
	1-year inspection frequency
	15-year frequency
CCW Pumps	Annual spares allowance
	1-year frequency
	3-year frequency
	15-year frequency
Cooling Tower	Annual spares allowance
	Annual maintenance
	Annual from year 10
	10 year frequency
H_2O Separator	Parts replacement, 7-year frequency
	Annual inspection & maintenance
BoP Heat Exchangers	3-year frequency
Electrical Equipment	Initial GSU capital spares
	3-year frequency
	Initial UAT capital spares
	3-year frequency
	10-year frequency
	Initial motor / breaker spares
	3-year frequency
	1-year frequency

Generator	1-year frequency
Distributed Control System	OEM support
	15-year parts replacement
	30-year module replacement
	Annual cable maintenance
	15-year frequency
Control Valves	Yearly soft good replacement
	3-year replacement frequency
Transmitters	Annual equipment replacement
Gas Analyzers	Quarterly inspection
Flowmeters	15-year parts replacement
	5-year frequency

Table 3 - Fixed Maintenance Cost Assumptions

5 Estimate of Annual Operating Costs

Calendar Year	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
Project Year	-03	-02	-01	0	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15
Days	365	365	365	365	366	365	365	365	366	365	365	365	366	365	365	365	366	365	365
Capacity Factor	0%	0%	0%	0%	50.0%	80.0%	92.5%	92.5%	92.5%	92.5%	92.5%	92.5%	92.5%	92.5%	92.5%	92.5%	92.5%	92.5%	92.5%
Operating Hours	0	0	0	0	4392	7008	8103	8103	8127	8103	8103	8103	8127	8103	8103	8103	8127	8103	8103
Total (GBP ‘000)	0	0	0	3,112	75,052	115,101	131,483	131,099	132,023	131,534	131,167	131,130	131,840	131,172	131,252	131,485	131,529	131,177	131,508

Calendar Year	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	5053
Project Year	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Days	365	366	365	365	365	366	365	365	365	366	365	365	365	366	365
Capacity Factor	92.5%	92.5%	92.5%	92.5%	92.5%	92.5%	92.5%	92.5%	92.5%	92.5%	92.5%	92.5%	92.5%	92.5%	92.5%
Operating Hours	8103	8127	8103	8103	8103	8127	8103	8103	8103	8127	8103	8103	8103	8127	8103
Total (GBP ‘000)	133,663	131,529	131,561	131,177	131,115	131,935	131,177	131,177	131,535	131,534	131,177	131,514	131,110	131,529	131,639

8 Rivers Capital LLC

ALLAM CYCLE UK PRE-FEED

Geotechnical Desk Study

70053760-WSP-00-XX-RP-GE-0001-S0_P01
SEPTEMBER 2020

CONFIDENTIAL

8 Rivers Capital LLC

ALLAM CYCLE UK PRE-FEED

Geotechnical Desk Study

REPORT (VERSION P01) CONFIDENTIAL

PROJECT NO. 70053760

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REPORT LIMITATIONS

1 INTRODUCTION

1.1 TERMS OF REFERENCE

WSP were instructed by 8 Rivers Capital LLC to carry out a geotechnical desk study review of the supplied and readily available information at the former Teesside Power Station, Wilton International, Redcar and Cleveland (hereafter referred to as “the site”). The site is being considered for re-development with an Allam-Fetvedt cycle power plant. The aim of the desk study is to identify any gaps in the existing information and ultimately design and prepare an appropriate ground investigation specification to fill the identified gaps.

This geotechnical desk study has been carried out as part of site-specific study, to enable the development of the site to continue to Front End Engineering Design (FEED) with confidence and cost certainty. The work has been undertaken in accordance with our proposal dated June 2020.

The site location plan and the site boundary plans are presented in **Appendix A**. The proposed power plant layout drawing is presented in Sembcorp’s drawing GIS-00-L-03019 in **Appendix B**, although final layout of plant may be subject to minor alteration as the design develops.

1.2 OBJECTIVES OF THE REPORT

This geotechnical desk study report has been completed to address the following:

- Present the findings from the review of all readily available information on ground and groundwater conditions at the site;
- Establish a preliminary ground model and identify any key ground constraints/risks to the proposed development;
- Establish a preliminary contaminated land conceptual site model setting out reasonably foreseeable contaminated land risks to sensitive receptors;
- Make recommendations for managing geotechnical risks;
- Identify gaps in the available geotechnical information and make recommendation for additional ground investigation that may be required for the proposed development; and
- Make recommendations on the potential issue associated with re-use of the existing piles at the site.

1.3 STATUTORY GUIDANCE

The following good practice and statutory guidance was considered in the preparation of this geotechnical desk study report:

- British Standard ‘Code of Practice for Ground Investigations’, BS 5930:2015.
- British Standard ‘Code of Practice for Foundations’, BS8004:2015.
- British Standard ‘Eurocode 7: Geotechnical Design - Part 1 General Rules’, BS EN 1997-1:2004.
- CIRIA Report 653 ‘Re-use of Foundations’, CIRIA 2007.
- BRE ‘A Best Practice Handbook on the Re-use of Foundations for Urban Sites’, BRE 2006.
- HSG47 ‘Avoiding Danger from Underground Services’, HSE, 2014.

1.4 SOURCES OF INFORMATION

The following relevant sources of information were used in the production of this report. Information from these sources relating to the underlying ground conditions and existing pile foundations is summarised in Sections 2 to 7 of this report, where appropriate.

Table 1-1 – Sources of Information

Source	Reference
Third Party Reports	▪ Environ Power UK Ltd, Teesside Power Project Geotechnical Report Prepared for Northern Engineering Inc, Houston Texas by STATS Geotechnical, August 1990. ▪ GDF Suez Teesside Limited, Teesside Power Station Phase 2 Ground Investigation Report, by Entec UK Ltd, January 2011 ▪ Surrender Site Condition report for Teesside Power Station by Environ, October 2015. ▪ S180323 Sembcorp, Tees CCPP, Wilton Phase 1 desk Study, May 2018 by Solmek Ltd ▪ S180323 Sembcorp, Tees CCPP, Wilton Phase 2 Site Investigation Report, June 2018 by Solmek Ltd
Third Party Drawings	▪ Environ Power Corp. Teesside Power Project Master Key Plan Foundation Location, drawing No CD-3040, Rev 3 dated April 1993, by NE Inc. ▪ Environ Power Corp. Teesside Power Project Foundation Location Plans, Area 01 to Area 33, certified final drawings, drawing Nos CD-3041 to CD-3073, varying revision numbers, dated May/June 1993, by NE Inc. ▪ Environ Power Corp. Teesside Power Project Pile Details, certified final drawing, drawing No CD-4046, dated May 1993, by NE Inc. ▪ Environ Power Corp. Teesside Power Project Gas Turbine GEN. G101 to G108 Pile Location Plans, certified final drawings, drawing Nos CD-4072, CD-4082, CD-4133, CD-4143, CD-4153, CD-4163, CD-4173, and CD-4183, dated June 1993, by NE Inc. ▪ Environ Power Corp. Teesside Power Project HRSG B-201 to B208 Pile Location Plans, certified final drawings, drawing Nos CD-4045, CD-4051, CD-4058, CD-4065, CD-3016, CD-3035, CD-3085, and CD-3095, dated June 1993, by NE Inc. ▪ Environ Power Corp. Teesside Power Project Pipe Rack and Stack Pile Location Plans, certified final drawings, drawing Nos CD-3102 to CD-3104, dated June 1993, by NE Inc. ▪ Environ Power Corp. Teesside Power Project Deaerator Structure Pile Location Plan, certified final drawing, drawing Nos CD-4233, dated June 1993, by NE Inc.
Public Information	▪ British Geological Society (BGS) 1:50,000 Series Geological Map Sheet 34 Guisborough (Solid & Drift). ▪ BGS information and datasets accessed through the online BGS GeoIndex viewer, accessed on 11th August 2020. ▪ Other BGS information and datasets (including historical borehole logs) (accessed through http://www.bgs.ac.uk/) (extracts presented in Appendix C) ▪ Coal Authority Mining information and datasets accessed through http://www.gov.uk/ on 11th August 2020. ▪ Zetica online UXO risk maps accessed through https://zeticauxo.com/downloads-and-resources/risk-maps/ on 13th August 2020 (extract presented in Appendix D).
Notes:	The report contains British Geological Survey materials ©NERC 2019 and Environment Agency information ©Environment Agency and database right.

1.5 CONFIDENTIALITY STATEMENT & LIMITATIONS

This assessment desk study has been prepared for the sole use of the 8 Rivers Capital LLC and has been prepared in accordance with WSP Standard Terms and Conditions. This report shall not be relied upon or transferred to any other parties without the express written authorisation of WSP. No responsibility will be accepted where this report is used in its entirety or in part, by any other party. Information provided by others is taken in good faith as being accurate. WSP cannot and will not accept liability for any deficiencies in third party information. General Limitations are presented in **Appendix F.**

2 SITE DETAILS

2.1 SITE DESCRIPTION AND CURRENT USE

The site is located on a land south of River Tees, within the Wilton International Site, Redcar and Cleveland. The site was formerly occupied by the Teesside Power Station. The site description and its current use is summarised in Table 2-1. The site location and site boundary plans are presented in **Appendix A**.

Table 2-1 – Site Description and Current Use

Item	Details
Site Location	Land along the southern flank of Wilton International, a multi-occupancy industrial processing and manufacturing complex. It is located at about 6.5km east of Middlesbrough town centre. The site is to the southeast of Grangetown and northeast of Old Lackenby. Access to the site is off the southbound carriage way of Greystone Road (A1053). The site postcode is TS6 8JF.
National Grid Coordinates	456500, 520380
Area, Elevation and Topography	The site area is approximately 15ha. Majority of the site is flat concrete hard standing with ground level at approximately 16.0m OD
Current Use / Site Description	Majority of the site comprise concrete hard standing preserved from the demolition of the former Teesside Power Station. There are two existing substations in the south of the site. There are also existing control buildings for above ground 24” Gas main and 8” propane lines in the north of the site.
Surrounding Land Use	The following land uses surround the Site: ▪ North: There are above ground gas and propane pipelines to the immediate north of the site. Beyond are open plots of land with concrete hard standing from demolished industries within the Wilton Chemical Complex. ▪ South: There are overhead transmission lines connecting to the substations in the south of the site and open agricultural fields beyond the site in the south. ▪ West: There is a substation and associated control building to the northwest of the site. Beyond the substation, there are agricultural fields. ▪ East: An operational chemical plant is present to the immediate east of the site.

3 GEOLOGY AND GROUND CONDITIONS

3.1 GEOLOGY

3.1.1 PUBLISHED GEOLOGY

British Geological Survey (BGS) mapping for the Site ('1:50,000 map Sheet 34, Guisborough, Solid and Drift Geology', 1999) and information and datasets accessed through the online BGS GeoIndex viewer have been reviewed.

Superficial deposits at the site are indicated to comprise Glaciolacustrine Deposits (clay and silt) in the extreme west of the site. Glacial Till (clays with pebbles and lenses of gravel) is indicated to directly underlie other parts of the site.

BGS mapping does not record any Made Ground to be present at surface at the Site, however it is noted that this information may be outdated by the more recent development and demolition at the site.

Solid geology beneath the site is recorded to be Lower Jurassic Lias Group Redcar Mudstone Formation. It is described as comprising mudstone with this sandstone and limestone beds in lower parts. Extracts of the 1:50;000 BGS online Geoindex superficial and bedrock geology maps for the site are presented in Figure 3-2 and Figure 3-2**.**

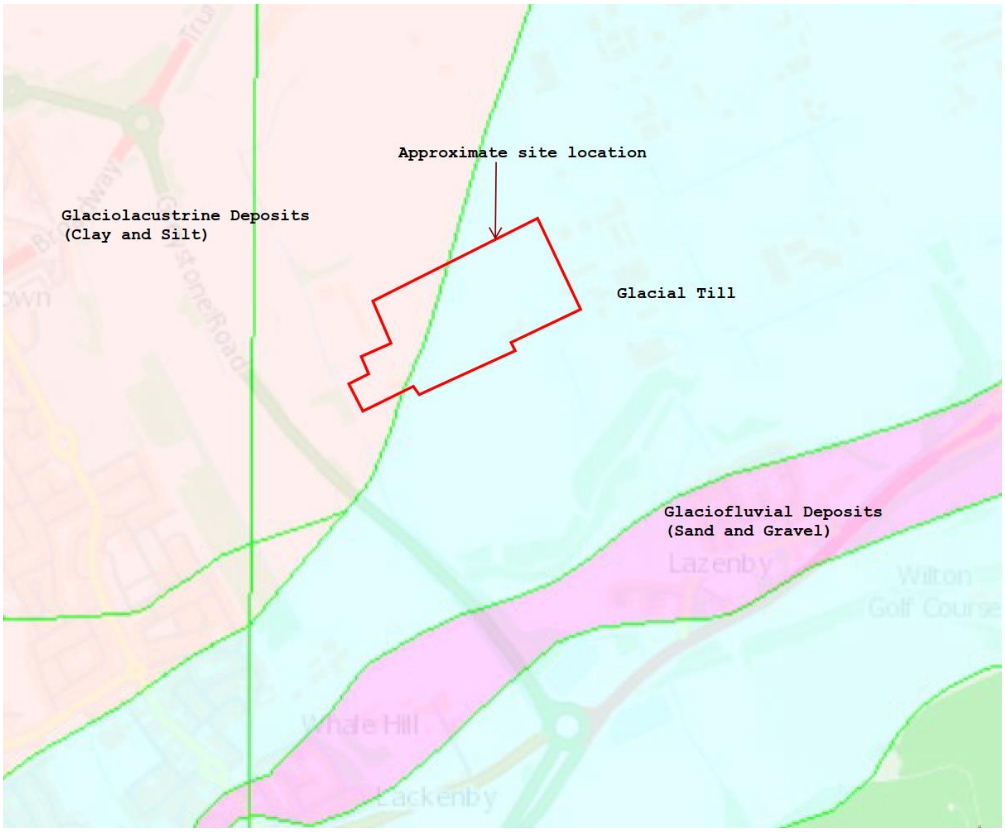

Figure 3-1 - Annotated extract of the 1:50,000 superficial geology map from the BGS online GeoIndex

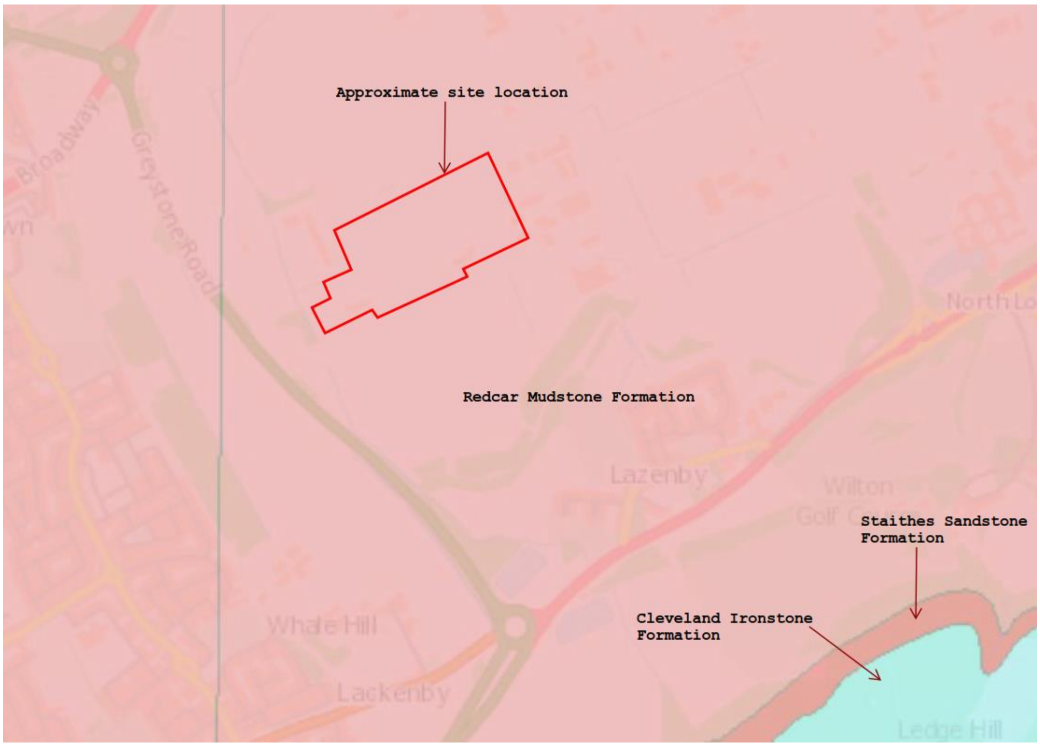

Figure 3-2 – Annotated extract of the 1:50,000 solid geology map from the BGS online GeoIndex

3.2 HISTORICAL GROUND INVESTIGATIONS

Available historical ground investigation information has been reviewed and summarised in the following sections.

3.2.1 HISTORICAL BRITISH GEOLOGICAL SOCIETY (BGS) BOREHOLE RECORDS

There are no available historical BGS exploratory holes within the site. There are however available records of five historical exploratory holes within approximately 250m of the site boundary. These include BGS borehole reference NZ52SE13722/932, NZ52SE13722/933, NZ52SE13722/934, NZ52SE13722/935 and NZ52SE13722/936. The BGS historical exploratory hole logs are presented in **Appendix C**. All the available BGS historical exploratory holes are located to the west of the site, on the land between the site and the A1053. An extract from the BGS Geoindex website showing the location of the available BGS historical exploratory holes is presented in Figure 3-3.

The available BGS exploratory holes comprise boreholes drilled to depths ranging between 10.0m and 11.2m bgl. They show the ground conditions to generally comprise Topsoil (about 0.2m thick), underlain by an upper clay layer generally described as firm and stiff sandy stoney brown grey clay. This upper clay layer is considered to possibly be weathered Glacial Till. The upper clay layer is underlain by Glacial Till generally described as firm stiff red brown boulder clay. All the available BGS exploratory holes except BGS borehole NZ52SE13722/932 were terminated within the Glacial Till. BGS borehole NZ52SE13722/932 encountered bedrock described as Lias Shale at 9.1m bgl and was terminated in Lias Shale at 11.15m bgl.

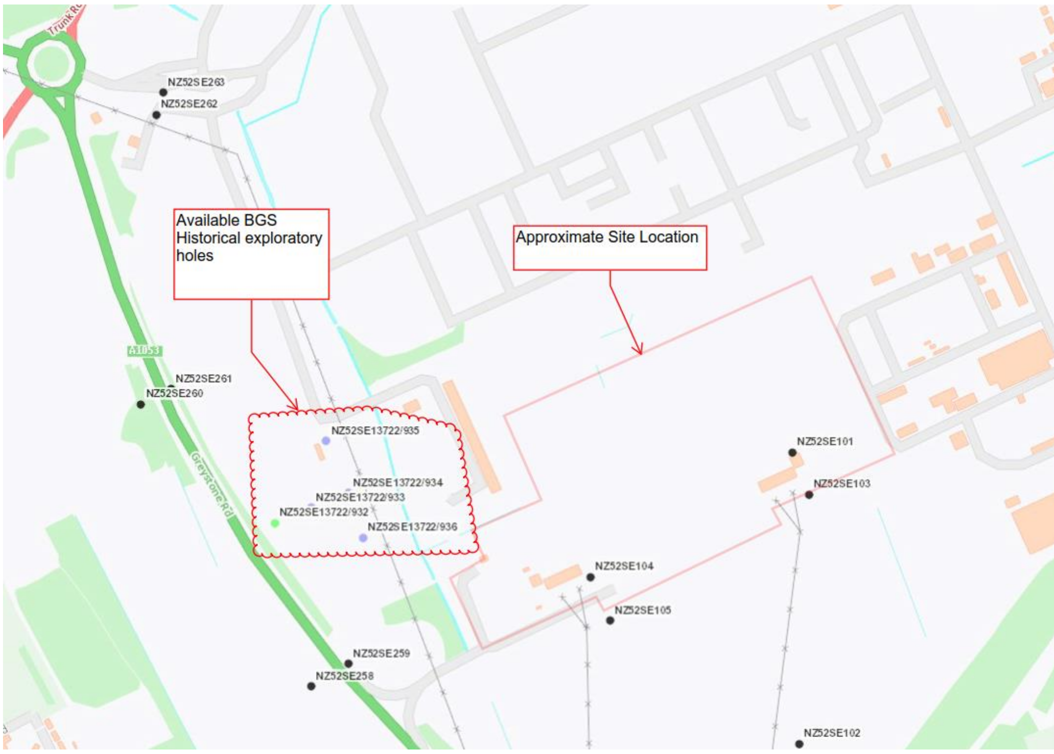

Figure 3-3 – Annotated extract from the online BGS online GeoIndex showing the locations of the available BGS exploratory holes

3.2.2 TEESSIDE POWER PLANT PROJECT GEOTECHNICAL REPORT BY STATS GEOTECHNICAL, 1990

This geotechnical report presents the findings of the site investigation carried out at the site in 1990 by STATS geotechnical for Northern Engineering Inc to enable the development of the former Teesside Power Plant. The site investigation comprised nineteen cable percussion boreholes of which eleven were extended by rotary drilling into bedrock. A further four of the cable percussion boreholes were extended by rotary open hole. The nineteen boreholes were spread across the site (see Figure 3-4 for an indication of the exploratory hole locations).

In-situ tests carried out include standard penetration tests (SPTs) in the boreholes, resistivity tests around ten borehole locations, and downhole geophysical tests in eleven boreholes to determine seismic p and s wave velocities.

The laboratory tests carried out on recovered soil samples comprised classification tests (moisture content, particle size distribution, Atterberg limit tests, bulk density and dry density tests), chemical tests, strength tests (quick undrained triaxial tests), compressibility tests (oedometer tests), compaction tests and California Bearing Ratio (CBR) tests.

Laboratory tests carried out on recovered rock samples include moisture content tests, bulk and dry density tests and uniaxial compressive strength tests.

The site investigation indicated the ground conditions at the site to generally comprise between 8.0m and 13.0m thick Glacial Till generally described as stiff and very stiff sandy becoming gravelly clay overlying bedrock of mudstones, shales and sub-ordinate limestone and sandstones of the Redcar Mudstone Formation.

Most of the exploratory holes were dry during drilling and water strikes were only recorded at rockhead in three of the boreholes in the eastern half of the site. The report noted that sub-artesian and locally artesian groundwater in the Redcar Mudstone Formation is present at the site.

3.2.3 TEESSIDE POWER STATION PHASE 2 GROUND INVESTIGATION REPORT BY ENTEC UK LTD, 2011

This report presents the findings of a contaminated land ground investigation carried out by Entec UK Ltd for GDF Suez Ltd in 2011 to provide an initial indication of potential ground contamination issues ahead of re-planting works proposed within the site at that time.

The ground investigation comprised three scheduled cable percussion boreholes to 10.0m bgl. Two of which were completed, and one abandoned during site works due to the presence of underground services at its proposed location. The exploratory hole coordinates were not included in the report. However, the report included plans suggesting that the two completed boreholes were carried out in the north and northwest of the site.

The ground conditions encountered comprise 0.6m thick Made Ground described as reinforced concrete slab overlying granular Type 1 sub-base material. The gravelly sub-base material is noted to be underlain by cohesive Made Ground material described as slightly gravelly clay. The Made Ground was noted to be underlain by Glacial Till described as firm to stiff, slightly sandy slightly gravelly clay. The two boreholes were terminated within Glacial Till. Perched groundwater seepage was recorded in the two boreholes at the interface between the Made Ground and the Glacial Till. No geotechnical in-situ or laboratory tests were completed as part of this site investigation. The results from laboratory analysis for soils was screened against the Guideline Assessments Criteria (GAC) published at the time of the investigation. The screen was for commercial/industrial land end use. With the exception of water soluble sulphate (which is considered an aggressive chemical environment for concrete), no determinands were recorded at concentrations exceeding the adopted GAC.

3.2.4 TEES CCPP, WILTON PHASE 2 SITE INVESTIGATION REPORT BY SOLMEK LTD, 2018

This ground investigation report presents the findings of a combined geotechnical and geo-environmental investigation carried out at the site by Solmek Ltd for Sembcorp Utilities UK Ltd in 2018. The ground investigation was planned based a proposed layout of a combined cycle power plant (CCPP) to be constructed at the site. The proposed CCPP layout had the power station complex located in the western half of the site and cooling infrastructure in the extreme north of the site. The ground investigation was therefore concentrated on the proposed infrastructure locations. An extract of the exploratory hole location from the Solmek 2018 Phase 2 report is presented as Figure 3-4.

The ground investigation comprised the following:

- Eight cable percussion boreholes to drilled to maximum depth of 12.0m bgl with rotary coring follow-on in rock in four of them to maximum depth of 22.5m bgl;
- Installation of four groundwater and ground gas monitoring wells with sampling and testing of groundwater;
- Down-hole seismic survey in the four boreholes extended into rock (SB03 to SB06 shown in Figure 3-4);

- Eleven machine dug trial pits to maximum depth of 4.0m bgl; and
- Geotechnical and contamination sampling and laboratory testing.

The ground conditions encountered in the ground investigation comprised Made Ground with thickness varying between 0.4m and 2.4m. The Made Ground was proven as reinforced concrete underlain by gravel fill or clay fill with brick, concrete slag and dolomite. The trial pits logs recorded numerous buried concrete obstructions.

The Made Ground is underlain by Glacial Till, generally described as stiff and very stiff locally firm slight slightly sandy slightly gravelly clay. Bedrock of the Redcar Mudstone Formation is shown to underlie the Glacial Till. The uppermost sections of the Redcar Mudstone Formation were generally described as very weak completely weathered dark grey mudstone. Weak thinly laminated light and dark grey calcareous mudstone with interbedded calcareous siltstone were encountered with depth. Rock head was recorded across the site generally between 9.1m bgl and 10.5m bgl.

Perched groundwater in the Made Ground was recorded across the site with local water strikes recorded in SB05 at 10.0m bgl rising to 9.5m bgl after 20 minutes monitoring, and B08 at 8.2m bgl rising to 8.0m bgl after 20 minutes monitoring. No post site works ground water monitoring results were presented in the report. The report based on the results of the laboratory tests carried out recommended a Design Sulphate Class DS-3 and ACEC classification of AC-3 for buried concrete at the site. The report also advised there was no long-term risk to human health from the samples subject to testing assuming the site is covered in hardstanding.

Figure Redacted

Figure 3-4 - An extract of the exploratory hole location plan from the Solmek Phase 2 report, 2018 (Solmek 2018 exploratory holes in colour and plotted locations of STATS 1990 investigation greyed out)

3.3 CONCEPTUAL SITE GROUND MODEL

The available ground investigation information at the site suggests that ground condition at the site generally comprises Hard Standing and buried relict foundations over Made Ground of varying composition and thickness, underlain by firm or stiff clay Glacial Till. This is in turn underlain by bedrock of Redcar Mudstone Formation at depths of approximately 9-10.5m bgl. This is generally in agreement with the mapped geology information with the exception that the mapped Glaciolacustrine deposits in the northwest of the site has not been identified in the available ground investigation information. Based on the available information, a conceptual site ground model has been developed and presented in Table 3-1.

The conceptual site ground model should be confirmed by further intrusive ground investigations considering the actual locations of the proposed development at the site.

Table 3-1 - Conceptual Ground Model

Strata	Approximate Depth from (m bgl)	Approximate Depth to (m bgl)	Thickness range (m)
Concrete Hard Standing (old surfaces, building slabs, foundations etc)	Ground Level (GL)	Between 0.2 and 2.1	0.2 and 2.1
Made Ground (variable - gravel fill or clay fill with brick, concrete slag and dolomite)	Between GL and 2.1	Between 0.4 and 2.4	Between 0.2 and 2.2
Glacial Till (stiff and very stiff locally firm slight slightly sandy slightly gravelly clay)	Between 0.4 and 2.4	Between 9.1and 10.5	Between 0.4 and 9.9
Redcar Mudstone Formation (very weak completely weathered dark grey mudstone becoming weak thinly laminated light and dark grey calcareous mudstone with interbedded calcareous siltstone with depth)	Between 9.1 and 10.5	-	-

The Entec 2011 and Solmek 2018 ground investigations suggest that perched groundwater is present in the Made Ground across the site. Perched groundwater within the Made Ground should therefore be expected and taken into consideration in any future proposed development.

All the available information suggests that the Glacial Till at the site is generally dry with only localised groundwater strikes recorded near its base in two boreholes during Solmek 2018 ground investigation. No long-term groundwater monitoring information is available within the Glacial Till at the site from the Solmek 2018 ground investigation. Furthermore, the STATS Geotechnical 1990 ground investigation noted that sub-artesian and locally artesian groundwater in the Redcar Mudstone Formation may be present at the site. This was however not recorded in the Solmek 2018 ground investigation.

Further information would be required on the groundwater conditions at the site for the assessment of appropriate design groundwater levels. Any future ground investigation should consider monitoring of the existing groundwater wells (if any) at the site in addition to groundwater monitoring in newly proposed exploratory holes. Any groundwater monitoring programme as part of future ground investigations should cover monitoring both within the Glacial Till and Redcar Mudstone bedrock.

3.4 HYDROGEOLOGY

Landmark Envirocheck included in Solmek's Phase 1 Desk Study shows that the solid geology (Redcar Mudstone Formation) at the site is classified as Secondary Aquifer – Undifferentiated. The overlying drift geology (Glacial Till) is classified as an Unproductive Strata and Secondary Aquifer - Undifferentiated. The site does not lie within a Source Protection Zone.

3.5 MINING AND QUARRYING

The site is not in a coal mining affected area. There is an active BGS recorded mineral site relating to Wilton Power Station Ash Plant at the site. The listed commodities are Furnace Bottom Ash and Pulverised Fuel Ash.

3.6 HYDROLOGY AND FLOODING

Available information shows that there are no surface water features on-site. The closest surface water feature to the site is the Kettle Beck which runs along the western site boundary and flows northerly.

The Envirocheck report indicate that the site is not located in a zone at risk of flooding from rivers or the sea. There are no flood defences, flood water storage areas or areas benefitting from flood defences and flood storage within 250m of the site.

3.7 SENSITIVE LAND USES

Available information shows that the site has not been designated with a sensitive land use neither does it lie within 2000m of any form of designated environmentally sensitive site.

3.8 GROUND HAZARDS

A summary of the ground hazard information for the site and its immediate surroundings, obtained from the Envirocheck Report is presented in Table 3-2.

Table 3-2 – Geohazard Summary

Hazard Description	Hazard Potential (on-Site)
Potential for collapsible ground stability hazards	Very low
Potential for compressible ground stability hazards	Moderate
Potential for ground dissolution stability hazard	No hazard
Potential for landslide stability hazard	Very low
Potential for running sand ground stability hazard	Very low
Potential for shrinking or swelling clay ground stability hazard	Low

3.9 REGULATORY INFORMATION

A summary of the regulatory information for the site and its immediate surroundings, obtained from the Envirocheck Report is presented in Table 3-3.

Table 3-3: Regulatory Information

Permit	Name of Permit holder	Permit specifications	Distance from site
Discharge Consent	Teesside Power Station	Trade Discharge – site drainage, discharge to river/stream. Receiving water: Kettle Beck	26m East
Registered Radioactive Substances	Gdf Suez Teesside Ltd	Authorisation under S13 RSA for the disposal of Radioactive waste	On site
Registered Radioactive Substances	Gdf Suez Teesside Ltd	Registration under S7 RSA for the keeping and use of Radioactive Materials	On site
Registered Radioactive Substances	Teesside Power Ltd	Authorisation under S13 RSA for the disposal of Radioactive waste (Authorisation has since been revoked)	211m North
Planning Hazardous Substances Consent	Ensus Uk Ltd	Hazardous Substance: Propylene oxide	On site
Historical Landfill Site	Imperial Chemicals and Polymers Limited		113m Northwest

3.10 RADON

The Envirocheck Report included in the 2018 Solmek Phase 1 report shows that the site is not within a Radon Affected Area, as less than 1% of properties are above the action level. Radon protection measures are not required.

3.11 UNEXPLODED ORDNANCE (UXO)

The Zetica online UXO risk map shows the site to be within an area with low UXO risk. No further UXO mitigation is considered necessary in any future ground investigation works. The Zetica UXO risk map is presented in **Appendix D**.

4 SITE HISTORY

4.1 HISTORICAL REVIEW

The historical maps contained in the Envirocheck Report included in the Solmek 2018 Phase 1 report have been reviewed and notable on-site and off-site features are presented in the following sections.

4.1.1 ON-SITE FEATURES

Notable historic on-site features shown on the historical maps include the following:

- Between 1856 and 1992, 1:10:560; 1:10,000 and 1:2,500 maps show the site to be an agricultural land. Ratten lane is shown to run north-south through the centre of the site.
- From 1993, 1:10,000 and 1:2,500 maps show the former Teesside Power Station to have been constructed at the site and two overhead electricity transmission lines terminated within two substations in the south of the site.
- The 2018 1:10,000 map shows the former Teesside Power Station to have been demolished except for the two substations in the south of the site.

4.1.2 OFF-SITE FEATURES

Notable historic off-site features shown on the historical maps include the following:

- Between 1856 and 1919, 1:10,560 and 1:2,500 maps show the surround area to comprise agricultural land with drains and becks located between the fields. Kettle beck runs along the western site boundary.
- 1929 - 1:2,500 map show sewage filter beds located approximately 250m southeast of the site.
- Between 1953 and 1971, 1:10,000 and 1:2,500 maps show remarkable industrial development (chemical works) to the immediate north of the site. Earthworks likely to be associated with the A1053 construction is shown at approximately 100m west of the site. Overhead electricity transmission lines are also shown to the immediate west of the site.
- Between 1976 and 1989, 1:10,000 and 1:2,500 maps show further development of the Wilton chemical works to the north and north-east of the site. The 1:10,00 maps from 1981 onwards show an electricity substation to have been constructed immediately northwest of the site.
- By 2018, 1:10,000 historical map shows the chemical works north of the site to have been demolished.

5 PRELIMINARY GROUND ENGINEERING ASSESSMENT

5.1 BACKGROUND

The preliminary engineering assessment presented in this section is based on the layout for the proposed power plant presented in Appendix B. The layout shows the proposed power station complex structures to occupy the western half of the site and aligned approximately north to south. The proposed cooling towers are to the far north of the site and there would be an administrative building and a control building further west of the power station complex.

5.2 FOUNDATIONS

The proposed power plant will comprise heavily loaded and settlement sensitive structures. It is therefore considered based on the available information on ground conditions that the proposed power plant structures (the power station complex structures and the cooling towers in particular) would require piled foundations. The piles would likely end bear in the Redcar Mudstone bedrock. Shallow foundations such as pad foundations or raft foundations may be suitable for the proposed administration and control buildings subject to confirmatory ground investigations in those areas.

The piled foundations for the former Teesside power station are still present below the site with significant thickness of reinforced concrete caps. This will require careful consideration in planning foundations for the proposed power plant development. Two foundation options may be feasible for the proposed power plant development and they include:

- Option 1 – Install new piles avoiding the old foundations
- Option 2 – Install new piles to supplement existing piles i.e. re-use existing piles in combination with new piles.

Further consideration on the pile foundation options for the proposed development and the existing pile foundations at the site are presented in **Section 7**.

5.3 EXCAVATIONS

Based on the available information on ground conditions, significant excavation works would be required for the development of the site due to the thickness and volume of the underlying concrete across the site. Excavation works is therefore likely to require significant earthwork plant and machinery.

Allowance should be made for significant breaking out of ground obstructions and for over-dig in future excavations. All excavation sites should be battered back to safe angles or supported as appropriate.

5.4 GROUNDWATER

Perched groundwater was recorded in the Made Ground across the site in the Solmek 2018 ground investigation. This may increase the risk of flooding and instability of excavations in future works. It is however considered that flows from such perched groundwater should not be very high and should be controllable using methods such as sump pumping.

STATS Geotechnical 1990 report noted sub-artesian and locally artesian groundwater in the Redcar Mudstone Formation is present at the site. Solmek 2018 ground investigation however did not record groundwater strikes in the bedrock though it noted local groundwater strikes at depth in Glacial Till in two boreholes.

Further monitoring of groundwater conditions should be carried out as part of future ground investigations to suitably assess the groundwater conditions for design purpose.

5.5 PRELIMINARY GEOTECHNICAL RISK REGISTER

A preliminary Geotechnical Risk Register has been prepared for the proposed development at the site and is presented as Table 5-1. This considers key geotechnical risks and other key risks that may affect geotechnical activities at the site. These geotechnical risks have been identified following a review of the available information presented in this report.

It is recommended the designer maintains a live geotechnical risk register, updated throughout the design process.

The key geotechnical constraints have been identified with an associated risk rating as follows:

- Very Low (very unlikely to affect the development)
- Low (unlikely to affect development but cannot be entirely ruled out; further assessment required)
- Medium (likely to affect the development with moderate impact to programme or cost and further assessment required and)
- High (expected to affect the development with significant impact - further assessment required during design and contingency should be made for mitigation during construction stage).

Table 5-1 - Preliminary Geotechnical Risk Register

Ref.	Hazard	Works Affected	Details	Recommendation	Risk Rating*
GEO 01	Unknown ground conditions	Earthworks, Excavations, Foundations	There are gaps in the available ground investigation information e.g. there is no site-specific ground investigation information at the proposed location of the administration and control buildings. 8 Rivers Capital LLC does not have reliance on some of the available ground investigations, and these ground investigations were not targeted to the proposed development.	A carefully planned site-specific intrusive ground investigation should be carried out to fill the gaps identified in the existing ground investigation information and targeted to areas of the proposed power plant structures.	Medium
GEO 02	Potential for compressible ground stability hazard	Construction works and permanent works (foundations)	The Envirocheck report in the Solmek 2018 Phase 1 Desk Study suggest a moderate potential for compressible ground stability hazard within the site. Available ground investigation information however suggests this may only be a local occurrence rather than the condition across the site.	Further assess risk by targeted intrusive ground investigation particularly at the proposed locations of lightly loaded structures where shallow foundations may be considered. To limit settlements, consideration should be given to piled foundations end bearing in bedrock for all heavy and settlement sensitive structures.	Medium
GEO 03	Made Ground Variability	Excavations, Foundations, Earthworks	Available ground investigation information shows variable Made Ground composition (reinforced concrete underlain by gravel fill or clay fill with brick, concrete slag and dolomite)**.** Thickness also varies across the site with the greatest thickness encountered in trial pits carried out within	Further assess risk by targeted ground investigation. Made Ground is not considered a suitable founding stratum.	Low

Ref.	Hazard	Works Affected	Details	Recommendation	Risk Rating*
			the former power complex of the demolished Teesside Power Station (Solmek 2018). Made Ground can present the risk of soft and hard spots beneath the site and potential down-drag effect on piles.		
GEO 04	Ground obstructions	Ground Investigations; Excavations, Foundations	Significant concrete obstruction is noted to be present at the site. This comprise reinforced concrete hard standing, thick reinforced concrete pile caps as well as the existing pile foundations. Some of the trial pits in the Solmek 2018 ground investigation also encountered other concrete obstruction at significant depth below ground level. Large cobbles or boulders may also be present in the Glacial Till and present obstructions to pile installation. Unforeseen obstructions may delay site works and lead to increased cost	Ground obstructions should be assessed as part of future targeted ground investigation. Future ground investigations should consider appropriate investigation techniques that can get through ground obstructions. Any contractors carrying out ground investigations or excavations to be aware of potential for buried obstructions. Allowance to be made for digging out ground obstruction and potential over-dig during construction works. Consideration to be given to rotary bored piles for the proposed development.	Medium
GEO 05	Groundwater	Excavations	The available ground investigation information noted perched ground water in the Made Ground. This may require management for excavations. This poses risks that include the flooding of excavations or unexpectedly high	Groundwater observations and monitoring should be carried out as part of targeted ground investigation. This should incorporate monitoring of existing exploratory holes (if any) at the site.	Medium

Ref.	Hazard	Works Affected	Details	Recommendation	Risk Rating*
			groundwater levels that could threaten the safety of foundation designs. The effect of groundwater on foundations need to be considered.	Design and construction to make appropriate consideration to high groundwater if confirmed by targeted ground investigation.	
GEO 06	Aggressive ground conditions	Foundations, (buried concrete)	The presence of Made Ground at the site indicates that there is a likelihood for high water-soluble sulphate or low pH conditions to be present on-site which may require additional protection to buried concrete. Solmek 2018 ground investigation suggest Design Sulphate Class DS-3 and ACEC classification AC-3.	Undertake further chemical testing on soil and water samples in accordance with BRE SD1 as part of targeted ground investigation and specify concrete type and cover accordingly.	Medium
GEO 07	Contaminated Land	Ground Investigation Construction works	The presence of Made Ground across the site indicates the potential for contaminated ground. The ENTEC 2011 investigation did not report any exceedances for their screen for commercial/industrial use. The Solmek 2018 investigation reported there was no long-term risk to human health from the samples of subject to testing assuming the site is covered in hardstanding.	Undertake further chemical testing on soil and water samples as part of targeted ground investigation. Ground gas observations and monitoring should be carried out as part of targeted ground investigation. This should incorporate monitoring of existing exploratory holes (if any) at the site.	Medium
GEO 08	Buried Utilities	Ground Investigation, Excavations,	Utilities assessment is beyond the scope of this study. However available	Up to date utility records should be obtained and reviewed prior to any intrusive work on-site.	Medium

Ref.	Hazard	Works Affected	Details	Recommendation	Risk Rating*
		Site Personnel	information shows that there are buried utilities at the site, Utility strikes can occur during ground investigation, excavation, or pile installation.	The design and construction to be in accordance with HSG47 and other relevant industry guidance.	

6 ENVIRONMENTAL CONCEPTUAL SITE MODEL

Contaminated land assessment in the UK is based on the relationship between contaminant sources, pathways and receptors developed on the basis of hazard identification. The risk assessment is the process of collating known information on a hazard or set of hazards to estimate actual or potential risks to receptors. The guiding principle behind this approach is an attempt to establish connecting links between a hazardous source, via an exposure pathway to a potential receptor, referred to as a 'contaminant linkage'. If there is no contaminant linkage, then there is no risk. Therefore, only where a viable pollutant linkage is established does this assessment go on to consider the level of risk.

Plausible source-pathway-receptor contaminant linkages have therefore been defined in line with industry good practice (principally CLR11 and R&D66). The conceptual site model (CSM) provides a preliminary understanding of the site based on the information provided from the site walkover and desk study.

6.1 POTENTIAL CONTAMINATION SOURCES

Based on the desk-based information, potential sources of contamination which could potentially impact sensitive receptors are considered to be:

On Site

- Made Ground associated with the power station (asbestos, polycyclic aromatic hydrocarbons (PAHs), total petroleum hydrocarbons (TPHs), heavy metals, polychlorinated biphenyls (PCBs), sulphates, volatile organic compounds (VOCs)).
- Radioactive material(s).
- Hazardous ground gases (carbon dioxide and methane) from potential Made Ground present across the site.

Off Site

- Chemical works: TPH, PAHs, heavy metals, VOCs, and sVOCs
- Landfill: TPH, PAHs, heavy metals, VOCs and sVOCs. Hazardous ground gases (carbon dioxide, methane, hydrogen sulphide)
- Sewage Filter beds: PCBs hazardous ground gas (carbon dioxide and methane)

6.2 POTENTIAL PATHWAYS

Potential pathways include:

- Direct contact, ingestion or inhalation of soil bound contaminants/ dust.
- Leaching or mobilisation of contaminants into groundwater from soil or damaged drainage infrastructure and migration to the underlying aquifer.
- Chemical attack on buried concrete.

6.3 POTENTIAL RECEPTORS

Relevant potential receptors are considered to include:

Human Health

- Future end users (i.e. Plant workers).
- Future maintenance workers.

- Third parties during construction (adjacent site users and adjacent residents).

Controlled Waters

- Development and construction workers involved in building and excavations.
- The underlying superficial and bed rock aquifers.
- Kettle Beck watercourse.

Other

- The built environment (new buildings and underground structures).

6.4 PLAUSIBLE CONTAMINANT LINKAGES

Table 6-1 provides an evaluation of the potential contaminant linkages considered to be plausible for the future use of the Site.

Table 6-1 - Potential Contaminant Linkages

Exposure Linkages	Potentially Active (✓) Inactive (×)
HUMAN HEALTH	
Exposure to contaminated soils via ingestion/dermal contact/inhalation (current and future site users, maintenance and construction workers)	✓
Ground gas / vapour inhalation (indoor)	✓
CONTROLLED WATERS	
Contamination of groundwater	✓
Contamination of surface waters	✓
Contamination of abstraction wells	×
BUILT ENVIRONMENT	
Aggressive ground conditions to building material (e.g. concrete)	✓
Migration of ground gas into buildings	✓
Permeation of contaminants through water pipework leading to contamination of drinking water supply	✓

6.5 PRELIMINARY CONTAMINANT LINKAGE ASSESSMENT

Source	Exposure Pathways	Potential Receptor	Probability of Exposure	Consequence of Exposure	Discussion of Pollutant Linkage	Risk Rating
On Site: Made Ground including areas of deeper Made Ground	Inhalation, Ingestion and Dermal contact with Made Ground	Human - future site users	Low	Medium	Potential for future site occupants to encounter contaminated soil at the surface if present. The presence of building structures and hardstanding will limit exposure to landscaped areas.	Low to Moderate Risk
		Human-construction and maintenance workers	Likely	Medium	Potential for construction and maintenance workers to encounter contaminated soil. Exposure times likely to be limited and risks would be reduced by wearing appropriate personal protective equipment (PPE)	Moderate Risk reduced to Low with use of PPE
	Direct Contact	Below ground buildings and services (water pipes)	Low	Mild	Possible if contaminated soil remains in-situ post redevelopment.	Low Risk
	Migration via infiltration into groundwater or surface water	Underlying aquifer or Kettle Beck	Low	Mild	Potential for vertical migration of the contaminants from the Made Ground into the principal aquifer. Potential contaminants likely to be localised,	Low Risk

Source	Exposure Pathways	Potential Receptor	Probability of Exposure	Consequence of Exposure	Discussion of Pollutant Linkage	Risk Rating
Hazardous Ground Gases from Made Ground	Migration via preferential pathways i.e. Made Ground or service ducts	Future site users and maintenance workers	Low	Medium	Possible if considerable thicknesses of Made Ground are present. Ground gas monitoring during site investigation would assess concentrations of ground gas.	Low to Moderate Risk
Off site: Made Ground associated with adjacent Chemical Works and historic landfill	Migration via infiltration into groundwater or surface water	Groundwater aquifers or Kettle beck	Low	Mild	Potential for lateral migration of the contaminants from the off site Made Ground onto site.	Low Risk

Source	Exposure Pathways	Potential Receptor	Probability of Exposure	Consequence of Exposure	Discussion of Pollutant Linkage	Risk Rating
Off site: Hazardous Ground Gases from degrading material in the landfill and sewage filter beds	Migration via preferential pathways i.e. Made Ground or service ducts	Future site users and maintenance workers	Low	Medium	Possible depending on the material disposed of in the landfill and the material remaining in the sewage filter beds.	Low to Moderate Risk

7 EXISTING GROUND INVESTIGATION GAPS AND RECOMMENDATIONS

7.1 GAPS AND LIMITATIONS OF THE EXISTING GROUND INVESTIGATION INFORMATION

Further to the review of the existing ground investigation, it is considered that the most relevant existing information is the Solmek 2018 ground investigations. The STATS 1990 ground investigation covered the site, but it was carried out prior to the construction of the former Teesside Power Plant and do not represent the current ground conditions at the site. Solmek 2018 ground investigation was however carried out after the demolition of the former Teesside Power Plant and should be more representative of the current ground conditions at the site. It is worth noting that all the available historical ground investigations were not targeted to the proposed power plant development and 8 Rivers Capital LLC do not have reliance on the existing information for design. The existing information is however useful for the preliminary appreciation of ground conditions and development of conceptual site ground model.

Having considered the proposed development layout and reviewed the existing ground investigation information, the following gaps in information have been identified:

- No exploratory hole is present in the south of the proposed power station complex e.g. at the proposed locations of diesel generator/switchgear PDC and the Main PDC
- Additional exploratory holes would be required to better assess the Made Ground composition and thickness and confirm weathering profile within the bedrock at the proposed cooling tower locations.
- No existing ground investigation information at the proposed administrative building
- No existing ground investigation information at the proposed control building
- No long-term groundwater monitoring information at the site. No groundwater monitoring in the Solmek 2018 ground investigation within the Glacial Till and bedrock.
- No ground gas monitoring information at the site.
- Further ground investigations would be required to further assess ground contamination generally across the site.
- The Solmek 2018 ground investigation was not targeted towards the proposed power plant development. Some targeted exploratory holes are considered necessary at the proposed power station complex to confirm ground and ground water conditions.

7.2 RECOMMENDATION FOR FURTHER GROUND INVESTIGATION WORK

The following outline scope of ground investigation (GI) is considered necessary to fill the gaps in information identified above and to support detailed civil and structural design of the proposed development.

- Twelve cable percussion boreholes to prove rock head with associated in-situ testing and sampling.
- Six of the of the cable percussion boreholes to be extended into bedrock with rotary follow-on to prove 10m of rock.

- Downhole seismic tests in two boreholes at the proposed locations of the CO_2 turbine and generator.
- Ten trial pits to maximum of 4.5m bgl with associated geotechnical and geo-environmental sampling and in-situ tests.
- Groundwater monitoring in the existing boreholes on site and in the proposed new boreholes
- Ground gas monitoring of installations within new boreholes (and where possible in the historic boreholes)
- Geotechnical laboratory tests on soil samples comprising classification tests (moisture content, particle size distribution, Atterberg limit tests, bulk density and dry density tests), chemical tests, strength tests (quick undrained triaxial tests), compressibility tests (oedometer tests).
- Geotechnical laboratory tests carried out on recovered rock samples include moisture content tests, point load tests and uniaxial compressive strength tests.
- Geo-environmental laboratory tests to include asbestos, PAHs, heavy metals, TPH, PCBs, sulphate, VOCs and sVOCs.

A sketch showing the locations of the existing exploratory holes relative to the recommended further ground investigations and the proposed power plant layout is presented in Figure 7-1.

Figure Redacted

Figure 7-1 - Sketch showing the location of the existing Solmek 2018 exploratory holes relative to the proposed plant layout and the recommended further ground investigations (GI).

8 PILE RE-USE CONSIDERATION

8.1 BACKGROUND

The layout plans presented in Appendix B suggests that the proposed power station complex would lie within the former power block of the demolished Teesside Power Station. Available information shows that the former/demolished power station structures were orientated east-west, but the proposed power station complex structures would be orientated north-south. Some of the pile foundations that supported the former power plant structures would therefore underlie the proposed power plant structures.

It is considered that it may not be prudent to remove the old pile foundations as the cost of removal would be very high as some or all may extend into the underlying rock and would result in significant disturbance and softening of the ground. Re-using the existing pile foundations alone is also not considered feasible as the foundation requirement of the proposed new structures would be different to what could be provided by the old piles in terms of location and capacity. Two potential foundation options for the proposed power plant development presented in **Section 5** are:

- Option 1 – Install new piles avoiding the old foundations
- Option 2 – Install new piles to supplement existing piles i.e. re-use existing piles in combination with new piles.

Relative cost elements for the above options based on recommendations in CIRIA report C653 is presented in the Table 8-1.

Table 8-1 – Relative cost elements for foundation options for bored piles from CIRIA report C653

Foundation Option	Material Costs	Disposal cost	Design costs	Investigation costs	Insurance costs
Option 1 Install new piles avoiding the old foundations	High	High	Medium	Medium	Low
Option 2 Install new piles to supplement existing piles	Medium	Low	High	High	Potentially higher

To support consideration of the feasibility of re-use of the existing piled foundations, testing of the old piles would be required. This will include destructive testing of selected piles not proposed for re-use (outside of the footprint of the new structures) prior to construction (i.e. at feasibility stage) and further testing of each pile intended for re-use during construction. Existing piles to be re-used shall not carry more load than the re-assessed capacities suggested by pile tests.

Risks and restrictions on re-use of piles is described in detail in the following document, and all parties involved in design, warranty, insurance and construction of any structure supported on re-used piles must fully understand their liabilities:

- Re-use of Foundations for Urban Sites - A best practice handbook - BRE EP75 2006 (RUFUS).

8.2 SUMMARY INFORMATION ON THE EXISTING FOUNDATIONS

Available foundation design information and drawings for the former Teesside Power Station suggest that the existing piled foundations at the site comprise 0.6m diameter bored piles socketed into Redcar Mudstone Formation (3 x pile diameter minimum embedment). The piles were designed to a nominal length of 13.0m to develop shaft capacity.

Available information shows that the piles were set at varying spacings under the different structures and in most cases, centre to centre spacing are greater than 2.5 x pile diameter. The pile caps under the former gas turbine generator (GTG), heat recovery steam generator (HRSG) and steam turbine generator (STG) structures have a thickness of 0.85m whilst those under the stacks, pipe rack, and deaerator structures have a thickness of 1.10m. Available information further suggest that the sizes of the pile caps vary under the different structures.

The piles supporting the former GTG, HRSG and STG structures were designed to compressional load capacity of 1,500kN, uplift capacity of 150kN and horizontal shear capacity of 40kN. Those under the stacks, pipe rack, and deaerator structures were designed to compressional load capacity of 1,500kN, uplift capacity of 330kN and horizontal shear capacity of 120kN.

The pile detail drawing and pile location plans under the former Teesside Power Plant HRSG B-201 and GTG G-101 are presented in **Appendix E** for reference.

8.3 RE-USE OF PILE FOUNDATIONS

A detailed discussion on the technical and design liability issues of pile re-use, or the techniques and limitations for various pile tests, is outside the scope of this geotechnical desk study, but the following general observations are made and warrant further consideration by the client and the designer.

There are potential economic, programming and sustainability benefits to be gained if the existing piles can be re-used. Piles are occasionally re-used on refurbishment projects but less frequently on new build projects. The potential issues that will arise if the existing piles are re-used are listed below:

- Reduction in the construction programme;
- Less risk arising from obstructions in the ground;
- If new pile positions clash with existing, the existing piles may have to be removed or over-cored which involves an expensive process, or adjustment to the pile cap arrangement may be required piles;
- Lower foundation costs;
- Ground congestion would be minimised. (This is important for the very long-term future and value of the site).
- Reduction of new works and therefore of embodied energy.

8.4 PILE TESTING

To support consideration of the feasibility of re-use of the existing piled foundations, testing of piles to be re-used should be completed in two stages - Stage 1 *feasibility testing phase* and a Stage 2 *construction verification phase*.

The aims of the *Stage 1* testing are to:

- Confirm the type of pile.
- Check the diameter of the tested piles are as expected.
- Determine the length of the tested piles.
- Assess integrity and possible defects of the tested piles.
- Investigate the nature of the reinforcement and concrete of the tested piles.
- Assess the load capacity of the tested pile.

All piles to be tested at Stage 1 should be outside the footprint of the any proposed structure to avoid possible damage to piles which may be considered for re-use and to allow an assessment to take place early in the programme. On completion of the Stage 1 testing, the structural designer of the proposed structure will need to assess the feasibility of re-using the existing piles to support the proposed structure.

The aims of the Stage 2 testing are to:

- Investigate each pile proposed for re-use to verify integrity and assess for defects.

On completion of the Stage 2 testing the structural designer of the proposed structure will need to assess the suitability of each pile to be re-used to support the proposed structure. Defective or unsuitable piles may need to be either discounted for load bearing or replaced.

An outline of tests to be carried out as part of Stage 1 and Stage 2 are presented in Table 8-2 and Table 8-3. Number of tests and other details should be confirmed in a carefully prepared specification prior to testing.

Table 8-2 – Proposed Pile Tests – Stage 1 Feasibility

Test	Purpose
Excavation to expose pile head	To examine selected piles to confirm type, diameter, reinforcement etc.
Full length coring of pile	To examine concrete conditions for full length of pile and collect samples for concrete testing.
Low Strain Integrity test*	To examine pile length and detect defects.
Dynamic Load test (e.g. SIMBAT)	To assess the performance of a pile under load.
Material testing	To determine concrete type, condition strength and evidence of corrosion including petrographic analysis and re-bar assessment

Table 8-3 - Proposed Pile Tests – Stage 2 Construction

Test	Purpose
Low Strain Integrity test*	To examine pile length and detect defects.

8.5 DESIGN RESPONSIBILITY, INSURANCES AND ACCEPTANCE BY STAKEHOLDERS

Typically for piling in the UK, the design consultant is responsible for specifying the performance required while the specialist contractor is responsible for the detailed design and construction. The original piling organisation (if still trading) would not likely warrant the existing piles for change in use and increased design life. In fact, no party is likely to guarantee the future performance of the existing piles in the new development. 8 Rivers Capital LLC should discuss any consideration for the existing pile re-use with their insurance provider to involve them in risk mitigation.

A fall-back scheme should be in place to guard against a situation where the site investigation and inspection shows that re-use is not suitable or if these proposals are rejected by the local authority or insurers, or if significant differences between the as-built detail and the information shown on construction drawings are discovered. Redundancy in foundation design to mitigate against failure risk of a single pile should also be considered.

An extract of the recommended 'decision making process' advocated in the BRE Handbook is presented in Figure 8-1 for reference.

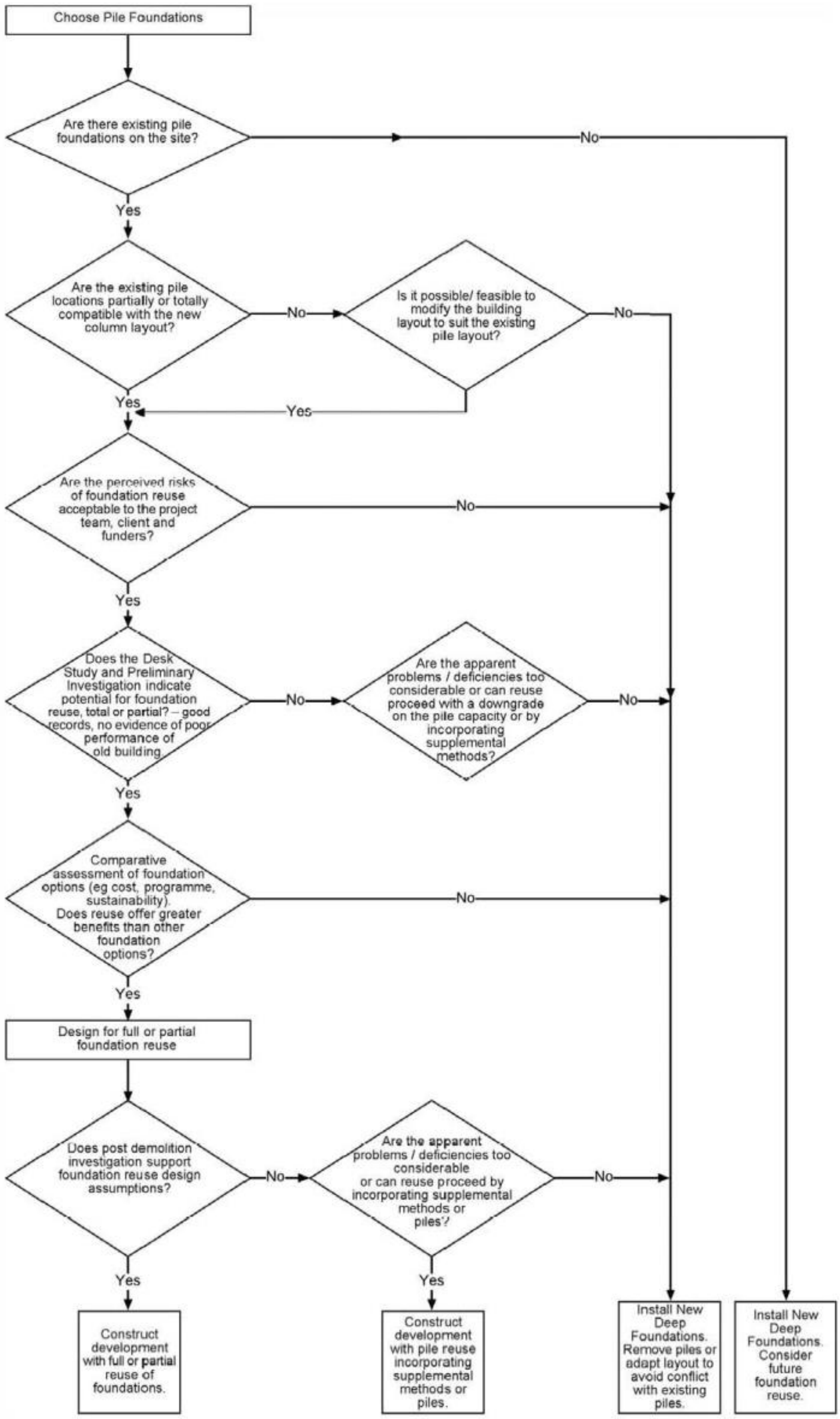

Figure 8-1 - *Foundation re-use decision process: deep foundations* (extract from BRE handbook on re-use of foundations for urban sites, 2006)

Appendix A

SITE LOCATION AND SITE BOUNDARY PLANS

Appendix B

SITE LAYOUT FOR THE PROPOSED POWER PLANT (SEMBCORP DRAWING GIS-00-L-03019)

Appendix C

HISTORICAL BGS BOREHOLE LOGS

Appendix D

ZETICA BOMP RISK MAP

Appendix E

FORMER TEESSIDE POWER PLANT DRAWINGS CD-4045, CD-4046 AND CD-4072

Appendix F

REPORT LIMITATIONS

Amber Court
William Armstrong Drive
Newcastle upon Tyne
NE4 7YQ

wsp.com

8 Rivers Capital LLC

ALLAM CYCLE UK PRE-FEED

Specification & Schedules for Intrusive Ground Investigations

70053760 -WSP-00-XX-SP-GE-0001-S3_P01
DECEMBER 2020

CONFIDENTIAL

8 **Rivers Capital LLC**

ALLAM CYCLE UK PRE-FEED

Specification & Schedules for Intrusive Ground Investigations

SPECIFICATION (VERSION P01) CONFIDENTIAL

PROJECT NO. 70053760

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APPENDICES

INTRODUCTION TO THE SPECIFICATION & SCHEDULES

GENERAL

1.1.1. WSP has been instructed to specify and report on an intrusive ground investigation at the site of the former Teesside Power Station, Wilton International, Redcar and Cleveland (hereafter referred to as "the site"). The site is being considered for re-development with an Allam-Fetvedt cycle power plant. The site location and proposed ground investigation locations are shown on drawings presented in **Appendix A**.

1.1.2. The Specification shall be the Institution of Civil Engineers publication '*UK Specification for Ground Investigation*' Second Edition (2012), with information, amendments, and additions as described in these Schedules. The Proposed Bill of Quantities for the works is appended to this Specification. The appointed Ground Investigation Contractor (hereafter referred to in this specification and under the contract as 'The Contractor') shall hold a paper copy of the Specification and these Schedules and the completed Bill of Quantities on site for use by the Contractor and the Investigation Supervisor.

1.1.3. These Schedules and the Bill of Quantities will provide a basis for and assist the Contractor in carrying out the Ground Investigation and cover the intrusive exploratory work, the required in situ and laboratory testing, and the format in which this information is to be reported. In undertaking the works, the Contractor shall also include any requirements or requests made by the Client, Principal Designer, Principal Contractor or within the Pre-construction Information. In the event of any ambiguity in requirements, the Contractor shall refer the issue to the Investigation Supervisor.

1.1.4. The scope of the investigation is described in detail in these Schedules. In the event of any ambiguity regarding the scope, the Contractor shall refer the issue to the Investigation Supervisor for confirmation of requirements.

1.1.5. Where the term '*As specified*' is used in these Schedules, this shall mean that no additional information is provided in this schedule and the relevant standard Clause of the Specification shall apply (i.e. the option to provide additional specification has not been taken). Where the term '*Not required*' is used in these Schedules, this shall mean that the item(s) referred to are not required as part of the Contracted works.

1.1.6. Unless superseded by the information provided in the Schedules, or amended or additional Specification Clauses, the information and guidance provided in the Specification 'Notes for Guidance' shall apply to the works.

1.1.7. The Contractor for the works (as defined by the Contract), as defined by the UK Specification for Ground Investigation, is to be confirmed.

1.1.8. All co-ordination, supervision, and management of the site works, along with logging of exploratory locations, will be undertaken by the Contractor. WSP, as Investigation Supervisor, will act as an independent contractor and will undertake a technical guidance role and works monitoring role, including undertaking of check logging of exploratory locations as considered appropriate.

COMPLIANCE WITH APPLICABLE LAWS AND STATUTORY REQUIREMENTS

1.1.9. The Contractor shall comply with all applicable laws and statutory requirements including any environmental protection measures.

RELEVANT SCHEDULES

1.1.10. The following schedules are included:

- Schedule 1. Information
- Schedule 2. Exploratory Holes
- Schedule 3. Investigation Supervisor's Facilities
- Schedule 4. Specification Amendments
- Schedule 5. Specification Additions

AMENDMENTS AND ADDITIONS

1.1.11. The following Specification Clauses are amended. Where the original Clause is referenced within either the Specification or these schedules, this shall be taken as reference to the amended clause.

Table 1 – Amended Specification and Schedule Clauses

Original Clause	Amended Clause	Clause Topic
3.2	3.2A	General requirements: British standards and equivalent
3.3	3.3A	General requirements: Quality management
3.8.1	3.8.1A	General requirements: General safety requirements: Safety Legislation
3.8.2	3.8.2A	General requirements: General safety requirements: Risk assessment and method statements
3.8.4	3.8.4A	General requirements: General safety requirements: Welfare facilities
3.9	3.9A	General requirements: Notice of entry
3.15.2	3.15.2A	General requirements: Care in executing the work: Avoidance of further contamination
3.16.1	3.16.1A	General requirements: Working areas: General
3.21	3.21A	General requirements: Exploratory work
3.25.3	3.25.3A	General requirements: Photographs
3.25.4	3.25.4A	General requirements: Photographs
3.26	3.26A	General requirements: Disposal of Arisings
4.1	4.1A	Percussion boring: Method and diameter
4.6.6	4.6.6A	Percussion boring: Packing and labelling of windowless samples

6.6	6.6A	Pitting and trenching: Excavation
7.1	7.1A	Sampling and monitoring during the intrusive investigation: General
7.4	7.4A	Sampling and monitoring during the intrusive investigation: Description of samples
7.6.5	7.6.5A	Sampling and monitoring during the intrusive investigation: Samples for geotechnical purposes: Open-tube and piston samples
13.1	13.1A	Daily records: General
16.1	16.1A	Reporting: Preliminary logs
16.2.1	16.2.1A	Reporting: Exploratory hole logs: General
16.6.3	16.6.3A	Reporting: Form of reports
16.8.2	16.8.2A	Reporting: Contents of Ground Investigation Report
16.11	16.11A	Reporting: Approval of report

1.1.12. The following Specification and Schedule Clauses are added to the Specification.

Table 2 - Additional Specification and Schedule Clauses

Additional Clause	Clause Topic
3.8.6Ad	General requirements: Service strikes
3.27Ad	General requirements: Logging & description of soils and rocks
10.11Ad	In situ testing: Standard Penetration Testing (SPT)
S1.8.20	General Requirements: Construction (Design and Management) Regulation 2015 (Clause 3.8.1A)
S1.8.21	General Requirements: Contractor Accreditation and Membership (Clause 3.3A)

SCHEDULE 1: INFORMATION

GENERAL COMMENTS		*Schedules S1.1 to S1.7, provided below, are generally provided as information for the benefit of the Contractor in the planning, undertaking, and reporting of the investigation. Any requirements presented in these schedules shall be adhered to.* *Schedules S1.8 to S21 provide site-specific requirements of the investigation. All Schedules providing requirements shall be adhered to.* *In the event of any ambiguity, the Contractor shall refer the issue to the Investigation Supervisor for confirmation.*
S1.1	**Name of Contract**	For the purposes of these works, the name of the Contract shall be: '*Project Whitetail Allam Cycle UK: Intrusive Ground Investigation'*. The above title shall be used on all Contractor documentation and reporting and shall not be shortened, abbreviated, or amended in any way unless as instructed by the Investigation Supervisor.
S1.2	**Investigation Supervisor**	For the duration of the works, the Investigation Supervisor shall be: *(TBC - Engineer from* WSP) Tel: 0191 298 1000 The Investigation Supervisor shall have a part-time presence on site during the works. The Investigation Supervisor shall be reasonably contactable by telephone during the site hours. Alongside other duties, the Investigation Supervisor will act as an independent contractor and will undertake check logging of exploratory locations. In line with the Contract, the Investigation Supervisor may from time to time delegate to other persons responsible to the Investigation Supervisor any of the duties and authorisations vested in the Investigation Supervisor. It is anticipated that a maximum of 1 (one) person will be on site at any one time in the role of Investigation Supervisor.
S1.3	**Description of Site**	The information in this Clause provides a summary of information presented in the previous Desk Study report (copy provided as part of Contract Information), prepared by WSP (Allam Cycle UK Pre-FEED Geotechnical Desk Study Report Ref:70053760-WSP-00-XX-RP-GE-0001-S4_P03*)*, other reports as referenced, and in the referenced clauses. In the event of any ambiguity, the Contractor shall refer the issue to the Investigation Supervisor for confirmation.

		Location: Land within the Wilton International Site, Redcar and Cleveland, TS6 8JF. National Grid coordinates E456500, N520380. **Access:** Site is accessed from the west via the A1053 (Greystone Road). The site area is fenced and access to the area will be provided by the Client. **Boundaries:** The extents of the investigation area lie unmarked within the larger Wilton International Site, and are as shown on Figures 1 and 2 in **Appendix A**. **Topography:** The site area is approximately 15Ha and the elevation is generally level at approximately 16m AOD. **Current use:** The site currently comprises extensive areas of concrete hardstanding, preserved from the demolition of the former Teesside Power Station. There are two existing substations in the south of the site. There are also existing control buildings for above ground 24" Gas main and 8" propane lines in the north of the site. **Historical site use:** The site is recorded to have been agricultural land until 1992. Teeside Power Station is recorded from 1993, with two substations in the south of the site connecting to overhead electricity transmission lines to the south of the site. Teeside Power Station is recorded to have been demolished by 2017, except for the two substations in the south of the site. **Site classification** (in accordance with the guidance published in the Site Investigation Steering Group (SISG) document, Guidance for the Safe Investigation of Potentially Contaminated Land) (Schedule S1.8.4): **Red** - due to potential Asbestos/ACMs related to the power station and potential radioactive materials relating to on site permits for keeping, use of radioactive materials and disposal of radioactive waste. **Known or expected contamination (Schedule S1.8.4):** The historical and current site uses present a risk of soil and groundwater contamination including asbestos, radioactive materials and hydrocarbons. **Unexploded Ordnance status (Schedule S1.8.4):** The potential for the presence of unexploded ordnance on the site has been assessed as 'Low' from a high-level review. No further UXO mitigation is considered necessary in any future ground investigation works. **Mining status of the site (Schedule S1.8.6):** The site is not in a coal mining affected area. There is an active BGS recorded mineral site relating to Wilton Power Station Ash Plant at the site. The listed commodities are Furnace Bottom Ash and Pulverised Fuel Ash.

		Ecological constraints (Schedules S1.8.4 & S1.8.7): None expected. **Archaeological constraints (Schedule S1.8.8):** None expected. **Access restrictions (Clause S1.7):** Vehicular access routes to all work areas are to be confirmed with the Client prior to commencement – expected to be from the A1053. Access to third party land is not expected. The Client / Principal Designer shall be responsible for arranging access / providing notice of entry on to the site with the owner and / or occupier (Clause 3.9A).
S1.4	**Main works proposed and purpose of this Contract**	The information in this Clause provides a summary of information presented in the referenced documents and clauses. At this stage the scheme is in concept design stage, with the following broad requirements identified: - Construction of foundations and groundworks associated with the proposed Allam-Fetvedt cycle power plant, including heavily loaded and settlement sensitive structures. The purpose of the investigation is to determine ground and groundwater conditions at the site in order to determine any significant environmental risks and obtain geotechnical information to inform the design. Specific objectives are to: ▪ Determine the depth and nature of strata beneath the site; ▪ Establish groundwater and ground gas conditions beneath the site; ▪ Obtain soil and groundwater samples for laboratory geotechnical and chemical analysis; and, ▪ Undertake laboratory geotechnical and chemical analysis.
S1.5	**Scope of investigation**	The information in this Clause provides a summary of information presented in the referenced clauses. The proposed investigation layout plan is presented on the Contract Drawings. The proposed investigation includes the following as detailed within Schedule 2: ▪ Provision of welfare; ▪ Setting out and surveying (to preliminary XY coordinates provided in Schedule 2) of exploratory holes; ▪ GPR utility clearance survey; ▪ Breaking out of concrete hardstanding to allow boreholes and trial pits to be advanced (allowance of 2 days has been

		made for breaking out concrete obstructions at borehole locations using excavator with breaker attachment); ▪ 12 No. cable percussion boreholes, of which: • 5 No. to rockhead (anticipated to be in the region of 10m bgl) • 7 No. to rockhead with rotary coring follow on to 10m below rockhead (anticipated total depth to be in the region of 20m bgl) ▪ 2 No. downhole seismic tests in boreholes at the proposed locations of the CO2 turbine and generator; ▪ 10 No. trial pits to a maximum of 4.5m bgl with a large (e.g. >12T) 360-degree excavator with breaker attachment; ▪ 12 No. groundwater / gas monitoring wells to be installed; ▪ In situ testing and sampling in boreholes; ▪ In situ testing (hand shear vane testing and plate load testing) and sampling from trial pits; ▪ Headspace testing shall be undertaken on all environmental soil samples using a Photo Ionisation Detector (PID). ; ▪ Geotechnical laboratory tests; ▪ Geo-environmental laboratory tests; ▪ Post site works gas and groundwater monitoring of the installations in the 12 boreholes from this ground investigation and where possible of the installations in existing boreholes from previous ground investigations. Existing boreholes at the site from previous ground investigations, where accessible and serviceable, shall be purged in line with Clause 12.3.2 (three installation groundwater volumes) by the Contractor. This is to include the development of groundwater boreholes prior to sampling; and, ▪ Factual Reporting. The Ground Investigation Contractor is required to undertake the site works, including taking of samples, in situ testing, geotechnical and geo-environmental laboratory testing and post site works monitoring. The Ground Investigation Contractor is required to produce a 'Factual Report' for the works (as defined in Clause 16.6). Schedule section S1.13 is not anticipated to be required and has been removed (in line with Clause 3.1). Access at the site shall be arranged by The Client / Principal Contractor, dependent on area of site to be accessed (Clause 3.9A). The Contractor shall act in the role of '*Contractor*', as defined by the Construction (Design and Management) Regulations 2015 (CDM) (Clause 3.8.1A).

		The following other CDM duty holder roles are identified for the works (Schedule S1.8.20): ▪ ***Client:*** 8 Rivers Capital LLC ▪ ***Principal Designer:*** TBC ▪ ***Investigation Designer:*** WSP ▪ ***Principal Contractor:*** TBC - appointed by Client. ▪ ***Contractor:*** Appointed Ground Investigation Contractor. ▪ ***Sub-contractor:*** Any sub-contractor working for the Contractor (e.g. specialist survey, sub contracted drillers etc.)
S1.6	**Geology and ground conditions**	The information in this Clause provides a summary of information presented in the in the Desk Study prepared by WSP and in the referenced clauses. In the event of any ambiguity, the Contractor shall refer the issue to the Investigation Supervisor for confirmation. The ground conditions expected at the site are as follows:

Strata	Approximate Depth	Typical Description
Concrete Hardstanding	GL – 1.5m bgl	Concrete relating to old hardstanding, building slabs, foundations etc.)
Made Ground	1.5 – 2.4m bgl	Variable – gravel fill or clay fill with brick, concrete slag and dolomite
Glacial Till	2.4 – 10.0m bgl	Stiff and very stiff locally firm slightly sandy slightly gravelly clay
Redcar Mudstone	10m bgl +	Very weak becoming weak mudstone with interbedded siltstone
Groundwater	Approximately 8.0 – 10.0m bgl, locally perched at base of Made Ground	

Hydrogeological Setting:

Hydrogeological Aspect	Details
Geology	Superficial Designation - Glacial Till – Unproductive Strata and Secondary (Undifferentiated) Aquifer

			Bedrock Designation – Redcar Mudstone - Secondary (Undifferentiated) Aquifer
		Groundwater Source Protection Zones	The site is not located within a groundwater Source Protection Zone (SPZ).
		Groundwater Abstractions	There are no groundwater abstractions located within 500m of the site.
S1.7	**Schedule of drawings and documents**	Drawings (Appendix A): - *Figure 1 – Site Location Plan* - *Figure 2 – Site Boundary Plan* - *Proposed development plan* - *Proposed Exploratory Hole Location Plan* Documentation: - Pre-Construction Information pack (including utilities information and existing GI information – (available from Client directly); - WSP, Allam Cycle UK Pre-FEED Geotechnical Desk Study 70053760-WSP-00-XX-RP-GE-0001-S4_P03, dated December 2020; and - This Specification, Schedules and the Bill of Quantities document.	
GENERAL REQUIREMENTS			
S1.8	**General requirements (Specification Section 3) Particular restrictions / relaxations**	*See Schedules S1.8.1 to S1.8.20.*	
S1.8.1	**Quality Management Systems (Clause 3.3)**	See amended Clause 3.3A.	
S1.8.2	**Professional Attendance (Clause 3.5.2)**	The Contractor shall provide a '*Site Agent*' who shall have a full-time site presence for the duration of the works. The Site Agent shall fulfil the requirements of Clauses 3.5.1 and 3.5.2 and shall be responsible for the works being carried out in accordance with the Contract, Specification, and Schedules and to the technical, logistical, and quality requirements of the works. The Site Agent shall be an Experienced Ground Engineer (Clause 2.3), defined as having at least 3 years of relevant experience since graduation with an appropriate degree, or alternatively with at least 5 years of experience if not a graduate, supported by a Registered Ground Engineering Professional. If no Registered Ground Engineering Professional	

		is available, the Site Agent role may be fulfilled by an equivalently qualified Engineer as agreed by the Investigation Supervisor (following review of an appropriately detailed CV). Further to the requirements of Clause 3.14.1, the Site Agent shall hold a valid and current CSCS card ('White / Yellow – Professionally Qualified Person' (in the case of a Registered Ground Engineering Professional) or equivalent as agreed with the Investigation Supervisor, or 'White / Yellow – Academically Qualified Person' (in the case of an Experienced Ground Engineer'). The term '*Site Agent*' shall be used on all Contractor documentation and reporting and shall not be shortened, abbreviated, or amended in any way unless as instructed by the Investigation Supervisor.
S1.8.3	**Provision of ground practitioners and other personnel (Clauses 3.6.1 and 3.6.2)**	The Site Agent may have the support of other on- or off-site staff; this may include sufficient technical staff to fulfil the requirements of the works (including technical supervision of site activities, site liaison, logistics, logging, preparation of daily records and preliminary logs, and management of site operatives in the undertaking of in situ testing, sampling, and photography).
S1.8.4	**Hazardous ground, land effected by contamination and notifiable and invasive weed (Clauses 3.7.1 and 3.22)**	The Contractor shall prepare a suitable '*Environmental Management Plan*' for the works, in line with CIRIA C741. The site is considered to potentially contain hazardous ground in the form of Made Ground potentially containing contaminants. The site has been assigned an Unexploded Ordnance Risk Rating of 'Low' from a high-level assessment. The site classification (in accordance with the guidance published in the Site Investigation Steering Group (SISG) document, Guidance for the Safe Investigation of Potentially Contaminated Land) is ***Red***. All the Contractor's site personnel shall have undertaken suitable demonstrable asbestos awareness training prior to attending site. This may be an in-house course provided record of training is available. A specific asbestos awareness tool box talk shall be given on site by the Contractor to all their site personnel (including the Investigation Supervisor) prior to works commencing (and to any new personnel undertaking works on the site on behalf of the Contractor at the time of their site induction). The Contractor shall ensure that their site operatives wear appropriate Respiratory Protective Equipment / Personal Protective Equipment in the event that contaminated soils including potentially asbestos containing soils (i.e. stockpiled material and Made Ground) are encountered.

		This Specification covers the technical aspects of the ground investigation and does not include site specific aspects of safety or operational procedure which may be required by the Client or Principal Designer.
S1.8.5	**Additional information on services not shown on Contract drawings (Clause 3.7.2)**	Services information is provided in the Pre-Construction Information (Schedule S1.7). If not presented within the Pre-Construction Information Pack the Contractor shall identify any statutory distances or required safe distances and include these in their working Method Statement and Risk Assessments. No further information regarding services is available.
S1.8.6	**Known / Suspected mine workings, mineral extractions, etc. (Clause 3.7.3)**	There is no evidence of historic mining within the area surrounding the site as summarised in Schedule S1.3, and the site is not considered to be at risk from shallow mine working.
S1.8.7	**Protected species (Clause 3.7.4)**	None expected.
S1.8.8	**Archaeological remains (Clause 3.7.5)**	No specific information is available for the site. The works shall be undertaken to the best practice guidance provided in CIRIA C741.
S1.8.9	**Security of site (Clause 3.11)**	The Principal Contractor shall be responsible for establishing and maintaining the security of the site.
S1.8.10	**Traffic Management Measures (Clause 3.12)**	Not required.
S1.8.11	**Restricted Working Hours (Clause 3.13)**	Work within the site shall be carried out only during between 08:00 and 18:00, Monday to Friday, or by agreement with the Client outside these hours. Other activities, such as logging samples, may be performed outside these hours at an off-site location, if appropriate / suitable.
S1.8.12	**Trainee site operatives (Clause 3.14.1)**	If agreed in writing with the Principal Contractor, trainee site operatives are allowed to work on the investigation in a 'shadow' role only and as such the Contractor shall ensure that any trainee operatives on site are supervised by an appropriately qualified and experienced operative. Responsibility for any Contractor trainee, including the quality of any work undertaken by them, is the responsibility of the Contractor.
S1.8.13	**Contamination avoidance and / or aquifer protection measures required (Clauses 3.15.2 and 3.15.3)**	Only vegetable-based lubricants are to be used. Where cable percussion boreholes are anticipated to extend through Made Ground, aquifer protection measures shall be utilised to limit cross contamination risk. This should include as a minimum reducing the casing from 8 inch to 6 inch at the

		interface between the two strata types and installing a bentonite seal at the base of the Made Ground. Installation of monitoring wells within boreholes shall have a response zone in a single stratum to avoid pathway creation within installations. Installation instructions should be sought from the Investigation Supervisor. In the event that significantly impacted soils are encountered, all drilling tools shall be appropriately de-contaminated prior to use within subsequent exploratory locations to prevent cross-contamination between exploratory locations.
S1.8.14	**Maximum period of boring, pitting or trenching through hard material, hard stratum or obstruction (Clauses 2.8, 4.8 and 6.4)**	After 0.5 hours the Investigation Supervisor shall be informed and boring, pitting, or trenching continued unless instructed to stop by the Investigation Supervisor. After a further 0.5 hours (i.e. 1 hour total) boring or pitting shall cease and instruction shall be sought from the Investigation Supervisor. The penetration in hard stratum shall be recorded so that the rate of penetration may be determined by the Investigation Supervisor.
S1.8.15	**Reinstatement requirements (Clauses 3.16)**	Reinstatement shall be undertaken to the satisfaction of the Client, at this stage this is anticipated to include backfilling trial pits in compacted layers of fill and leaving the ground heaped. For borehole locations they should be reinstated to a standard considered suitable for the ongoing use of the site in its current use. All reinstatement shall be carried out immediately on completion of each exploratory hole, with none left open. If reinstatement is undertaken using products that require set time to achieve full strength (such as grout or concrete) then the location shall be protected by fencing or other until suitable strength is achieved to prevent accidental access over the area. Any deterioration of reinstated exploratory holes shall be rectified by the Contractor as instructed by the Investigation Supervisor. Exploratory holes with installations shall be decommissioned on the instruction of the Investigation Supervisor.
S1.8.16	**Hygiene facilities required (clauses 2.20 and 3.16.1)**	The welfare facility requirements of the Construction (Design and Management) Regulations shall apply to the investigation. Unless agreed with the Principal Contractor, Welfare and Hygiene facilities in line with the requirements of the specified site classification (Schedule S1.8.4) shall be provided by the Contractor for the Contractor's staff plus 2 (two) additional persons.
S1.8.17	**Unavoidable damage to be reinstated by Contractor (Clause 3.16.1)**	The Contractor shall highlight to the Investigation Supervisor any areas where unavoidable damage may occur and shall be responsible for making good (to the satisfaction of the

		Investigation Supervisor) if instructed by the Investigation Supervisor to proceed.
S1.8.18	**Accuracy of exploratory hole locations (Clauses 3.19 and 3.20)**	Exploratory locations shall be agreed with the Investigation Supervisor prior to stockpile clearance (where required) and subsequent utility clearance. The Contractor shall arrange for removal of the spoil material local to access to each exploratory hole location, where below slab investigation is required to enable utility clearance. The final locations and ground levels at each exploratory hole location shall be recorded by the Contractor in relation to the National Grid and Ordnance Datum. As-built surveying shall be to an accuracy of 0.10m in plan. Ground levels at exploratory holes shall be recorded to 0.05m accuracy.
S1.8.19	**Photography requirements (Clause 3.25)**	In addition to the requirements of Clauses 5.8 and 6.12, photographs shall be taken of all exploratory hole locations prior to set up and on completion of works (following removal of rig and reinstatement). Photographs shall be taken at a standard and consistent height and distance from the exploratory hole, sufficient to cover the whole of the area affected by the works to that hole. Photographs shall be taken of all trial pits to meet the requirements of Clause 3.25. All photographs shall include a photo board containing as a minimum (in addition to the requirements of Clause 3.25), the following information: ▪ The name of contract (Schedule S1.1); ▪ The exploratory hole number (Schedule S2.1); ▪ The date the photograph is taken. All photographs shall be clearly legible in all parts. The Contractor shall check the legibility of all photographs at the time of photography and shall be responsible for taking additional / repeat photographs as necessary. The Contractor shall supply any artificial lighting required dependent on the ambient light conditions at the time of the works. See also Clauses 3.25, 5.8, and 6.12, as applicable.
S1.8.20	**Construction (Design and Management) Regulation 2015 (Clause 3.8.1A)**	The following Construction (Design and Management) Regulations 2015 duty holder roles shall apply to the works: ▪ Client: 8 Rivers Capital LLC ▪ Principal Designer: TBC ▪ Investigation Designer: WSP ▪ Principal Contractor: TBC ▪ Contractor: Appointed Ground Investigation Contractor

		▪ Sub-contractor(s): Any sub-contractor working for the Contractor (e.g. specialist survey, sub contracted drillers etc)
S1.8.21	**Contractor Accreditation and Membership (Clause 3.3A)**	The Contractor shall be certified as meeting the requirements of the following accreditation standards (for works relevant to those specified): ▪ BS EN ISO 9001:2015; ▪ BS EN ISO 14001:2015; and, ▪ ISO 45001. Equivalent quality management provision may be considered acceptable on agreement with the Investigation Supervisor.
PERCUSSION BORING		
S1.9	**Percussion Boring (Specification Section 4) Particular restrictions / relaxations**	*See Schedules S1.9.1 to S1.9.3.*
S1.9.1	**Permitted methods and restrictions (Clauses 4.1 to 4.4)**	*As specified.*
S1.9.2	**Backfilling (Clause 4.5)**	For reinstatement requirements see Schedule S1.8.15. All boreholes are to have monitoring installations and therefore shall be backfilled in line with instruction from the Investigation Supervisor, and this Specification. Any excess spoil may be appropriately removed from site or left in an agreed location on site by the Contractor and the work areas left in a tidy state.
S1.9.3	**Dynamic Sampling (Clause 4.6)**	Not required.
ROTARY DRILLING		
S1.10	**Rotary drilling (Specification Section 5) Particular restrictions / relaxations**	*See Schedules S1.10.1 to S1.10.13.*
S1.10.1	**Augering requirements and restrictions (Clause 5.1)**	Not required.
S1.10.2	**Particular rotary drilling techniques (Clause 5.2)**	The plant, method of advancement, and the diameter of a borehole shall be such that the boring can be completed (without undue ground disturbance or ground loss) and logged to the scheduled depth, samples of the specified diameter can be obtained, in situ testing carried out, and instrumentation

		installed as described in the Schedule S2 and other Clauses of these Schedules (as applicable). Rotary drilling shall accurately identify strata type and changes in strata and must be capable of penetrating cobbles, boulders and Made Ground. The Contractor shall keep a Daily Drilling Record for each borehole, in a form approved by the Investigation Supervisor, while work proceeds at that borehole. The Daily Drilling Record shall be in accordance with Clause 13 and shall record the following information as a minimum: (a) Job name and location (b) Borehole reference (c) Date (d) Contractor's name (e) Method of drilling and flushing medium (f) Type of bit used (g) Diameter and depths of all casing used (h) Depth to each change of stratum (i) Geological description of each stratum (j) Details of any loose ground or voids penetrated (k) Details of any loss of flushing medium (l) Details of any emission of gas, water, foul air etc (m) A continuous record of drilling rate, drill pressure and drill rotation rate. No borehole shall be commenced, terminated or backfilled without the agreement of the Investigation Supervisor.
S1.10.3	**Drilling fluid type and collection (Clause 5.3)**	The Contractor shall be responsible for choosing the most appropriate drill fluid type to permit maximum recovery, provided that it meets the requirements any applicable licences or permits. The Contractor shall put in place suitable precautions to prevent run-off or drilling fluid from the area immediately surrounding the borehole. The Contractor shall put in place suitable precautions to prevent drilling fluid, water, slurry, arisings, spoil, rock fragments, dust, exhaust smoke and run-off from the area immediately surrounding the borehole in order that these do not cause damage/disturbance to site users, infrastructure, does not dirty vehicles, reach existing drainage, watercourses and the like. Any proposals for drilling muds, additives or foams are to be agreed with the Investigation Supervisor.

S1.10.4	**Rotary core drilling equipment and core diameter (Clauses 5.4.1 and 5.4.2)**	Core diameter, where required, shall be minimum 76mm. A semi rigid core liner shall be used for all rotary coring to maximise core recovery. The first drill run in each borehole shall not exceed 1m in length. Subsequent drill runs shall not exceed 1.5m in length. The core barrel shall be removed from the borehole as often as may be required to obtain the best possible core recovery. When recovery is less than 95%, or such other percentage as directed by the Investigation Supervisor, for a full length drill run then the next drill run shall be reduced to 1m. If core recovery is still less than 95% then drilling shall cease and the fact shall be reported to the Investigation Supervisor immediately who will determine the course of action in consultation with the Contractor. If groundwater inflow is noted then the relevant information shall be recorded in accordance with S1.17 and Clause 7.7.
S1.10.5	**Core logging (Clause 5.4.6)**	On site logging facilities are not required, but can be provided by the Contractor if deemed appropriate.
S1.10.6	**Core sub-samples for laboratory testing (Clause 5.4.7)**	The Investigation Supervisor shall identify core sub-samples for testing through inspection of the core and / or from the Contractor's photographs of the core and preliminary logs.
S1.10.7	**Address for delivery of selected cores (Clauses 5.4.8 and 5.4.9)**	All cores shall be securely stored at the Contractor's premises for a period of 1 year following completion of the detailed logging and laboratory testing of the cores. The Contractor is to seek advice from the Investigation Supervisor after 6 months for instruction on further storage.
S1.10.8	**Rotary open hole drilling general requirements (Clause 5.5.1)**	Not required.
S1.10.9	**Rotary open hole drilling for locating mineral seams, mine workings, etc. (Clause 5.5.2)**	Not required.
S1.10.10	**Open hole resonance (sonic) drilling (Clause 5.6.1)**	Not required.
S1.10.11	**Resonance (sonic) drilling with sampling or continuous coring (Clause 5.6.2)**	Not required.
S1.10.12	**Backfilling (Clause 5.7)**	See Clause 1.9.2.

S1.10.13	**Core photographic requirements (Clause 5.8)**	The photographic criteria noted in Clause 5.8 shall apply.
PITTING AND TRENCHING		
S1.11	**Pitting and trenching (Specification Section 6) Particular restrictions / relaxations**	*See Schedules S1.11.1 to S1.11.9.*
S1.11.1	**Indirect detection of buried services and inspection pits (Clauses 3.8.3 and 6.1)**	The requirements of Clause 3.8.3 apply. In addition to the requirements of Clause 3.8.3, following surface access being enabled and clearance of the location the Contractor shall undertake ground-probing radar across the location of each exploratory hole prior to breaking ground or undertaking any in situ testing of the ground. The Contractor shall adopt his own a '*Permit-to-Dig*' system for every exploratory hole to be signed off by the Site Agent (Schedule S1.8.2) prior to breaking ground. The Contractor shall also comply with any such system which the Principal Contractor may operate. Inspection pits shall be excavated by hand to a minimum depth of 1.2m below ground level at the locations of all exploratory holes formed by boring, drilling, probing, and penetration methods. There shall be no reduction in the required depth of excavation without agreement of the Investigation Supervisor. If required, observation pits shall be excavated by hand to an appropriate depth for testing.
S1.11.2	**Restrictions on plant or pitting / trenching methods (Clause 6.2 and 6.3)**	The plant, method of advancement, and the size of the exploratory hole shall be such that the excavation can be completed (without undue ground disturbance or ground loss) and logged to the scheduled depth, samples of the specified size and quality class (BS EN 1997-2 and BS EN ISO 22475-1) can be obtained, in situ testing carried out, and instrumentation installed as described in the Schedule S2 and other Clauses of these Schedules (as applicable).
S1.11.3	**Entry of personnel (Clause 6.5)**	No personnel shall enter any excavation during the duration of the works.
S1.11.4	**Alternative pit and trench dimensions (Clause 6.7)**	Trial pits shall have a minimum base area of $0.25m^2$.
S1.11.5	**Abstracted groundwater from land affected by contamination (Clause 6.9.2)**	*As specified. See also 3.15.2A.*
S1.11.6	**Backfilling (Clause 6.10)**	All pits to be backfilled on the day of excavation.

S1.11.7	**Photographic requirements (Clause 6.12)**	In addition to the requirements of Clause 6.12, the requirements of Schedule S1.8.19 shall apply.
S1.11.8	**Artificial Lighting (Clause 6.12.2)**	The Contractor shall supply any artificial lighting required dependent on the ambient light conditions at the time of the works.
S1.11.9	**Provision of pitting equipment and crew for investigation supervisors use (Clause 6.13)**	*Not required.*
SAMPLING AND MONITORING DURING INTRUSIVE INVESTIGATION		
S1.12	**Sampling and monitoring during intrusive investigation (Specification Section 7) Particular requirements / relaxations**	*See Schedules S1.12.1 to S1.12.15.*
S1.12.1	**Address for delivery of selected geotechnical samples (Clause 7.6.1)**	*As specified.*
S1.12.2	**Retention and disposal of geotechnical samples (Clause 7.6.2)**	*As specified.*
S1.12.3	**Frequency of sampling for geotechnical purposes (Clauses 7.6.3-7.6.11)**	The requirements of Clauses 7.6.4 to 7.6.11 shall apply. In Cable Percussion Boreholes, open-tube samples and SPTs shall be undertaken alternately at 1.0m intervals in cohesive soils. No open-tube samples shall be required in granular soils (SPT only, at 1.0m intervals). In Cable Percussion boreholes, disturbed samples and bulk disturbed samples shall be taken at 1.0m intervals. In Trial Pits, disturbed samples and bulk disturbed samples shall be taken at 1.0m intervals. The sampling regime may be altered during site operations, at the instruction of the Investigation Supervisor to suit the ground conditions. All geotechnical samples taken from exploratory holes shall, at the end of each day's shift, be stored in a suitable environment to preserve the original moisture and physical conditions as in-situ, and protected from excessive heat or freezing conditions.
S1.12.4	**Open-tube and piston sample diameter (Clause 7.6.5)**	*As specified.*
S1.12.5	**Retention of cutting shoe samples (Clause 7.6.5)**	*As specified.*

S1.12.6	**Delft and Mostap sampling (Clause 7.6.12)**	*Not required.*
S1.12.7	**Groundwater level measurement during exploratory hole construction (Clause 7.7)**	*As specified.*
S1.12.8	**Special geotechnical sampling (Clause 7.8)**	Thin walled samplers shall be used for obtaining open-tube samples unless prevailing ground conditions result in unacceptable damage to the sampling equipment (to be agreed with the Investigation Supervisor).
S1.12.9	**Address for delivery of selected samples (Clause 7.9.2)**	*As specified.*
S1.12.10	**Retention and disposal of contamination / WAC samples (Clause 7.9.3)**	*As specified.*
S1.12.11	**Frequency of sampling (Clause 7.9.4)**	In all exploratory holes, one environmental soil sample (i.e. for assessment of contamination) shall be taken every one metre through Made Ground, or at every change in Made Ground type, whichever is more frequent. Further to this, in Made Ground of consistent type, two environmental soil samples shall be collected in the top metre from the inspection pit, at varying depths (for example at 0.3 and 0.7m). A minimum of one environmental soil sample shall also be obtained from the top metre of encountered natural strata below the Made Ground and, if natural strata are considered to be potentially contaminated, as advised by the Investigation Supervisor. A single environmental soil sample shall consist of 1 x 1kg plastic tub, 1 x 250ml amber glass jar, and 4 x 125ml amber glass jars.
S1.12.12	**Sampling method (Clause 7.9.5)**	*Not required.*
S1.12.13	**Headspace testing (Clause 7.9.8)**	Headspace testing shall be undertaken on all environmental soil samples using a Photo Ionisation Detector (PID).
S1.12.14	**Coring Survey (general)**	*Not required.*
S1.12.15	**Core survey (logging)**	*Not required.*
GEOPHYSICAL TESTING		
S1.14	**Geophysical testing (Specification Section 9)**	*See Schedules S1.14.1 to S1.14.8.*

	Particular restrictions/relaxations	
S1.14.1	**Geophysical survey objectives (Clause 9.1.1)**	Downhole seismic survey is required at two locations on site (CPR07 and CPR10) to provide information for design of the Power Plant. P and S wave velocities and relevant dynamic moduli shall be derived at 1.0m interval to a minimum depth of 20.0m bgl in each of these boreholes. Derived values of shear modulus, derived values of constrained modulus, inferred values of Poisson's ratio, density and derived values of Young's modulus shall be reported down the hole. Downhole seismic survey to be carried out in accordance with ASTM D7400-08 '*Standard Test Methods for Down-hole Seismic Testing'*.
S1.14.2	**Requirement for Ground Specialist geophysicist (Clause 9.1.1)**	As specified.
S1.14.3	**Trials of geophysical methods (Clause 9.1.1)**	Not required.
S1.14.4	**Types of geophysics required (Clause 9.1.1)**	Downhole seismic tests are required in two boreholes at the proposed locations of the CO2 turbine and generator, as detailed in S1.14.1.
S1.14.5	**Information provided (Clause 9.2)**	The following existing ground investigation information will be provided: ▪ WSP, Allam Cycle UK Pre-FEED Geotechnical Desk Study 70053760-WSP-00-XX-RP-GE-0001-S4_P03, dated December 2020 ▪ Teeside Power Plant Project, Geotechnical Report, STATS Geotechnical, 1990 ▪ Teesside Power Station Phase 2 ground Investigation Report, Entec UK ltd, 2011 ▪ Tees CCPP, Wilton Phase 2 Site Investigation Report, Solmek Ltd, 2018
S1.14.6	**Horizontal data density (Clause 9.3)**	The data density requirements are detailed in S1.14.1.
S1.14.7	**Level datum (Clause 9.4)**	The ground level at each exploratory hole is to be determined by the Contractor in accordance with S1.8.18.
S1.14.8	**Geophysical survey report (Clause 9.7)**	As specified.

IN SITU TESTING		
S1.15	**In-situ testing (Specification Section 10) Particular restrictions / relaxations**	*See Schedules S1.15.1 to S1.15.10.*
S1.15.1	**Tests in accordance with British Standard (Clause 10.3)**	The following in situ tests shall be carried out and reported in accordance with the appropriate standards: 1. Standard Penetration Test (SPT); undertaken to BS EN ISO 22476-3 (Clause 10.11Ad and Schedule S1.15.11).
S1.15.2	**Hand penetrometer and hand vane for shear strength (Clause 10.4.1)**	Hand vane tests or Hand Penetrometer tests (set of three readings) shall be carried out on suitable recovered samples from the trial pits as instructed by the Investigation Supervisor.
S1.15.3	**Self-boring pressuremeter and high-pressure dilatometer testing and reporting (Clause 10.5.1)**	*Not required.*
S1.15.4	**Driven or push-in pressuremeter testing and reporting requirements (Clause 10.5.2)**	*Not required.*
S1.15.5	**Menard Pressuremeter tests (Clause 10.5.3)**	*Not required.*
S1.15.6	**Soil infiltration test (Clause 10.6)**	*Not required.*
S1.15.7	**Special in situ testing and reporting requirements (Clause 10.7)**	*Not required.*
S1.15.8	**Interface probes (Clause 10.8)**	*As specified S 17.1.*
S1.15.9	**Contamination screening tests (Clause 10.9)**	*Not required.*
S1.15.10	**Metal detection (Clause 10.10)**	*Not required.*
INSTRUMENTATION		
S1.16	**Instrumentation (Specification Section 11) Particular restrictions / relaxations**	*See Schedules S1.16.1 to S1.16.12.*
S1.16.1	**Protective covers for installations (Clause 11.2)**	Protective covers shall be lockable flush steel covers set in good quality concrete surround flush to ground level. A set of

		keys shall be provided to the Investigation Supervisor. All covers shall be of the same type and locking mechanism.
S1.16.2	**Protective fencing (Clause 11.3)**	*Not required.*
S1.16.3	**Standpipe and standpipe piezometer installations (Clauses11.4.1 and 11.4.2)**	Standpipe piezometers shall also act as ground gas monitoring installations and shall be installed in line with Schedule S1.16.6.
S1.16.4	**Other piezometer installations (Clause 11.4.3)**	*Not required.*
S1.16.5	**Development of standpipes and standpipe piezometers (Clause 11.4.5)**	All installed borehole wells shall be developed by purging in line with Clause 12.3.2 (three installation groundwater volumes) by the Contractor. Existing boreholes at the site from previous ground investigations, where accessible and serviceable, shall be purged in line with Clause 12.3.2 (three installation groundwater volumes) by the Contractor.
S1.16.6	**Ground gas standpipes (Clause 11.5)**	Gas monitoring installations shall be installed at locations and depths as advised by the Investigation Supervisor with the following additional requirement: ▪ Ground gas standpipe tubing shall be installed within a 'geosock' unless hydrocarbon product is / is suspected to be present in groundwater. The exact depths are dependent upon the strata encountered within each borehole and shall be confirmed by the Investigation Supervisor. Installation response zones shall be targeted to specific strata.
S1.16.7	**Inclinometer installations (Clause 11.6)**	*Not required.*
S1.16.8	**Slip indicators (Clause 11.7)**	*Not required.*
S1.16.9	**Extensometer and settlement gauges (Clause 11.8)**	*Not required.*
S1.16.10	**Settlement monuments (Clause 11.9)**	*Not required.*
S1.16.11	**Removal of installations (Clause 11.10)**	*Not required.*
S1.16.12	**Other instrumentation (Clause 11.11)**	*Not required.*
INSTALLATION MONITORING AND SAMPLING		
S1.17	**Installation monitoring and sampling (Specification**	*See Schedules S1.17.1 to S1.17.7.*

	Section 12) Particular restrictions / relaxations	
S1.17.1	**Groundwater level readings in installations (Clause 12.2)**	The Contractor shall record the groundwater level in each completed installation on a daily basis during the investigation. The Contractor shall undertake return visits to the site and undertake groundwater level monitoring on not less than six occasions (fortnightly for three months) following completion of each installation. This may be undertaken on the same visit as the ground gas monitoring specified in Schedule S1.17.4. The groundwater readings shall also include measurement of any free product using an interface probe on each occasion, to be used prior to any sampling.
S1.17.2	**Groundwater sampling from installations (Clause 12.3.1)**	The requirements for groundwater sampling shall be instructed by the Investigation Supervisor. At least one round of sampling is required, potentially up to 3 total visits.
S1.17.3	**Purging / micro-purging (Clause 12.3.2)**	Apart from during development of the installation (Schedule S1.16.5), the requirements for purging / micro-purging, including water quality parameter recording, shall be instructed by the Investigation Supervisor.
S1.17.4	**Ground gas monitoring (Clause 12.4)**	The Contractor shall undertake return visits to the site and undertake ground gas monitoring on not less than six occasions (at a frequency to be agreed) following completion of each installation. This may be undertaken on the same visit as the groundwater level monitoring specified in Schedule S1.17.1. Ground gas monitoring shall be undertaken to the recommendations of CIRIA C665 and shall aim to be undertaken in all pressure conditions (high/low and rising/falling)
S1.17.5	**Sampling from ground gas installations (Clause 12.5)**	The requirements for ground gas sampling shall be instructed by the Investigation Supervisor.
S1.17.6	**Other monitoring (Clause 12.8)**	*Not required.*
S1.17.7	**Sampling and testing of surface water bodies (Clause 12.9)**	*As specified.*
DAILY RECORDS		
S1.18	**Daily records (Specification Section 13) Particular restrictions / relaxations**	*See Schedules S1.18.1 to S1.18.2.*
S1.18.1	**Information for daily records (Clause 13.1)**	*As specified.*

S1.18.2	**Special in situ tests and instrumentation records (Clause 13.4)**	*Not required.*
GEOTECHNICAL LABORATORY TESTING		
S1.19	**Geotechnical laboratory testing (Specification Section 14) Particular restrictions / relaxations**	*See Schedules S1.19.1 to S1.19.8.*
S1.19.1	**Investigation supervisor or Contractor to schedule testing (Clause 14.1.1)**	All laboratory testing shall be scheduled by the Investigation Supervisor. The Contractor shall submit a blank laboratory testing schedule in editable electronic format (such as Microsoft Excel) to the Investigation Supervisor, listing all samples available for testing and their quality class (BS EN 1997-2 and BS EN ISO 22475-1) within 2 working days of the exploratory hole being completed.
S1.19.2	**Tests required (Clause 14.1.2)**	Geotechnical testing is likely to include the following non-specialist testing. Additional testing may be specified following the intrusive works / once the preliminary logs have been reviewed (i.e. at the time of scheduling). Classification ▪ Moisture content; ▪ Liquid limit, plastic limit, and plasticity index; ▪ Particle size distribution by wet / dry sieving; ▪ Sedimentation by pipette; ▪ Bulk density and dry density. Compressibility, permeability, and durability ▪ One-dimensional consolidation properties; Shear strength (total stress) ▪ Undrained shear strength of a set of three 38mm diameter specimens in triaxial compression without the measurement of pore pressure; ▪ Undrained strength of a single 100mm diameter specimen in triaxial compression without the measurement of pore pressure. Compaction related ▪ Dry density/moisture content relationship using 2.5kg hammer ▪ Dry density/moisture content relationship using 4.5kg hammer
S1.19.3	**Specification for tests not covered by BS 1377 and**	All testing shall be undertaken in line with relevant British Standards or as agreed with the Investigation Supervisor.

	options under BS 1377 (Clauses 14.2.1 and 14.4)	
S1.19.4	**UKAS accreditation to be adopted (Clause 14.3)**	The testing laboratory shall hold UKAS accreditation for all testing scheduled where such accreditation is available. Should the Contractor's favoured laboratory not hold suitable accreditation instruction shall be sought from the Investigation Supervisor. Alternative testing facilities may be required to be used.
S1.19.5	**Rock testing requirements (Clause 14.5)**	Rock testing is likely to include the following non-specialist testing. Additional testing may be specified following the intrusive works / once the preliminary logs have been reviewed (i.e. at the time of scheduling). ▪ Moisture content tests; ▪ Point load tests; ▪ Uniaxial compressive strength tests.
S1.19.6	**Chemical testing for aggressive ground / groundwater for concrete (Clause 14.6)**	Chemical testing for aggressive ground / groundwater for concrete is likely to be to test Suite D (BRE Special Digest 1). The Contractor is to confirm their preferred test methods for agreement by the Investigation Supervisor prior to testing being specified. Alternative test methods may be required to be used. Additional / alternative testing may be specified once the preliminary logs have been reviewed (i.e. at the time of scheduling).
S1.19.7	**Laboratory testing on site (Clause 14.7)**	*Not required.*
S1.19.8	**Special laboratory testing (Clause 14.8)**	*None anticipated.* Special laboratory testing may be specified once the preliminary logs have been reviewed (i.e. at the time of scheduling).
GEOENVIRONMENTAL LABORATORY TESTING		
S1.20	**Geoenvironmental laboratory testing (Specification Section 15) Particular restrictions / relaxations**	*See Schedules S1.20.1 to S1.20.7.*
S1.20.1	**Investigation supervisor or Contractor to schedule testing (Clause 15.1)**	All laboratory testing shall be scheduled by the Investigation Supervisor. The Contractor shall submit a blank laboratory testing schedule in editable electronic format (such as Microsoft Excel) to the Investigation Supervisor, within 24 hours of the sample being taken.
S1.20.2	**Accreditation required (Clause 15.2)**	The testing laboratory shall hold UKAS accreditation for all testing scheduled where such accreditation is available. All

		laboratory testing shall conform to the MCERTs standard. Should the Contractor's favoured laboratory not hold suitable accreditation or be able to conform to the MCERTs standard, instruction shall be sought from the Investigation Supervisor. Alternative testing facilities may be required to be used.
S1.20.3	**Chemical testing for contamination (Clause 15.3)**	All soils samples sent for analysis are to be screened in the field with a PID (headspace test) to assess volatile hydrocarbon content. Chemical testing for contamination is likely to be to the amended test suites ('*E(a), E(b), F(a) and F(b)*) presented at the rear of Schedule 4. Additional testing may be specified following the intrusive works / once the preliminary logs have been reviewed (i.e. at the time of scheduling). Testing shall be undertaken on the laboratories standard turnaround or no more than 10 working days, whichever is the shorter.
S1.20.4	**Waste characterisation (Clause 15.4)**	The Contractor shall assess and classify all waste from the works prior to removal or disposal from site. All wastewater and waste soils resulting from the site investigation are to be removed from site and disposed of or recycled appropriately.
S1.20.5	**Waste Acceptance Criteria testing (Clause 15.5)**	*As specified.*
S1.20.6	**Laboratory testing on site (Clause 15.6)**	*Not required.*
S1.20.7	**Special laboratory testing (Clause 15.7)**	*Not required.*
REPORTING		
S1.21	**Reporting (Specification Section 16) Particular restrictions / relaxations**	*See Schedules S1.21.1 to S1.21.12.*
S1.21.1	**Form of exploratory hole logs (Clauses 16.1 and 16.2.1)**	*As specified.*
S1.21.2	**Information on exploratory hole logs (Clause 16.2.2)**	*As specified.*
S1.21.3	**Variations to final digital data supply requirements (Clause 16.5.1)**	The Contractor shall provide fieldwork, monitoring, and laboratory data in digital form in a single file in accordance with the Association of Geotechnical and Geo-environmental Specialists (AGS) format version 4.1. The digital data shall be from the same source as that used to produce the exploratory hole logs.

S1.21.4	**Preliminary digital data (Clause 16.5.3)**	Preliminary digital data shall be in the same format as the final digital data and be supplied within three working days following completion of the intrusive stage of the investigation. The digital data shall be from the same source as that used to produce the preliminary logs.
S1.21.5	**Type(s) of report required (Clause 16.6)**	The Contractor shall provide a '*Factual Report*', being a presentation of the factual information described in Clause 16.8.1 and Schedule S1.21.8. The term '*Factual Report*' shall be used on all Contractor documentation and reporting and shall not be shortened, abbreviated, or amended in any way unless as instructed by the Investigation Supervisor. A draft Factual Report shall be issued on completion of laboratory testing. The site works are anticipated to be completed within two weeks of commencement. Laboratory tests shall take place concurrently with the site works and be completed within three weeks of site works completion. A final Factual Report shall be issued maximum two weeks following receipt of comments on the draft Factual Report by the Investigation Supervisor.
S1.21.6	**Electronic report requirements (Clause 16.6.3)**	Drawings shall be provided in .dwg format compatible with Autodesk® AutoCAD® 2015.
S1.21.7	**Format and contents of Desk Study Report (Clause 16.7)**	*Not required.*
S1.21.8	**Contents of Ground Investigation Report (Clause 16.8)**	The factual report (Schedule S1.21.5) shall be suitable to be included within the project Ground Investigation Report as the 'factual information' (Clause 16.8.1). In addition to the requirements of Clause 16.8.1 and Schedule S1.21.5, the factual report shall meet the requirements of the following sections of Table 43 of BS 5930:2015: ▪ Field reports including investigation holes, sampling and groundwater measurements (including as specified in BS EN ISO 22475-1:2006); ▪ Field test report; ▪ Laboratory test reports; ▪ Other reports (groundwater and gas monitoring reports); and, ▪ Factual report. The factual report shall summarise the Contractual arrangements during the works, stating the Employer, and any sub-contractors.

		The factual report shall summarise the duty holder arrangements to satisfy the Construction (Design and Management) Regulations during the works, stating the Client, Principal Designer, Principal Contractor, Designer, and Contractors. Exploratory hole logs presented in the factual report shall, in line with BS 5930, be based on the visual examination and description of the exposures / samples, the laboratory test results, the daily reports, and what is known of the geology of the site. The exploratory hole logs presented in the final version of the factual report shall incorporate any interpretative comments / notes as required by the Investigation Supervisor. All laboratory test reports shall be in the form recommended by the relevant testing standard or similar as agreed by the Investigation Supervisor. Individual test plots shall be provided where appropriate (in line with the relevant testing standard). The groundwater and gas monitoring reports should be presented up to the point at which the Factual Report is required to be issued (in line with S1.21.5). Subsequent monitoring undertaken shall be presented in an addendum to the Factual Report, if required.
S1.21.9	**Contents of Geotechnical Design Report (Clause 16.9)**	*Not required.*
S1.21.10	**Times for supply of electronic information (Clause 16.10.1)**	A complete set of digital data (Clause 16.5) shall be supplied with every transmission of preliminary data and with the draft and final Factual Report.
S1.21.11	**Electronic information transmission media (Clause 16.10.2)**	Transmission of the digital data shall be via WSP large file transfer server, or other media as agreed with the Investigation Supervisor.
S1.21.12	**Report approval (Clause 16.11)**	Draft and final reporting, and approval from the Investigation Supervisor, shall be in line with the timescales presented in S1.21.5. Draft reporting is required in electronic copy only, submitted to the Investigation Supervisor. The final Factual Report (and any required Addendums) shall be issued in electronic format only, submitted to the Investigation Supervisor.

SCHEDULE 2: EXPLORATORY HOLES

The proposed exploration holes are summarised in Table 3. The table is to be read in conjunction with the exploration hole location plans in Appendix A.

Table 3 - Schedule of Ground Investigation

Borehole	Type	Anticipated depth (m bgl)	Eastings	Northings	Installation
CP01	Cable Percussion	10 (target rockhead)	456312	520192	Groundwater and ground gas installations in all boreholes. Depths of response zones to be confirmed by the Investigation Supervisor during the site works.
CP02	Cable Percussion	10 (target rockhead)	456340	520292	
CP03	Cable Percussion	10 (target rockhead)	456425	520301	
CP04	Cable Percussion	10 (target rockhead)	456494	520336	
CP05	Cable Percussion	10 (target rockhead)	456471	520426	
CPR06	Cable Percussion with Rotary Coring Follow On	20 (target 10m below rockhead)	456444	520261	
CPR07	Cable Percussion with Rotary Coring Follow On (with downhole seismic)	21 (target 11m below rockhead)	456438	520324	
CPR08	Cable Percussion with Rotary Coring Follow On	20 (target 10m below rockhead)	456383	520392	
CPR09	Cable Percussion with Rotary Coring Follow On	20 (target 10m below rockhead)	456535	520302	
CPR10	Cable Percussion with Rotary Coring Follow On (with downhole seismic)	21 (target 11m below rockhead)	456513	520358	
CPR11	Cable Percussion with Rotary Coring Follow On	20 (target 10m below rockhead)	456451	520471	
CPR12	Cable Percussion with Rotary Coring Follow On	20 (target 10m below rockhead)	456629	520509	
TP01	Trial Pit	4.0	456312	520217	N/A
TP02	Trial Pit	4.0	456360	520304	N/A

Borehole	Type	Anticipated depth (m bgl)	Eastings	Northings	Installation
TP03	Trial Pit	4.0	456466	520262	N/A
TP04	Trial Pit	4.0	456465	520298	N/A
TP05	Trial Pit	4.0	456442	520357	N/A
TP06	Trial Pit	4.0	456396	520355	N/A
TP07	Trial Pit	4.0	456512	520321	N/A
TP08	Trial Pit	4.0	456535	520339	N/A
TP09	Trial Pit	4.0	456502	520387	N/A
TP10	Trial Pit	4.0	456486	520404	N/A

SCHEDULE 3: INVESTIGATION SUPERVISOR'S FACILITIES

S3.1	**Accommodation**	The Investigation Supervisor shall have access to the whole of the Contractor's facilities for the duration of the works. This includes site welfare and toilet facilities, Contractor's store, and skip (or suitable alternative). The Contractor shall provide suitable provisions for the Contractor's staff plus an additional 2 (two) persons (Clause 3.8.4A and Schedule S1.8.16). Seating must be provided within the Welfare facilities for all persons simultaneously. The location of this accommodation shall be agreed with the Client, the Investigation Supervisor and site management. The Contractor shall make suitable provision for both male and female staff. Additional facility requirements for Covid-19 compliance are to be discussed and agreed by the Contractor with the Client and Investigation Supervisor.
S3.2	**Furnishings**	See Schedules S3.1 and S3.3.
S3.3	**Services**	The Contractor shall include suitable reliable electrical supply to allow the Investigation Supervisor to use and charge portable electronic equipment such cameras, laptop computers, and mobile phones.
S3.4	**Equipment**	*Not required*.
S3.5	**Transport**	*Not required*.
S3.6	**Personal Protective Equipment for Investigation Supervisor**	*Not required*.

SCHEDULE 4: SPECIFICATION AMENDMENTS

The following clauses are amended

Section number	Clause number	Delete the following	Substitute the following
3	**3.2**	The work shall be carried out in accordance with the relevant British Standards or equivalent European Standards, in particular BS EN 1997-2, BS EN ISO 22475-1, BS EN ISO 22475-2, BS EN ISO 22475-3, BS 1377, BS 5930, and BS 10175, or other recognised standards or Codes of Practice, current on the date of invitation to tender.	The work shall be carried out in accordance with the relevant British Standards or equivalent European Standards, in particular BS EN 1997-1, BS EN 1997-2, BS EN ISO 22475-1, BS EN ISO 22475-2, BS EN ISO 22475-3, BS 1377, BS 5930, and BS 10175, or other recognised standards or Codes of Practice applicable to the works, current on the date of invitation to tender or as agreed with the Investigation Supervisor.
3	**3.3**	Whole Clause	**Contractor Accreditation and Membership** The Contractor shall hold current and valid membership of the following bodies: ▪ Corporate Member, British Drilling Association (BDA); and, ▪ Member Firm, Association of Geotechnical & Geo-environmental Specialists (AGS). The Contractor shall also hold current and valid membership / accreditation to the organisations / standards specified in Schedule S1.8.21. Records to demonstrate compliance shall be made available to the Investigation Supervisor on request.
3	**3.8.1**	*Addition to end of Clause*	The works shall be undertaken to the Construction (Design and Management) Regulations 2015. The identified duty holders are defined in Schedule S1.8.20. The Contractor shall comply with all requests for information from the Principal Contractor (CDM) or other duty holder as appropriate. Any additional works requested by the Principal Contractor (CDM) shall be agreed with the Investigation Supervisor.

			In the event of any ambiguity in the Specification regards the referencing and requirements of the Construction (Design and Management) Regulation 2015, the Contractor shall refer the issue to the Investigation Supervisor for confirmation of requirements.
3	**3.8.2**	*Addition to end of Clause*	The Contractor's method statements shall describe, as a minimum, the following tasks and activities: ▪ Main works as described by the Schedule S1.5. ▪ Procedures to be put in place by the Contractor to control of pollution and waste management at least in accordance with the Environment Agency Pollution Prevention Guidelines (PPG) (now withdrawn) in particular, but not necessarily limited to PPG5 'Works and maintenance in or near water' and PPG6 'Working at construction and demolition sites'.
3	**3.8.4**	*Addition to end of Clause*	Welfare facilities for use by the Contractor and the Investigation Supervisor (Schedule 3) shall be supplied by the Contractor for the full duration of the site works for the Contractor's staff plus 2 (two) additional persons. Sufficient seats must be available within the Welfare facilities for all site personnel to use at the same time. Additional facility requirements for Covid-19 compliance are to be discussed and agreed by the Contractor with the Client and Investigation Supervisor.
3	**3.9**	Whole Clause	The Principal Designer shall be responsible for arranging access / providing notice of entry on to the site with the owner and / or occupier. The Contractor shall give at least five working days' notice to the Investigation Supervisor of the intended time of entry on to the site.
3	**3.15.2**	*Addition to end of Clause*	On land identified as potentially contaminated (Schedule S1.8.4), or on

			the instruction of the Investigation Supervisor, any groundwater pumped from an exploratory hole shall be regarded as potentially contaminated.
3	**3.16.1**	Unless otherwise specified in Schedule S1.8.15, on completion of each exploratory hole all equipment, surplus material, and rubbish of every kind shall be cleared away. Surplus material and rubbish shall be removed from the site to a disposal point licensed to accept the waste concerned.	Unless otherwise specified in Schedule S1.8.15, on completion of each exploratory hole all equipment, surplus material (including surplus spoil / arisings not sampled or returned to the exploratory hole during backfilling), and rubbish of every kind shall be cleared away. Surplus material and rubbish shall be removed from the site to a disposal point licensed to accept the waste concerned.
3	**3.16.1**	On land affected by contamination, arisings from exploratory holes shall be placed on heavy-gauge polythene sheeting and covered in wet or windy weather in order to prevent the spread of contamination (or alternatively placed in covered skips).	On land containing Made Ground or affected by contamination, arisings from exploratory holes shall be placed on heavy-gauge polythene sheeting, or good quality solid plastic, metal, or wood boarding and covered in wet or windy weather in order to prevent the spread of contamination (or alternatively placed in covered skips).
3	**3.16.1**	*Addition to end of Clause*	The Contractor's site compound shall include all necessary facilities for sample logging and re-sealing (if necessary) to be carried out on site.
3	**3.21**	*Addition to end of Clause*	The hole number shall be referenced exactly as per Schedule 2 on all Contractor documentation and shall not be shortened, abbreviated, or amended in any way unless as instructed by the Investigation Supervisor. Where additional holes have been added to the scope by the Investigation Supervisor they shall be referenced (hole number) as advised by the Investigation Supervisor. Where additional holes have been instructed by the Investigation Supervisor due to encountering hard stratum or an obstruction, they shall be referenced with the original hole number and an additional alphabetical suffix (increasing sequentially if multiple

			additional holes are required) (e.g. CP001, CP001A, CP001B etc.).
3	**3.25.3**	*Addition to end of Clause*	Photographs shall be submitted to the Investigation Supervisor via one of the methods described in Schedule S1.21.11.
3	**3.25.4**	On acceptance of the quality of the photographs, a complete set of prints (minimum size 150 x 100mm) of all the photographs shall be presented with the Ground Investigation Report (as applicable). Unless otherwise specified in Schedule S1.8.19, only a single copy of each photograph will be required.	On acceptance of the quality of the photographs, all accepted photographs shall be reproduced to an appropriate quality (minimum 300ppi) and size (minimum 150 x 100mm) within the factual report. In addition a JPG format copy of all accepted photographs shall be provided with the factual report. Unless otherwise specified in Schedule S1.8.19, only a single copy of each photograph will be required.
3	**3.26**	Whole Clause	The Contractor shall be responsible for the appropriate disposal of all types of arisings. The off-site disposal of all types of arisings shall be subject to the relevant waste transport and disposal regulations.
4	**4.1**	**Method and diameter** The method of advancement and the diameter of a borehole shall be such that the boring can be completed (without undue ground disturbance or ground loss) and logged to the scheduled depth, samples of the specified diameter can be obtained, in situ testing carried out, and instrumentation installed as described in the Schedule S2.	**Method, diameter, and scheduled depth** The plant, method of advancement, and the diameter of a borehole shall be such that the boring can be completed (without undue ground disturbance or ground loss) and logged to the scheduled depth, samples of the specified diameter and quality class (BS EN 1997-2 and BS EN ISO 22475-1) can be obtained, in situ testing carried out, and instrumentation installed as described in the Schedule S2 and other Clauses of these Schedules (as applicable). Percussion boreholes (not being Dynamic Samples) shall be advanced to the depth described in Schedule 2, or such that a minimum of 5m of natural material may be logged, whichever is the deeper, or until refusal, or as instructed by the Investigation Supervisor.
4	**4.6.6**	Whole Clause	Where windowless samples have been taken to obtain environmental samples

			(Clause 7.9), the liner tubes shall immediately be split on extraction, logged, and sub-sampled for chemical testing. The remainder of the opened sample shall then be sub-sampled as geotechnical sample (Clause 7.6) with sample type (small, bulk, or large bulk disturbed) based on the encountered ground conditions (i.e. sample type based on available quantity of an individual stratum). Where windowless samples have not been split for the purpose of collecting environmental samples, the sample shall be treated in one of the following ways: 1. Windowless samples shall immediately have the top and bottom of the liner tube marked in indelible ink and the ends of liners shall be capped and sealed using adhesive tape. Liners shall be cut to the length of the enclosed sample; or, 2. The liner tubes shall immediately on extraction be split and logged. The opened sample shall then be sub-sampled as geotechnical sample (Clause 7.6) with sample type (small, bulk, or large bulk disturbed) based on the encountered ground conditions (i.e. sample type based on available quantity of an individual stratum).
6	**6.6**	Whole Clause	Arisings from distinctly different soil layers shall be stockpiled separately. On land containing Made Ground or affected by contamination, the excavation shall proceed in a series of shallow 'cuts' between 0.2 and 0.3 m thick. Over and above the requirements of Clause 3.16.1A, the arisings from distinctly different soil layers shall be stockpiled on separate polythene sheets, or good quality solid plastic, metal, or wood boarding.
7	**7.1**	*Addition to end of Clause*	The lowest sample quality class, as described by BS EN 1997-2 and BS EN ISO 22475-1, shall, as far as is reasonably practicable, be achieved for

			the respective sample type as described in Clauses 7.6.5A to 7.6.9, 7.6.12, and 7.8.
7	**7.4**	Whole Clause	Samples shall be described in accordance with BS EN ISO 14688-1, BS EN ISO 14688-2, BS EN ISO 14689-1, and BS 5930 by an Experienced Ground Engineer (Clause 2.3), defined as having at least 3 years of relevant experience since graduation with an appropriate degree, or alternatively with at least 5 years of experience if not a graduate.
7	**7.6.5**	*Addition to end of Clause*	Blow counts shall be recorded for each open-tube sample taken.
13	**13.1**	The Contractor shall prepare for each exploratory hole a daily record which shall be submitted to the Investigation Supervisor at the beginning of the next working day. Information shall be recorded as work proceeds and, except as specified in Schedule S1.18.1, shall include the following where relevant.	The Contractor shall prepare for each exploratory hole a daily record which shall be submitted to the Investigation Supervisor in electronic format by the end of the next working day. Information shall be recorded as work proceeds and, except as specified in Schedule S1.18.1, shall include the following where relevant.
16	**16.1**	*Addition to end of Clause*	Preliminary logs shall be checked for quality (spelling and grammar) and technical content by the Contractor prior to issue.
16	**16.2.1**	The logs shall be presented to a single, consistent vertical scale.	The logs shall be presented to a single, consistent vertical scale as recommended by BS EN ISO 5455.
16	**16.6.3**	The electronic report shall be submitted in PDF format and include all sections of the report.	The electronic report shall be submitted in a single PDF format file, including all sections of the report regardless of the total file size.
16	**16.6.3**	*Addition to end of Clause*	The electronic report shall be submitted to the Investigation Supervisor via one of the methods described in Schedule S1.21.11.
16	**16.8.2**	The plans shall be to a stated scale and shall include a scale bar and direction of north.	The plans shall be to a stated scale and shall include a scale bar and direction of north. The scale of plans shall be as recommended by BS EN ISO 5455.
16	**16.11**	*Addition to end of Clause*	The final factual report shall include agreed resolution of all comments made

			on the draft report by the Investigation Supervisor.

SCHEDULE 1.20.3 CHEMICAL LABORATORY TESTING FOR CONTAMINATION

Table 4 - SUITE E(a) – Soil Samples

SUITE E(a) – Soil Samples		
Determinand	**Limit of detection required / units**	**Test method required**
Asbestos		
Asbestos screen and quantification	<0.001	HSG 248, Asbestos: The analysts' guide for sampling, analysis and clearance procedures '*Identification of Asbestos in Bulk Material*'
Routine metals		
Arsenic	<0.6 mg/kg	US EPA Method 6010B '*Determination of Routine Metals in Soil by iCap 6500 Duo ICP-OES*' By a MCERTs and UKAS accredited laboratory
Cadmium	<0.02 mg/kg	
Chromium	<0.9 mg/kg	
Chromium (Hexavalent)	<0.6 mg/kg	
Copper	<1.4 mg/kg	
Lead	<0.7 mg/kg	
Mercury	<0.14 mg/kg	
Nickel	<0.2 mg/kg	
Selenium	<1 mg/kg	
Zinc	<1.9 mg/kg	
Cyanide	<1 mg/kg	Method 4500A,B,C, I, M AWWA/APHA, 20th Ed., 1999 '*Determination of Total Cyanide, Free (Easily Liberatable) Cyanide and Thiocyanate using the Skalar SANS+ System Segmented Flow Analyser*'
Speciated polycyclic aromatic hydrocarbons (PAHs)		
Naphthalene	<0.009 mg/kg	Gas chromatography–mass spectrometry.
Acenaphthylene	<0.012 mg/kg	
Acenaphthene	<0.008 mg/kg	

SUITE E(a) – Soil Samples		
Determinand	**Limit of detection required / units**	**Test method required**
Fluorene	<0.01 mg/kg	
Phenanthrene	<0.015 mg/kg	
Anthracene	<0.016 mg/kg	
Fluoranthene	<0.017 mg/kg	
Pyrene	<0.015 mg/kg	
Benz(a)anthracene	<0.014 mg/kg	
Chrysene	<0.01 mg/kg	
Benzo(b)fluoranthene	<0.015 mg/kg	
Benzo(k)fluoranthene	<0.014 mg/kg	
Benzo(a)pyrene	<0.015 mg/kg	
Indeno(1,2,3-cd)pyrene	<0.018 mg/kg	
Dibenzo(a,h)anthracene	<0.023 mg/kg	
Benzo(g,h,i)perylene	<0.024 mg/kg	
PAH, Total Detected USEPA 16	<0.118 mg/kg	

SUITE E(b) – Soil Samples		
Determinand	**Limit of detection required / units**	**Test method required**
As Suite E(a) with additional as below		
pH	1 pH Units	BS 1377: Part 3 1990;BS 6068-2.5 '*Determination of pH in Soil and Water using the GLpH pH Meter*'
Water Soluble Sulphate as SO4 2:1 Extract	<0.004 g/l	Mixed Anions In Soils By Kone
Soil Organic Matter Content (SOM)	<0.35 %	Infra-Red analysis

SUITE E(b) – Soil Samples		
Determinand	**Limit of detection required / units**	**Test method required**
Semi Volatile Organic Compounds (SVOCs) excluding PAHs	<0.1 mg/kg	Gas chromatography–mass spectrometry.
Volatile Organic Compounds (SVOCs) excluding PAHs	<0.02mg/kg	Gas chromatography–mass spectrometry.
BTEX	<0.024 mg/kg	Gas chromatography–mass spectrometry.
Phenols Monohydric	<0.035 mg/kg	High-performance liquid chromatography (HPLC)
Polychlorinated Biphenyls (PCBs)	<3 µg/kg	
Total petroleum hydrocarbons (TPH) by Criteria Working Group method		
GRO Surrogate % recovery	%	Modified: US EPA Methods 8020 & 602 ‘*Determination of Gasoline Range Hydrocarbons (GRO) and BTEX (MTBE) compounds by Headspace GC-FID (C4-C12)*’
GRO TOT (Moisture Corrected)	<0.044 mg/kg	
Methyl tertiary butyl ether (MTBE)	<0.005 mg/kg	
Aliphatics >C5-C6	<0.01 mg/kg	
Aliphatics >C6-C8	<0.01 mg/kg	
Aliphatics >C8-C10	<0.01 mg/kg	
Aliphatics >C10-C12	<0.01 mg/kg	
Aliphatics >C12-C16	<0.1 mg/kg	Analysis of Petroleum Hydrocarbons in Environmental Media – Total Petroleum Hydrocarbon Criteria ‘*Determination of Speciated Extractable Petroleum Hydrocarbons in Soils by GC-FID*’
Aliphatics >C16-C21	<0.1 mg/kg	
Aliphatics >C21-C35	<0.1 mg/kg	
Aliphatics >C35-C44	<0.1 mg/kg	
Total Aliphatics >C12-C44	<0.1 mg/kg	
Aromatics >EC5-EC7	<0.01 mg/kg	Modified: US EPA Methods 8020 & 602 ‘*Determination of Gasoline Range Hydrocarbons (GRO) and BTEX (MTBE) compounds by Headspace GC-FID (C4-C12)*’
Aromatics >EC7-EC8	<0.01 mg/kg	
Aromatics >EC8-EC10	<0.01 mg/kg	
Aromatics >EC10-EC12	<0.01 mg/kg	
Aromatics >EC12-EC16	<0.1 mg/kg	

SUITE E(b) – Soil Samples		
Determinand	**Limit of detection required / units**	**Test method required**
Aromatics >EC16-EC21	<0.1 mg/kg	Analysis of Petroleum Hydrocarbons in Environmental Media – Total Petroleum Hydrocarbon Criteria 'Determination of Speciated Extractable Petroleum Hydrocarbons in Soils by GC-FID'
Aromatics >EC21-EC35	<0.1 mg/kg	
Aromatics >EC35-EC44	<0.1 mg/kg	
Aromatics >EC40-EC44	<0.1 mg/kg	
Total Aromatics >EC12-EC44	<0.1 mg/kg	
Total Aliphatics & Aromatics >C5-C44	<0.1 mg/kg	
Aromatics >EC16-EC35	<0.1 mg/kg	

SUITE F(a) – Water Samples		
Determinand	**Limit of detection required / units**	**Test method required**
pH	<1	Filtered by meter
Water soluble sulphate	<1000 µg/l	BRE by IC (ion chromatography)
Ammonical Nitrogen	<300 µg/l	Spectrophotometric
Semi Volatile Organic Compounds (SVOCs) excluding PAHs	<1 µg/l	Gas chromatography–mass spectrometry.
Volatile Organic Compounds (VOCs)	<1 µg/l	Gas chromatography–mass spectrometry.
BTEX	<1 µg/l	Gas chromatography–mass spectrometry.
Phenols Monohydric	<0.5 µg/l	High-performance liquid chromatography (HPLC)
Routine Metals		
Arsenic	<2 µg/l	Inductively coupled plasma mass spectrometry (ICP-MS)
Cadmium	<0.07 µg/l	
Chromium	<0.6 µg/l	
Chromium (Hexavalent)	<0.6 µg/l	

SUITE F(a) – Water Samples		
Determinand	**Limit of detection required / units**	**Test method required**
Copper	<3 ug/l	
Lead	<1 µg/l	
Mercury	<0.06 µg/l	
Nickel	<8 µg/l	
Zinc	<6 µg/l	
Cyanide	<1 µg/l	SFA
Cyanide (Free)	<1 µg/l	SFA
Speciated polycyclic aromatic hydrocarbons (PAHs)		
Naphthalene	<0.2/µg/l	Gas chromatography–mass spectrometry
Acenaphthene	<0.1 µg/l	
Anthracene	<0.1µg/l	
Fluoranthene	<0.006 µg/l	
Benzo(b)fluoranthene	<0.017 µg/l	
Benzo(k)fluoranthene	<0.017 µg/l	
Benzo(a)pyrene	<0.00017 µg/l	
Benzo(g,h,i)perylene	<0.008 µg/l	
Total petroleum hydrocarbons (TPH) by Criteria Working Group method		
GRO Surrogate % recovery	%	Modified: US EPA Methods 8020 & 602 '*Determination of Gasoline Range Hydrocarbons (GRO) and BTEX (MTBE) compounds by Headspace GC-FID (C4-C12)*'
GRO TOT (Moisture Corrected)	<0.044 mg/kg	
Methyl tertiary butyl ether (MTBE)	<0.005 mg/kg	
Aliphatics >C5-C6	<0.01 mg/kg	
Aliphatics >C6-C8	<0.01 mg/kg	
Aliphatics >C8-C10	<0.01 mg/kg	
Aliphatics >C10-C12	<0.01 mg/l	
Aliphatics >C12-C16	<0.1 mg/l	

SUITE F(a) – Water Samples		
Determinand	**Limit of detection required / units**	**Test method required**
Aliphatics >C16-C21	<0.1 mg/l	Analysis of Petroleum Hydrocarbons in Environmental Media – Total Petroleum Hydrocarbon Criteria '*Determination of Speciated Extractable Petroleum Hydrocarbons in Soils by GC-FID*'
Aliphatics >C21-C35	<0.1 mg/l	
Aliphatics >C35-C44	<0.1 mg/l	
Total Aliphatics >C12-C44	<0.1 mg/l	
Aromatics >EC5-EC7	<0.01 mg/l	Modified: US EPA Methods 8020 & 602 '*Determination of Gasoline Range Hydrocarbons (GRO) and BTEX (MTBE) compounds by Headspace GC-FID (C4-C12)*'
Aromatics >EC7-EC8	<0.01 mg/l	
Aromatics >EC8-EC10	<0.01 mg/l	
Aromatics >EC10-EC12	<0.01 mg/l	
Aromatics >EC12-EC16	<0.1 mg/l	Analysis of Petroleum Hydrocarbons in Environmental Media – Total Petroleum Hydrocarbon Criteria 'Determination of Speciated Extractable Petroleum Hydrocarbons in Soils by GC-FID'
Aromatics >EC16-EC21	<0.1 mg/l	
Aromatics >EC21-EC35	<0.1 mg/l	
Aromatics >EC35-EC44	<0.1 mg/l	
Aromatics >EC40-EC44	<0.1 mg/l	
Total Aromatics >EC12-EC44	<0.1 mg/l	
Total Aliphatics & Aromatics >C5-C44	<0.1 mg/kg	
Aromatics >EC16-EC35	<0.1 mg/kg	

SUITE F(b) – Water Samples		
Determinand	**Limit of detection required / units**	**Test method required**
As Suite F(a) with additional as below		
Dissolved organic carbon	<3	Dissolved filtered Infra-Red analysis
Calcium	<0.05 mg/l	
Hardness	<0.5 mg/l	$CaCO_3$ Inductively coupled plasma atomic emission spectroscopy

SCHEDULE 5: SPECIFICATION ADDITIONS

The following clauses are added to the Specification

Section	Clause Number	Addition
3	**3.8.6Ad**	**Service strikes** In addition to Clauses 3.7.2, 3.8.3, and 6.1. On the occasion of any unintended suspected service strike (of either known or unknown services) all works on site shall cease and the Principal Contractor (CDM), Investigation Supervisor, and Principal Designer (CDM) informed. No further works may be undertaken without instruction from the Investigation Supervisor.
3	**3.27Ad**	**Logging & description of soils and rocks** Logging of exploratory holes (as presented on the preliminary logs and within the factual report) shall be undertaken by an Experienced Ground Engineer (Clause 2.3), defined as having at least 3 years of relevant experience since graduation with an appropriate degree, or alternatively with at least 5 years of experience if not a graduate. Soil and rock descriptions shall be undertaken in line with BS 5930 and shall be as objective a record as possible made from samples recovered from exploratory holes, arisings, examination of in situ materials, and from reference to other factual records (such as daily records, drillers notes, and in situ and laboratory test records etc.). The order of secondary constituents in soil descriptions shall be as described / promoted by Norbury '*Soil and Rock Description in Engineering Practice*'. The final exploratory logs presented in the factual report shall incorporate any interpretative notes as required by the Investigation Supervisor.
10	**10.11Ad**	**Standard Penetration Testing (SPT)** With respect to the options given in BS EN ISO 22476-3, the test drive shall be undertaken in four 75 mm increments. If the test is undertaken at suspected rock head then the number of blows to be undertaken prior to termination shall be 100.

Appendix A

DRAWINGS

Figures Redacted

Amber Court
William Armstrong Drive
Newcastle upon Tyne
NE4 7YQ

8 RIVERS POTENTIAL UK SUPPLY CHAIN ASSESSMENT REPORT

23 February 2021

Contents

Preface

Following a successful pilot of their Allam Fetvedt Cycle (AFC) technology in Texas, USA, 8 Rivers Capital, LLC and affiliates are planning the development of a full scale commercial facility in Teesside, UK, as the first of a potential programme of multiple facilities nationally and internationally. This new gas to power thermal generation technology represents an opportunity for the UK to access low-cost power with zero air emissions, and position UK industry for a key role in supplying this growing technology sector. 8 Rivers Capital has received support from the Department for Business, Energy, and Industrial Strategy (BEIS) via the CCUS (Carbon Capture, Usage and Storage) innovation fund to carry out a pre-FEED (Front-End Engineering and Design) study to develop their first UK deployment and initiate this project.

As part of the pre-FEED study 8 Rivers wanted to provide BEIS an overview of the potential UK supply chain for major items of process equipment and key components for the first UK facility. Although not directly addressed in this report, the Teesside development of 3 AFC plants at the one facility can be scaled from this report and this project demonstrate how this would impact the UK supply chain to 2030 from one facility.

8 Rivers have engaged PA Consulting to support in assessing the UK supply chain and the expected opportunities for UK industry, which are documented in this report.

This report has named some UK suppliers who we believe have the potential to manufacture the sub-systems and components required for the potential Teesside plant. Our naming of suppliers is not exclusive to them and implies no preference or procurement decision by either NET Power or 8 Rivers. This report is intended to identify whether the required capabilities exist within the UK manufacturing sector to meet the project requirements of the AFC and specifications. A full and formal market engagement would likely identify further capabilities and suppliers within the UK supply chain who could participate in a procurement event.

Key References

[1] WORLDWIDE GAS TURBINE FORECAST, Turbomachinery magazine, https://www.turbomachinerymag.com/worldwide-gas-turbine-forecast-2/

[2] EY OFS Report – Energy Industry manufacturing: A Wind of Change by Brian Davis, https://ukmfgreview.com/sectors/energy/

[3] The mapping of materials supply chain in the UK’s power generation sector, Materials UK Energy Review (2008) http://www.matuk.co.uk/docs/Mapping_Materials_Supply%20locked.pdf

Executive Summary

A review of the engineering and manufacturing requirements for the technology. Identify existing capabilities within the UK supply chain for the provision of key sub-systems and components?

The proposed construction of the first full scale Allam-Fetvedt cycle (AFC) generation plant in the UK presents significant opportunities for UK companies and supply chains to support this ground-breaking and novel project. As this report concludes; **The UK engineering and manufacturing sector is well placed from existing energy and aerospace capability to support the project across the value chain through supporting infrastructure, potential OEM support and sub-tier suppliers.** The key sub-systems (combustor, compressor, heat exchangers, turbine, and ancillaries) all have elements of uniqueness in specification and design that would require modifications to standard generation or aerospace technologies and processes.

This report examines whether the requirements can be provided by UK companies and supply chains. The UK supply chain is strongest for the heat exchanger and turbine systems, a potential supply chain exists but not in depth for the compressor, pumps and valves systems and only with the combustor system do we have a concern on current UK capability. Our assessment is based on our understanding of the specifications and designs to date and may vary when designs and specifications are finalised. Our research and this report conclude that there are options to use the UK supply chain (noting the strengths and weaknesses identified) for all sub-systems.

Sub-System	UK Engineering Capability	UK Manufacturing Capability	UK Market Viability
Combustor	A	A	A
Compressor	G	G	A
Heat Exchanger	G	G	G
Pumps & Valves	G	A	G
Turbine	G	G	G

Key:

- R — Red: No significant UK industry presence identified
- A — Amber: There is a UK industry presence that could suit
- G — Green: High level of UK industry presence

8 Rivers has several key decisions to make regarding the potential procurement of this plant. The choice between seeking OEM suppliers who could supply finished products or to engage Tier 2 and Tier 3 suppliers with specific engineering capabilities e.g. machining, casting, forging or who can provide specific components e.g. casings and turbine blades.

The report identifies and names potential suppliers at all levels. The report is not intended to be exhaustive in this regard, rather seeking to establish that a credible capability exists. Further development of this project will require a more formal market engagement to identify the full extent of potential suppliers. As the project moves from the current pre-FEED stage and into FEED 8 Rivers intends to commission a further, more detailed, study to ensure the supply chain can react to their predicted growth of the AFC both in the UK and globally.

Report Introduction

Approach:

The review was conducted using 3 phases:

- Collation and desktop review of key systems and processes
- UK Market Research focused on key component manufacturing capabilities and potential suppliers in oil and gas and aerospace markets.
- Write up of findings with additional supplementary questions and considerations

Interviewee Name	Interviewee Role
Steve Milward	8 Rivers Engineering Director
Brock Forrest	NET Power Chief Engineer
Iain Hollister	8 Rivers Senior Project Engineer

In March 2016, 8 Rivers and NET Power broke ground on its 25 MWe pilot plant at La Porte just outside Houston, Texas. The pilot plant uses the novel Allam-Fetvedt Cycle which combines carbon capture technology with oxy-combustion of natural gas in a semi-closed cycle. The companies are currently developing the first full scale AFC plant which will be commissioned in Teesside, UK. Many of the technologies and specifications for the original pilot plant were unique and involved the adaptation of existing related technologies for this new application. 8 Rivers and NET Power have continued to learn from the experience gained from on-going operation of the pilot plant and have refined their specifications and designs accordingly for the commercial scale facilities.

Given the unique nature of the sub-systems and components, we have had a number of discussions with the 8 Rivers and the NET Power team (above) to understand the preliminary equipment list and nuances of the technology that could act as constraining or promoting factors for the potential UK supply chain.

This report reviews the overall market in the UK for the energy sector and gas turbine manufacture, particularly related to aerospace. We then explore some of the key sub-systems and processes in the context of UK manufacturing capabilities. This novel technology contains the following key sub-systems that follow the process for an industrial gas-turbine.

- Combustor
- Compressor
- Heat Exchanger
- Pumps & Valves
- Turbine

In addition to this there are some ancillary services and manufacturing processes that UK industry could provide which, whilst not called out specifically in this report, do exist to support Original Equipment Manufacturer (OEM)s and Tier 1/2 suppliers across key manufacturing industries.

The report provides some potential supplier profiles to highlight the level of capability in this sector.

Market Overview

Both the Oil and Gas and Aerospace industries rely on gas turbine technology. Through discussions with stakeholders on this project we highlight the similarities between the required project technologies and specifications to current aero-engine specifications and technologies. Some key systems and components for the proposed plant can be described as 'aero-derivative' in design. Therefore, there is some market assessment into aerospace grade materials and manufacturing, where the UK supply chain could support especially considering the UK's rich history in aerospace manufacturing. Oil and Gas, and Aerospace are advanced engineering markets and have few prime manufacturers which the industries rotate around. These prime manufacturers then have Tier 1 suppliers and a network of smaller suppliers that compete to secure a place within the overall supply chain.

The UK energy industry has for several decades faced a shrinking or slowing of the general market, driven by factors including customer preference away from fossil fuels and the drive towards more renewable energy. This has meant that the OEM, and sub-tier engineering and manufacturing organisations, have experienced a reduction in overall demand. For example, oil and gas supply chain revenues in the UK have shrunk by a third from £40 billion in 2014 to £27 billion in 2017[1]. The Oil and Gas UK (OGUK) Economic Report maintains there has been some growth and improvement in investment levels for 2018 and 2019. There is a growing trend that many companies who operate as part of the oil and gas supply chain have begun to shift their engineering and manufacturing capabilities to renewable energy options. For example, companies are switching to building wind turbines to diversify their capabilities and customer base to survive the downturn by spreading risk and limiting their exposure to the oil and gas market. In 2019, the OGUK Business Outlook industry association said

"The drive to achieve a net-zero economy will provide further opportunities, with estimates suggesting that achieving this aim could require up to £1 trillion of investment," and that "The supply chain can continue to be a global leader in oil and gas services, whilst embracing the opportunities presented by the energy transition. This will ensure that the industry's supply chain continues to contribute to the UK economy in the decades to come."[2]

There is evidence that the oil and gas industry in the UK, recognises the opportunity to support a transition through technology for CCUS and the alternative use of infrastructure.

Mike Tholen, Upstream Policy Director at OGUK said; "The transition to a lower carbon, diverse energy mix is an exciting opportunity for our transforming industry. With extensive skills, capabilities, and infrastructure, we are well placed to support the development of low carbon technologies such as CCUS and hydrogen while reducing emissions from production operations,".[3]

The 2020 Covid-19 pandemic has resulted in a significant downturn for the aerospace gas turbine market. This has resulted in reduced demand and unfilled capacity for the OEMs and sub-tiers suppliers, forcing aero suppliers to branch out to other areas to preserve revenue.

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[1] EY OFS Report – Energy Industry manufacturing: A Wind of Change by Brian Davis, https://ukmfgreview.com/sectors/energy/
[2] https://www.ogv.energy/news-item/overview-supply-chain-procurement-in-the-oil-gas-industry
[3] https://www.pwc.co.uk/turningthetide

Relevant Global Gas Turbine Market Trends

Rising demand for distributed power generation systems will drive the gas turbine industry outlook	• 50 kW - 500 kW capacity segment of gas turbine market is projected to witness an annual deployment of over 2 GW by 2026. Advancements to combustor technology, operating range, and durability in line with expansion of effective re-generative systems to withstand high heat requirements will accelerate the product penetration. Moreover, there will be a growing inclination towards combined cycle power generation plants due to their high efficiency, reliability and operational performance compared to open cycle generation. • Light weight, improved efficiency, potential to use flue gas, lesser number of mechanical links, and lower electricity generated cost are the key parameters which will drive market trends. Growing adoption of on-site energy generation systems across static power applications will boost the product penetration. Rising energy demand across refineries, petrochemical industries and process plants will further instigate the adoption of regenerative turbine units.
Lower turbine dimensions and cost along with high capacity operation will complement the product deployment	• The heavy-duty gas turbine market is anticipated to witness significant growth on account of economic cost structure, high capacity operations and lower pressure ratios to yield maximum specific power. Growing product demand across utility aided and heat recovery power generating plants owing to lower turbine dimensions and cost along with maximum cycle efficiency will further drive the business landscape. Ongoing technological developments on account of efficiency, reliability and flexibility enhancements across both recuperated and un-recuperated systems will fuel the industry dynamics. • The aero-derivative gas turbine market is projected to witness an upsurge on account of higher turbo-machinery efficiency, enhanced turbine inlet temperature and better cooling blades. In addition, ongoing investments toward the development of sustainable energy generation plants along with growing regenerative turbine integration.
Compact size, high operational efficiency and low fuel consumption will complement the product deployment	• Comparatively compact size and operational versatility along with quick start and lower warm up time are a few prominent factors complementing the open cycle combustion turbine market statistics. Onshore and offshore industries find a varied applicability of turbines across mechanical and direct drive.
Demand of improved gas turbine establishments will act as the focal point for the market players	• Ongoing mergers and acquisition along with growing R&D investments toward product durability, efficiency and versatility by major manufacturing participants will complement the industry scenario. Eminent players operational across the global gas turbine market includes Wartsila, Siemens AG, Man Diesel & Turbo, General Electric, Mitsubishi Hitachi Power Systems, NPO Saturn, Kawasaki Heavy Industries, Harbin Electric International Company, BHEL, Solar Turbines, Capstone Turbine, Vericor Power Systems, Ansaldo Energia, Opra Turbines, Zorya-Mashproekt and Cryostar.

Sub-Systems and Manufacturing Capabilities

From the high-level equipment list provided by 8 Rivers and NET Power and related interviews, the key areas for discussion were broken down into sub-systems.

This section will focus first on some key characteristics of the sub-systems and their relevance to a potential UK market before discussing the manufacturing capabilities in the UK.

There is a large presence in the North East of England and East of Scotland for the gas industry due to the North Sea gas reserves. This has meant a manufacturing and servicing presence for Tier 1/2 suppliers. To remain competitive in the market, major gas turbine manufacturers are developing and incorporating advanced technologies such as gas turbine combined cycle (GTCC) and integrated goal gasification combined cycle (IGCC). This means suppliers are needing to adapt offerings to meet those new requirements.

The project will require suppliers to meet higher material and engineering specifications than conventional industrial gas turbines. There is opportunity here for aero-engine sub-tier manufacturers in the UK who have a combination of engineering and manufacturing capability at higher specifications.

8 Rivers and NET Power have options on how they choose to engage the supply chain to get best value and service. These options include the use of integrators or sub-tier suppliers, or to align with an OEM. The global aerospace OEM Rolls-Royce plc sold their aero-derivative industrial gas turbine and compressor energy business to Siemens Energy in 2014[4]. Nevertheless, much of the Tier 1 infrastructure and assembly/manufacturing sites for industrial gas turbines (aero-derivative) exist at UK sites. These include sites in the West Midlands, East Midlands & North East – all whom have a network of local Tier 2 suppliers and small/medium enterprises who could support this project. Both Rolls-Royce and Siemens Energy UK based operations could support this project.

Combustor

The combustor for the pilot plant, like the turbine, was manufactured specially by Toshiba. The specification requires that it is capable of oxy-combustion of natural gas using CO_2 as a dilutant. These requirements make the combustor novel in the market.

The UK supply chain for specialized fabricated combustors is not extensive with specialized fabrication being more USA centric. The main UK OEM capability derives from aerospace at Rolls-Royce Hucknall (soon to be moved under Industria de Turbo Propulsores (ITP) who were a subsidiary of Rolls-Royce based in Spain, who are now independent and will be owning the Nottingham site going forward), which assembles and manufactures combustion housings and chambers and related complex fabrications. Depending on the specific design, companies who provide housing castings could potentially supply parts or sub-assemblies. For example, Siemens Energy have used companies like Russel Ductile castings (Scunthorpe) for steel castings and William Cook Cast Products Ltd. (Sheffield) for combustion chamber housing and casings. There are a variety of machinists who can machine a cannular casing for industrial gas turbines, such as Bromford Industries in Birmingham and Manthorpe Engineering. There is a proven fabrication capability for the UK aerospace and energy sector that could be employed but this would depend on the level of specialism that the novel combustor would require.

[4] Siemens to acquire the Rolls-Royce Energy gas turbine and compressor business and enter into a long-term technology partnership - https://press.siemens.com/global/en/pressrelease/siemens-acquire-rolls-royce-energy-gas-turbine-and-compressor-business-and-enter-long

Compressor

Through discussions and review, there are two main compressor systems required, the first being a hot-gas internally geared compressor, the second is a recycled CO_2 compressor with accompanying coolers and pumps.

Both compressors and accompanying equipment, are commercially available from multiple vendors. The hot gas compressor is more challenging as it requires three stages of compression that would need a high level of engineering capability. Key manufacturers include organisations such as Siemens (within their UK footprint) and Howden who have a global presence across energy manufacturing but compressor specific sites across UK. There are other compressor. Note that if hot gas compression system was broken down into some of the sub-components such as the compressor blades, this is a large supply chain that exists in the UK to support aero requirements.

Heat Exchanger

One advantage this project has relates to the plant's size. The heat exchangers are much smaller and cheaper to build than massive boilers that other thermal power generation plants require as are many of the other components. This means that the constraint of 'machine size' is less critical, which favours the UK market where large-scale manufacture has moved towards being off-shored. Heatric, a well-regarded global heat exchanger manufacturer, is based out of Poole. They are a provider to both the oil and gas and the nuclear markets, providing field service engineering of the 'compact' type heat exchangers which may be required by this project. A profile of Heatric is available later in this report. Other energy sector suppliers include Thermex.

Pumps & Valves

Flowserve is a global supplier of pumps and valves who have a 'flow' centre for manufacturing in Sussex. Doosan Babcock in Renfrew is a specialist energy company across thermal, nuclear, and petrochemical markets. Whilst they are primarily boiler specialists, they have experience across steam generation and in particular pipework and pressure valves which could be utilised by this project. Mersen are conveniently located on Teesside and have a division dedicated to anti-corrosion/graphite solutions. The company also have maintenance and service-based offerings. There are of course sub-components around precision machining and general fabrication and supporting infrastructure that the UK industry would be able to provide across a variety of manufacturers and engineering firms.

Turbine

The pilot plant turbine which needs to work at intense temperatures and pressures[5] was manufactured by Toshiba. Whilst steam turbines sometimes reach the extreme operating temperatures and pressures experience with this type of plant, "no one had ever designed a turbine to do that with CO_2 as the working fluid," - NET Power spokesperson Walker Dimmig. The pilot plant turbine was manufactured as a modification to a standard Toshiba steam turbine to work with supercritical CO_2.

The turbine itself is a 'first of a kind' and much of the engineering is aero-derivative to work with the supercritical CO_2. Through interviews we established that the 8 Rivers and NET Power engineers agree that most established and capable gas turbine manufacturers could manufacture this component but that they would need a degree of engineering collaboration and support from 8 Rivers and NET Power. For the pilot plant the 25 MWe turbine is about 10% the size of the equivalent steam turbine and the technology requires higher grade materials and engineering specifications which closely resemble aero engine requirements.

[5] https://www.utilitydive.com/news/toshiba-ships-turbine-for-net-power-supercritical-co2-carbon-capture-plant/429513/

Broken down into its main components, the turbine is a series of blades and vanes (a mixture of rotating and static) through several stages, with the fixed blades attached to the turbine casing. In part due to UK gas turbine industry, the UK has full value chains for this type of engineering. The novelty of this specific turbine is the higher temperature required which pushes the engineering and manufacturing closer to aero-derivative turbines which the UK supply chain is equipped to provide. Rolls-Royce has significant experience in ensuring that turbine blades can reach extreme temperatures and has the Advanced Turbine Blades Facility in Rotherham[6] which produces turbine blades through growing single-form crystal. Rolls-Royce also has a Turbine Disc facility in Tyne[7] so depending if they were engaged on this project, they might see an opportunity from an engineering or manufacturing perspective. Considering the casing on it's own, there are a number of capable machinists in the UK, and for example later in this report there is a profile for Goodwin International based out of Stoke-on-Trent.

A significant number of UK-based companies have experience in the supply of high integrity components such as castings and forgings (eg. Doncasters, Howmet Aerospace). There is a mature supply chain for machinists with vertical turret lathes or CNC capability versed in high-grade materials and working with these suppliers.

Sub-System	Comments	UK Engineering Capability	UK Manufacturing Capability	UK Market Viability
Combustor	CO2 combustor, UK Specialised fabrication capability is weaker than US and Europe. However, there are potentially a few suppliers that could support.	A	A	A
Compressor	Commercially available, big players have manufacturing based out of UK. However, if volumes are there Siemens could support with their compressor capability and there is a supply chain for some of the key components.	G	G	A
Heat Exchanger	World-class capability exists in UK, especially due to the relative smaller size required for this project.	G	G	G
Pumps & Valves	More conventional in design and UK supply chain exists for oil & gas already.	G	A	G
Turbine	Turbine design and engineering is strong in UK, the high-pressure requirement for a turbine capable at high temperatures is a key aspect of aero-market with leading world class capability in UK.	G	G	G

Key:

R — Red: No significant UK industry presence identified

A — Amber: There is a UK industry presence that could suit

G — Green: High level of UK industry presence

[6] https://www.theengineer.co.uk/rolls-royce-single-crystal-turbine-blade/

[7] https://www.aerospacemanufacturinganddesign.com/article/rolls-royce-opens-new-uk-disc-manufacturing-061014/

Key Manufacturing Processes

The UK gas turbine market is dominated by primary actors, who rely on a robust supply chain with various transferrable capabilities for areas of the manufacturing process. For example, the metallurgical properties required for turbine and compressor blades may require special processes such as coatings and seals. Industrial forgings that are considered large have mostly been off-shored over several decades due in part to the high capex requirements for forges of a certain size/scale. However, as previously noted, the size of sub-systems for this project is closer to aerospace, so that allows more UK based forgers and casters to potentially play a role. Precision machinists exist in a variety of areas to meet most requirements based on size and scale of project.

Manufacturing Capability	UK Engineering Capability	UK Manufacturing Capability	UK Market Viability
Gas Turbine OEM	G	G	A
Raw Material, Forging and Machining	G	G	G
Casting and Machining	G	G	G
Pipes, Valves and Precision Machining	G	A	A
Blades, Vanes and Casing Machining	G	G	G
Coatings and Seals	G	G	G
Combustion and Complex Fabrication	G	A	A

Key:

- R — Red: No significant UK industry presence identified
- A — Amber: There is a UK industry presence that could suit
- G — Green: High level of UK industry presence

Whilst the following lists of suppliers are not exhaustive, it does demonstrate some of the capable supply chains in the UK that could meet the manufacturing requirements. This list would no doubt be increased through a Request for Information (RFI) or further market engagement work.

Pipes, Precision Machining, and Valves	Raw Material, Forging and Machining	Coatings and Seals
Doosan Babcock (Renfrew)	Sheffield Forgemasters (Sheffield)	Chromalloy (Glasgow, Crewe, Derbyshire)
Pump Engineering (Sussex)	Independent Forgings & Alloys (Sheffield)	Praxair Surface Technologies (Lincoln)
Cross Manufacturing Company Ltd (Somerset)	Special Metals (Wiggin, Hereford)	Sulzer Metco (Stockport)
Mersen UK (Teeside)	Wyman Gordon (Lincoln)	**Blades, Vanes and Casing Machining**
Combustion Casing and Fabrication	TIMET Ltd (Birmingham & Swansea)	Centrax Gas Turbines (Newton Abbot)
William Cook Cast Products Ltd. (Sheffield)	Howmet Aerospace (Exeter)	Trac Precision (Derby)
Russel Ductile castings (Scunthorpe)	**Casting and Machining**	Goodwin International Ltd (Stoke-on-Trent)
Bromford Industries (Birmingham)	Goodwin International Ltd (Stoke-on-Trent)	
Manthorpe Engineering (Ripley)	Doncasters (Chard)	
	Howmet Aerospace (Exeter)	

Potential Supplier Profiles

Siemens Energy

Company Overview

Siemens Energy AG operates through two segments: 'Gas & Power' and 'Siemens & Gamesa Renewable Energy'. The Gas & Power segment offers a wide range of products and services in the fields of power transmission and conventional central and distributed power generation alongside industrial applications for the oil and gas industry and for industrial process applications. The Siemens & Gamesa Renewable Energy segment focuses on the promotion, design, development, manufacture and supply of products, installation, and technologically advanced services in the renewable energy sector with a focus on wind power plants.

Key UK Locations:

Lincoln (Gas Turbine Service Centre)

Warwick (Aero-derivative Gas Turbines)

York (Power Generation & Transportation Systems)

Capabilities

Compressor Portfolio:

- Single-shaft Centrifugal Compressors
- Pipeline Centrifugal Compressors
- Axial Compressors
- Integrally Geared Centrifugal Compressors
- Reciprocating Compressors
- Single-stage Compressors
- Expansion Turbines
- Compressor Services

Gas Turbines Portfolio:

- Heavy-duty Gas Turbines
- Industrial Gas Turbines
- Aeroderivative Gas Turbines

Source: Siemens UK Website, Siemens Energy Website, Siemens Energy Annual Report 2020, WSJ profile: Siemens Energy AG, Siemens Energy Gas Turbine Overview, Compressors and Expansion Turbines Portfolio

Doosan Babcock

Company Overview

Doosan Babcock Limited provides construction services. The Company designs and constructs thermal and nuclear power stations, as well as offers plant monitoring and repair, shutdown and turnaround management, boiler upgrades, biomass co-firing, and non-destructive evaluation services to thermal power, nuclear, oil and gas, and petrochemical industries.

Key UK Locations:

The company has offices in Renfrew, Katowice, Bristol, Westlakes, Gateshead, Selby and Tipton.

Capabilities

For the Thermal Power market, the company has the following capabilities:

- Precision Combustion systems with NOx control technology
- Boiler Retrofit and Upgrades

Retrofit services include:

- Combustion systems for primary Nitrogen Oxide (NOx) control or change of fuel
- Secondary NOx control
- Major integrated projects including Carbon Capture & Storage (CCS)

Secondary NOx Control Technology spans:

- Selective non-catalytic reduction
- Selective catalytic reduction

Asset Support capabilities:

- **Manufacturing and Fabrication**
- **OEM Pressure Parts and Spares**
- **Welding Development and Welder Training**

Source: Company Website, Company House Document – Full Accounts, Bloomberg, Office Locations

Heatric (A Meggitt Plc division)

Company Overview

Heatric, a division of Meggitt (UK) Limited, designs and manufactures bespoke heat transfer solutions for selected energy markets. Heatric is a world leader in heat exchanger technology. The company has produced over 2,500 Printed Circuit Heat Exchangers (PCHEs) for operation in extreme environments across the globe, for both existing and emerging energy markets.

Key UK Locations:

Poole (Component sub-assembly and final assembly of Heatric's exchangers)

Capabilities

- Manufacturing of PCHEs using a specialised solid-state joining process known as 'diffusion-bonding'. This process creates a heat exchanger core with no joints, welds, or points of failure.
- Heatric also offers services such as Heat Exchanger Cleaning, field Service Engineers, Heat Exchanger Spares, Strainers and Technical Support
- It should also be note that the wider Meggitt operates across the UK in aerospace as well as power station support but also manufacture engine systems to manage high pressure and temperature through valve control systems (flow control valves) & ducting.

*The values represent the Printed Circuit Heat Exchanger Segment Revenue Generated by Meggitt Plc

Source: Heatric Company Website, Meggitt Plc Annual Report 2019, Employee Size, Key UK Locations

Goodwin International

Company Overview

Goodwin International specialises in heavy project engineering, offering comprehensive and streamlined solutions to a wide range of industries. The company also markets and sells their own valve products internationally, mainly to the petrochemical industry.

Goodwin International also works with Goodwin Steel Castings, enabling them to supply machined castings.

Key UK Locations:

Has site in Trentham (Engineering Capabilities)

Capabilities

Products and services offered by the company are:

- Heavy Project Engineering
- Dual Plate Check Valves
- Axial Check Valves
- Axial Control Valves
- Submersible Pumps & Pontoons

Source: Companies House Document: Full accounts made up to 30 April 2020, Goodwin Website

Conclusion and Further Considerations

The UK engineering and manufacturing sector is well placed to support the project with both the capability and locality to meet overall requirements.

The key sub-systems all have elements of uniqueness in specification and design that would require modifications to standard generation or aerospace technologies and processes, however there are options across all that could be utilised. The project will require suppliers to meet higher material and engineering specifications than conventional industrial gas turbines and there is opportunity here for aero-engine sub-tier manufacturers in the UK who have this capability already to meet the needs of the project.

Further Considerations

- Whilst there are novel aspects of the project/technology that mean some oil/gas power generation equipment is not suitable, the higher integrity materials and engineering align closely to aerospace. These aerospace organisations have likely been impacted by Covid-19 and many may be wishing to use their engineering resource on cross-sector opportunities. The timing to approach these suppliers may be critical, ie before they begin to consider any ramping up of traditional aerospace work.
- The UK is well placed with its extensive network of Advanced Technology Centres – for example the Advanced Manufacturing Research (AMRC) next to the Nuclear Advanced Manufacturing Research Centre (NAMRC) and brand-new turbine sites across the road aligned to Rolls-Royce and the Advanced Forging Research Centre (Inchinnan). Technology Research Centres often seek out collaborative partnerships to advance research and would no doubt be interested in many aspects of this project including but not limited to the supercritical CO_2 turbine.
- Partnering with Tier 1 OEMs (non-competitor aligned) Siemens Energy or Rolls-Royce (even though they no longer operate in energy) would present assembly advantage and access to local qualified SME supplier markets through strategy alignment.
- This report does not address the subject of capacity at providers, but next steps would be to take indicative timelines and volumes through a level of market engagement with potential key suppliers. Reviewing the engineering requirements to understand which components can be modified versus commercial ‘off-the-shelf’ availability. Creating commodity/category-based integrated strategies for the supply chain and looking at how procurement policy could be used to leverage UK manufacturing capability for priority areas

The catalytic potential of the Allam Fetvedt cycle technology within the UK CCS sector

Report prepared for 8 Rivers

As part of BEIS CCUS Innovation Incubation support provided by Carbon Limiting Technologies

Draft

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:vivideconomics

putting economics to good use

Executive Summary

The Allam Fetvedt Cycle technology will lower the costs of reaching the UK's net zero target. Under the CCC's 6th Carbon Budget, the UK will require 15GW of gas-fired generation with carbon capture and storage (gas CCS) generation capacity by 2050 to meet its net zero target. The Allam Fetvedt Cycle (AFC) promises higher efficiency than other existing gas CCS technologies while providing a near 100% carbon capture rate.[1] Its ability to generate clean electricity at a reasonable cost was recognised by the MIT Technology Review as one of the 10 Breakthrough Technologies in 2018, with a significant potential to be deployed widely across the globe.

This report quantifies the direct, indirect and induced jobs that can be brought by deploying AFC technology in the UK. The estimates focus on domestic jobs supported by (a) the planned deployment of a 300MW unit at the Wilton International industrial site in Teesside, and (b) wider UK deployment of the AFC technology assuming it reaches half of the UK's gas CCS capacity, i.e. 7.5GW by 2050. The key results are presented in Table 1 below. It should be noted that these estimates do not distinguish jobs that are additional to what would otherwise occur in the economy.

The deployment of a single AFC unit at Wilton could support 610 direct jobs, during the peak of the construction phase. This contains a mix of manufacturing and services jobs required for construction and installation, some of which represent key technologies such as advanced heat exchangers. Besides, the project supports another 1,620 indirect and induced jobs in 2023. During its operation, the project could support 90 direct jobs alongside 560 indirect and induced jobs per year.

UK wide deployment of AFC technology could support 1,050 direct jobs in 2030, in addition to 1,790 indirect and 1,700 induced jobs. Indirect jobs are spread across UK firms in all major sectors, with a higher concentration along the supply chain for necessary goods and services. These sectors include fabricated metal products, gas distribution, electricity, and construction. Induced jobs are supported by extra spending in the economy, concentrated in retail trade and the hospitality sector. The estimated number of direct jobs represent 15-20% of long-run estimates of domestic CCUS direct jobs in the EINAs report published by BEIS.[2]

Early deployment of the AFC technology could act as a much-needed catalyst to increase skilled labour in the CCUS sector, which will help the UK reach Net Zero and support up to 50,000 export jobs by 2050. While the deployment of CCUS promises some high quality jobs, it also demands a large number of skilled workers that will be key to the green economy. Labour market statistics indicate a widening shortage of skilled workers in the manufacturing and construction sectors. This may hinder the development of CCUS infrastructure in key industrial regions. Expanding and upskilling the existing workforce will be important to realise the PM's Ten Point Plan for a green industrial revolution.

Table 1 Job estimates of the annual number of jobs supported by deploying AFC technology

AFC deployment scope	Direct jobs	Indirect jobs	Induced jobs	Annual total
Single unit at Wilton – *Construction peak*	610	840	780	2,230
Single unit at Wilton – *Operation phase*	30	90	90	210
UK wide deployment – *2030*	1,050	1,790	1,700	4,540
UK wide deployment – *2040*	1,180	2,340	2,280	5,800

Source: Vivid Economics

[1] The Allam Fetvedt Cycle is a recent innovation that eliminates the steam cycle by using supercritical carbon dioxide as the main working fluid. Throughout the cycle, carbon dioxide is gradually removed from the process, ready to ship by pipeline. This avoids most of the water costs and uses a fraction of the space of standard natural gas plants. Importantly, it has a 59% net efficiency with near 100% carbon capture, compared to conventional carbon capture equipped CCGTs that achieve a net efficiency of 48% when capturing just 90% of the carbon dioxide. NET Power first built a 50MWth demonstration plant in Texas in 2018, with the planned 300MW plant at Wilton being the first commercial plant.
[2] The CCUS report in the BEIS Energy Innovation Needs Assessment (2019) examines a much wider range of power and industrial CCS applications.

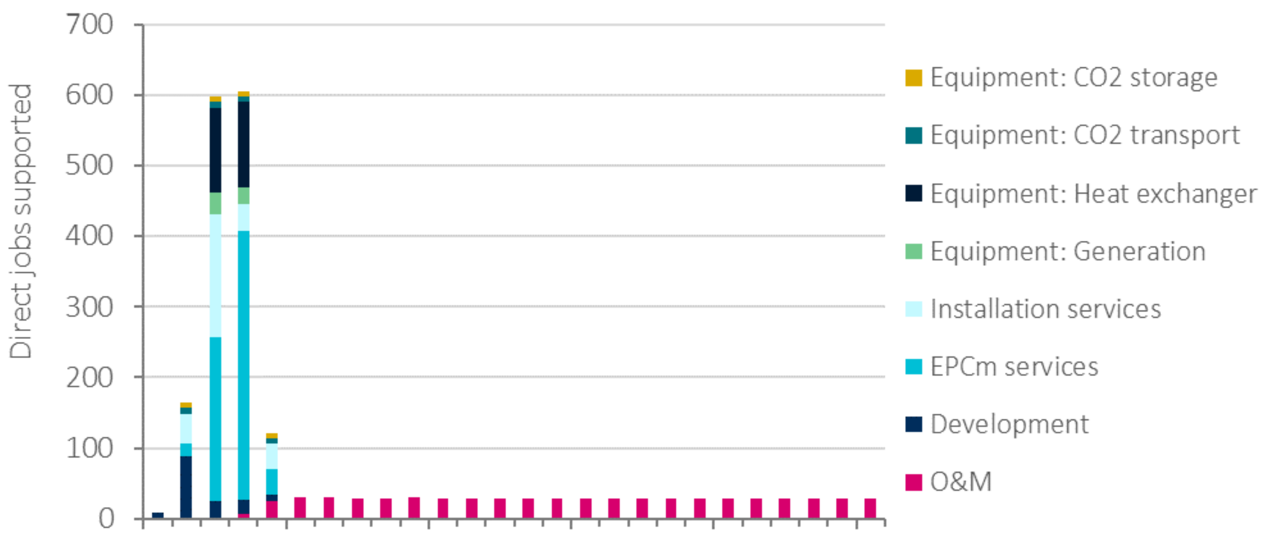
1 Opportunity from AFC facility at Wilton

The planned development at the Wilton International industrial site consists of a 300MW oxyfuel combustion facility that utilises the Allam Fetvedt cycle technology. The technology is advantageous compared to other forms of gas CCS because the Allam Fetvedt cycle (AFC) produces a nearly pure stream of carbon dioxide that is ready for the pipeline and sequestration, minimising the energy required for carbon capture, resulting in higher efficiency. This section quantifies the direct, indirect, and induced jobs that can be supported by the first unit (see Box 1 for definitions of job types), with methodology and assumptions described in the Appendix.

1.1 Direct jobs

The development of a 300MW AFC unit can support 610 direct jobs at the peak of the construction phase. During the construction phase, annual capital expenditure could exceed £200m. Most of this capital expenditure goes towards the purchase of machinery equipment, which will support manufacturing jobs if they are produced domestically. The remainder of the direct jobs concentrates on development, EPCm of EPC (engineering, procurement, and construction management) and installation services. These services are mostly provided by local companies and therefore have a higher UK content than machinery equipment, supporting relatively more domestic jobs. During the operation phase, operation, and maintenance (O&M) could further support 30 direct jobs each year, like a traditional thermal power plant of this scale. The breakdown of direct jobs over time is shown in Figure 1.

Figure 1 Direct jobs supported by an AFC unit at Wilton



Note: O&M jobs primarily refer to jobs at the Wilton site, with less than 10% representing O&M jobs for the CO_2 transport and storage infrastructure.

Source: Vivid Economics

Box 1 Defining jobs

The definition of jobs is aligned with conventional practice within the literature as follows:

1. **Direct jobs** are jobs supported by direct project expenditure, such as jobs supported when a compressor is purchased for installation on site. For this report, direct jobs are driven by capital and

operating expenditure in deploying AFC technology alongside the required CO_2 transport and storage infrastructure.

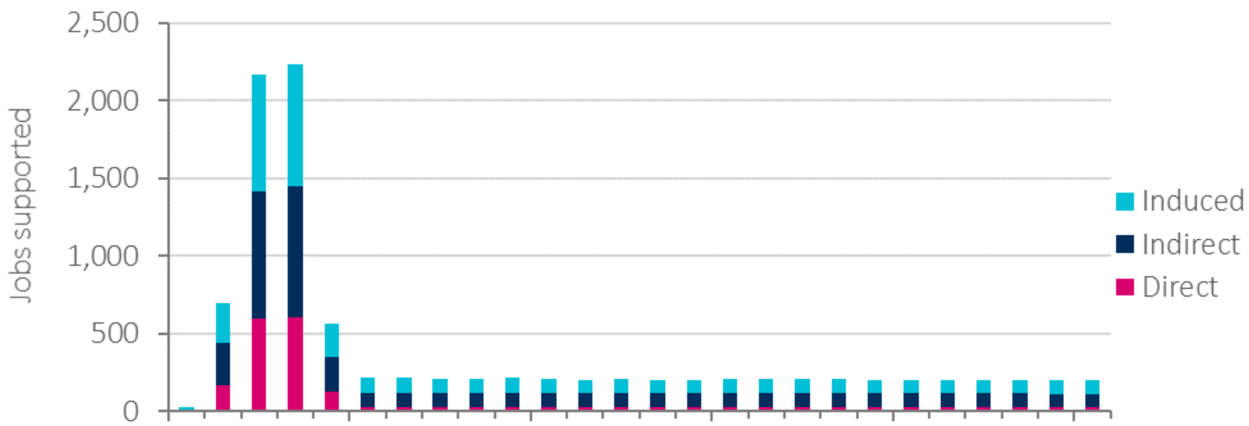
2. **Indirect jobs** are those which are supported by spending in the wider supply chain, such as those supported when the manufacturer of the compressor pays for instrumentation to install on the compressor before it is sent to site for installation.

3. **Induced jobs** are those which are supported by spending in the local economy by employees, such as when the technician commissioning the compressor purchases a coffee at a local restaurant.

1.2 Indirect and induced jobs

The deployment of a 300MW AFC unit at Wilton further supports 1,600 indirect and induced jobs on average during the construction phase. Indirect and induced jobs are a result of supply chain linkages that generate demand for goods and services in the rest of the UK economy, beyond the immediate project expenditure noted in the previous section (see definition in Box 1).[3] As shown in Figure 2, indirect and induced jobs reach a maximum of 840 and 780 jobs respectively as capital expenditure peaks in the same year. In the operation phase, indirect and induced jobs remain stable at over 170 jobs in total each year. The sectoral composition of these indirect and induced jobs is discussed in Section 2.2 as supply chain opportunities are best understood within the context of wider UK deployment. These estimates are also comparable to existing ONS employment multipliers in the economy, where the ratio of indirect jobs to direct jobs on average is slightly larger than 1, with higher ratios in gas distribution and electric power generation.[4]

Figure 2 Direct, indirect, and induced jobs supported by an AFC unit at Wilton



Source: Vivid Economics

[3] Indirect and induced economic jobs are estimated using Vivid's Investment Impact Model (IIM), described in the Appendix.
[4] ONS (2019) - Type I employment multipliers and effects by industry and sector

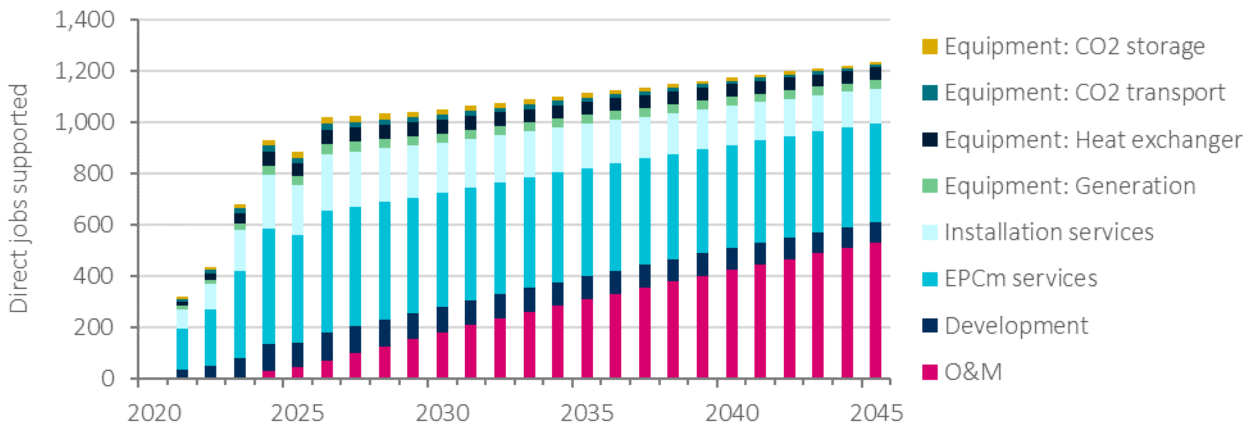
2 Opportunity from wider UK deployment

The AFC technology can be applied widely within the UK by 2050. Under the CCC's 6th carbon budget, the installed electricity generation capacity for gas CCS reaches 15GW by 2050. The deployment scenario considered below assumes that half of this capacity, or 7.5GW, will operate on AFC technology and is built at a constant rate up to 2050. This deployment scenario is therefore anchored on UK's overall climate ambition while being agnostic about the location of individual projects.

2.1 Direct jobs

The deployment of 7.5GW AFC technology generation capacity in the UK could support over 1,050 direct jobs each year by 2030. Under this deployment scenario, the first units in the UK will be commissioned in 2024. By 2030, roughly 17% of direct jobs could be O&M jobs. The remaining 83% goes towards the construction of new AFC generation capacity, most of which in EPC and installation services. This would also include professional services such as engineers, finance, and legal employment, which is critical to the development and deployment of projects. Given the deployment trajectory, direct jobs can exceed 1,200 in the late 2040s. This represents 10-15% of long-run estimates of domestic CCS direct jobs in the EINAs report published by BEIS. Figure 3 below presents the number of direct jobs supported each year. On average, this corresponds to roughly 400 direct jobs during the construction peak of a single AFC unit.[5]

Figure 3 Direct jobs supported by deploying AFC technology in the UK



Source: Vivid Economics

2.2 Indirect and induced jobs

The deployment of AFC technology offers wider economic benefits, including indirect spending in the supply chain and induced spending in the wider economy. Wider economic benefits flow through the economy throughout the construction and operation phase of the facilities. This includes spending in the wider supply chain, as equipment manufacturing causes suppliers to purchase goods and services from some domestic manufacturers, as well as spending in the wider economy as workers purchase goods and services from local businesses such as food and drink, leisure, healthcare, and education.

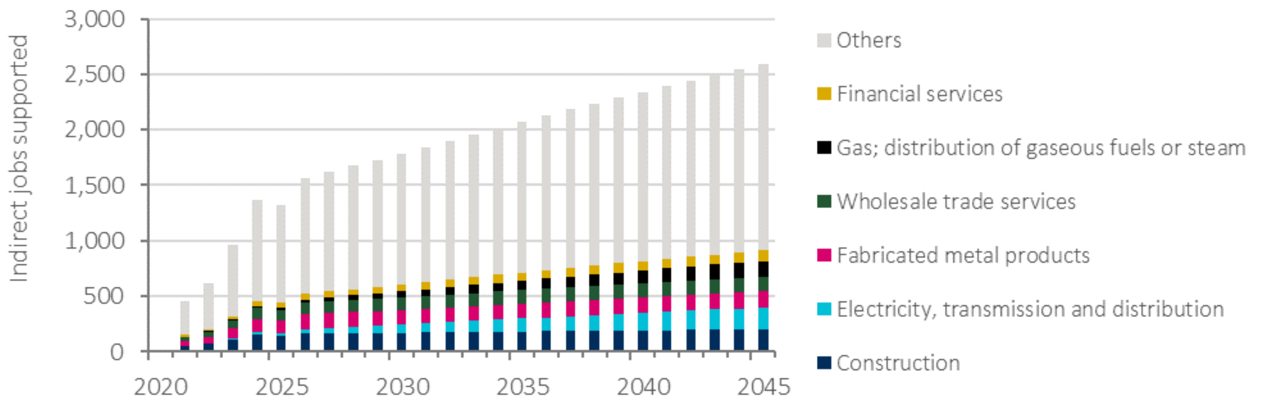
UK deployment of AFC technology could support 1,790 indirect and 1,700 induced jobs each year by 2030. While indirect and induced jobs are spread throughout the economy, some industries are more proximate to the supply chain and could see a greater increase in economic activity. For instance, indirect jobs associated

[5] The estimated number of direct jobs discussed in this report excludes the expenditure on the air separation unit (ASU), which costs roughly £100m each and is necessary for deploying AFC technology. If this is manufactured in the UK, each unit would support roughly 150 jobs during the construction phase. Its operation would support roughly 15 full time jobs each year.

with capital expenditure concentrate on fabricated metal products (7% of all 2030 indirect jobs) and wholesale trade (6%). Indirect jobs associated with operations will concentrate on construction (10%) and electricity (4%). Meanwhile, the spending will lead to extra income and consumption by households, supporting induced jobs that concentrate on retail trade (25% of all 2030 induced jobs), and food and beverage services (19%). Figure 4 and Figure 5 provides a breakdown of indirect and induced jobs over time.

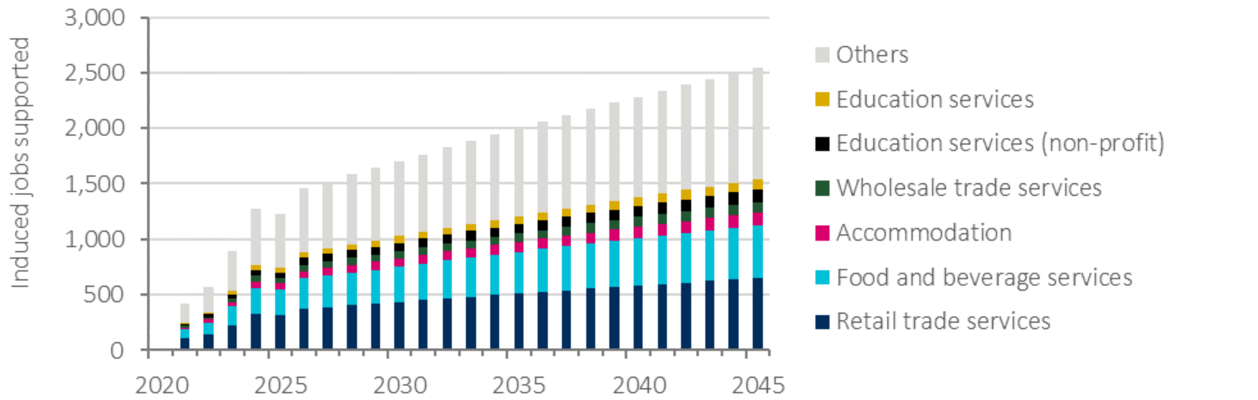
Other studies further indicate a potential for more jobs supported by exporting AFC-related goods and services. While there is currently no analysis for the size of exports related to AFC technology, existing studies suggest that AFC export opportunities can support a larger number of jobs in the UK. The BEIS EINAs report on CCUS, which examines a wide range of power and industrial CCS applications, estimated that UK export jobs can reach 50,000 by 2050 if the UK gains a strong competitive advantage in the area. This is more than five times larger than the number of jobs from deploying the technologies domestically.[6] The AFC project can be used as a hub for the deployment every year of two AFC plants outside the UK from 2027. Design, development, and training of engineers could occur in the use with construction jobs occurring internationally. Moreover, the deployment of each new AFC abroad will directly impact the UK services market as materials will be sourced in the domestic supply chain (e.g., casings). Deploying AFC technology in the UK can contribute to the development of CCS clusters, improving export competitiveness.

Figure 4 Indirect jobs from UK wide deployment of AFC technology, by sector



Note: Others represent jobs spread across many sectors (50+) such as computer programming and education.
Source: Vivid Economics

Figure 5 Induced jobs from UK wide deployment of AFC technology, by sector



Note: Others represent jobs spread across many sectors (50+) such as health services and air transport.
Source: Vivid Economics

[6] BEIS Energy Innovation Needs Assessment (2019) – CCUS report

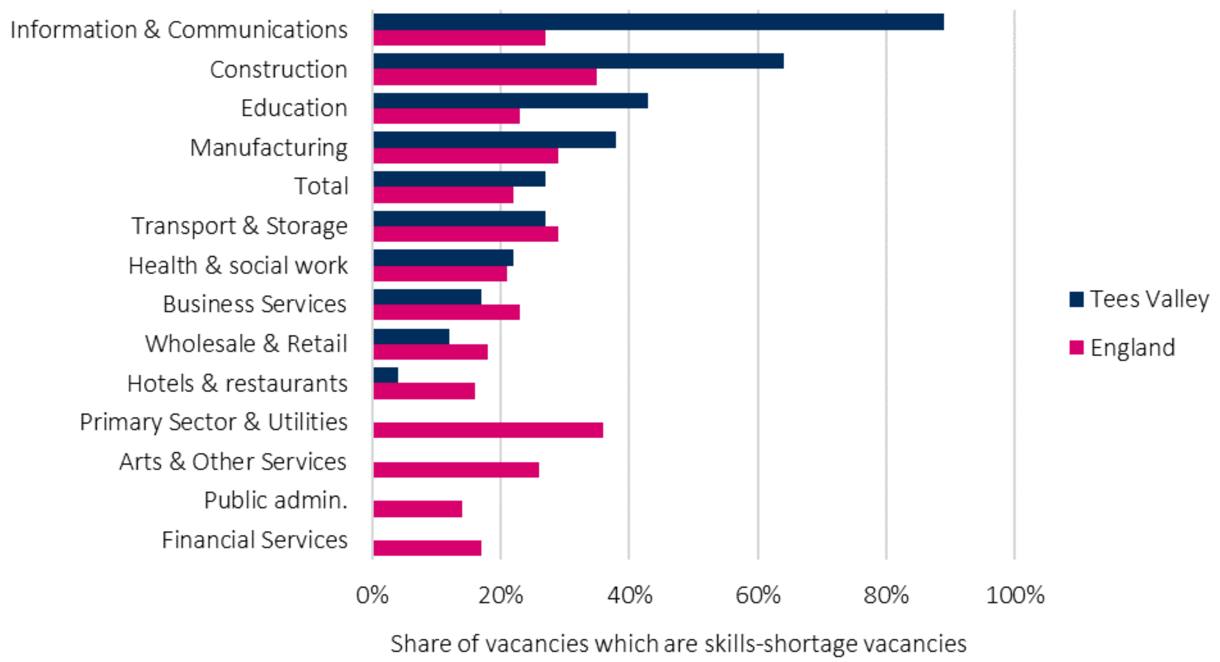
3 Skills gaps

AFC technology offers the opportunity to create high quality jobs. The construction phase will support a variety of high- and low-skilled construction and installation workers and a variety of support roles, but the overwhelming demand will be for skilled trades occupations. The operation phase will demand skilled trades occupations and process, plant, and machine operatives. These jobs are likely to offer workers relatively high wages and a chance to enhance their skills that are in high demand in the green economy. As an example, NET Power has developed an operation simulator to help train workers for the oxyfuel combustion sector.

However, there is currently a specialist skills gap that could widen in the future. This is particularly critical in key industrial clusters. For example, in the Tees Valley, skills shortage vacancies concentrate on skilled trades and professionals according to data from the 2017 Employer Skills Survey by the DfE. As shown in Figure 6, construction and manufacturing are two of the several sectors where skills shortage vacancies are particularly prevalent. In construction, over 60% of vacancies in the Tees Valley were attributed to skills shortages, compared to the national average of 35%.[7] Key sectors such as electricity and gas, engineering and construction will all require more highly qualified workers than currently available in the region. Another study focused on the Humber region also found similar trends.[8]

Enhancing both the regional and national supply of skilled workers in construction and manufacturing will be necessary to unlock the full economic opportunities from CCS. If planned and announced infrastructure investments go ahead across UK industrial clusters, there will be a more acute shortage of construction contractors and workers. Given the existing infrastructure project pipeline and announced infrastructure spending commitments by government, competition for UK contractors and workers is likely to increase to 2025. Upskilling and actively recruiting workers will be essential to provide sufficient labour to the market.

Figure 6. Share of vacancies which are skills-shortage vacancies by sector



Source: Vivid Economics analysis based on Employer Skills Survey by DfE in 2017

[7] Vivid Economics report on "Net Zero Teesside Economic Benefits"
[8] Vivid Economics report on "Capturing Carbon at Drax: Delivering Jobs, Clean growth and Levelling up the Humber"

4 Conclusion

As a key innovation that will lower the cost of decarbonisation within the UK, the deployment of AFC technology can support many jobs within the green economy.

- The planned deployment of a 300MW AFC facility at the Wilton International industrial site can support over 600 direct jobs at the peak of its construction for the first unit deployed. Under a plausible scenario of nationwide deployment, the technology can support close to 1,300 direct jobs in 2030.
- Beyond these direct effects, the deployment of AFC technology can help catalyse the UK economy through spending along the supply chain and the wider economy, supporting a further 2,500 indirect jobs and 2,400 induced jobs in 2030.
- Importantly, some of these jobs will serve as a pillar for the UK's growing CCS supply chain. For instance, the project at the Wilton site can help develop UK manufacturing capacity in advanced heat exchangers and turbine casings. More generally, the deployment of AFC technology can underpin the development of CCS clusters in the UK and support export competitiveness in related technologies.
- Skills gaps are likely to widen in key industrial regions where CCS will be necessary.is considered a priority, such as the Humber and Teesside. Labour shortages in construction and manufacturing may hinder the development of CCS clusters within the UK. Policy measures are required to expand and upskill the existing workforce.
- There is room for further analysis of the economic impact of deploying AFC technology. The indirect and induced job analysis in this report relies on recent input-output tables, hence it is unable to account for future changes in the economic structure. Dynamic general equilibrium models will be more appropriate to investigate long-run economic outcomes.

Appendix: Methodology

Direct benefits

The jobs calculations follow industry-standard methodology, drawing on the same approach as BEIS in the 2019 Energy Innovation Needs Assessments. The methodology breaks down CAPEX and OPEX components to a product or service-specific level, then quantify the UK-captured turnover in the corresponding markets.

1. The markets are sized based on deployment forecasts and cost data of AFC technology and CO_2 transport and storage infrastructure.
2. The tradability of the market is estimated based on current trade data, where available, and informed by expert judgement. This determines how much of the UK market is likely to be accessible to foreign competition and gives a figure for the tradeable market.
3. The UK's market share is estimated based on current trade data, research, and expert consultation.
4. The market size from step (1) is multiplied by tradability estimates in step (2) and the market shares in step (3) to yield an estimate for UK-captured turnover.
5. The captured turnover figure from step (4) is multiplied by a GVA / turnover multiplier which most closely resembles the market to obtain GVA.
6. The GVA figure is divided by productivity figures (GVA per job) for the proximate sectors to obtain the total number of direct jobs.

For estimating the direct jobs from the Wilton site project, step (1) is simplified by using the projected investment profile specific to the project, and market shares under step (3) are adjusted using project-specific estimates of supply sources. Meanwhile, the estimation of direct jobs from UK wide deployment follows steps (1) to (6) in full.

Table 2 Modelling assumptions

Issue	Assumption	Source
Wilton site deployment	A 300MW unit with the provided construction schedule.	Provided by 8Rivers
UK deployment	UK gas CCS capacity reaches 15GW by 2050.	CCC 6th Carbon Budget
UK deployment	50% of UK gas CCS capacity in 2050 runs on Allam Fetvedt Cycle technology. Constant build rate leading up to 2050.	Simplifying assumption based on the relative advantage of AFC
CO_2 T&S infrastructure deployment	For each 100 MW of generation capacity, a corresponding CO_2 T&S infrastructure capacity of 0.29MtCO_2 per annum is required.	Technology specification from 8Rivers
Costs/ expenditure	CAPEX and OPEX breakdown per MW; LCOE	Provided by 8Rivers, confidential
Tradability & UK market share	For each equipment type, trade data for proximate HS-6-digit product codes were extracted to calculate UK domestic market share. For each service type, market shares assumed were drawn from EINA reports. 2016-2018 three-year averages were used.	COMTRADE; BEIS Energy Innovation Needs Assessment (EINA)
Ratios between turnover, GVA and employment	For each equipment and service type, data were estimated based on proximate SIC sector codes were identified. 2016-2018 three-year averages were used.	ONS Annual Business Survey

Source: Vivid Economics

Indirect and induced benefits

Indirect and induced benefits are estimated using the Vivid Investment Impact Model (IIM). For the UK economy, the model is calibrated to account for the interactions between 127 sectors, to provide an accurate picture of the supply chain impacts.

The IIM estimates the impact on GDP of an increase in output, based on the existing average technology observed in the I/O tables from the ONS. The tables take the form of a square matrix, where outputs are calculated down the columns of the matrix, and inputs fed in via rows (that is, column X gives the output of sector X, while row X gives the sectors that use sector X as an input). The I/O table approach provides a complete high-level picture of the UK economy, including economic activity in 127 sectors and household consumption. GDP effects can be extracted using either the final demand or factor payments.

From the I/O tables, we built a schematic representation of all transactions happening in the UK economy, in the form of a Social Accounting Matrix (SAM). The SAM is easier to interpret as all economic agents are represented in a single matrix: firms, households, government, and foreign sector. Yet, the relationships are those provided by the I/O tables, so both terms can be used interchangeably. The column header is the buyer and the row header the seller. Hence, activities (firms) buy inputs from domestic output and imported goods, which taken together amount to the total intermediate demand. Similarly, activities need inputs from the factors of production to produce (labour and capital).

The model implicitly makes three major assumptions:

- **Constant returns to scale as production is increased:** in other words, the empirical technology observed in the I/O tables is assumed to be the same at any level of production.
- **Slack capacity:** there is enough underused capacity in the economy to scale up production without requiring additional investment.
- **Fixed prices:** the model does not allow for price adjustments. This assumption is critical, as the model does not consider substitution effects between inputs, but rather assumes they will always be used in the same proportions. In the short run, this is a reasonable assumption, yet in the longer run, prices will adjust to reflect the increase in demand. As a result, the estimated impact is likely to be slightly larger than the actual effect after prices adjusts (upwards) and should be taken as an upper-bound estimate in the long run.

The indirect and induced impact is modelled as a positive production shock to sectors involved with deploying AFC facilities and related carbon dioxide transport and storage infrastructure. We calibrate a series of modules to assess the indirect and induced distributional effects:

- **Gross Value Added (GVA):** we transform the total impact on domestic production into GVA by netting out all domestic and imported inputs required to produce the total domestic impact. This is equivalent to adding factor payments together, that is labour and capital, and adjusting for indirect taxes. Estimating the indirect impact requires exhausting all the higher-order effects (i.e., remove the value of the inputs, etc). This exercise also allows for isolation of the total increase in domestic demand for intermediate inputs. From there we get induced effect by removing from the total domestic impact both the initial investment shock and intermediate domestic inputs. Finally, to transform induced production into induced GVA, we net out the value of inputs until exhaustion.
- **Employment:** first we estimate the increase in total labour payments in each sector. We combine this output with the latest data on average salaries per sector from the ONS to estimate the employment impact. Using the indirect and induced effects described above, we also produce the job estimates using that level of disaggregation into 127 sectors.

Reference

BEIS. (2019). Sub-theme report: Carbon capture, utilisation, and storage. In *Energy Innovation Needs Assessment*. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/845655/energy-innovation-needs-assessment-ccus.pdf

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Company profile

Vivid Economics is a leading strategic economics consultancy with global reach. We strive to create lasting value for our clients, both in government and the private sector, and for society at large.

We are a premier consultant in the policy-commerce interface and resource- and environment-intensive sectors, where we advise on the most critical and complex policy and commercial questions facing clients around the world. The success we bring to our clients reflects a strong partnership culture, solid foundation of skills and analytical assets, and close cooperation with a large network of contacts across key organisations.

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8 RIVERS

NETPOWER CCUS OWNERS ENGINEER

HAZID Report

70053760-WSP-0001-RP-PE-0002-S0_P02
AUGUST 2020

CONFIDENTIAL

8 RIVERS

NETPOWER CCUS OWNERS ENGINEER

HAZID Report

REPORT (VERSION P02) CONFIDENTIAL

PROJECT NO. 70053760

OUR REF. NO. 70053760-WSP-0001-RP-PE-0002-S0_P02

DATE: AUGUST 2020

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QUALITY CONTROL

Issue/revision	First issue	Revision 1	Revision 2	Revision 3
Remarks	Interim Report Issue	Final Report Incorporating Client Comments		
Date	31/07/2020	25/08/2020		
Prepared by	Lauren Lavery	Lauren Lavery		
Signature				
Checked by	Andy Mustoe	Andy Mustoe		
Signature				
Authorised by	Ben Clarke	Ben Platt		
Signature				
Project number	70053760	70053760		
Report number	70053760-WSP-0001-RP-PE-0002-S0_P01	70053760-WSP-0001-RP-PE-0002-S0_P02		
File reference				

CONTENTS

Tables

APPENDICES

Executive Summary

The HAZID study for the proposed NetPower, Allam - Fetvedt cycle plant in the UK was held on 23rd / 24th July 2020 as a virtual Formal Process Safety Study using Microsoft Teams due to COVID-19 restrictions on face-to-face meetings in the United Kingdom.

The HAZID study was completed covering two different time zones and so two sessions were held over a two-day period. A total of 15 team members were present at the meeting involving the Client - 8 Rivers, Designer - McDermott and WSP as the Owners Engineer and provider of the HAZID Chair and Scribe. A list of attendees may be found in Section 2.1 of this report.

The HAZID study comprised a pre-agreed set of guidewords, which may be found in Section 3.2 of this report, and nodes, found in Section 1 of the Report.

In total, **8 HAZID** actions were identified and recorded during the study. The HAZID actions were circulated to the action holders and have been closed out with signed responses received by WSP**.** The completed action sheets may be found in Appendix D.

Some actions and their requisite responses contained within this report, are not able to be completely closed out at this stage of the project, at least until the Front-End Engineering Design (FEED) phase takes place. It was agreed with the attendees that actions could be closed (for the purposes of this report) by appending them to the pre-FEED risk register or including in the pre-FEED report as issues that need to be included in the FEED scope, and then reviewing the items again at the FEED HAZID/HAZOP study where further design, to a higher level, will be carried out.

The HAZID focused on the Allam - Fetvedt cycle in the context of a UK commercially deployed power plant to UK/EU acceptable legislation, codes, standards and practices. The HAZID will form the basis of the HAZOP, which should be completed during the FEED and will then encompass the site-specific aspects of the project when they are fully understood.

It was agreed once a site location for the NetPower project is confirmed, and FEED Design commences, then a further site-specific HAZID should be performed.

1. PROCESS AREAS

The purpose of this report is to detail and record the findings of a Hazards Identification (HAZID) study performed on 23rd / 24th July 2020. Hazards, risks and mitigation measures were identified for the design and operation of a proposed NetPower, Allam - Fetvedt cycle plant in the UK on a non-specific, generic site, where the necessary utility inputs and outputs of the plant are assumed to be available for use at the required process conditions with no restrictions, such as a large industrial cluster or similar location.

For the purposes of the HAZID study, the system was broken down into four nodes based on a combination of plant layout and process systems.

The four nodes as defined were:

- **Node 1 – NET Power Allam-Fetvedt Cycle**
  Combustion Turbine Generator; Recompression System; Recuperative Heat Exchanger; Hot Gas Compression; Water Separation System; Oxidant System
- **Node 2 – Other Process Systems**
  Oxygen Supply; Fuel Gas System; Hydrogen System; Plant Vent
- **Node 3 – Support Systems**
  Cooling Water System; CO2 Storage System; Main Electrical Systems (frequency converters)
- **Node 4 – Utilities**
  Plant water & Raw Water; Turbine Gland Seal; Fire Protection System; Instrument Air; Potable Water; Effluents & Drains; Essential Power (Diesel Generators); Control Room

During the HAZID study it was agreed with the study team members that Node 1 would be considered first as a stand-alone node, separately, and Node 2, 3 and 4 would be considered on the second day by considering each guideword and then each node in turn before moving on to the next guideword.

N.B. It should be noted that in allowing for the Pre-FEED stage of design, that the HAZID study was not site-specific and considered a generic site layout that is anticipated to be feasible for any location.

2. HAZID STUDY DETAILS

2.1. HAZID STUDY TEAM

Table 1 - HAZID Study Team Day 1

Name	Designation	Organisation
Andy Mustoe	Chair	WSP
Lauren Lavery	Scribe	WSP
Ben Platt	WSP Project Manager	WSP
Rob Makin	Mechanical Engineer	WSP
Scott Armstrong	Control and Instrumentation Engineer	WSP
Simon Smith	NetPower UK Project Engineering Manager	McDermott
Ping Yang	Safety & Environmental Engineer	McDermott
John Bolton	Mechanical Engineer	McDermott
Julia Turner	NetPower UK Process Engineer	McDermott
Jason Garrett	Project Engineering Manager	McDermott
Ali Abdallah	Electrical Engineer	McDermott
Stephen Jansen	Control and Instrumentation Engineer	McDermott
Daniel McKenzie	NetPower Project Manger	McDermott
Jeremy Fetvedt	Chief Engineer	8 Rivers
Brock Forrest	Chief Engineer NetPower	8 Rivers

Table 2 - HAZID Study Team Day 2

Name	Designation	Organisation
Andy Mustoe	Chair	WSP
Lauren Lavery	Scribe	WSP
Rob Makin	Mechanical Engineer	WSP
Scott Armstrong	Control and Instrumentation Engineer	WSP
Simon Smith	NetPower UK Project Engineering Manager	McDermott
Ping Yang	Safety & Environmental Engineer	McDermott
John Bolton	Mechanical Engineer	McDermott
Julia Turner	NetPower UK Process Engineer	McDermott
Jason Garrett	Project Engineering Manager	McDermott
Ali Abdallah	Electrical Engineer	McDermott
Daniel McKenzie	NetPower Project Manger	McDermott
Jeremy Fetvedt	Chief Engineer	8 Rivers
Brock Forrest	Chief Engineer NetPower	8 Rivers

COVID-19 restrictions in the UK at the time of the HAZID study, prevented a face-to-face format which had been in the original project agreement. Therefore, the HAZID study took place over two five-hour sessions on the 23rd and 24th of July 2020, virtually using Microsoft Teams. The two sessions were required as the meeting was being held across two different time zones with team members present in both the U.S.A. and U.K.

3. HAZID STUDY

3.1. METHODOLOGY

The HAZID study, which was conducted by Chairperson (Andy Mustoe - WSP), used a pre-prepared list of HAZID study guidewords which were pre-selected and agreed upon prior to the study to specifically highlight reasonable and foreseeable hazardous events in the NetPower project (non-site specific).

Each guideword was considered in turn for each node. The study identified hazards related to a guideword, then considered any safeguards that are already present and included in the design. If any additional safeguard not already in place was identified and required, an action was raised against the team member most suited to take the action and report back. Actions were raised by the production of an action sheet (see Appendix D).

Reference documents on which the HAZID were based on are detailed in Section 3.3.

3.2. HAZID GUIDEWORDS

The following guidewords were used in the HAZID study:

- Loss of Containment
- External Fire
- Internal Fire
- Unconfined Explosion
- Internal Explosion
- Physical Overpressure / Underpressure
- Overtemperature
- Moving Objects
- Acute Exposure
- Chronic Exposure
- Release to Environment
- Violent Energy Release
- Noise
- Visual Impact
- Electricity
- Severe Weather / Natural Events
- Third Party Interference
- Utilities and Services
- Human Factors / Working Environment
- Construction / Commissioning
- Start-Up / Shut down/Maintenance
- Major Financial Effect (n.b. It was agreed by the team that this would not be used as there will be a separate commercial risk workshop. Refer to the Project Risk Register, document reference 70053760-WSP-00-XX-RG-PM-0002-S0)

3.3. REFERENCE DOCUMENTATION

The following documents were used for reference when studying each node:

Table 3 - HAZID Reference Drawings

202000624 NET POWER COMMERCIAL PLANT PFD REV 10 (UK BEIS)	NetPower Allam Cycle Process Flow Diagram
626236060-000-PI-01-000001_Plot Plan	NetPower Plot Plan
626236060-000-PI-01-000001 (Nodes)	NetPower Plot Plan Considering HAZID Nodes
NET POWER UK BEIS HMB DATA	NetPower Heat and Mass Balance Data

3.4. RECORD OF STUDY

Specific hazards and their causes together with preventive and protective measures identified as part of a HAZID study are presented on the HAZID study record sheets which may be found in in Appendix C of this report.

3.5. HAZID ACTIONS

A total of 8 actions were raised during the HAZID Study. Table 4 shows the actions raised and if they have been completed.

Table 4 – Action Information

Action No.	Node	Guideword	Action	By	Responded
1	1	Physical Overpressure/ Underpressure	Clarify general overpressure protection philosophy for the project	Jason Garrett	Yes
2	1	Overtemperature	Consider closed loop cooling on critical locations	Jason Garrett	Yes
3	1	Moving Objects	Include item on high level traffic management in pre-FEED report	Jason Garrett	Yes
4	1	Noise	Ensure FEED scope of works includes noise analysis	Jason Garrett	Yes
5	1	Severe Weather/ Natural Events	Consider anticipated (severe weather/natural events) climate change effects within the risk register	Jason Garrett	Yes
6	1	Start-Up/ Shut-Down /Maintenance	Ensure and agree a process for knowledge transfer from demonstration plant	Brock Forrest	Yes
7	2	Loss of Containment	Review gas detection requirements for unodourised gas at HP (high pressure) within site	Jason Garrett	Yes
8	2	Loss of Containment	Review stand-off distances from hydrogen trailer to adjacent plant and equipment	Jason Garrett	Yes

The nature of some actions identified, and the requisite responses contained within this report, are not able to be completely closed out, at least until the Front-End Engineering Design (FEED) phase of the project takes place. It was agreed, when this was the case, the actions could be closed (for the purposes of this report) by appending them to the pre-FEED risk register or including in the pre-FEED report as issues that need to be included in the FEED scope, and then reviewing the items again at the FEED HAZID/HAZOP study where further design, to a higher level, will be carried out.

The completed action sheets arising from the discussion may be found in Appendix D of this report.

Appendix A

AGENDA (INCLUDING STUDY GUIDEWORDS)

AGENDA & MEETING NOTES

PROJECT NUMBER	70053760	**MEETING DATE**	23 July 2020
PROJECT NAME	8 Rivers CCUS Owners Engineer	**VENUE**	Microsoft Teams
CLIENT	8 Rivers	**RECORDED BY**	LL
MEETING SUBJECT	HAZID Study		

PRESENT	Andy Mustoe (Chair -WSP), Rob Makin (WSP), Scott Armstrong (WSP), Lauren Lavery (Scribe-WSP), Steve Milward (8 Rivers), Jeremy Fetvedt (8 Rivers), Brock Forrest (8 Rivers), Simon Smith (McDermott), Ping Yang (McDermott), John Bolton (McDermott), Julia Turner (McDermott), Jason Garrett (McDermott), Ali Abdallah (McDermott), Daniel McKenzie (McDermott)
APOLOGIES	Apologies
DISTRIBUTION	As above plus:
CONFIDENTIALITY	**Confidential**

ITEM	SUBJECT	ACTION	DUE
	Day 1 (23/07/20)		
1	Welcome and introductions		
2	Overview of HAZID process		
3	Project description/ scope of work		
4	Commence HAZID analysis		
5	15-minute break		
6	End day at 17:00 (12:00 in Charlotte)		
	Day 2 (24/07/20)		
7	Recommence HAZID		
8	15-minute break		
9	Target Completion time at 16:45 (11:45 in Charlotte)		
10	Wrap up/ review/ next steps		

NEXT MEETING

An invitation will be issued if an additional meeting is required.

HAZID GUIDEWORDS

Table 1 - HAZID Guidewords

Loss of Containment	External Fire	Internal Fire	Unconfined Explosion
Internal Explosion	Physical Overpressure/ Underpressure	Overtemperature	Moving Objects
Acute Exposure	Chronic Exposure	Release to Environment	Violent Energy Release
Noise	Visual Impact	Electricity	Severe Weather/ Natural Events
Third Party Interference	Utilities and Services	Human Factors/ Working Environment	Construction/ Commissioning
Start-Up/Shut-down/Maintenance	Major Financial Effect		

NODES

Node 1 - NET Power Allam-Fetvedt Cycle

Combustion Turbine Generator; Recompression System; Recuperative Heat Exchanger; Hot Gas Compression; Water Separation System; Oxidant System

Node 2 – Other Process Systems

Oxygen Supply; Fuel Gas System; Hydrogen System; Plant Vent

Node 3 – Support Systems

Cooling Water System; CO_2 Storage System; Main Electrical Systems (frequency converters)

Node 4 – Utilities

Plant water & Raw Water; Turbine Gland Seal; Fire Protection System; Instrument Air; Potable Water; Effluents & Drains; Essential Power (Diesel Generators); Control Room

Appendix C

HAZID MINUTES

HAZID STUDY	**Project Number:** 70053760 **Node:** 1,2,3 & 4 **System Title:** CCUS Owners Engineer	8RIVERS	**Chair: Andy Mustoe** **Scribe: Lauren Lavery** **Date:** 23-24/07/2020
	Details: Node 1 - NET Power Allam-Fetvedt Cycle Node 2 - Other Process Systems Node 3 - Support Systems Node 4 - Utilities	**Team Members:** Andy Mustoe (Chair -WSP), Rob Makin (WSP), Scott Armstrong (WSP), Lauren Lavery (Scribe-WSP), Ben Platt (WSP), Jeremy Fetvedt (8 Rivers), Brock Forrest (8 Rivers), Simon Smith (McDermott), Ping Yang (McDermott), John Bolton (McDermott), Julia Turner (McDermott), Jason Garrett (McDermott), Ali Abdallah (McDermott), Daniel McKenzie (McDermott), Stephen Jansen (McDermott)	**Action Responses:** Andy Mustoe

DEVIATION		CAUSE	CONSEQUENCE	SAFEGUARDS	ACTION NO.	ACTION	ACTION BY	RESPOND BY
1. LOSS OF CONTAINMENT								
				NODE 1				
1.01	Node 1	Piping system failure on carbon dioxide systems	asphyxiation, burns (hot/cold), toxic reaction (accute), injury, fatalities,	design to relevent design codes and standards, relief valves, adhere to UK statutory and legislative requirements, PED, PSSR, gas detection monitoring, written scheme of examination				
1.02	Node 1	Piping system failure on oxygen and oxidant systems	enhanced combustion of materials external to system, auto-ignition of pipe insulation and /or other material in immediate vicinity, asphyxiation, burns (hot/cold), chronic illness, physical injuries and fatalities	design to relevent design codes and standards, relief valves, adhere to UK statutory and legislative requirements, PED, PSSR, written scheme of examination, instrumentation would detect loss of containment, piping layout to minimise risk were possible,				
1.03	Node 1	lube oil and hydraulic tanks	environmental incident, toxic to people, possible turbine machinery failure	all tanks will be bunded with 110% capacity (UK), tank level instrumentation				
1.04	Node 1	breach of process stream on heat exchangers (recuperative heat exchanger)	irregularity of composition and temperature of various streams	heat exchanger will be of proprietary design				

DEVIATION		CAUSE	CONSEQUENCE	SAFEGUARDS	ACTION NO.	ACTION	ACTION BY	RESPOND BY
1. LOSS OF CONTAINMENT								
				NODE 2				
1.05	Node 2	Piping system rupture oxygen	enhanced combustion of materials external to system, auto-ignition of pipe insulation and /or other material in immediate vicinity, asphyxiation, burns (hot/cold), chronic illness, physical injuries and fatalities	design to relevent design codes and standards, relief valves, adhere to UK statutory and legislative requirements, PED, PSSR, written scheme of examination, instrumentation would detect loss of containment, piping layout to minimise risk were possible,				
1.06	Node 2	piping system rupture fuel gas, piping system and equipment rupture	fuel gas cloud, equipment damage, possible ignition, resulting explosion, possible fatality	design to relevent design codes and standards, relief valves,adhere to UK statutory and legislative requirements, PED, PSSR, written scheme of examination, hazardous area classification calculations	7	Review gas detection requirements for unodourised gas at HP within site.	Jason Garrett	14.08.20
1.07	Node 2	rupture from hydrogen fuel tank	hydrogen gas cloud, equipment damage, possible ignition, resulting explosion, possible fatality	hydrogen trailers supplied by reputable supplier	8	Review stand off distances from hydrogen trailer to adjacent plant and equipment.	Jason Garrett	14.08.20
1.08	Node 2	traffic issues when swapping over hydrogen trailers	risk to personnel and hydrogen trailer, risk of damage and rupture of trailer	see action Item 8.0 Moving Objects, 8.1 Node 1 on traffic management				
1.09	Node 2	plant vent - not applicable	plant vent - not applicable	plant vent - not applicable				

DEVIATION		CAUSE	CONSEQUENCE	SAFEGUARDS	ACTION NO.	ACTION	ACTION BY	RESPOND BY
1. LOSS OF CONTAINMENT								
				NODE 3				
1.10	Node 3	rupture of cooling water system	potential for localised flooding, lack of cooling to necessary equipment, potential for plant shutdown	designing to relevent codes and standards, plant shutdown, control system will detect loss of cooling water, make up water system for leakage, site levels promote drainage				
1.11	Node 3	rupture/leakage from carbon dioxide storage and vapourisers	asphyxiation, burns (cold), toxic reaction (accute), injury, fatalities, potential equipment failure, carbon dioxide ingress to air intakes on adjacent plant and equipment	design to relevent design codes and standards, relief valves, adhere to UK statutory and legislative requirements, PED, PSSR, gas detection monitoring, written scheme of examination, storage location away from air intakes				
1.12	Node 3	transformer oil leakage	environmental issue, overheating and potential fire	containment, I&C systems to alert control room				
1. LOSS OF CONTAINMENT								
				NODE 4				
1.13	Node 4	turbine gland seal	asphyxiation, burns (cold), toxic reaction (accute), injury, fatalities, potential equipment failure, carbon dioxide ingress to air intakes on adjacent plant and equip	design to relevent design codes and standards, relief valves, adhere to UK statutory & legislative requirements PED, PSSR, gas detection monitoring, written scheme of examination, storage location away from air intakes				

DEVIATION		CAUSE	CONSEQUENCE	SAFEGUARDS	ACTION NO.	ACTION	ACTION BY	RESPOND BY
2. EXTERNAL FIRE								
				NODE 1				
2.01	Node 1	various causes of fire within node 1	facility shutdown, loss of pressure boundary, ignition/explosion, personnel injury/fatalities,	fire detection/suppression systems installed, handheld fire extinguishers, fire walls for specific equipment, fire proofing where appropriate,		note: fire fighting plan should be considered for specific site.		
2. EXTERNAL FIRE								
				NODE 2				
2.02	Node 2	external fire in vicinity of hydrogen tanker	overpressure of tanker vessel leading to rupture or explosion	hydrogen tanker is in area with sufficient stand off distance from adjacent equipment, fire and explosion assessment included in FEED				
2. EXTERNAL FIRE								
				NODE 3				
2.03	Node 3	fire in vicinity of carbon dioxide storage tank	over pressure of tank leading to possible rupture	pressure relief system activated, fire detection system				
2. EXTERNAL FIRE								
				NODE 4				
2.04	Node 4	diesel generator leakage	loss of diesel generator, possible injury to personnel	smoke/heat detectors within package container, double bunded tank, bunded container, diesel fire pump				
2.05	Node 4	diesel fire pump	loss of diesel pump, possible injury to personnel, potential loss of fire water	smoke/heat detectors within package container, double bunded tank, bunded container				
2. EXTERNAL FIRE								
				NODE 2, 3 & 4				
2.06	Nodes 2,3 & 4	various causes of fire within node 2/3/4	facility shutdown, loss of pressure boundary, ignition/explosion, personnel injury/fatalities	fire detection/suppression systems installed, handheld fire extinguishers, fire walls for specific equipment, fire proofing where appropriate				

DEVIATION		CAUSE	CONSEQUENCE	SAFEGUARDS	ACTION NO.	ACTION	ACTION BY	RESPOND BY
3. INTERNAL FIRE								
				NODE 1				
3.01	Node 1	inappropriate materials of construction in oxygen enriched and/or in high temperature oxygen enriched fluid service	loss of containment	use existing standards, use competent design organisations experienced with relevent oxygen systems, concentrate high risk services to local area as possible				
3.02	Node 1	deficient design of pure oxygen interface service	possibilty of catastrophic failure	use specialist consultant/sub-contractor for the design and installation				
3. INTERNAL FIRE								
				NODE 3				
3.03	Node 3	HV oil filled transformer fire	fire impact on adjacent plant/equipment	fire walls and containment, fire protection according to standard regulations/legislation/BS standards				
3.04	Node 3	LV non-oil filled transformer	smoke, possible fire	fire protection according to standard regulations/legislation/BS standards				
3.05	Node 3	internal building fire	smoke, damage to equipment, injury, plant shutdown	fire protection according to standard regulations/legislation/BS standards, fire detection systems				

DEVIATION		CAUSE	CONSEQUENCE	SAFEGUARDS	ACTION NO.	ACTION	ACTION BY	RESPOND BY
4. UNCONFINED EXPLOSION								
				NODE 1				
4.01	Node 1	explosion from hydrogen release from generator	catastrophic failure, fatality/injury	hydrogen detection, loss of seal oil, hydrogen vents to atmosphere at safe location, carbon dioxide automatically injected to make it safe, low purity shutdown also				
4. UNCONFINED EXPLOSION								
				NODE 2				
4.02	Node 2	explosion from hydrogen release	hydrogen gas cloud, equipment damage, possible ignition, resulting explosion, possible fatality	hydrogen trailers supplied by reputable supplier, control of ignition sources				
4.03	Node 2	explosion from natural gas release	natural gas gas cloud, equipment damage, possible ignition, resulting explosion, possible fatality	fuel gas materials and design to recognised codes and standards, see loss of containment above also, control of ignition source (ATEX, DSEAR)				
5. INTERNAL EXPLOSION								
				NODE 1				
5.01	Node 1	incorrect oxidant fuel mixture can lead to internal explosion	internal explosion leading to damage upsteam/downsteam of turbine	turbine protection system, flame scanners, combustion monitoring				
5. INTERNAL EXPLOSION								
				NODE 3				
5.02	Node 3	ignition of hydrogen within battery room	acid leakage, injury, fatality, damage to building, loss of UPS	battery room requires hazardous area assessment, hydrogen detection system, forced ventilation				

DEVIATION		CAUSE	CONSEQUENCE	SAFEGUARDS	ACTION NO.	ACTION	ACTION BY	RESPOND BY
6. PHYSICAL OVERPRESSURE/UNDERPRESSURE								
NODE 1								
6.01	Node 1	overpressure of carbon dioxide and oxidant system	loss of containment, pipe rupture, damage to downstream components	design to relevent design codes and standards, relief valves, adhere to UK statutory and legislative requirements, PED, PSSR, gas detection monitoring, written scheme of examination, pressure regulating valves	1	Clarify general overpressure protection philosophy for the project,	Jason Garrett	14.08.20
6.02	Node 1	lube oil pressure low	damage bearings and turbine machinery outage	emergency DC oil pumps				
6.03	Node 1	underpressure carbon dioxide lines following rapid pressure reduction	icing, brittle failure through cold temp, exceeds low design temp, brittle fracture,	pressure control systems with redundancy to prevent underpressure where necessary				
6.04	Node 1	underpressure of oxidant and/or fuel gas supply to combustion chamber	incomplete combustion, unintended exhaust emissions, increased carbon monoxide and methane, accumulation of combustible gases within oxidant system leads to explosion risk	plant chemistry monitoring which would trip plant, pressure control with redundancy,				
6. PHYSICAL OVERPRESSURE/UNDERPRESSURE								
NODE 3								
6.05	Node 3	vaccum in CO2 storage tanks	tank collapse, injury/fatality,	tank designed for vacuum conditions, design codes and standards				

DEVIATION		CAUSE	CONSEQUENCE	SAFEGUARDS	ACTION NO.	ACTION	ACTION BY	RESPOND BY
6. PHYSICAL OVERPRESSURE/UNDERPRESSURE								
				NODE 4				
6.06	Node 4	pressure control systems failure (overpressure)	see individual fluid loss of containment above					
6.07	Node 4	vacuum in fire protection tank (inadequate vent sizing)	tank collapse, injury/fatality	design codes and standards, maintenance				
6.08	Node 4	gland seal underpressure	loss of positive pressure at turbine gland seals, undesirable operating conditions (no personnel hazard consequence)	gland seal pressure instrumentation detects underpressure				
7. OVERTEMPERATURE								
				NODE 1				
7.01	Node 1	heat exchanger fouling	loss of plant efficiency, tripping of plant and equipment, plant damage and shutdown	chemcial dosing of cooling water system, regular cleaning	2	consider closed loop cooling on critical locations	Jason Garrett	14.08.20
7.02	Node 1	failure of intercooler/aftercooler water system	loss of plant efficiency, tripping of plant and equip, plant damage and shutdown,	design margins for cooled machinery, I&C to detect high cooling water temps, redundancy where appropriate on cooling water equipment, control room HMI will display alarms				
7.03	Node 1	failure of circulating pump on the recirculation cooler (See node 3)	failure of circulating pump on the recirculation cooler (See node 3)	failure of circulating pump on the recirculation cooler (See node 3)				
7.04	Node 1	failure of suction cooler	excessive temp HGC, possible HGC compressor trip,	suction cooler not employed during normal conditions, temperature monitoring of outlet cooler				
7.05	Node 1	turbine fails to properly regulate fuel injection	excessive temperature rise at turbine outlet, turbine damage, loss of containment, equipment damage, catastrophic failure, injury/fatality	turbine protection system will protect turbine from any damage, balance of plant , DCS ESD will self protect plant				

DEVIATION		CAUSE	CONSEQUENCE	SAFEGUARDS	ACTION NO.	ACTION	ACTION BY	RESPOND BY
7.0 OVERTEMPERATURE								
				NODE 3				
7.06	Node 3	inadequate operation of cooling water system leading to higher than required cooling water	loss of plant efficiency, tripping of plant and equipment, plant damage and shutdown	design margins for cooled machinery, I&C to detect high cooling water temperatures, redundancy where appropriate on cooling water equipment, control room HMI will display alarms				
7.07	Node 3	loss of refrigeration to carbon dioxide tank	overpressure of tank, potential rupture, loss of containment, injury/fatality	overpressure protections, controlled venting,				
8. MOVING OBJECTS								
				NODE 1				
8.01	Node 1	vehicle movements	personnel injury, damage to plant	separation of pedestrian and plant	3	Include item on high level traffic management in pre-FEED report	Jason Garrett	14.08.20
8.02	Node 1	rotating machinery	injury, possible fatality	coupling guards, secure area for main generator coupling, equipment specification including guards, operation permit to work				
8. MOVING OBJECTS								
				NODE 2, 3 & 4				
8.03	Nodes 2,3 & 4	mobile plant movement during normal operations	injury/fatality, damage to equipment	vehicle protection (bollards/barriers)				
8.04	Nodes 2,3 & 4	rotating equipment (see node 1 item 8.2)	rotating equipment (see node 1 item 8.2)	rotating equipment (see node 1 item 8.2)				

DEVIATION		CAUSE	CONSEQUENCE	SAFEGUARDS	ACTION NO.	ACTION	ACTION BY	RESPOND BY
9. ACUTE EXPOSURE								
				NODE 3				
9.01	Node 3	legion diease from cooling towers	serious illness/fatality	regular biocidal dosing of cooling water circuit				
9. ACUTE EXPOSURE								
				ALL NODES				
9.02	All Nodes	carbon dixoxide caustic materials, hydrochlorides, acids, etc	burns, corrosive, acid burns etc, biological impairment	material safety data sheets, COSHH, eye wash stations, safety showers				
10. CHRONIC EXPOSURE								
				ALL NODES				
10.01	All Nodes	low level permissble equipment leakage	exposure of elevated levels of substances hazardous to health	upgraded designs for ingress instead of egress, force ventilation where appropriate, approriate PPE where other measures are not possible, camera monitoring systems, gas monitoring,				
10.02	All Nodes	ionising radiation exposure during construction /testing	radiation sickness, cancer risk,	NDT procedures, dose badge, complying with ionising radiation regulations (2017)				
10.03	All Nodes	dosing chemicals	long term occupational health	appropriate venting, material safety data sheets, COSHH assessments				

DEVIATION		CAUSE	CONSEQUENCE	SAFEGUARDS	ACTION NO.	ACTION	ACTION BY	RESPOND BY
11.0 RELEASE TO ENVIRONMENT								
				NODE 1				
11.01	Node 1	incorrect oxidant fuel mixture can lead to internal explosion	internal explosion leading to damage upsteam/downsteam of turbine	turbine protection system, flame scanners, combustion monitoring				
11.02	Node 1	water seperation drainage - incomplete combustion	leading to contamination of water	contamination minimal with no adverse to plant operation				
11.03	Node 1	venting/purging of oxygen systems	enhanced combustion risk, hazard to human health	route vent discharges to safe location				
11.0 RELEASE TO ENVIRONMENT								
				NODE 2				
11.04	Node 2	plant vent emissions containing carbon dioxide during startup/shutdown	carbon dioxide gas cloud	disperation modelling, use vents with appropriate height				
11.05	Node 2	venting/purging of fuel gas systems	gas cloud, local accumulation of gas, fire, explosion, asphyxiation	route vent discharges to safe location, hazardous area zoning				
11.06	Node 2	venting/purging of hydrogen systems	gas cloud, local accumulation of gas, fire, explosion, asphyxiation	route vent discharges to safe location, hazardous area zoning				
11.07	Node 2	accidental hydrocarbon release to plant effluent system	potential contamination of water body	oil/water seperator design, secondary containment, lube oil tanks bunded, oil seperator will have instrumentation				
11.0 RELEASE TO ENVIRONMENT								
				NODE 3				
11.08	Node 3	release of SF6 gas (insulation gas in switchgear)	potent GHG	seals/fittings/gaskets etc, I&C, maintenance, gas level indicators				
11.RELEASE TO ENVIRONMENT								
				ALL NODES				
11.09	All Nodes	chemical release within plant	potential contamination of water body	secondary containment, spillage procedures, instrumentation on tanks and equipment				

DEVIATION		CAUSE	CONSEQUENCE	SAFEGUARDS	ACTION NO.	ACTION	ACTION BY	RESPOND BY
12. VIOLENT ENERGY RELEASE								
				NODE 1				
12.01	Node 1	pressure equipment puncture	injury/fatality to personnel, vibration damage to equipment, missile generation	design to recognised codes and standards, control of works and permit to works, physical protection where appropriate near live operating plant, distance between equipment				
12.02	Node 1	pressure release valve exhaust	high pressure gas release, high noise levels,	all vents routed to safe location				
12.03	Node 1	turbine overspeeds	catastrophic failure, fatality/injury, missile generation	turbine control system, secondary turbine protection system, turbine bypass				
12.04	Node 1	turbine integrity	catastrophic failure, fatality/injury, missile generation	independent SME review prior to commercial operation, incorporate pilot plant lessons learnt				
12. VIOLENT ENERGY RELEASE								
				NODE 2, 3 & 4				
12.05	Nodes 2,3 & 4	see node 1	refer to node 1	refer to node 1				

DEVIATION		CAUSE	CONSEQUENCE	SAFEGUARDS	ACTION NO.	ACTION	ACTION BY	RESPOND BY
13. NOISE								
				NODE 1				
13.01	Node 1	rotating machinery/cooling tower noise levels	short term/long term hearing damage, environmental noise complaints	undefined at pre-FEED	4	Ensure FEED scope of works includes noise analysis	Jason Garrett	14.08.20
13.0.2	Node 1	venting/purging noise levels	short term/long term hearing damage, environmental noise complaints	see action 4				
13.03	Node 1	plant vent noise levels	short term/long term hearing damage, environmental noise complaints	awareness of noise limitations, design to noise limitations, see action 4				
13. NOISE								
				NODE 2, 3 & 4				
13.04	Nodes 2,3 & 4	see node 1	refer to node 1	refer to node 1				
14.0 VISUAL IMPACT								
				NODE 1				
14.01	Node 1	generic visual impact of plant does not meet local conditions	planning permisson difficulties	comply with local/national planning conditions				
14.0 VISUAL IMPACT								
				NODE 3				
14.02	Node 3	plume from cooling tower	plume creates ground level fog	appropriate location of cooling towers				

DEVIATION		CAUSE	CONSEQUENCE	SAFEGUARDS	ACTION NO.	ACTION	ACTION BY	RESPOND BY
15. ELECTRICITY								
				NODE 1				
15.01	Node 1	generator - fault within generator windings	significant damage to generator, injury to personnel	comply with codes/standards for generating equipment				
15. ELECTRICITY								
				NODE 3				
15.02	Node 3	arc flash (switchgear)	explosion, plant shutdown, injury/fatality	maintenance procedures, qualified personnel, PPE, PTW, isolation certificates, design to limit arc flash, electrical protection relays				
15. ELECTRICITY								
				ALL NODES				
15.03	All Nodes	LV faults	electricution, fire, damage to equipment	maintenance procedures, qualified personnel, PPE, PTW, isolation certificates, design to IET 18th ed, electrical protection relays				

DEVIATION		CAUSE	CONSEQUENCE	SAFEGUARDS	ACTION NO.	ACTION	ACTION BY	RESPOND BY
16. SEVERE WEATHER/NATURAL EVENTS								
				NODE 1				
16.01	Node 1	earthquake - low risk in UK	damage to plant/equipment	site specific seismic assessment	5	Consider anticipated (severe weather/natural events) climate change effects within risk register.	Jason Garrett	14.08.20
16.02	Node 1	snow loading	damage to plant/equipment	design to recognised codes and standards				
16.03	Node 1	flooding	damage to plant/equipment	design to recognised codes and standards, consultation during planning process				
16.04	Node 1	high winds	damage to plant/equipment	design to recognised codes and standards				
16. SEVERE WEATHER/NATURAL EVENTS								
				NODE 2, 3 & 4				
16.05	Nodes 2,3 & 4	refer to node 1	refer to node 1	refer to node 1				
17. THIRD PARTY INTERFERENCE								
				NODE 1				
17.01	Node 1	unauthorised access	theft, damage to plant, injury/fatality to unauthorised persons	security perimeter fencing, security gate, defined access point, CCTV				
17. THIRD PARTY INTERFERENCE								
				NODE 2, 3 & 4				
17.02	Nodes 2,3 & 4	refer to node 1	refer to node 1	refer to node 1				

DEVIATION		CAUSE	CONSEQUENCE	SAFEGUARDS	ACTION NO.	ACTION	ACTION BY	RESPOND BY
18. UTILITIES AND SERVICES								
				NODE 1				
18.01	Node 1	see utilities node (node 4)	see utilities node (node 4)	see utilities node (node 4)				
18. UTILITIES AND SERVICES								
				NODE 2, 3 & 4				
18.02	Nodes 2,3 & 4	Utilities and services considered in all other guidewords	Utilities and services considered in all other guidewords	Utilities and services considered in all other guidewords				
19. HUMAN FACTORS/ WORKING ENVIRONMENT								
				NODE 1				
19.01	Node 1	workers in potentially dangerous working environment	injury/fatality	design will follow risk reduction processes as required by CDM 2015, to ensure individual and societal risk is ALARP				
19. HUMAN FACTORS/ WORKING ENVIRONMENT								
				NODE 2, 3 & 4				
19.02	Nodes 2,3 & 4	see node 1	see node 1	see node 1				
19. HUMAN FACTORS/ WORKING ENVIRONMENT								
				ALL NODES				
19.03	All Nodes	novel technology requires new working practices	increased risk of maloperations, increased risk of injury/fatality	lessons learnt from pilot plant, automation, training, competent persons, draft site procedures in existence				
20. CONSTRUCTION/COMMISSIONING								
				NODE 1				
20.01	Node 1	Repeat of issues found with allam cycle project	inefficient construction, problematic commissioning	reference to lessons learnt register from previous project				
20. CONSTRUCTION/COMMISSIONING								
				NODE 2, 3 & 4				
20.02	Nodes 2,3 & 4	refer to node 1	see node 1	see node 1				

DEVIATION		CAUSE	CONSEQUENCE	SAFEGUARDS	ACTION NO.	ACTION	ACTION BY	RESPOND BY
21. START-UP/SHUT-DOWN/MAINTENANCE								
				NODE 1				
21.01	Node 1	technology specific	new technology means lack of established procedures	knowledge transfer from existing demonstration plant, further process safety studies, risk analysis on startup shutdown/maintenance	6	Ensure and agree a process for knowledge transfer from demonstration plant	Brock Forrest	14.08.20
21. START-UP/SHUT-DOWN/MAINTENANCE								
				NODE 2, 3 & 4				
21.02	Nodes 2,3 & 4	refer to node 1	refer to node 1	refer to node 1				

HAZID STUDY ACTION AND RESPONSE SHEET	
PROJECT:	
70053760	Node 1
ACTION ON:	RESPOND BY:
Jason Garrett	14.08.20
ACTION NUMBER:	MEETING DATES:
1	23/07/2020
DRAWINGS AND DOCUMENTS	
202000624 NET POWER COMMERCIAL PLANT PFD REV 10 (UK BEIS) 626236060-000-PI-01-000001 (Nodes) NET POWER UK BEIS HMB DATA	
ITEM:	
6.10	6.0 PHYSICAL OVERPRESSURE/UNDERPRESSURE
CAUSE:	
overpressure of co2 and oxidant system	
CONSEQUENCE:	
loss of containment, pipe rupture, damage to downstream components	
SAFEGUARDS:	
design to relevent design codes and standards, relief valves, UK statutory and legislative, PED, PSSR, gas detection monitoring, written scheme of examination, pressure regulating valves	
ACTION:	
Clarify general overpressure protection philosophy for the project,	
RESPONSE: Jason Garrett	DATED: 11-Aug-2020
During Pre-FEED contractor has designed pressure piping systems in accordance with the governing codes and standards with regard to overpressure protection. General overpressure protection philosophy to be formally documented in design basis and process philosophy documents to be completed during FEED/EPC phase. A section will be included in the Pre-FEED Final Report to capture this and other unresolved HAZID actions that must be addressed during subsequent FEED/EPC project execution phases.	
SIGNED: Jason Garrett 2020.08.11 15:41:43-04'00'	
ENTER RESPONSE ABOVE , THEN SIGN AND RETURN TO:	
Andy Mustoe	

HAZID STUDY ACTION AND RESPONSE SHEET	
PROJECT:	
70053760	Node 1
ACTION ON:	RESPOND BY:
Jason Garrett	14.08.20
ACTION NUMBER:	MEETING DATES:
2	23/07/2020
DRAWINGS AND DOCUMENTS	
202000624 NET POWER COMMERCIAL PLANT PFD REV 10 (UK BEIS) 626236060-000-PI-01-000001 (Nodes) NET POWER UK BEIS HMB DATA	
ITEM:	
7.10	7.0 OVERTEMPERATURE
CAUSE:	
heat exchanger fouling	
CONSEQUENCE:	
loss of plant efficiency, tripping of plant and equipment, plant damage and shutdown	
SAFEGUARDS:	
chemcial dosing of cooling water system, regular cleaning	
ACTION:	
Consider closed loop cooling on critical locations	
RESPONSE: Jason Garrett	DATED: 11-Aug-2020
A section will be included in the Pre-FEED Final Report to capture this and other unresolved HAZID actions that must be addressed during subsequent FEED/EPC project execution phases.	
SIGNED: Jason Garrett 2020.08.11 15:43:07-04'00'	
ENTER RESPONSE ABOVE , THEN SIGN AND RETURN TO:	
Andy Mustoe	

HAZID STUDY ACTION AND RESPONSE SHEET	
PROJECT:	
70053760	Node 1
ACTION ON:	RESPOND BY:
Jason Garrett	14.08.20
ACTION NUMBER:	MEETING DATES:
3	23/07/2020
DRAWINGS AND DOCUMENTS	
202000624 NET POWER COMMERCIAL PLANT PFD REV 10 (UK BEIS) 626236060-000-PI-01-000001 (Nodes) NET POWER UK BEIS HMB DATA	
ITEM:	
8.10	8.0 MOVING OBJECTS
CAUSE:	
vehicle movements	
CONSEQUENCE:	
personnel injury, damage to plant	
SAFEGUARDS:	
separation of pedestrian and plant	
ACTION:	
Include item on high level traffic management in pre-FEED report	
RESPONSE: Jason Garrett	DATED: 11-Aug-2020
On site traffic management is beyond the scope of the Pre-FEED. A section will be included in the Pre-FEED Final Report to capture this and other unresolved HAZID actions that must be addressed during subsequent FEED/EPC project execution phases.	
SIGNED: Jason Garrett 2020.08.11 15:44:13-04'00'	
ENTER RESPONSE ABOVE , THEN SIGN AND RETURN TO:	
Andy Mustoe	

HAZID STUDY ACTION AND RESPONSE SHEET	
PROJECT:	
70053760	Node 1
ACTION ON:	RESPOND BY:
Jason Garrett	14.08.20
ACTION NUMBER:	MEETING DATES:
4	23/07/2020
DRAWINGS AND DOCUMENTS	
202000624 NET POWER COMMERCIAL PLANT PFD REV 10 (UK BEIS) 626236060-000-PI-01-000001 (Nodes) NET POWER UK BEIS HMB DATA	
ITEM:	
13.10	13.0 NOISE
CAUSE:	
rotating machinery/cooling tower noise levels	
CONSEQUENCE:	
short term/long term hearing damage, environmental noise complaints	
SAFEGUARDS:	
undefined at pre-FEED	
ACTION:	
Ensure FEED scope of works includes noise analysis	
RESPONSE: Jason Garrett	DATED: 11-Aug-2020
Noise Analysis is beyond the scope of the Pre-FEED. A section will be included in the Pre-FEED Final Report to capture this and other unresolved HAZID actions that must be addressed during subsequent FEED/EPC project execution phases.	
SIGNED: Jason Garrett 2020.08.11 15:53:23-04'00'	
ENTER RESPONSE ABOVE , THEN SIGN AND RETURN TO:	
Andy Mustoe	

HAZID STUDY ACTION AND RESPONSE SHEET	
PROJECT:	
70053760	Node 1
ACTION ON:	RESPOND BY:
Jason Garrett	14.08.20
ACTION NUMBER:	MEETING DATES:
5	23/07/2020
DRAWINGS AND DOCUMENTS	
202000624 NET POWER COMMERCIAL PLANT PFD REV 10 (UK BEIS) 626236060-000-PI-01-000001 (Nodes) NET POWER UK BEIS HMB DATA	
ITEM:	
16.10	16.0 SEVERE WEATHER/NATURAL EVENTS
CAUSE:	
earthquake - low risk in UK	
CONSEQUENCE:	
damage to plant/equipment	
SAFEGUARDS:	
site specific seismic assessment	
ACTION:	
Consider anticipated (severe weather/natural events) climate change effects within risk register.	
RESPONSE: Jason Garrett	DATED: 11-Aug-2020
A section will be included in the Pre-FEED Final Report to capture this and other unresolved HAZID actions that must be addressed during subsequent FEED/EPC project execution phases.	
SIGNED: Jason Garrett 2020.08.11 15:54:43-04'00'	
ENTER RESPONSE ABOVE , THEN SIGN AND RETURN TO:	
Andy Mustoe	

wsp **HAZID STUDY ACTION AND RESPONSE SHEET** 8 RIVERS

PROJECT:

NET Power Allam Cycle Power Plant for UK Deployment Node 1

ACTION ON:	RESPOND BY:
Brock Forrest	14.08.20
ACTION NUMBER:	MEETING DATES:
6	23/07/2020

DRAWINGS AND DOCUMENTS

202000624 NET POWER COMMERCIAL PLANT PFD REV 10 (UK BEIS)
626236060-000-PI-01-000001 (Nodes)
NET POWER UK BEIS HMB DATA

ITEM:

21.01 21.0 START-UP/SHUT-DOWN/MAINTENANCE

CAUSE:

technology specific

CONSEQUENCE:

new technology means lack of established procedures

SAFEGUARDS:

knowledge transfer from existing demonstration plant, further process safety studies, risk analysis on startup shutdown/maintenance

ACTION:

Ensure and agree a process for knowledge transfer from demonstration plant

RESPONSE: DATED: 21/08/2020

As part of the "Basic Engineering Package" provided by NET Power in conjunction with a technology license, a developer will receive a test plant lessons learned register, a commercial plant risk register, and a complete operations manual that was develop at the La Porte facility. Additional materials of this nature will continue to be added to the "Basic Engineering Package" as they are finalized.

SIGNED:

ENTER RESPONSE ABOVE , THEN SIGN AND RETURN TO:

Andy Mustoe

HAZID STUDY ACTION AND RESPONSE SHEET	
PROJECT:	
70053760	Node 2
ACTION ON:	RESPOND BY:
Jason Garrett	14.08.20
ACTION NUMBER:	MEETING DATES:
7	24/07/2020
DRAWINGS AND DOCUMENTS	
202000624 NET POWER COMMERCIAL PLANT PFD REV 10 (UK BEIS) 626236060-000-PI-01-000001 (Nodes) NET POWER UK BEIS HMB DATA	
ITEM:	
1.60	1.0 LOSS OF CONTAINMENT
CAUSE:	
piping system rupture fuel gas, piping system and equipment rupture	
CONSEQUENCE:	
fuel gas cloud, equipment damage, possible ignition, resulting explosion, possible fatality	
SAFEGUARDS:	
design to relevent design codes and standards, relief valves, UK statutory and legislative, PED, PSSR, written scheme of examination, hazardous area classification calculations	
ACTION:	
Review gas detection requirements for unodourised gas at HP within site.	
RESPONSE: Jason Garrett	DATED: 11-Aug-2020
Gas detection requirements are dependent on site specific design basis and gas supply specification, and are therefore outside the scope of this Pre-FEED. A section will be included in the Pre-FEED Final Report to capture this and other unresolved HAZID actions that must be addressed during subsequent FEED/EPC project execution phases.	
SIGNED: Jason Garrett 2020.08.11 15:55:51-04'00'	
ENTER RESPONSE ABOVE , THEN SIGN AND RETURN TO:	
Andy Mustoe	

HAZID STUDY ACTION AND RESPONSE SHEET	
PROJECT:	
70053760	Node 2
ACTION ON:	RESPOND BY:
Jason Garrett	14.08.20
ACTION NUMBER:	MEETING DATES:
8	24/07/2020
DRAWINGS AND DOCUMENTS	
202000624 NET POWER COMMERCIAL PLANT PFD REV 10 (UK BEIS) 626236060-000-PI-01-000001 (Nodes) NET POWER UK BEIS HMB DATA	
ITEM:	
1.70	1.0 LOSS OF CONTAINMENT
CAUSE:	
rupture from hydrogen fuel tank	
CONSEQUENCE:	
hydrogen gas cloud, equipment damage, possible ignition, resulting explosion, possible fatality	
SAFEGUARDS:	
hydrogen trailers supplied by reputable supplier	
ACTION:	
Review stand off distances from hydrogen trailer to adjacent plant and equipment.	
RESPONSE: Jason Garrett	DATED: 11-Aug-2020
During pre-FEED contractor has considered requirements of NFPA 55 and BCGA (British Compressed Gas Association) code of practice 33 for initial location of hydrogen storage. Safety distances are acceptable for both of these standards. It is recommended that these safety distances are checked again during FEED, when additional design details of hydrogen storage volume, type and pressures have been confirmed, and further more detailed safety risk analysis is performed. A section will be included in the Pre-FEED Final Report to capture this and other unresolved HAZID actions that must be addressed during subsequent FEED/EPC project execution phases.	
SIGNED: Jason Garrett 2020.08.11 15:57:04-04'00'	
ENTER RESPONSE ABOVE , THEN SIGN AND RETURN TO:	
Andy Mustoe	

8 First Street
Manchester
M15 4RP

8RIVERS

Project Risk Management Tool

8RIVER

Project No	Project Name	Project Whitetail

Risk ID	Category	Risk or Opportunity?	Risk Description (Describe Cost, Programme & Quality Impacts)	Initial Impact	Initial Probability	Initial Rating	Response (Mitigation and/or Contingency)	Residual Impact	Residual Probability	Residual Rating	Contingency amounts would be spent in:
3	Commercial & Contracts	Risk	EPC and LTSA warranties/guarantees that will enable Project Finance debt, traditional BI/ALOP insurance, etc. What will a bankable EPC look like? How will assurances (Guarantees and warranties) flow through from EPC to LTSA (backing the turbine and BOP). Risk of warranties / guarantees mis-matched between contracts, potential cost impact of exposure to commercial risks.	High	Probable	High	Risk to be negotiated out during financial / contractual negotiations. 3rd party insurance already explored	Low	Unlikely	Low	CAPEX
4	Commercial & Contracts	Risk	Delay to financial close due stalled negotiation of indivuidual contract terms.	High	Unlikely	Medium	Process to appoint Financial Adviser commenced Q4 2020 and discussions held with up to 20 different banks/institutions; appointment to be made by 15 Jan 2021. Financial model to be developed and finalzied by end Feb 2021; Initial debt analytics / structuring done by end Mar 2021; Finance plan development, hedging strategy completed by end May 2021; RfP for lenders' technical consultant to be done and consultant appointed by end Mar 2021; Phase 1 due dilience report process between Apr 2021 and comp;eted report by Aug 2021; Financeability reivew / input to term sheets done by end Mar 2021; Financeability reivew / input to all contracts (including supply and procurement) to be done in Q3 2021; Initial draft of long-form financing term sheet to be completed in May 2021; review and redrfat of term sheet in Jun-Jul 2021 with Final draft for inclusion with bank RFP in Aug 2021; Prepare Information Memorandum, RFP, Review and finalise IM and RFP for Lead Arrangers issued to banks between May and Sep 2021; in Q3 2021 Bank due diligence and credit process, Bank responses, Review and discuss responses / clarifications Banks selected; commitment letter signed, Due dilgence updated and finalised; then in Q4 2021-Q1 2022 Draft Finance Documents, Negotiation of Finance Documents, Finance Documents in final form and Financial Close. in the event that during the whole financing process there was a funding gap at senior debt level or ECA coverage, junior debt would be considered as would mezzanine finance. if a shortfall was still there at the end then the sponsors would commit to fund through additional equity or debt.	Very Low	Very Unlikely	Low	CAPEX
5	Programme	Risk	Labour Availability. Risk of poor labour availability and productivity based on Site Location. May cause time delays due to unsuitable/unavailable labour.	High	Possible	Medium	Ensure suitable labour is available and identification/mitigation plan where not. Vetting of EPC contractors/subcontractors and their labour pools	Very Low	Very Unlikely	Low	CAPEX
6	Project Capital Cost	Risk	Plant Deliverables Changing. Future adjustment of the assumed life cycles of the plant affecting the design assumptions impacting HX DBHEs. Cost impact to re-design HX specification.	Moderate	Possible	Medium	Number of startups and shutdowns and plant life agreed up-front with the client in Pre-FEED. Pass the requirements on to the Suppliers within the technical specifications. Ensure robust change control is used on project.	Low	Very Unlikely	Low	CAPEX

Project No	Project Name	Project Whitetail

Risk ID	Category	Risk or Opportunity?	Risk Description (Describe Cost, Programme & Quality Impacts)	Initial Impact	Initial Probability	Initial Rating	Response (Mitigation and/or Contingency)	Residual Impact	Residual Probability	Residual Rating	Contingency amounts would be spent in:
7	Technical	Risk	Plant Durability During Life Cycles. The plant design has not had significant work performed to determine how the plant will react when ramping-up and when running at part-load. Availability studies need also be performed. Technical risk due to unknown plant responses.	Moderate	Possible	Medium	Design of the rotating equipiment and plant controls were performed to allow for variability in operation. The heat exchanger thermal design will be worked on for partial load cases in the next Phases of the project. Shell and tube HXs were selected for HX-H, which will experience the most significant temperature swings which mitigates this risk substantially over DBHE technology. Availabilty studies are planned for FEED and will be discussed and reviewed with client to determine if additional availability is required.	Low	Unlikely	Low	OPEX
8	Health & Safety - Other	Risk	Site Selection Risks - Brownfield, etc Underground ordinance (i.e. WW2), obstruction and asbestos risk is to be considered. H&S Risk for construction team.	Moderate	Possible	Medium	Site assessment report carried out for Wilton site Currently undertaking one site selection study which will address risks. Any site risks to be addressed during design phase if practicable. For all other sites similar mitigation will be required.	Low	Very Unlikely	Low	CAPEX
9	Commercial & Contracts	Risk	Third Party Interfaces - Currently not considered as site is generic. Must be considered during site selection process and once site location is confirmed. Risk type unknown until stakeholder engagement commences.	Moderate	Possible	Medium	Production of interface matrix based on appropriate studies. Early engagement with interfaces to identify any risks as soon as possible.	Very Low	Very Unlikely	Low	CAPEX
10	Programme	Risk	Site Dependant: Late survey data in FEED may delay design – ensure surveys are considered in FEED planning. Time risk to programme due to design re-work.	Moderate	Possible	Medium	Ensure survey data is available at suitable point in design stage To be considered in the project schedule	Very Low	Very Unlikely	Low	CAPEX
12	Programme	Risk	No local CO2 transport / storage infrastructure in place. Long-duration construction of CO2 infrastructure may delay plant going operational.	Moderate	Possible	Medium	Exploring other routes for CO2. Engagement with 3rd parties for buffer storage/shipping.	Low	Unlikely	Low	CAPEX
13	Programme	Risk	Current DCO may not be applicable to the Power Plant. A new DCO application may be required, causing delay to programme.	Moderate	Possible	Medium	WSP Planning option report prepared including comparison of new DCO with amendment to existing DCO. [Full Response redacted]	Very Low	Very Unlikely	Low	CAPEX
14	Programme	Risk	Current DCO may not be applicable to the Power Plant. Varying timescales for different approaches to DCO approval. a) Material amendment without examination required (best outcome). b) Material amendment with examination required - risk c) New DCO (worst outcome).	Moderate	Possible	Medium	Preparation of comparison of DCO with proposed plant. WSP DCO optioneering advice provided. External Legal opinion sought [Full Response redacted]	Very Low	Very Unlikely	Low	CAPEX
15	Technical	Risk	Site Dependant (brownfield site consideration): Current piling matt may not be suitable. New piling matt may be required. Design to incorporate.	Moderate	Possible	Medium	Engaged WSP to assess geotechnical requirements. Desktop study phase 1 complete. Engage Geotech contractor for opinion	Low	Possible	Low	CAPEX
16	Programme	Risk	Transfer of current Geotech information to other contractor may lead to data ownership issues. New contractor would not rely on existing data and new survey required. Design delay risk due to re-work surveys.	Moderate	Possible	Medium	Contract for Whitetail assigned to same Geotechnical contractor therefore no transfer of ownership.	Very Low	Very Unlikely	Low	

8RIVERS

Project Risk Management Tool

8RIVER

Project No	Project Name	Project Whitetail

Risk ID	Category	Risk or Opportunity?	Risk Description (Describe Cost, Programme & Quality Impacts)	Initial Impact	Initial Probability	Initial Rating	Response (Mitigation and/or Contingency)	Residual Impact	Residual Probability	Residual Rating	Contingency amounts would be spent in:
17	Staff/Resources	Risk	COVID 19 Impact. Resources within project team or contractors contract Covid 19. Reduced availability within project team and/or supply chain potentially impacting whole life cycle	Moderate	Possible	Medium	Ensuring that other staff can cover anyone who contracts C-19.	Moderate	Possible	Medium	CAPEX&OPEX
18	Programme	Risk	COVID 19 Impact. Resources within supply chain contract Covid 19. Potential delays to supply of materials and equipment.	Moderate	Possible	Medium	Appropriate mitigations to be considered once information available	Moderate	Possible	Medium	CAPEX
19	Programme	Risk	COVID 19 Impact. Resources within construction team, contractors and/or suppliers contract Covid 19. Delays to construction phase if suitably skilled alternative resource cannot be sourced.	Moderate	Possible	Medium	Appropriate mitigations to be considered once information available	Moderate	Possible	Medium	CAPEX
20	Programme	Risk	COVID 19 Impact. Resources within commissioning team and/or 3rd party interface teams contract Covid 19. Delays to commissioning phase if suitably skilled alternative resource cannot be sourced.	Moderate	Possible	Medium	Appropriate mitigations to be considered once information available	Moderate	Possible	Medium	CAPEX
21	Technical	Risk	COVID 19 Impact. Resources within operations team contract Covid 19. Risk to plant operation if suitably skilled alternative resource cannot be sourced.	Moderate	Possible	Medium	Appropriate mitigations to be considered once information available	Moderate	Possible	Medium	OPEX
22	Programme	Risk	COVID 19 Impact. Resources within construction management team contract Covid 19. Delays to construction phase if suitably skilled alternative resource cannot be sourced.	Moderate	Possible	Medium	Appropriate mitigations to be considered once information available	Moderate	Possible	Medium	
23	Staff/Resources	Risk	General future pandemic considerations - as yet unknown. (see Risk 18 also)	Moderate	Possible	Medium	Appropriate mitigations to be considered once information available	None	None	0	
24	Commercial & Contracts	Risk	Security of O2 supply. Long term agreement (15-20 years) for O2 supply may not be feasible. Risk of higher unit price for shorter agreements. There are site specific elements to risk	Moderate	Possible	Medium	Independent market report on O2 supply completed and confirms 15-20 year contracts available.[Full Response redacted]	Very Low	Unlikely	Low	OPEX
25	Programme	Risk	Sequestration hubs not mature enough to accept volume of CO2 produced. Programme delay, reduced output (Mwe)	Moderate	Unlikely	Low	Liasing with all potential CO2 sequestration partners, buffer storage for shipping. Acquire LOI with Sequestration partner for all CO2.	Low	Unlikely	Low	OPEX
26	Commercial & Contracts	Risk	Not achieving predicted performance data (LHV, HHV, heat rate, net efficiency, heat and mass balance) across the full operating range of the plant. Cost impact of under-performance and cost to rectify.	High	Possible	Medium	Validation of thermal models by NET Power/8 Rivers/OE to ensure that the EPC contractor model is correct and the EPC is guarateeing the plant performance within the contract	Low	Unlikely	Low	OPEX
27	Commercial & Contracts	Risk	Movement of CO2 in a nation without onshore CCS or pipelines Risk of higher price per unit. (See Risk 13 also)	Moderate	Possible	Medium	Proactive engagement with third parties (e.g.rail companies, ports) with CO2 shipping and storage capabilities. Pipeline in place already for Project Whitetail and T&S aligned with port and offtakers in the North Sea	Very Low	Very Unlikely	Low	OPEX

Project No	Project Name	Project Whitetail

Risk ID	Category	Risk or Opportunity?	Risk Description (Describe Cost, Programme & Quality Impacts)	Initial Impact	Initial Probability	Initial Rating	Response (Mitigation and/or Contingency)	Residual Impact	Residual Probability	Residual Rating	Contingency amounts would be spent in:
28	Programme	Risk	Movement of CO_2 in a nation without onshore CCS or pipelines Risk of slower/lower capacity export. (See Risk 13 also)	Moderate	Possible	Medium	Proactive engagement with third parties (e.g.rail companies, ports) with CO_2 shipping and storage capabilities. Pipeline in place already for Project Whitetail and T&S aligned with port and offtakers in the North Sea	Very Low	Very Unlikely	Low	OPEX
29	Commercial & Contracts	Risk	Flexible CfD - contractual structure, risk allocation of power and carbon pricing and volumes; protection from Force Majeure (beyond insurable risks and quantum), change in law, change in tax - basically all risks which could adversely affect DSCR beyond EPC/LTSA/operational risk	High	Possible	Medium	Risk to be negotiated out during contractual negotiations - BEIS award CfD	Moderate	Possible	Medium	OPEX
30	Technical	Risk	Unclear regulatory requirements due to Brexit, CE marking, codes and standards, ATEX, PED etc. Changes to requirements throughout design stages applicable risk	Moderate	Possible	Medium	Requirements to be encorporated into design once known and understood Verify and improve supply chain through anticipating impact on supply chains	Low	Unlikely	Low	CAPEX
31	Technical	Risk	Unclear regulatory requirements due to Brexit, Emissions trading, CE marking, codes and standards, ATEX, PED etc. Changes to requirements throughout procurement stages applicable risk	Moderate	Possible	Medium	Requirements to be encorporated once known and understood Verify and improve supply chain through anticipating impact on supply chains	Low	Unlikely	Low	CAPEX
32	Technical	Risk	Unclear regulatory requirements due to Brexit, Emissions trading, CE marking, codes and standards, ATEX, PED etc. Changes to requirements throughout construction stages applicable risk	Moderate	Possible	Medium	Requirements to be encorporated once known and understood Verify and improve supply chain through anticipating impact on supply chains	Low	Unlikely	Low	CAPEX
33	Technical	Risk	Unclear regulatory requirements due to Brexit, Emissions trading, CE marking, codes and standards, ATEX, PED etc. Changes to requirements throughout commissioning stages applicable risk	Moderate	Possible	Medium	Requirements to be encorporated once known and understood Verify and improve supply chain through anticipating impact on supply chains	Very Low	Unlikely	Low	CAPEX
34	Technical	Risk	Unclear regulatory requirements due to Brexit, Emissions trading, CE marking, codes and standards, ATEX, PED etc. Changes to requirements throughout operations stages applicable risk	Moderate	Possible	Medium	Requirements to be encorporated once known and understood Verify and improve supply chain through anticipating impact on supply chains	Low	Very Unlikely	Low	OPEX
35	Technical	Risk	Unclear regulatory requirements due to Brexit, Emissions trading, CE marking, codes and standards, ATEX, PED etc. Changes to requirements throughout EPCM stages applicable risk	Moderate	Possible	Medium	Requirements to be encorporated once known and understood Verify and improve supply chain through anticipating impact on supply chains			0	
36	Environmental	Risk	Blast and fire from adjacent sites – causes site shutdown	High	Very Unlikely	Low	Blast zone drawing shared with the design team Similar to be shared associated with any new sites. Chosen plot currently has no tennants.	Very Low	Very Unlikely	Low	OPEX

8 RIVERS

Project Risk Management Tool

8 RIVER

Project No	Project Name	Project Whitetail

Risk ID	Category	Risk or Opportunity?	Risk Description (Describe Cost, Programme & Quality Impacts)	Initial Impact	Initial Probability	Initial Rating	Response (Mitigation and/or Contingency)	Residual Impact	Residual Probability	Residual Rating	Contingency amounts would be spent in:
37	Technical	Risk	Blast and fire from adjacent sites – causes site shutdown Design implications (control room etc.)	High	Unlikely	Medium	Blast zone drawing shared with the design team Similar to be shared associated with any new sites Chosen plot currently has no tennants.	Very Low	Very Unlikely	Low	CAPEX
38	Quality	Risk	Equipment not performing as per specifications. Cost implications for reduced performance, and cost implications to rectify.	High	Possible	Medium	See item 23	None	None	0	
40	General	Risk	Local terrorism event directly impacting site and/or personnel. Potential harm to personnel or damage to plant.	High	Very Unlikely	Low	Ensure a response plan is established for such an event. May include direct communications with government agencies. Ensure insurance in place to cover all property and personnel terrorism risks: to be addessed by Insurance Adviser. insurance to be sculpted recognising different stages of development	Very Low	Very Unlikely	Low	CAPEX&OPEX
41	General	Risk	Local terrorism event without direct impact to site/personnel, but with indirect consequences. Potential site shutdown or restricted movement/operations.	High	Very Unlikely	Low	Ensure a response plan is established for such an event. May include direct communications with government agencies. Ensure insurance in place to cover all property and personnel terrorism risks: to be addessed by Insurance Adviser. Insurance to be sculpted recognising different stages of development	Very Low	Very Unlikely	Low	CAPEX&OPEX
42	Health & Safety - Other	Risk	Injury / Fatility during construction. Either Construction team OR Member of Public	High	Unlikely	Medium	Appropriate HSE regime/management/mitigation provisions, including CDM2015 adherance. Procurement of diligent and competent subcontractors via a thorough procurement process.	High	Very Unlikely	Low	CAPEX
43	Quality	Risk	Plant is not aligned with UK grid codes for power export	High	Unlikely	Medium	Design of electrical systems during pre-FEED are aligned with UK grid codes	Very Low	Very Unlikely	Low	
44	Quality	Risk	Plant operates outside of UK grid code parameters for power export	High	Unlikely	Medium	Ensuring early design aligned with applicable grid code Ensure plant operates within design parameters Ensure design team and OEMs are familiar with UK grid code	Very Low	Very Unlikely	Low	
48	Project Capital Cost	Risk	Construction Installation Rates Changing Over Time. Possibility of actual Construction Unit Installation Rates being higher than in the Estimate or more absenteeism and turnover than assumed in estimate requiring overtime and/or night shift. Cost impact to resolve.	Low	Possible	Low	Typical EPC concerns, this is normally included in the estimated contingency and varies by region and specific project. The risk will be mitigated by conducting a site labour survey of the specific area prior to proceeding with a EPC contract.	Very Low	Very Unlikely	Low	
49	Project Capital Cost	Risk	Material Escalation. No material escalation provided in estimate. Cost implication to account for escalation	Low	Unlikely	Low	Provide material escalation in actual EPC contract during Client negotiations. Can also mitigate with pre-buys at LNTP.	Very Low	Very Unlikely	Low	
50	Programme	Risk	COVID 19 Impact. Resources within design team contract Covid 19, limiting ability to work. Potential delays to design programme.	Low	Possible	Low	Appropriate mitigations to be considered once information available	Very Low	Very Unlikely	Low	CAPEX
51	Programme	Risk	60Hz to 50Hz conversion risk.	Low	Unlikely	Low	Redesign plant for 50Hz output during Pre-FEED/FEED			0	
52	Project Capital Cost	Risk	Low availability of scaled-up components e.g. CO2 compressors Risk of higher equipment unit price.	Low	Possible	Low	Procurement strategy - ensuring that appropriate checks are made with potential suppliers	Very Low	Unlikely	Low	CAPEX

8RIVERS
Project Risk Management Tool

8RIVER

Project No	Project Name	Project Whitetail

Risk ID	Category	Risk or Opportunity?	Risk Description (Describe Cost, Programme & Quality Impacts)	Initial Impact	Initial Probability	Initial Rating	Response (Mitigation and/or Contingency)	Residual Impact	Residual Probability	Residual Rating	Contingency amounts would be spent in:
53	Programme	Risk	Low availability of scaled-up components e.g. CO_2 compressors Risk of delays to equipment supply.	Low	Possible	Low	Procurement strategy - ensuring that appropriate checks are made with potential suppliers	Very Low	Unlikely	Low	
54	Technical	Risk	Summary of key metallurgical findings found so far, ensure considered in design. Risk of sub-optimal material decisions if findings are not transferred.	Low	Unlikely	Low	Ensure considered prior to detailed design. 8Rivers to engage NETPower about disclosing proprietary testing results	Low	Unlikely	Low	CAPEX
55	Technical	Risk	CO_2 and water analysis results from demonstration plant findings. Risk of sub-optimal process design if findings are not transferred.	Low	Unlikely	Low	Ensure considered prior to detailed design. 8Rivers to engage NETPower about disclosing proprietary testing results	Low	Very Unlikely	Low	CAPEX
56	Commercial & Contracts	Risk	Environmental Permit: Release of process liquid outside of permit limits. Financial penalties.	Moderate	Unlikely	Low	Ensure that design doesn't allow for release of liquid outside of permit limits. Design to include mitigation in case of release. Covered in O&M contract	Very Low	Unlikely	Low	
57	Commercial & Contracts	Risk	Environmental Permit: Noise exceeds permit limits. Financial penalties.	Moderate	Unlikely	Low	Ensure that design doesn't allow for noise outside of permit limits. Design to include mitigation in case of noise exceeding limits. Covered in O&M contract	Very Low	Unlikely	Low	
58	Technical	Risk	Lack of a deep water port for large module delivery. Delivery may be needed via other ports, risks associated with additional travel legs.	Moderate	Unlikely	Low	Teesport has deepwater berths and infrastructure to accept North Sea drilling platforms. Road and rail infrastruture aligned with Oil and Gas engineering.	Very Low	Very Unlikely	Low	
59	Commercial & Contracts	Risk	Site Specific: Toxic alert at neighbouring site causes emergency shutdown. Cost impact associated with non-operation.	Moderate	Unlikely	Low	Operational control room to be designed with appropriate IP etc.	Moderate	Unlikely	Low	OPEX
60	Technical	Risk	Site Specific: Toxic alert at neighbouring site causes emergency shutdown. Impact on ability of plant / personnel to complete certain operations.	Low	Unlikely	Low	Operational control room to be designed with appropriate IP etc.	Moderate	Unlikely	Low	
61	Project Capital Cost	Risk	Future Aspen software upgrades and impact to design. Changes to software processes may cause unwanted changes in design.	Low	Unlikely	Low	QA/QC check of Aspen properties to ensure within design parameters Side by side comparison with demo plant to simulate new inputs	Very Low	Very Unlikely	Low	
62	Technical	Risk	Future Aspen software upgrades and impact to design Changes to software processes may cause unwanted changes in design.	Low	Unlikely	Low	QA/QC check of Aspen properties to ensure within design parameters Side by side comparison with demo plant to simulate new inputs	Very Low	Very Unlikely	Low	
64	Quality	Risk	Site Specific: Coastal site with sea mist, risk of accelerated corrosion if correct paint and coatings are not used.	Low	Unlikely	Low	Wilton is an estuary location	Very Low	Very Unlikely	Low	
71	Programme	Risk	Supplier delay causing knock-on construction delays	Moderate	Unlikely	Low	Ensure supply chain contract are robust and mitigation is included	Very Low	Very Unlikely	Low	

8 RIVERS

Project Risk Management Tool

8 RIVER

Project No	Project Name	Project Whitetail

Risk ID	Category	Risk or Opportunity?	Risk Description (Describe Cost, Programme & Quality Impacts)	Initial Impact	Initial Probability	Initial Rating	Response (Mitigation and/or Contingency)	Residual Impact	Residual Probability	Residual Rating	Contingency amounts would be spent in:
72	General	Risk	UK/US differentiation (regulations/permitting/CDM etc.) Risk of design not meeting UK requirements.	Moderate	Unlikely	Low	This is the main purpose of the UK pre-FEED study grant funded by UK goverment. Any applicable local/regional/national regulations, standards and permitting are incorporated into design. Ensure staff employed have level of knowledge required	Very Low	Very Unlikely	Low	
73	General	Risk	UK/US differentiation (regulations/permitting/CDM etc.) Risk of construction phase activities not meeting UK requirements	Moderate	Unlikely	Low	This is the main purpose of the UK pre-FEED study grant funded by UK goverment. Any applicable local/regional/national regulations, standards and permitting are incorporated into design. Ensure staff employed have level of knowledge required	Very Low	Very Unlikely	Low	
74	General	Risk	UK/US differentiation (regulations/permitting/CDM etc.) Risk of operation phase activities not meeting UK requirements	Moderate	Unlikely	Low	This is the main purpose of the UK pre-FEED study grant funded by UK goverment. Any applicable local/regional/national regulations, standards and permitting are incorporated into design. Ensure staff employed have level of knowledge required	Very Low	Very Unlikely	Low	
75	Technical	Risk	Security during construction - Theft of equipment during construction due to lack of security. Resulting in project delay	Moderate	Unlikely	Low	Appropriate construction security provisions within EPC scope Costing allowance for appropriate security measures	Very Low	Very Unlikely	Low	
77	Staff/Resources	Risk	Lack of skilled labour with high pressure/temperature welding (30 MPa/600 C systems) - unprecedented site conditions in locality	Moderate	Unlikely	Low	Ensure EPC contractor has competent resources for project before appointment.	Very Low	Very Unlikely	Low	
78	Health & Safety - Other	Risk	Negligence by EPC Contractor due to inadequate quality control and poor internal management causing construction H&S risks.	Moderate	Unlikely	Low	Vetting of EPC contractor to ensure appropriate management controls and suitable workforce	Very Low	Very Unlikely	Low	
79	Quality	Risk	Negligence by EPC Contractor due to inadequate quality control and poor internal management causing programme delays and increase in design and construction costs.	Moderate	Unlikely	Low	Vetting of EPC contractor to ensure appropriate management controls and suitable workforce	Very Low	Very Unlikely	Low	
80	Health & Safety - Other	Risk	Negligence by O&M team due to inadequate QA/QC control and poor internal management causing site H&S risks	Moderate	Unlikely	Low	Vetting of O&M contractor to ensure appropriate management controls and suitable workforce	Very Low	Very Unlikely	Low	
81	Quality	Risk	Negligence by O&M team due to inadequate QA/QC control and poor internal management causing plant unavailability/downtime.	Moderate	Unlikely	Low	Vetting of O&M contractor to ensure appropriate management controls and suitable workforce	Very Low	Very Unlikely	Low	
84	Technical	Risk	Increase in Hydrogen content in gas network. Potential risk to process design if not considered	Low	Unlikely	Low	Appropriate modelling has been completed and Hydrogen up to 30% blended into gas has been considered	Very Low	Very Unlikely	Low	CAPEX
85	Technical	Risk	Increase in Hydrogen content in gas network. Operations risk if not considered.	Low	Unlikely	Low	Appropriate modelling has been completed and Hydrogen up to 30% blended into gas has been considered	Very Low	Very Unlikely	Low	OPEX
86	Quality	Risk	General constructability risk - major construction project delivery (labour availability etc.)	Low	Unlikely	Low	Risk reduction strategists already undertaken general review (as per public domain)	Very Low	Very Unlikely	Low	

Project Risk Management Tool

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Risk ID	Category	Risk or Opportunity?	Risk Description (Describe Cost, Programme & Quality Impacts)	Initial Impact	Initial Probability	Initial Rating	Response (Mitigation and/or Contingency)	Residual Impact	Residual Probability	Residual Rating	Contingency amounts would be spent in:
87	Technical	Risk	BREXIT doesn't actually happen and EU regulations on CO2 being a waste limit transport	Very Low	Very Unlikely	Low	EU regs may have to considered			0	
88	Commercial & Contracts	Risk	CO2 offtake T&S company fails to offtake as scheduled from buffer storage	High	Possible	Medium	Ensure that other contracts are in place with alternative CO2 offtakers or other buffer storage is used	Low	Unlikely	Low	OPEX
89	Technical	Risk	Failure of structural inegrtiy of external (beyond battery limits) CO2 pipeline or storage up to the Port causes escape of CO2	Very High	Very Unlikely	Low	Ensure correct engineering standards are adheared to and technical due diligence/quality control is carried out on all vendors including engineering, installtion and materials	Low	Very Unlikely	Low	OPEX
90	Technical	Risk	Failure of structural inegrtiy of internal (inside battery limits) CO2 pipeline or storage causes escape of CO2	Very High	Very Unlikely	Low	As part of the FEED works identify correct engineering standards and process (route, materials, scheduling etc) are fully specified. [Full Response redacted]	Low	Very Unlikely	Low	OPEX
91	Commercial & Contracts	Risk	Credit-worthiness of CO2 offtake counterparties	Very High	Possible	High	Carry our financial due diligence on counterparties and if required get credit support in place	Low	Unlikely	Low	OPEX
92	Commercial & Contracts	Risk	Negotiation of Contract for Difference results in a lower strike price	Very High	Possible	High	Ensure process for CfD is well understood, ensure development team are competent to negotiate CfD. External due diligence carried out on commmercial model before submission.	Low	Possible	Low	OPEX
93	Commercial & Contracts	Risk	CO2 offtake sequestration well/field fails and CO2 cannot be sequestered	Very High	Unlikely	Medium	Geological survey and historical data is avaialbe for review by external consultants. Carry out Technical Due diligence	Low	Very Unlikely	Low	OPEX
94	Technical	Risk	CO2 produced by plant is not within specification limit of CO2 offtake contract due to failure of CO2 purification skid	Low	Unlikely	Low	Ensure service and maintenance contract is in place. Ensure critical parts/spares available and design has redundant capacity	Low	Very Unlikely	Low	OPEX
95	Commercial & Contracts	Risk	CO2 offtaker company becomes insolvent	Very High	Unlikely	Medium	Ensure that mitigation strategies are in place for utilising other CO2 offtakers. Ensure Financial DD is carried out accordingly.	Low	Very Unlikely	Low	OPEX
96	Commercial & Contracts	Risk	UK Government strategy for CCUS projects changes	Very High	Very Unlikely	Low	UK has passed a law for UK to achive Net Zero by 2050. financial mechanisms in place to support decarbonisation of industrial clusters including CCUS have been agreed by government.	Low	Very Unlikely	Low	CAPEX&OPEX
98	Commercial & Contracts	Risk	Oxygen supply from Industrial gas supplier fails due to issues with ASU	Very High	Possible	High	Ensure that the contract with the O2 supplier is such that it ensures certaintly of supply through alteranitve ASU of O2 buffer storage	Low	Unlikely	Low	OPEX
99	Technical	Risk	Oxygen supply from Industrial gas supplier fails due to issues with pipeline (Beyond battery limits)	Very High	Very Unlikely	Low	Ensure correct engineering standards are adheared to and technical due diligence/quality control is carried out on all vendors including engineering, installtion and materials	Low	Very Unlikely	Low	OPEX
100	Technical	Risk	Oxygen supply from Industrial gas supplier fails due to issues with pipeline (inside battery limits)	Very High	Very Unlikely	Low	Ensure correct engineering standards are adheared to and contractor/skilled labour is competent to execute the work. Due diligence/quality control must be carried out on all vendors including engineering, installtion and materials	Low	Very Unlikely	Low	OPEX

Project No	Project Name	Project Whitetail

Risk ID	Category	Risk or Opportunity?	Risk Description (Describe Cost, Programme & Quality Impacts)	Initial Impact	Initial Probability	Initial Rating	Response (Mitigation and/or Contingency)	Residual Impact	Residual Probability	Residual Rating	Contingency amounts would be spent in:
101	Commercial & Contracts	Risk	Oxygen supply from Industrial gas supplier fails due to insolvency of supplier	Very High	Unlikely	Medium	Ensure that mitigation strategies are in place for utilising other O2 offtakers. Ensure Financial DD is carried out accordingly.	Low	Very Unlikely	Low	OPEX
102	Commercial & Contracts	Risk	Unable to export power due to National Grid failure	Very High	Very Unlikely	Low	analyse historical data for the Wilton/Teesside area and engage National Grid with regards to strategy should a black swan event occur	Low	Very Unlikely	Low	OPEX
103	Technical	Risk	Unable to export effluent to treatment plant due to failure of effluent pipeline	Very High	Very Unlikely	Low	Ensure correct engineering standards are adheared to and technical due diligence/quality control is carried out on all vendors including engineering, installtion and materials	Low	Very Unlikely	Low	OPEX
104	Technical	Risk	Unable to export effluent to treatment plant due to failure of treatment plant	Very High	Very Unlikely	Low	Ensure correct engineering standards are adheared to and technical due diligence/quality control is carried out on all vendors including engineering, installtion and materials. Ensure contract is written to cover commercial aspects of failure to offtake	Low	Very Unlikely	Low	OPEX
105	Commercial & Contracts	Risk	Agreement for utilities provided by counterparty cannot be reached	Very High	Very Unlikely	Low	Agree Heads of Terms during early phase of FEED study	Low	Very Unlikely	Low	CAPEX
106	Technical	Risk	Electrical connection agreement is revoked by National Grid	Very High	Very Unlikely	Low	Connection agreement for export is already in place.	Low	Very Unlikely	Low	CAPEX
107	Technical	Risk	Failure to connect to National Grid in Q4 2024 and grid agreement not met.	Very High	Possible	High	Ensure that project programme is managed and tracked daily and that mitigation strategies are in place for any anticipated delays.	Low	Possible	Low	OPEX
108	Technical	Risk	Geotechnical survey identifies contaminated land	Very High	Possible	High	Ensure Geotechnical study and site work is carried out as per the schedule in order to remediate contamination and no delay to schedule	Low	Very Unlikely	Low	CAPEX
109	Technical	Risk	Unable to export effluent to treatment plant due to failure of effluent pipeline	Very High	Very Unlikely	Low	Ensure correct engineering standards are adheared to and technical due diligence/quality control is carried out on all vendors including engineering, installtion and materials	Low	Very Unlikely	Low	OPEX
111	Commercial & Contracts	Risk	Rising renewables reduces grid capacity factor	High	Possible	Medium	Negotiate contract for difference with capacity/dispatch payment. Ensure model reflects future forecasts for renewables for high/mid/low generation forecast	Low	Possible	Low	OPEX
112	Commercial & Contracts	Risk	Too much demand for CO2 shipping delays offtake from Teessport	Very High	Possible	High	Ensure CO2 offtake contract secures shipping rights/slots commensurate with the requirements of the project. Ensure LD's are in place	Low	Possible	Low	OPEX
113	Commercial & Contracts	Risk	Plant availability lower due to failure of major equipment than predicted in the initial years	High	Possible	Medium	Ensure lessons learned from La Porte are fully intergrated into design and operations. Ensure contracts have a tuning period to ramp up output over time in initial years. Ensure financial model reflects tunining and is fully stress tested for all eventuality - Monte Carlo analysis. The tune period to ramp up will be agreed with BEIS as part of the CFD negotiations and is in line with Government expectations for new technologies similar to those allowed when CCGT first came on line	Very Low	Possible	Low	OPEX

8RIVERS

Project Risk Management Tool

8RIVER

Project No	Project Name	Project Whitetail

Risk ID	Category	Risk or Opportunity?	Risk Description (Describe Cost, Programme & Quality Impacts)	Initial Impact	Initial Probability	Initial Rating	Response (Mitigation and/or Contingency)	Residual Impact	Residual Probability	Residual Rating	Contingency amounts would be spent in:
114	Commercial & Contracts	Risk	Project partners change investment strategy with regards to fossil fuels and CCUS	Very High	Very Unlikely	Low	Ensure all partners are signed into definitive agreements at the appropraite stage.	Very Low	Very Unlikely	Low	CAPEX&OPEX
115	Programme	Risk	Unknown buried structures or services	High	Probable	High	Suitable precautions carried out during engineering and construction; ensure all previous engineering drawings and geotech drawings have been reviewed	Moderate	Possible	Medium	CAPEX
116	Programme	Risk	Changes to construction design during construction cause failure of structural integrity	Very High	Unlikely	Medium	Ensure correct change management and engineering controls are in place	Very Low	Very Unlikely	Low	CAPEX
123	Technical	Risk	CO2 exported from the Project does not comply with the specificaiton required by the carbon T&S	Moderate	Very Unlikely	Low	Monitoring and venting system aong with slam shut valve to be installed downsteam of the CO2 meter to purge out-of-spec CO2.	Low	Very Unlikely	Low	Opex

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8 Rivers Capital LLC

ALLAM CYCLE UK PRE-FEED

Independent Engineer Report

70053760-WSP-00-XX-RP-PM-0002-S3
FEBRUARY 2021

CONFIDENTIAL

8 Rivers Capital LLC

ALLAM CYCLE UK PRE-FEED

Independent Engineer Report

REPORT (VERSION P03) CONFIDENTIAL

PROJECT NO. 70053760

OUR REF. NO. 70053760-WSP-00-XX-RP-PM-0002-S3

DATE: FEBRUARY 2021

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QUALITY CONTROL

Issue/revision	P01	P02	P03	
Remarks	Draft issue	Comments incorporated, including Wilton site selection and 925°C design case	Updated with client comments	
Date	December 2020	January 2021	February 2021	
Prepared by	Rob Makin Graham Brown Scott Armstrong Simon Rothery Lindsey Summers Sunain Dassi	Rob Makin Graham Brown Scott Armstrong Simon Rothery Lindsey Summers Sunain Dassi	Rob Makin Graham Brown Scott Armstrong Simon Rothery Lindsey Summers Sunain Dassi	
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Checked by	Ben Platt	Ben Platt	Ben Platt	
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Signature				
Project number	70053760	70053760	70053760	
Report number	70053760-WSP-00-XX-RP-PM-0002-S3_P01	70053760-WSP-00-XX-RP-PM-0002-S3_P02	70053760-WSP-00-XX-RP-PM-0002-S3_P03	
File reference				

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EXECUTIVE SUMMARY

The Allam-Fetvedt Cycle (AFC) is a gas to power thermal generation technology that achieves highly efficient and low-cost electricity generation with zero emissions through use of supercritical carbon dioxide with an oxy-fuel mixture as the primary process fluid.

The Feasibility study is commissioned by BEIS and funded under the CCUS Innovation fund, and is aimed at advancing the technology and business case of a single 279.4 MW_e net output AFC generating unit, to the point of being ready to proceed with the Front-End Engineering Design (FEED) for a commercially operated plant located in the UK. WSP were appointed as Owners Engineer to support the project and ensure the cost basis is reasonable and the design basis is suitable for UK deployment with a specific focus on codes, standards and legislation. This report includes the topics necessary to inform and support capital funding decisions.

The Feasibility study for a UK commercial scale plant included a Pre-FEED, which developed a Proposed AFC plant design based on a generic UK site. This design represents a true 'base case' design and is suitable for deployment in the UK. The technical review highlighted five design comments that should be implemented at the next design stage. All five of the design comments evolve around the designer using favourable assumptions to reduce plant CAPEX, which would be expected to a certain degree at Pre-FEED stage, with the assumptions and CAPEX being refined at the FEED stage. It is noted that these comments do not prevent the project from moving to FEED.

The design of site-sensitive elements such as cooling towers and geotechnical structures will be refined at the FEED stage. There are opportunities and alternatives to enhance the Proposed AFC plant design to fine-tune the performance characteristics of the plant which are expected to be investigated during the FEED stage.

Initial data indicates that the Proposed AFC plant has competitive performance characteristics to similar scale abated natural gas plants, but with a clear zero-emissions benefit, in alignment with established net-zero and CCUS government policy. There is a clear need for dispatchable thermal energy to supplement renewable energy in the future of the UK electricity system. Following further refinement to align with the performance characteristics of the UK electricity market, the AFC power plant can be part of the energy mix in the UK to ensure security of supply whilst capturing nearly 100% of the CO_2 produced.

The characteristics of a suitable site are outlined in this report. The Pre-FEED and the Owner's Engineering scope was undertaken assuming a generic UK site. In parallel to these activities, a Site Specific Study was carried out, with 8 Rivers subsequently selecting Wilton International as the Proposed AFC plant location for the first UK facility. The geography together with the existing and planned infrastructure indicate the Wilton site as highly suitable to accommodate the AFC plant. It also located within the Teesside Industrial Cluster, close to the proposed Net Zero Teesside (NZT) project which could provide an economical long-term CO_2 offtake via the proposed transport and storage system with NZT.

The Proposed AFC plant requires a number of commercial interfaces to operate, such as oxygen supply and CO_2 export. Those negotiations are critically important to the project. 8 Rivers are in negotiation with associated stakeholders some of which are in an advanced position with letters of intent or memorandums of understanding received.

McDermott's EPC CAPEX estimate of £359.62 million for the Base Case plant appears reasonable for deployment at a generic UK site. WSP's cost assessment estimated a total CAPEX 3.2% lower than the McDermott estimate, using comparable assumptions and exclusions. (WSP had multiple correspondence with McDermott to verify assumptions and exclusions and are in agreement that they align with the methodology expected for a AACE Class IV Estimate. It is however noted that some quantities and quotations were confidential and could not be shared with WSP so the cost verification exercise in this report was unable to replicate all assumptions). Notwithstanding the foregoing, the low variance gives confidence that the costing is within the accuracy ranges expected at this early stage, and that the costs are reasonable.

McDermott's CAPEX estimate represents a standard design for deployment at a generic UK site. The McDermott assumptions and exclusions from the EPC CAPEX estimate have been indicatively quantified at an additional £20.95 million which should be allowed for in the total project CAPEX allowance. This would take the total Base Case EPC CAPEX cost to £380.57 million. It is also important to recognise other EPC CAPEX costs associated with the design comments remain unquantified at this stage. These include the unconfirmed cooling tower technology, duplicate plant for redundancy and increased electrical equipment ratings. Further design work is required at the FEED Stage to determine the relevance and extent of these items to allow EPC CAPEX additions to be quantified.

Risk studies were conducted throughout the project and analysed technical and project risks to a level of detail beyond that normally seen at Feasibility Stage. The commitment of a detailed suite of mitigation actions, including many which are already complete or in progress, is deemed to reduce project risk to low levels, which is reflected in the Monte Carlo Analysis.

This Feasibility Study presents a compelling case for the Proposed AFC plant to be deployed in the UK. The Pre-FEED is feasible for a generic UK site and there are no technical blockers which should prevent this project from moving to FEED.

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1 INTRODUCTION

8 Rivers Capital LLC (‘8 Rivers’) was awarded grant funding, under the BEIS Feasibility Study strand of the CCUS Innovation Competition, to further develop the Allam-Fetvedt Cycle (‘AFC’) for UK deployment.

The AFC is a technology that achieves highly efficient and low-cost electricity generation with zero emissions through use of supercritical carbon dioxide with an oxy-fuel mixture as the primary process fluid. This technology has been demonstrated at 50 MWth scale in La Porte, Texas, and is now being commercialised by NET Power LLC, with 8 Rivers leading development of full-scale commercial projects.

1.1 PROJECT OVERVIEW

The goal of the Feasibility Study was to advance both the technology and business case to the point of being ready to proceed with the Front End Engineering Design (FEED) for a commercially operated facility located in the UK.

To achieve this, the feasibility study objectives were to:

- Advance the design of the commercial scale unit to a level that enables a cost estimate to a Class IV level of certainty, as defined in the AACE 18R-97 Recommended Practice[1]; and
- Advance the existing US based commercial-scale designs to ensure that the process is aligned to UK conditions and conforms to all UK codes, standards and legislation.

1.2 PROJECT TEAM

Several consulting teams were involved in this Feasibility Study, as below. 8 Rivers engaged McDermott to undertake the power plant Pre-FEED and engaged WSP as Owners Engineer to support and advise the Study. The Feasibility Study was supported by the parties in Table 1-1.

Table 1-1 – Feasibility Study Team

Company	Role
8 Rivers Capital LLC (‘8 Rivers’)	Client & AFC Plant Developer
NET Power LLC (‘NET Power’)	AFC Technology Licensor
McDermott International, Inc. (‘McDermott’)	Pre-FEED Contractor
WSP UK Ltd (‘WSP’)	Owner’s Engineer
Sembcorp Utilities UK Limited (‘Sembcorp’)	Owner of Wilton International site

[1] *AACE International Recommended Practice No. 18R-97 - Cost Estimate Classification System – As Applied in Engineering, Procurement, and Construction for the Process Industries – March 6, 2019.*

With the exception of Sembcorp, all the Feasibility Study parties were involved in the design, construction and commissioning of the test facility in La Porte, Texas. Armed with the findings of the test facility, and with WSP providing expert knowledge on UK deployment, the team were equipped with suitable skills, knowledge and experience to undertake the Feasibility Study.

1.3 WORK COMPLETED WITHIN THIS FEASIBILITY STUDY

Various component studies were undertaken by different project partners within this Feasibility Study, to determine the suitability of this project for further development. The key studies are listed in Table 1-2.

Table 1-2 – Component studies which form the Feasibility Study

Party	Scope	Deliverables	Assumed site for scope
McDermott	Pre-FEED	▪ Pre-FEED Report ▪ Various Pre-FEED deliverables	Generic UK site
WSP	Owner's Engineering	▪ Independent Owner's Engineer Report (this report) ▪ HAZID Study ▪ Risk Workshops	Generic UK site
WSP	Site Specific Study	▪ CO2 Export Optioneering Report ▪ Environmental Permitting Strategy Report ▪ Geotechnical Desktop Study ▪ Geotechnical Survey Specification	Wilton International Site
Vivid Economics	Economic Benefit Analysis	▪ Supply chain report	Wilton International and Generic UK site
Spiritus Consulting	Oxygen Supply Review	▪ Oxygen Supply Optioneering Report	Wilton International Site and Generic UK site

1.4 SITE SELECTION

The McDermott Pre-FEED and the WSP Owner's Engineering scope was undertaken assuming a generic UK site. In parallel to these activities, a Site Specific Study was carried out, with 8 Rivers subsequently selecting Wilton International as the Proposed AFC plant location for the first UK facility. The Wilton Site owner, Sembcorp, has been engaged with all scope activities as part of the Feasibility Study and although the Pre-FEED has been based on a generic UK site in terms of layout and costing, consideration has been given to location at the Wilton Site throughout.

1.5 PURPOSE OF REPORT

This Independent Owner's Engineer report constitutes the professional opinion of WSP as to whether the project objectives have been achieved and comments on further development of the Project, and will summarise:

1. The findings of the feasibility study;

2. Whether key project objectives were achieved;
3. Whether key risks have been identified and mitigated;
4. Whether the project cost basis is in line with expectations; and
5. An independent commentary on future development of this project.

The following sections include the topics necessary to inform and support capital funding decisions to progress the project to its next stage:

- Section 2 – Overview of the Proposed AFC plant, and its place in the UK energy market
- Section 3 – Compliance with applicable UK consents, permits and regulation
- Section 4 – Site selection criteria, including evaluation of the Wilton site
- Section 5 – Review of the Pre-FEED, including adequacy of technical solutions, design opportunities and alternatives, and compliance with applicable UK/EU specifications
- Section 6 – Project risks, including discussion of residual risks
- Section 7 – Costing verification, including discussion of key assumptions, variances and site -specific costs
- Section 8 – Conclusion and recommendations

1.6 REFERENCE DOCUMENTS

A list of the key documentation used to complete the Feasibility Study has been provided in Table 1-3. Other information, data and correspondence provided by the project stakeholders was also used to inform the study but is not included in this list.

Table 1-3 – Key Feasibility Study Reference Documents

Document Reference/Number	Author	Document Title
626236060-000-PE-RP-00001	McDermott	NET Power UK Standard Plant BEIS Pre-FEED Report November 2020 (including WSP Comments)
(none)	McDermott	NET Power UK Standard Plant BEIS Pre-FEED - Class IV Indicative Estimate Summary - UK East Coast Location Base Case, 900°C Turbine Inlet Temp, 279 MWe Net Output
70053760-WSP-00-01-RP-PE-0002-S0_P02	WSP	HAZID Report
70053760-WSP-00-XX-RP-GE-0001-S4_P03	WSP	Geotechnical Desktop Study
70053760-WSP-00-XX-RP-PE-0001-S4_P03	WSP	CO2 Optioneering Report
70053760-WSP-00-XX-RP-PE-0004-S3_P01	WSP	Oxygen Supply Report Due Diligence
70053760-WSP-00-XX-RP-TC-0001-S4_P02	WSP	Environmental Permitting Strategy
70053760-WSP-00-XX-RG-PM-0002-S0_P03	WSP	Project Risk Register

70053760-WSP-00-XX-SP-GE-0001-S3_P01	WSP	Specification & Schedules for Intrusive Ground Investigations
(Various)	WSP	WSP technical queries and Pre-FEED design review comment sheets
(none)	Spiritus Consulting	Oxygen Supply Infrastructure in Teesside Area - An Independent Executive Report for 8 Rivers

1.7 TERMINOLOGY

For clarity, Table 1-4 defines key phrases used throughout this report.

Table 1-4 - Terminology

Term	Description
Feasibility Study	As per Table 1-2, the component studies undertaken to develop the AFC ready for FEED for UK deployment
Pre-FEED	The McDermott design to develop a UK Standard AFC Plant design. The Pre-FEED is a constituent part of the Feasibility Study
Base Case AFC plant	The 'Base Case' UK Standard AFC plant was the baseline design scenario for McDermott's Pre-FEED
Proposed AFC plant	The 'Optimised Alternate Case' UK Standard AFC plant was an optimised variant of the baseline scenario, which McDermott developed as part of their Pre-FEED work
Project Team	As per Table 1-1, the key parties involved in the Feasibility Study: WSP, 8 Rivers, NET Power, McDermott and Sembcorp

2 PROPOSED ALLAM-FETVEDT CYCLE PLANT OVERVIEW

The scale of the UK Government's net-zero ambition necessitates deployment of net-zero carbon projects at an increasing pace through to 2050. This section summarises the Proposed AFC plant and its place in the changing UK energy market.

2.1 PLANT DESCRIPTION

As part of their Pre-FEED work, McDermott have looked at three design cases:

1. Base Case: The 'Base Case' UK Standard AFC plant was the baseline design scenario for McDermott's Pre-FEED. The Pre-FEED deliverables and associated studies were undertaken using this baseline design scenario.
2. Alternate Case: A variant of the baseline design scenario with a focus on maintaining high net output and efficiency through a higher turbine inlet temperature but represents a more expensive CAPEX.
3. Optimised Alternate Case: An optimised version of the Alternate Case with a reduced CAPEX and a marginal reduction on net output and efficiency.

As outlined above, the Pre-FEED deliverables and associated studies were undertaken using the Base Case. Following completion of the McDermott Pre-FEED Report and through additional discussion and analysis with McDermott, 8 Rivers have indicated they intend to take forward the Optimised Alternate Case. As such, although this report primarily covers the Base Case, reference is drawn to the Optimised Alternate Case as well.

WSP have provided technical comment on the key plant changes and optimisations included in the Optimised Alternate Case to ensure they are feasible, technically sound and are achievable based on McDermott's assumptions. WSP comments have been included in Section 5.4.

Full plant descriptions of each design case are available in the Pre-FEED Report.

An extract of the Pre-FEED performance and cost comparison is presented in Table 2-1**Error! Reference source not found.** below.

Table 2-1 – Comparison of Base Case and Optimised Alternate Case, extracted from Pre-FEED Report, Table 9-1

Parameter	Units	Base Case	Optimised Alternate Case
Turbine Inlet Temperature	°C	900	925
Net Output	MW_e	279.4	296.0
AACE 18R-97 Estimate Class		Class IV	Class V
Total EPC Cost	£M	359.6	372.1
Cost per kW	**£/kW$_e$**	**1,287**	**1,257**

2.1.1 BASE CASE AFC PLANT

For convenience, key extracts of the Base Case AFC plant process are detailed below.

- The plant incorporates a single 279.4 MW_e net output generating unit in a generic UK location.
- The plant uses natural gas as fuel gas and uses many standard equipment packages alongside proprietary equipment, such as the supercritical CO_2 combustion turbine generator. No steam system is required.
- The key differentiator of the AFC process is the use of an oxy-fuel combustion mixture with a high-pressure, high-temperature recirculating CO_2 stream from the exhaust.
- The use of oxygen rather than air for combustion brings several benefits, such as near-elimination of NOx and SOx (based on fuel gas composition). It is likely the fuel gas composition will be GS(M)R compliant which allows for low levels of nitrogen and sulphur content, which would result in low levels of NOx and SOx in the exhaust gases.
- This plant captures approximately 98% of CO_2 emissions.
- The CO_2 produced is high-temperature and high-pressure, suitable for export with minimal post-process. Therefore 'carbon capture' is inherent in the combustion process and does not require expensive and load-heavy processing of the exhaust gas. The high pressure CO_2 is capable of being transmitted directly from the process into a transport and storage system without further compression therefore reducing CAPEX.
- The base case design includes for an electrical connection (parasitic load) from the AFC to the ASU. Heat integration to improve efficiency is possible but is not included in this case.
- The base case design assumes connections at the project boundary for supplies of natural gas and oxygen and for the export of CO_2.

2.1.2 OPTIMISED ALTERNATE CASE (PROPOSED AFC PLANT)

The Optimised Alternate Case is the assumed design for the Proposed AFC plant at Wilton International for Sembcorp, and is based on the Base Case design with plant configuration changes and optimisation to maximise plant output with minimised total plant CAPEX per kW (£/kW).

The key plant changes and optimisations which comprise the Optimised Alternate Case are detailed below.

- A closed-loop cooling water system is implemented that minimises potential for exchanger fouling from the open-loop cooling system.
- Dry gas seals are utilised on the turbine, allowing the Turbine Gland Seal System (TGS) to be removed. Alternative provisions for filling the plant from the CO_2 Storage System (CDS) are included.
- The Recycle CO_2 pump is uncoupled from the turbine, and is instead motor-driven.
- A fourth stage is added to the Recycle CO_2 Compressor, with an additional intercooler to improve efficiency.
- Temperatures, flows and other process conditions are optimised to minimise CAPEX cost per kW (£/kW_e).
- The oxygen supplied to the Optimised Alternate Case is 'over the fence' and there is no integration of ASU process heat or electrical load to the AFC plant.

The site specific considerations have been investigated and summarised in Section 4.

2.2 AFC PLANT OPERATION IN THE UK ELECTRICITY MARKET

The AFC technology provides net-zero, dispatchable power and has competitive performance characteristics to similar scale, modern natural gas plants. This gives the AFC technology a unique position in the UK electricity market that should be highlighted. The Proposed AFC plant presents a 'base case' design which represents the lowest CAPEX option but doesn't necessarily tap-in to the full value of the AFC plant in the UK.

To articulate the grid-value of a power plant (and hence potential revenue), a technical note has been produced: refer to 0. This details the current and forecasted UK energy markets, comparable technologies and an evaluation of the Proposed AFC plant to show where value can be derived in the UK electricity market.

For the reader's convenience, key extracts from 0 are stated below:

"A diverse portfolio of power generation sources will be required to meet the UK's needs"

"With a high wind and solar position there is likely to be the need for at least 30 GW of dispatchable capacity"

"Electricity Prices have become more varied and more volatile, not least because of the limited ability to store electricity. This situation is expected to continue and probably become substantially more volatile as varying renewable generation becomes a greater proportion of the market. The UK and other markets have seen clear indications of what is likely to happen already. Electricity price volatility together with renewable energy production volatility means that the demand for flexible plant becomes of primary importance."

"Many of the AFC plant performance characteristics align with those of likely competitors and as such place this plant in a reasonable position for the future."

This analysis excludes any financial benefits from, for example, the Contracts for Difference scheme, which would enhance the plant's operational finances. If the Proposed AFC plant is awarded a Contract for Difference, it will provide long-term revenue stabilisation by paying an agreed Strike Price for electricity. This 15-year contract would protect the plant from variable electricity wholesale prices and is critically important.

The technical note concludes with two key recommendations:

"examine various market scenarios and the potential for the plant to capture a viable market share and how that share and value changes with different Performance Characteristics."

"examine further the current basis of the performance characteristics and the technical parameters that are either setting or limiting a particular performance characteristic and thereby restricting the potential value."

3 REGULATORY COMPLIANCE, PERMITS AND CONSENTS

This section details the requirements of applicable consents, permits and regulations for the Proposed AFC plant, and any foreseeable implications for UK deployment. The consenting advice below was created for the Base Case design, however this advice remains applicable for the Optimised Alternate Case design.

The Proposed AFC plant is classified as Large Combustion Plant and will be subject to the requirements of the Environmental Permitting (England and Wales) Regulations 2016, as amended (EPR).

Securing these consents and permits in a timely manner is critical to UK deployment. Independent studies were conducted to develop strategies to achieve these consents and permits, which are described below.

3.1 ENVIRONMENTAL PERMITTING

An Environmental Permitting Strategy[2] has been developed which provides a recommended strategy for the projects' obligations under the Environmental Permitting (England and Wales) Regulations 2016, as amended (EPR). This strategy was based on the activities expected for the Proposed AFC Plant at the Wilton International site. These obligations will also apply if any other site is chosen in England or Wales, but the Directly Associated Activities for the plant may vary depending on the site's existing facilities.

For the reader's convenience, key extracts from the Environmental Permitting Strategy are detailed below.

"The Proposed AFC Plant design will be subject to the Environmental Permitting (England and Wales) Regulations 2016, as amended (EPR) Schedule 1, Part 2 (Section 1.1 Combustion Activities)."

"Chapter III requirements (Special Provisions for Large Combustion Plants) as stipulated in the Industrial Emissions Directive will apply to the Proposed AFC Plant. In addition, the plant must meet certain requirements set out in the BAT-Conclusions (& BAT Reference Note)."

"At the Wilton International site, there may be another prescribed activity (waste water treatment plant) which also falls under Part 2 of Schedule 1 to the EPR and, therefore, will be required to be regulated by the EA."

The report details each step in the permit programme and the required information is outlined. It is recommended to start the permit application at the FEED stage, once the design has been fixed or at least no significant further changes are expected.

[2] 70053760-WSP-00-XX-RP-TC-0001-S4_P02 – Environmental Permitting Strategy

The report assumes that the CO_2 will be piped off site for use by other industrial users and that the oxygen is supplied from beyond the site boundary via pipeline – so does not constitute a DAA – this will need to be confirmed for any pre-application discussion.

In summary, the obligations under EPR applicable to the Proposed AFC Plant are no more stringent than for an equivalent, conventional natural gas fired power plant.

It is recommended that the Regulator is engaged with at the earliest opportunity. Given the breakthrough nature of the Proposed AFC Plant, it should be expected to spend more time at pre-application stage in order to gain agreement with the Regulator on the permit application approach and supporting component studies. The permit application should be started once there is a design freeze, or at least when any further changes would not impact or delay the permitting process.

There are no blockers at this time, but the full scope of the permit application and the requisite component studies will require Regulator input.

3.2 CDM REGULATIONS

The Construction (Design and Management) Regulations 2015 apply to all UK design and construction projects and should be considered to apply to:

"the construction, alteration, conversion, fitting out, commissioning, renovation, repair, upkeep, redecoration or other maintenance (including cleaning which involves the use of water or an abrasive at high pressure, or the use of corrosive or toxic substances), de-commissioning, demolition or dismantling of a structure"

It should be noted for the FEED study that the whole lifecycle of a project: Design, Construction, Operation and Maintenance and future demolition and decommissioning must be taken into account at the outset. The Pre-FEED states a "Project CDM procedure" will be developed at the FEED to develop key project CDM documentation, which is a reasonable approach at this Stage.

Any subsequent project stage will require the Client to nominate a Principal Designer, which is likely to be the FEED Designer.

3.3 SUMMARY – CONSENTING AND PERMITTING

The strategies developed for achieving an Environmental Permit have provided clarity on the exact steps necessary to achieve these and has provided confidence that these are achievable within the project's current time and cost basis.

The Environmental Permitting Regulation obligations for the Proposed AFC plant are no more stringent than for an equivalent conventional natural gas fired power plant. There are no blockers at this stage, and we recommend the Environment Agency are engaged with at the earliest opportunity to gain agreement on the permit application approach and supporting component studies.

4 SITE SELECTION

This section details some of the important site selection considerations for the Proposed AFC plant, and where appropriate, discusses how the proposed site at Wilton International compares.

The following site specific works have been carried out assuming the Base Case plant design and although there would be minor changes to facilitate the Optimised Alternate Case design, such as site layout, the conclusions drawn are applicable to the Optimised Alternate Case design.

The Pre-FEED Report lists the key parameters for the evaluation of potential sites for the Proposed AFC Plant:

- Potential for local utilisation or proximity to captured CO_2 export infrastructure
- Availability of natural gas and oxygen
- Existing electrical transmission systems nearby
- Available site area with adequate space for construction laydown and parking
- Proximity to existing water supply and wastewater disposal system
- Proximity to adequate transportation – roads, railroads, and shipping ports
- Permit likelihood
- Political climate and support
- Captured CO_2 tax credits/Carbon allowance reductions
- Lack of flood zone concerns
- Topography – slightly elevated above adjacent area, gentle slopes
- Ground conditions – good suitable soils (no karst, minimal clays, etc.)
- Land planning and zoning – suitable for industrial plants
- Environmental sensitivity – no endangered or threatened species nor adverse impact to wildlife
- Cultural sensitivity – no significant archaeological or historical impacts
- Buried Ordinance – no significant removal necessary
- Noise – no sensitive noise requirements due to adjacent neighbours

4.1 SITE PLOT

The Proposed AFC plant requires at least three hectares for the power block, cooling towers and perimeter road.

An area with existing supporting infrastructure will be more cost and time effective to complete the required works to establish a suitable site. Furthermore, a site in an existing industrial area is more likely to satisfy some of the above listed key parameters with far less construction work and far less environmental disturbance and impact, making such a site a more attractive in terms of achieving consents and permits, and satisfying the project schedule.

Specific geotechnical requirements and utility connections are detailed in subsequent sections.

4.1.1 WILTON SITE

Wilton is located within the Teesside Industrial Cluster, which aims to decarbonise by 2030 to become the UK's first zero-carbon industrial cluster, via the Net Zero Teesside project. This location aligns with the net-zero credentials of the AFC plant and also appears favourable given many of the UK Government's commitments, such as the 2050 Net Zero target and Northern Powerhouse, examples of published governmental policy and strategy to invest in clusters to build decarbonisation schemes and also support economies in the North.

The Wilton site is classified as 'brownfield' and covers an area of approximately 15 hectares, including car parks and accesses beyond the site fence line. A full description of the site can be found in the Tees CCPP DCO Environmental Statement[3].

The plot within the fence line, excluding the Greystones A and B substations, is approximately 10 hectares. The Wilton site is sufficient in size and layout to accommodate at least two AFC plants and cooling tower banks.

This site previously accommodated the Teesside Power Station and benefits from the majority of parameters required of the Proposed AFC plant, such as suitable plot area, hardstanding, interfaces, access, drainage, land zones etc. The site is highly suited for re-use for the Proposed AFC plant and, excluding for piling works, there are minimal foreseeable works to make the site operational.

A provisional plot plan[4] has been developed by 8 Rivers for the Wilton site. This layout is based on the principles of the Proposed AFC plant, while aligning the location and orientation of plant with the Tees CCPP DCO. The purpose of the layout is to demonstrate that both a single AFC Plant and two AFC Plant solution can be accommodated within the Order Limits and Works areas defined in the existing Tees CCPP DCO.

The site benefits from a slip-road connection directly to the A1053 Greystone Road dual-carriageway, facilitating heavy vehicle access directly to/from the site entrance.

The existing hardstanding on the site allows for a construction lay-down area in the east of the site which is more than adequate. The sound acoustic barrier-wall on the southern boundary can also be removed during construction phase to increase available hardstanding area and improve access to the site by diverting traffic away from the existing site entrance on the western site boundary. This barrier must be in place once the Proposed AFC plant is operational to mitigate noise impact to nearby sensitive receptors, such as Lazenby Village to the south.

Overhead line infrastructure at the southern boundary is a minor risk to construction traffic, which can easily be managed using good construction practices.

There is one occupied site to the east, accommodating the Ensus Bio-ethanol Plant constructed in 2010.

4.2 CLIMATIC CONDITIONS

The Allam-Fetvedt Cycle utilises a semi closed Brayton Cycle with a high-pressure CO_2 working fluid. As such, the core equipment of the cycle; the turbine, compressors and pumps have negligible impact from ambient temperature conditions.

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[3] https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010082/EN010082-000170-EN010082-6.1-ES%20Non%20Technical%20Summary-Final-November%202017.pdf
[4] 10-XXXX-C3-DWG-EN-0007-P2 - Whitetail Two Unit Power Layout (Alternate 01)

The system most influenced by climatic conditions is the cooling towers, which favour low ambient temperatures and low humidity (for evaporative cooling towers). The prevailing wind direction will also have an impact on the location of the cooling tower system in relation to the other plant equipment.

During the FEED, Best Available Technology (BAT) for the cooling water system should be determined via environmental studies and discussions with the Regulator.

4.2.1 WILTON SITE

Climatic conditions in the Teesside region generally agree with the assumptions made within the Pre-FEED Report. From freely available weather data for Redcar covering the period between 2009 and 2020[5]:

- The maximum daily temperature is 20°C and the minimum is -1°C.
- Humidity varies between 77% and 91%.
- Prevailing wind is from the south west.

These conditions present no special considerations above and beyond the Proposed AFC plant design.

4.3 GEOTECHNICAL REQUIREMENTS

The Proposed AFC plant design assumes favourable geotechnical conditions such that structural and civil works are simplified, and cost is minimised. As the Pre-FEED is site-agnostic, this is a reasonable assumption as a geotechnical design must be site specific and therefore it is difficult to predict any further without a site and known ground conditions.

4.3.1 WILTON SITE

Geological information has been compiled by WSP based on existing Ground Investigation (GI) information available at the time. A Geotechnical Desktop Study[6] was performed to review the existing information on the ground and groundwater conditions at the Wilton site and a conceptual site model was developed.

This study confirms, amongst other findings, that the proposed power plant structures (the combustor and turbine pedestal and the cooling towers in particular) would require piled foundations.

Information suggests the piled foundations for the former Teesside Power Station are still present below the site with significant thickness of reinforced concrete caps. This risk is manageable by careful consideration of the final plant layout and a competent contractor, providing adequate time is allowed for construction and for post-installation testing.

To reflect the cost of piled construction, additional CAPEX amounts must be added to the Pre-FEED cost estimate. These have been estimated in Section 7.1.3.

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[5] https://www.worldweatheronline.com/redcar-weather-averages/north-yorkshire/gb.aspx
[6] 70053760-WSP-00-XX-RP-GE-0001-S4_P03 – Geotechnical Desktop Study

A Ground Investigation Specification[7] has been produced, specific to the Proposed AFC plant layout, which defines the investigations required to fill the gaps in existing geotechnical site information and to support future detailed geotechnical, civil and structural design of the proposed development.

4.4 CRITICAL UTILITY CONNECTIONS

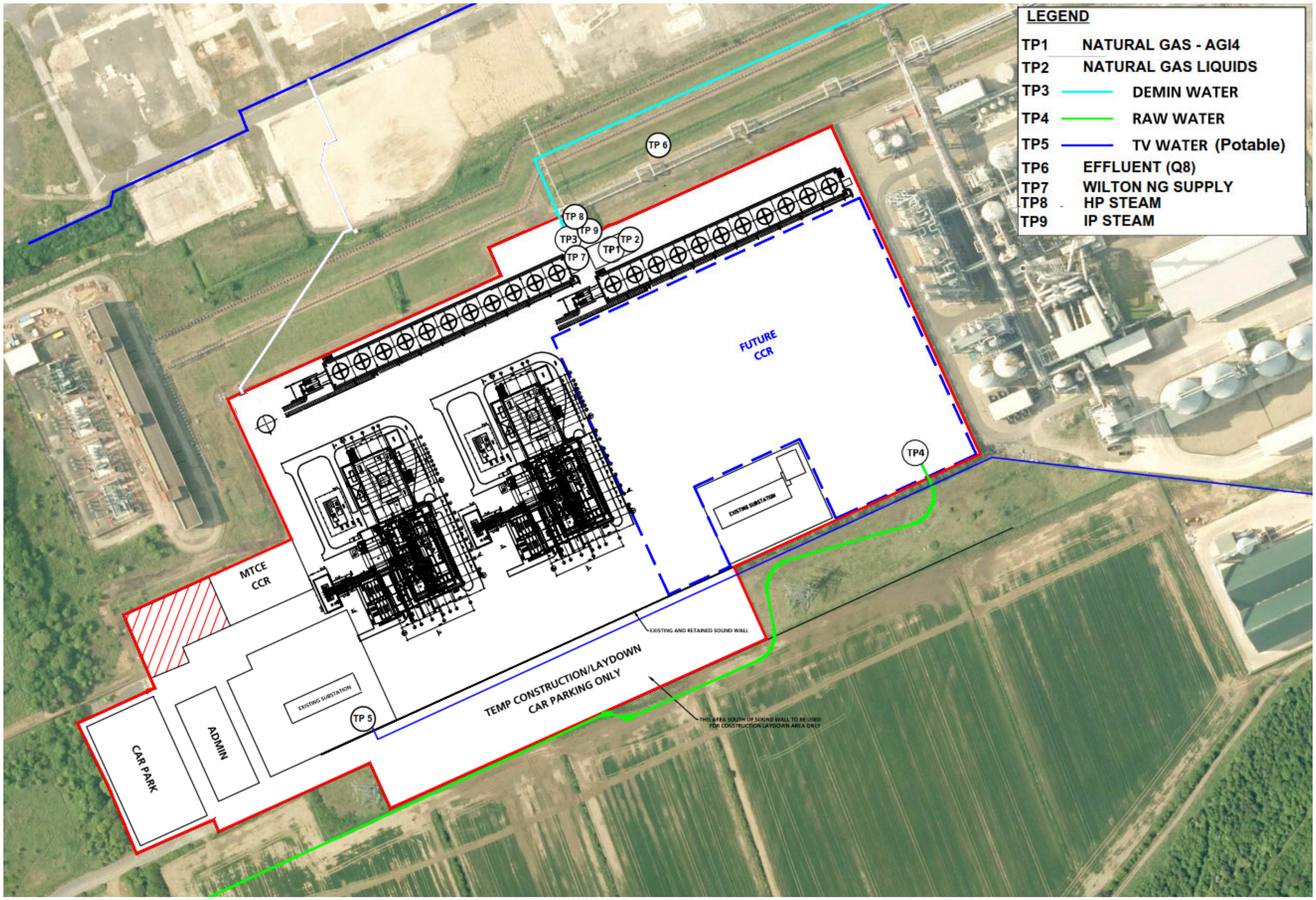
The required utility connections for the Proposed AFC Plant are listed in the Pre-FEED Report section 5.3. The critical connections are highlighted and discussed herein.

Following de-commissioning and demolition of the Teesside Power Station on the Wilton site, various utility infrastructure was left in place, including two grid connection substations, the gas connection and site drainage infrastructure.

Figure 4-1 below shows the available tie-ins at the Wilton site, as extracted from the Tees CCPP Tie-in Points for the previously consented CCGT. Drawing provided by permission of Sembcorp.

[7] 70053760 -WSP-00-XX-SP-GE-0001-S3_P01 - Specification & Schedules for Intrusive Ground Investigations

Figure 4-1 - Available Utility Tie-ins at Wilton, extract from Sembcorp Tees CCPP Tie-in Points



4.4.1 NATURAL GAS SUPPLY

A gas supply is a critical component for AFC plant operation. The Proposed AFC plant uses natural gas as the combustion product and requires supply of 39,600 kg/hr at 60 bar.

This gas supply could be satisfied by connection to the National Transmission System or to a private supplier. In either case, a gas supply pipeline would be required between the Proposed AFC plant and the gas connection point, with a gas receipt facility within the site boundary.

If a connection to the National Transmission System is pursued, the gas connection would require a Full Connection Offer from National Grid. Design, agreement and construction of a new gas supply pipeline and connection to the National Transmission System can require several years from inception to commencing operations. Based on the timelines of this Proposed AFC plant, this lends favour to any site with an existing gas pipeline which can be more readily adopted.

4.4.1.1 Wilton Site

There is an existing 24" natural gas pipeline connection (see TP1 in Figure 4-1) within the Wilton site which is currently mothballed and preserved. This routes to the original Enron Billingham NTS exit point although there is currently no physical connection the National Transmission System.

The NTS connection available capacity is 121 GWh/day, to approximately 350 tonnes/hr[8]. This is more than sufficient to provide the AFC plant gas flow rate of 39.6 tonnes/hr, or any number of AFC plants that the Wilton site could accommodate.

Sembcorp have confirmed the status of the gas connection is as stated in the Tees CCPP DCO Gas Connection Statement[9]. Key extracts are listed below:

"The existing gas connection is provided by a 14 km / 24" high-pressure buried pipeline, owned by Sembcorp, that connects to the NTS at Belasis Avenue in Billingham, North Tees. Since the decommissioning of TPS, the pipeline has been out of service, in a state of preservation pending recommissioning."

"Re-connection of the pipeline would require an initial application for connection and capacity to National Grid, in pursuit of a Full Connection Offer (FCO). This process would be required for any site without a live gas connection."

"The pipeline terminates within the Order Limits of the site (as defined by the existing Tees CCPP DCO application), at an existing above-ground installation. This means no further land requirement for the provision of the gas connection."

The gas connection at Wilton is suitable for the Proposed AFC plant flowrates and is low risk because:

- Existing pipeline can supply the required gas flowrates

[8] Assumed average higher heating value = 50 - 52 MJ/kg
[9] Tees CCPP DCO Gas Connection Statement: https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010082/EN010082-000218-EN010082-5.3-Gas%20Connection%20Statement-Final-November%202017.pdf

- Existing pipeline is in a state of preservation (but integrity and condition of the pipeline should be assessed during FEED)
- Existing pipeline terminates within the Tees CCPP DCO Order Limits boundary, at an existing above-ground installation. There is no further land requirement for the provision of the gas connection and would require only a small pipe length to connect to the Proposed AFC plant.

The integrity and condition of the pipeline should be assessed as part of FEED works to re-establish the pipeline.

4.4.2 ELECTRICAL TRANSMISSION SYSTEMS

A suitable connection to the UK electricity grid is critical to the project and will facilitate the plant's primary source of revenue - sale of electricity to the electricity system operator.

A 275 kV connection to the transmission grid is typical for this type of plant, and has been included in the Pre-FEED.

The Pre-FEED includes a Combustion Turbine Generator (rated at 470 MVA, 22 kV) which supplies all plant auxiliary loads via two Auxiliary Transformers that provide the necessary power supplies to the generating unit and the plant process. All other power is available for export.

Critical electrical systems also have connections to emergency backup generation, however the detail of this has not been developed to comment on its adequacy at this stage.

4.4.2.1 Wilton Site

The site benefits from two existing 275 kV switchyards and transmission systems, known as Greystones A and B (owned by National Grid) within the site boundary which are available for connection by the Proposed AFC plant. These are legacy systems from the 1,875 MW_e Teesside Power Station (Tees CCGT) plant which previously occupied this site and are explained in further detail in the Tees CCPP DCO Grid Connection Statement dated November 2017[10].

As the grid connection infrastructure will be provided by existing National Grid assets, connection to the Greystones substations appears entirely feasible and deliverable. There will be no additional land required for the Grid Connection. Environmental and visual parameters will remain largely unchanged. Both switchyards will be in close proximity to the generator step-up transformers and require a minimal run of HV line for connection.

The Combustion Turbine Generators are rated at 470 MVA, which exceeds the 400 MVA rating of the Greystones A and B sub-stations so it is likely the substation requires an upgrade to accommodate this output. It is expected no major works are required on the overhead line infrastructure.

[10] Tees CCPP DCO Grid Connection Statement dated November 2017: https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010082/EN010082-000217-EN010082-5.2-Grid%20Connection%20Statement-Final-November%202017.pdf

WSP understand a Grid Connection Application has been approved by National Grid for the Proposed AFC plant to connect to the Greystones A substation, with the provision for future additional units.

The Grid Connection Application documents allow for a maximum gross output of 460 MW_e and maximum net output of 330 MW_e to the grid. The actual net output of the Proposed AFC plant is 296.0 MW_e and therefore well within the application limits. Power may also be supplied to Wilton site via a transformer 22/66 kV at 140 MVA.

4.4.3 WATER SYSTEMS

In the wider Wilton Industrial Area, Sembcorp own and operate a variety of existing water pipelines and a waste-water treatment facility, with tie-ins available for this project at the site fence line. Sembcorp have confirmed these water connections have available capacity for supporting a 1,700 MW CCGT plant and further expansion if required, and as the Proposed AFC plant requires far less water, there is significant excess capacity.

The available water and waste-water connections at the Wilton site are summarised in Table 4-1.

Table 4-1 – Available Water and Waste Water Connections at Wilton

Water Service	Connection Type	Surplus Capacity	Suitable for Proposed AFC plant
Demineralised Water	18" pipeline	1,170 m^3/hr	- *
Raw Water	24" pipeline	16,280 m^3/hr	Yes
Potable Water	63mm pipeline	890 m^3/hr	Yes
Effluent	48" drain	14,000 m^3/hr	Yes

** Demineralised water supply to be confirmed. Minimal supply may be required but will most likely be provided by mobile tankers as opposed to connection.*

4.4.3.1 Water Supply

The Base Case design requires a raw water supply of 500 – 550 m^3/hr for the Plant Water make-up. The Proposed AFC plant raw water consumption increases by less than 10% due to increased cooling tower evaporation. This is based on open loop evaporative cooling tower technology and the required flowrate would significantly reduce if a dry or hybrid cooling tower system was specified (refer to Section 5.2.1). A minimal potable water supply is required for personnel use and site emergency shower.

The raw and potable water supplies at Wilton will provide more than sufficient capacity for the AFC water and waste-water treatment needs.

4.4.3.2 Wastewater Disposal

A wastewater discharge of 130 – 160 m^3/hr average is required, which is predominantly blowdown water from the open loop evaporative cooling towers. The wastewater discharge rate will reduce slightly with a hybrid cooling system (small reduction in amount of blowdown required) and reduce significantly with a dry cooling system (blowdown eliminated).

The effluent connection at Wilton has more than sufficient capacity to accommodate the AFC wastewater flowrates.

4.5 OXYGEN SUPPLY

A secure supply of oxygen is a critical component to the successful implementation of the Proposed AFC plant.

4.5.1 OXYGEN REQUIREMENTS

The Proposed AFC plant assumes an oxygen supply of 3,823 tonnes/day with purity of 99.5% O_2, supplied via a pipeline from beyond the project boundary. Both the flowrate and purity are achievable from either one or multiple ASUs, whether located within the project site or supplied from beyond the boundary. The two primary contracting forms available to achieve the oxygen supply are:

- Sale of Equipment (new-build ASU); or
- Sale of Gas (oxygen import via pipeline from an industrial-gases supplier).

4.5.2 OUTCOME OF OXYGEN SUPPLY STUDY

An independent oxygen supply study[11] was conducted to assess the methods of supplying 4000 tonnes/day of oxygen to the Wilton International site. While site-specific in nature, the study presents useful information on the capability of various UK industrial gas suppliers. The study details the considerations to be taken into account when determining the oxygen supply method. From this study, it is important to note:

- A new-build ASU carries significant CAPEX cost and would be the single most expensive piece of equipment for the AFC project.
- It is believed no single supplier has 4,000 tonnes/day of existing available capacity at any single location in the UK. Therefore, any Sale of Gas agreement would require new-build ASUs, or existing ASUs supplemented with new-build ASUs, which is likely to be reflected in the agreement.
- Partial oxygen capacity could be met using existing equipment depending on location and agreement.

Based on the CAPEX implications of a new-build ASU, it is reasonable at this stage to assume a long-term supply of oxygen agreement, with new-build ASUs constructed by the supplier. The oxygen supply agreement will be designed with the oxygen supply needs in mind to ensure there are no operational limitations (i.e. flowrate, pressure) to the supply.

A secure supply of oxygen is of paramount importance to ensure the Proposed AFC plant remains available to generate. Because of this, the selection of an oxygen supply method will consider wider project priorities beyond technical and financial competitiveness, such as commercial implications

[11] Oxygen Supply Infrastructure in Teesside Area - An Independent Executive Report for 8 Rivers (Spiritus Group Limited)

and long-term sustained security of supply. The development towards a confirmed oxygen supply has been prioritised for the FEED stage.

There is an opportunity to consider ASU heat integration with the Proposed AFC plant to increase the overall efficiency of the plant – this is discussed in Section 5.3.1.

4.5.3 WILTON SITE

The Oxygen Supply Study details the existing oxygen gas suppliers in the UK, their assets in the Teesside area and their ability to supply new ASU equipment. The requirements of the Proposed AFC plant and the capabilities of local oxygen assets are compared in **Error! Reference source not found.**.

From this study, it is important to note:

- The Wilton site benefits from an operational 8” oxygen pipeline network, owned by BOC and connected to BOC’s ASU facilities, however the operating pressure is significantly less than required by the Proposed AFC.
- BOC have by far the most extensive existing oxygen assets in the area (see **Error! Reference source not found.** below) but are unlikely to favour a joint-venture with other suppliers.
- Total existing ASU capacity in the area is not sufficient for the Proposed AFC plant oxygen needs. New build ASUs will be required in any scenario.
- There is manufacturing capacity for new-build ASUs from various suppliers.
- There is sufficient land space across the Wilton industrial area to accommodate new-build ASUs.

The existing oxygen pipeline at Wilton is of particular benefit. The FEED should examine the pressures and available flowrates versus the Proposed AFC plant. If capital investment is needed in the pipeline, or compressors for example, that cost would be reflected in the Oxygen Supply Agreement.

In summary, the report presents various viable options for Sale of Gas, Sale of Equipment and Joint-Venture agreements. It also highlights some interest in a toll-processing deal which would present synergies between the Proposed AFC plant and the oxygen supplier.

The study has investigated the potential oxygen supply methods as far as possible without directly engaging suppliers regarding this project and has laid the ground for commercial discussions with the suppliers. WSP understand 8 Rivers are now in discussions with various suppliers, which are developing and have so far confirmed that long-term contracts are preferred by the suppliers in order to re-coup their ASU CAPEX costs. Long term contracts are also the preference of this project as they provide OPEX stability.

4.6 CO_2 EXPORT

A reliable CO_2 export is a critical component to the successful implementation of the Proposed AFC plant.

In the Proposed AFC plant, 98% of CO_2 produced is recirculated within the plant and 2% is sent for export. The CO_2 produced is at high-pressure and can be exported between 4.0 MPa and 12.0 MPa depending on the export network requirements. The CO_2 is also high-purity (>98%) and may require some minimal processing to meet export specification – depending on the agreed CO_2 export conditions.

The Pre-FEED has defined the maximum CO_2 flowrate at export (107,530 kg/hr), which has allowed feasibility analysis of various transport modes for the export.

Various transport modes are suitable for CO_2 export in the UK, such as pipeline, road/rail tanker and marine loading – the selection of the transport mode requires careful consideration of many factors, including customer requirements and any existing infrastructure which could be utilised.

The CO_2 offtake agreement should include for shipping rights/slots to ensure the CO_2 export needs of the project are met by the offtaker. This has been accounted for in the Project Risk Register.

4.6.1 WILTON SITE

The Net Zero Teesside (NZT) project, formerly OGCI, proposes to develop a CO_2 pipeline network around the Tees Valley to transport captured CO_2 from multiple sources to offshore storage sites in the Southern North Sea. One arm of this network is anticipated to terminate on the Wilton site, and therefore will provide a suitable export route for CO_2 captured at the power plant. However, it is anticipated that the NZT pipeline may not be available until 2027 or later, while the Proposed AFC Plant could be deployed and exporting CO_2 before this time.

The NZT project, which includes the pipeline, will be consented by the DCO process and is currently in the Pre-Application phase, with an application expected to be submitted to the Planning Inspectorate in Q1/Q2 2021. The progress of this consent, and subsequent construction, should be closely monitored and is of importance to this project.

WSP conducted a CO_2 Optioneering Study[12] for the Wilton site, including a preliminary design for a future NZT pipeline connection and detailing alternative export options to bridge the duration until the NZT pipeline becomes available.

4.6.1.1 NZT Pipeline Connection

The NZT pipeline connection is currently deemed to be the most physically convenient and cost effective way to export CO_2, when compared with the alternatives in the following sub-sections, given the proximity of the proposed NZT route to the Wilton site. The tie-in is likely to be an industry standard pipeline connection, while considering the unique properties and safety risks of CO_2. With only a small length of pipeline outside the Wilton site boundary, much of the construction for an NZT pipeline connection would be within the site boundary.

The NZT project is targeting the capture of 10 million tonnes CO_2 per year[13] from a cluster of carbon-intensive businesses in the Teesside area and will deliver the UK's first zero-carbon industrial cluster. Based on this ambition, it is almost certain the pipeline will have sufficient capacity for the Proposed AFC plant's CO_2 offtake (initial maximum export is less than 1 million tonnes CO_2 per year). The capacity of the NZT pipeline should be confirmed once more details are available.

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[12] 70053760-WSP-00-XX-RP-PE-0001-S4_P03 - CO2 Optioneering Report
[13] https://www.netzeroteesside.co.uk/project/

WSP understand 8 Rivers are engaged with NZT in their project development which adds confidence that the two projects will be aligned. The risk of delay to the NZT project has been captured in the risk register, and 8 Rivers are engaging with third parties to secure other CO_2 offtake, shipping and storage partners.

It is reasonable at this stage to consider the NZT pipeline as the CO_2 export method once it is available. NZT export is very likely to be more cost-effective and capable than export via the alternatives below. Therefore, based on current knowledge, alternative export options are deemed to be an interim solution until the pipeline connection becomes available.

4.6.1.2 Alternative Export Methods

An alternative CO_2 export method would be required to bridge the duration between the time the Proposed AFC Plant becomes operational and the NZT pipeline becoming available.

The proximity of the Wilton site to various types and scales of transport infrastructure presents three key alternative export methods:

- New marine export facility on the Tees
- Existing marine export facility on the Tees
- Transport to remote marine export facility

There is an existing mothballed 8" pipeline from Wilton and Seal Sands that could be used for the export of CO2. It is sufficiently sized for gaseous CO_2 transport from the Proposed AFC plant and is assumed to be the CO_2 transport route until the NZT pipeline becomes available – it is yet to be decided how the CO_2 will be exported and sequestered beyond the pipeline. A full fatigue assessment should be undertaken to verify the condition of the pipeline and its remaining life.

This CO_2 pipeline route passes an available land plot on the north bank of the River Tees, adjacent to the Inter Terminals Seal Sands facility, which could be adopted as a new marine export facility. This location is also beside the north portal of the pipeline tunnel under the river, which would facilitate the installation and routing of a new CO_2 pipeline to the facility.

All three options are possible export methods to deploy at the Wilton site, and could be used as long-term export solutions (albeit with individual performance and cost implications) if the NZT pipeline connection is not chosen or available. Further assessment of the technical, commercial and economic aspects of each option should be conducted during the FEED stage.

WSP understand 8 Rivers are engaged with a number of potential parties for the offtake, transport, storage and export of CO_2. WSP are not party to these discussions and cannot pass comment.

4.7 SUMMARY – SITE EVALUATION

The Wilton site is highly suitable for the Proposed AFC Plant. The site previously accommodated the Teesside Power Station and the Tees CCPP was granted consent on this site in 2017, demonstrating that there was no fundamental issue with a power plant installation at Wilton. The site has sufficient land plot to accommodate at least two Proposed AFC plants.

The site benefits from existing electrical transmission connections and utility connections. The connections for natural gas, electrical transmission, water and wastewater all have sufficient capacity for the plant. The O_2 supply has a number of credible solutions and 8 Rivers are in advanced discussions with various stakeholders to progress these agreements.

Geographically, the site is located within the Teesside Industrial Cluster, with the local Net Zero Teesside project providing an economical long-term CO_2 offtake. Until a long-term solution is operational, the existing local marine, road and rail infrastructure provide several feasible options for an interim CO_2 offtake.

During the FEED Stage, Best Available Technology for the cooling water system should be determined via environmental studies and discussions with the Regulator.

It is likely the Proposed AFC plant would require piled foundations, which present an additional CAPEX cost versus the Pre-FEED cost estimate.

5 PRE-FEED TECHNICAL REVIEW

This section summarises WSP's technical design review of the Pre-FEED deliverables and outlines the key findings and recommendations for the AFC plant at a generic UK site. This excludes, for example, commercial and financial agreements.

The review considered the following key elements:

- Ensuring UK/EU standards were met
- Capturing all risks
- Design suitably developed to progress to FEED

Comments and technical queries were raised to the Project Team to ensure the deliverables produced were suitable for the Feasibility Study. Only the key findings with material potential impact are discussed herein.

All design deliverables were available for the Base Case design and selected deliverables were also reproduced for the alternative design cases. This is reasonable for alternative design cases at Pre-FEED stage and, due to design similarities, our review of the Base Case deliverables is mostly applicable to the alternative cases. The differences between the base and alternative design cases should be further analysed in FEED once more detail is available, to validate the Pre-FEED technical review for the alternative cases.

In general, the AFC plant design is more advanced than would typically be expected at Pre-FEED stage. For example, provisional P&IDs were provided which would normally be expected to be developed at later project stages. This additional level of detail has supported early development of key equipment such as the combustion turbine generator.

The design review highlighted:

- Five design assumptions which require resolution, detailed in Section 5.2.
- Some minor concerns, such as those which currently fall short of accepted good engineering practice in the UK and can be rectified at FEED with minimal impact. Refer to WSP's Independent OE Report Databook.

5.1 COMPLIANCE WITH APPLICABLE CODES & STANDARDS

In general and as is typical of this stage of project development, the Pre-FEED Report is preliminary in detail and does not state an exhaustive list of applied codes and standards, but provides general wording which indicates compliance with:

- Generally Recommended and Good Engineering Practices
- Applicable UK laws and regulations
- Applicable international codes and standards

The Pre-FEED Report defers the selection of an exhaustive list of codes and standards to the FEED, when a Project Specification document should be produced. Any re-work or impact at FEED due to adoption of different-than-expected codes and standards is unlikely to be significant due to the inherent engineering flexibility at this early stage of the project.

Based on the Pre-FEED report and the technical query responses, the designer intends to use the best-practice and internationally recognised standards for the UK (for example IEC 61511, BS 6739, BS 7671 and EN Eurocodes). These should be confirmed in the FEED Project Specification.

5.1.1 EUROPEAN DIRECTIVES

The Pre-FEED notes that any Proposed UK AFC Plant must be compliant with the CE Marking Directive 93/68/EEC, the Pressure Equipment Directive (PED) 2014/68/EU and the Equipment and Protective Systems Intended for Use in Potentially Explosive Atmospheres (ATEX) 2014/34/EU Directive.

It should be noted the Pre-FEED Report, section 3.2 states:

"The estimate has been developed based on globally sourcing equipment to international codes and standards, and the applicable codes applied are identified here-in"

This is an acceptable approach, but it should be noted that to secure CE marking, suppliers using anything other than BS EN codes must demonstrate compliance with the CE Marking Directive 93/68/EEC.

The ATEX and PED directives were a key consideration during WSP's risk management process (refer to Section 6), and particularly during the HAZID Study. The directives must be incorporated into the design of systems and equipment during FEED stage.

5.2 KEY COMMENTS FROM PRE-FEED REVIEW

The design review highlighted five technical design items worthy of highlight, detailed below, which constitute a moderate concern and must be addressed early in the FEED to mitigate their impact.

5.2.1 COOLING TOWERS

The Proposed AFC plant assumes an open-loop evaporative cooling tower system. While this will increase plant efficiency versus a dry or hybrid system, the selection of cooling technology must demonstrate a cost-benefit balance which is best suited for the chosen site and its environmental conditions. Until the site is selected, it cannot be confirmed whether a dry, hybrid or wet cooling system would be best suited.

However, virtually all recently consented power plants in the UK have specified hybrid or dry cooling systems and the consented Tees CCPP was specified with a hybrid cooling system. See the extract below from the Tees CCPP DCO Environmental Statement[14]:

"Selected Cooling Technology: Closed Circuit Evaporative Cooling (hybrid cooling towers)

5.47 Hybrid water coolers are considered to represent best available technique (BAT) in this instance due to the relatively low level of water use (140 kg s-1 versus 8,560 kg s-1 for once through), lower noise emissions than ACCs and lower vapour emissions than natural draught systems."

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[14] https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010082/EN010082-000176-EN010082-6.2.5-ES%20Chapter%205%20-Project%20Description-Final-November%202017.pdf

Since the Proposed AFC Plant has a far lower water supply need, it is unknown whether a hybrid system would still be deemed BAT at the Wilton location and at this scale. During the FEED, Best Available Technology for the cooling water system should be determined via environmental studies and discussions with the Regulator.

Refer to the BAT reference document for Industrial Cooling Systems for more details[15]. Particular environmental considerations for evaporative cooling systems include the environmental impacts of water discharged to the receiving water body, local water availability and local visual impact of plume emission.

There are implications to plant performance, footprint and CAPEX if deploying dry or hybrid cooling systems versus an open-loop evaporative system, the scale of the implications will depend on the selected site.

5.2.2 ASSUMED GROUND & CIVIL CONDITIONS

The Pre-FEED design and cost estimate make assumptions on a variety of ground and civil conditions (such as high soil bearing capacity and no deep foundations necessary) which individually are favourable in the UK, and collectively are very unlikely to occur at any single UK site. For example, it is highly likely that the plant will require deep piled foundations for concentrated loads.

The selected site is likely to be brownfield with previous use and groundworks, yet these assumptions remain optimistic and the Pre-FEED CAPEX estimate is based on these assumptions.

This risk has been accounted for in the Project Risk Register (refer to Risk 15). The Geotechnical Desktop Study has identified the ground conditions at the Wilton site and advises that piles would be required. To reflect the cost of piled construction, additional CAPEX amounts must be added to the cost plant estimate – these have been estimated in Section 7.1.3.

Risk 15 has therefore been mitigated based on the understanding of the conditions at the Wilton site. If another site is chosen, the ground and civil conditions should be re-assessed and a new mitigation identified.

5.2.3 EQUIPMENT REDUNDANCY

The equipment redundancy philosophy requires further refinement in FEED, for key plant systems under normal and abnormal plant conditions.

The Proposed AFC plant includes instances of lower than expected equipment redundancy, particularly in the electrical and control & instrumentation designs. For example, the unit auxiliary transformer has no redundancy. WSP would expect the plant redundancy philosophy to be refined in key areas to reflect the project objectives and improve system resilience.

It should be noted there is no single redundancy philosophy which is ‘correct’, and it is not expected that the philosophy would be fully developed at this stage. Rather, the redundancy philosophy must

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[15] Integrated Pollution Prevention and Control (IPPC) - Reference Document on the application of Best Available Techniques to Industrial Cooling Systems December 2001

be carefully considered and developed in harmony with the Project requirements, such as plant availability, resilience, CAPEX/OPEX implications and safety (noting that plant safety code requirements must be satisfied). These objectives should be agreed and outlined early in FEED.

As a first-of-a-kind plant, we also recommend that reputational impacts are considered when refining the redundancy philosophy. The cost-benefit of plant resilience should be considered, along with its effects on the technology's reputation as a highly reliable and available plant.

The redundancy philosophy of the Proposed AFC plant was queried in various WSP review comments. At the time of writing, responses to some of those queries are outstanding, however the response to technical query 14 regarding control and instrumentation redundancy provides more detail:

WSP TQ 14:

"Will redundancy be inherent in design so that no single point of failure shall trip the unit?"

TQ 14 Response:

"For the 'base case' presented in the pre-FEED, equipment redundancy is as per the PFD and equipment list. For any future phases, equipment redundancy will be specified to meet target availability/reliability requirements. The demonstration facility was developed using triple redundant systems and we anticipate that this will also be designed into the commercial facilities during FEED"

It should be noted that the quantity of additional redundant plant will not be known until further design work is undertaken at FEED so the additional costs cannot yet be quantified.

5.2.4 FUEL GAS COMPOSITION

The Proposed AFC plant has been modelled assuming 100% methane fuel gas, which in the UK is highly unlikely to be the fuel gas composition. The actual fuel gas composition will likely be in accordance with Gas Safety (Management) Regulations 1996, Schedule 3, which includes other constituents such as nitrogen, sulphurs and hydrogen (this assumes gas is sourced from the National Transmission System).

The Pre-FEED (Table 10-1) defers the modelling of location specific fuel gas composition to the FEED. When this is performed, the models should ensure no adverse effects are anticipated from GS(M)R specification gas. Possible effects could include:

- Variance in exhaust-gas composition
- Changes or additions to plant design, such as additional gas treatment plant
- A change in plant performance due to different heating values

A variance in fuel gas heating value is not a concern, this can be rectified during FEED by modifying flow rates. The potential effects of SOx and NOx on the plant (e.g. potential corrosion and operational issues) are not yet known, but are not expected to be of concern due to the low concentration levels. Also, the CO_2 offtaker's gas composition requirements are not yet known and should be investigated to determine to what degree these compounds are acceptable in the export CO_2.

WSP engaged with 8 Rivers to investigate whether these effects apply to the AFC plant and if so, to what degree.

WSP query regarding composition of CO_2 export gas due to GS(M)R specification gas:

"Has modelling considered the concentration of NOx and SOx in the CO2 exhaust stream? How will these be managed?"

8 Rivers response:

"As pure oxygen is used in the combustion process, the only source of nitrogen or sulphur is from natural gas. NOx/SOx in the process gas from the AFC combustor is removed in the CO_2-water separator and as a result there are expected to be no NOx/SOx in the CO_2 export stream from the Plant."

This response is acceptable and indicates that no NOx/SOx will be present in the export to the CO_2 offtaker. This avoids the risk of producing 'off-spec' CO_2 export gas due to a fuel gas supply which includes nitrogen or sulphurs within the GS(M)R limits.

WSP query regarding operational issues due to GS(M)R specification gas:

"Have potential corrosion and operational issues been assessed? At low concentrations, could be problematic when the flue gas gets close to its dew point (downstream of the Recuperating HX)."

8 Rivers response:

"The test facility at La Porte has been operational for a significant period of time with no indication of any potential corrosion issues within the main process equipment. Due to the trace amount of sulphur that could be present in GSMR specification natural gas, this is not expected to be an issue."

This response is reasonable at Pre-FEED stage. Corrosion potential should be further investigated during the FEED stage.

In the longer term we advise GS(M)R regulations are under review with a view to changing the gas content specification to allow future blends of hydrogen and biomethane in the gas transmission networks. The impacts are yet unknown but should be investigated during FEED.

5.2.5 ELECTRICAL EQUIPMENT SIZING

WSP preliminary system calculations indicate the equipment ratings for various electrical equipment appears to be undersized. It is expected at Pre-FEED stage that preliminary system calculations are used to inform indicative equipment sizes. Through discussion with McDermott, it is understood that system calculations have not been used to size the equipment.

It is typical for designs to be conservative rather than undersized at this Pre-FEED stage. The equipment ratings should be reviewed and revised, and it is likely to require increased equipment ratings which would also increase equipment CAPEX.

5.3 OPPORTUNITIES

This section highlights some of the key opportunities to benefit the Proposed AFC Plant in different ways.

5.3.1 ASU HEAT INTEGRATION

The secure supply of oxygen to the project at any UK location is likely to require construction of new ASUs, even if existing ASUs are also utilised (see Section 4.5). The Pre-FEED Report anticipates heat integration between the Proposed AFC plant and the ASU would result in an overall improvement to performance of both plants. This would be subject to commercial agreements and would increase CAPEX, but presents a promising option to increase plant output.

5.3.2 PLANT RESPONSE AND FLEXIBILITY

There is an opportunity to improve plant performance, response and flexibility beyond the Proposed AFC plant design with the installation of additional equipment. Any performance improvements (and hence potential revenue increase) should be assessed as part of a Net Present Value assessment. 0 elaborates further.

5.4 ALTERNATIVE DESIGNS

This section provides commentary on the Section 9 of the Pre-FEED Report.

While the Optimised Alternate Case has been selected by 8 Rivers to be taken forward as the Proposed AFC plant design, the two alternate design cases are presented in the Pre-FEED as alternatives to the Base Case design so are discussed here for consistency.

5.4.1 ALTERNATE CASE (925 °C TURBINE INLET)

The alternate case is a pragmatic approach combining some improved performance without pushing the technology too far. Throughout the development of gas turbines, OEMs have pushed material development to accommodate increased turbine inlet temperatures and secure the efficiency gain that goes with it. The 925 °C alternative is therefore an obvious step to improving plant performance.

Pushing the CO_2 turbine generator well beyond where it has gone so far would have further performance benefits but may introduce a series of unexpected consequences. As with most technologies, a better chance of success is achieved through incremental change rather than step change. To put the 925 °C into context, current gas turbine technology is pushing towards 1700 °C.

Modifications to the plant design have been included to support the 925 °C alternative.

The introduction of closed loop cooling is on balance a favourable inclusion, the benefits of minimising heat exchanger fouling and increased plant availability are deemed to outweigh the additional pumping duties and lower efficiencies.

Dry gas seals are promoted by major OEMs and are utilised in modern high-performance gas turbines. Seal systems are supplied as a cartridge and should run for 10-15 years between replacement. The elimination of the turbine gland seal system is beneficial for the plant cost and parasitic load.

The uncoupling of the Recycle CO_2 pump from the turbine removes what can be a problematic item – independent motor driven pumps such as this alternate case simplify the turbine and reduce the risk of failure.

Adding a fourth stage to the CO_2 compressor will improve efficiency and reduce power consumption. However, the added complexity of a fourth stage will increase both the capital and maintenance cost of the machine. Ultimately the choice is financial rather than technical. If the through life benefit of 4 stage over 3 can be demonstrated, then the choice is justified.

These modifications have been proven on other plants though not necessarily with CO_2 as the working fluid. The modifications will add to the CAPEX and therefore a cost benefit of the increased CAPEX should be analysed to determine its net worth.

5.4.2 OPTIMISED ALTERNATE CASE (925 °C TURBINE INLET)

This design case is a result of a cost optimisation of the Alternate Case, seeking the lowest CAPEX 925 °C option. The range of equipment is equivalent to the Alternate Case, but with changes to process parameters, such as heat exchanger temperatures and hot gas compressor flow, which allow the design of certain plant items to be relaxed and CAPEX reduced.

We agree with McDermott that there is significant scope to increase temperature to further increase net efficiency, however, with CO_2 as the working fluid, this would be moving away from proven technology and hence increase project risk.

The FEED should prioritise the determination of a design case which optimises CAPEX amongst other project priorities.

5.5 ELECTRICAL EXPORT PHILOSOPHY

It is well understood that a 50 Hz AFC Plant is required for connection to the UK electricity transmission system. However, previous plant designs developed by McDermott are based on a 60 Hz CTG and this project requires the development of a 50 Hz CTG by the vendor.

OEMs are used to producing steam and gas turbines for both the 50 Hz and 60 Hz markets, so the development process is already understood. The key issue is likely to be the time required for the detail design.

The Pre-FEED assumes the CTG vendor can develop a 50 Hz CTG with similar performance. It should be noted that such technology development risks are to be expected with first-of-a-kind projects, and WSP are aware that 50 Hz CTG development is in progress with close collaboration between 8 Rivers and the vendor.

However, there are substantial time and cost impacts if this cannot be achieved, and the development and delivery of the CTG is on the critical path, so delays will directly impact the Proposed AFC Plant. This has been raised on the Project Risk Register.

5.6 SUMMARY – PRE-FEED REVIEW

The Pre-FEED presents a range of CAPEX-optimised design cases which are all suitable for deployment in the UK. There are no technical blockers from our review of the Base Case design which would prevent the project from moving to FEED stage. The FEED should, amongst other design activities, incorporate piles into the geotechnical design, determine the most suitable cooling system technology, review the redundancy philosophy, assess any effects of site-specific gas composition and revisit the electrical equipment ratings.

The 925 °C alternative cases are a pragmatic design option which increases plant performance and should be pursued further at FEED. 8 Rivers have indicated they intend to pursue the alternative cases. From review of the information made available, WSP have no technical issues with these modifications which have been proven on conventional gas to power plants.

6 RISK MANAGEMENT

Effective risk management requires the identification and mitigation of risk as early as possible in project development. As outlined in the subsequent sections, a thorough risk identification and mitigation process was employed to ensure the project development is robust and resilient and ultimately more likely to succeed.

This project team were knowledgeable and experienced, having been involved in previous iterations of AFC Plant projects and provided expert knowledge into the risk management process. The learnings from previous Allam-Fetvedt Cycle plant projects were used to the benefit of this Feasibility Study and should continue to be used as the project develops.

All stakeholders were engaged throughout, in a collaborative way. Due to travel restrictions, workshops were hosted via video conference. Nevertheless, the risk workshops and HAZID study were thorough and achieved their objective.

6.1 HAZARD IDENTIFICATION STUDY

WSP hosted a Hazard Identification (HAZID) study[16] together with 8 Rivers, McDermott, NET Power and Sembcorp to identify potentially serious omissions and issues in conceptual design, planning, utilities service provision, environmental and safety. The purpose of the HAZID was to capture all technical risks and subsequently identify mitigations to support the successful deployment of the project at a generic UK site.

It is important to note that the AFC process involves very high temperature and pressure combinations, including supercritical CO_2, and as such requires a suitably knowledgeable team to deliver a functional and operationally safe system.

For the purpose of the HAZID, the Proposed AFC plant was segregated into four nodes, based on the AFC processes, reviewing all the keywords for one system before moving to the next system. The HAZID utilised the Pre-FEED information available at the time and this is reflected in the subsequent depth of examination.

The attendees as a group comprised expert knowledge in all categories where technical risk could arise, such as the AFC process, typical power plant hazards and operation and maintenance requirements. WSP are satisfied the HAZID team contained the skills, knowledge and experience necessary to suitably identify risk and safeguards for this plant, and the HAZID study was chaired by an experienced HAZID Chairperson.

Importantly, this study was successful in identifying technical risks, due to technical expertise of the project team and the formalised process of review. The HAZID Report identified that the majority of safeguards required will be addressed by implementation of the applicable design standards, compliance with rules and regulations, and following Recommended and Generally Accepted Good Engineering Practices, and hence will be covered in the FEED.

[16] 70053760-WSP-0001-RP-PE-0002-S0_P02 - HAZID Report

The HAZID identified eight actions requiring resolution, all of which were addressed during the Feasibility Study. Some actions required tasks which could not be undertaken with the available information at this stage of the project, refer to Table 6-1. These were closed out for the purposes of the Feasibility Study by detailing in this report as issues with residual actions and should be reviewed again at the FEED FPSA studies where further design will have been carried out.

Table 6-1 – Actions deferred from Feasibility Study HAZID to later project stages

HAZID Action	Cause	Residual Action for FEED
1	Overpressure of CO_2 and oxidant systems	FEED to develop general overpressure protection philosophy and process philosophy documents in design basis
2	Heat Exchanger fouling	FEED to consider closed loop cooling on critical locations
3	Vehicle Movements	FEED to develop site traffic management plan
4	Rotating machinery / cooling tower noise levels	FEED scope of works to include noise analysis
6	Lack of established procedures for new technology	Ensure knowledge transfer from La Porte test plant
7	Piping system rupture	FEED to review gas detection requirements for un-odourised gas at selected site
8	Rupture from Hydrogen fuel tank	Stand-off safety distances should be checked again during FEED, when additional design details of hydrogen storage volume, type and pressures have been confirmed, and detailed safety risk analysis is performed.

The safeguards identified for each hazard must be incorporated into future project stages in order to mitigate the currently known hazards. Further FPSA's should also be conducted during the FEED as the plant design develops to identify new hazards, or changes to existing hazards.

In summary the outcome of the HAZID study and follow up actions has suitably identified technical risks of the process and highlighted the safeguards required to mitigate. WSP deem this a suitable level of process risk management for this Feasibility Study, and sufficient to progress to the start of the FEED stage.

6.2 PROJECT RISK AND RISK WORKSHOPS

During the Pre-FEED study, WSP together with 8 Rivers, NET Power, McDermott and Sembcorp held a total of three risk workshops, chaired by a qualified risk consultant from WSP. The selected attendees provided expertise in all areas of project development. Project risks were identified with a specific focus on UK implementation. Where a risk was deemed to have more than one potential impact, each impact was listed as a unique risk item.

Risks were assessed using a qualitative system, with probabilities from 'Very Unlikely' to 'Very Likely' and impacts from 'Very Low' to 'Very High'. The translation scales between qualitative and quantitative values was agreed before risks were assessment, so that risks were accurately categorised on their range. Refer to the Project Risk Register for details.

The Project Team reviewed the risks and mitigations on a number of occasions and comprehensive mitigation actions were agreed which are expected to be highly effective in reducing the residual risks. Some of the actions were able to be closed out during the Feasibility Study, such as design of a 50 Hz system. This demonstrates a strong commitment to risk mitigation from the Project Team. It is noted many of the mitigation actions are already underway. Although some risks are conceptual in nature, all the risks discussed that are still valid are included in the final Project Risk Register[17].

Learnings transferred from previous AFC projects have allowed effective mitigations to be identified for the majority of AFC specific technical risks.

At the time, the Feasibility Study considered a generic UK site and therefore site-selection risks are present. Where appropriate, the mitigation actions have assumed the Wilton site, which has allowed early progress of the mitigation actions. Example risks include suitable local CO_2 infrastructure, unknown geotechnical conditions and provision of adequate utility supplies. If the Wilton site is not used, value can be derived by using these risks as site selection criteria to understand the risk profile of each site.

The Proposed AFC plant includes several commercial agreements to support the finance and operation of the project, such as Contracts for Difference, oxygen supply and CO_2 export, each of which has their own terms and commercial effects. These agreements should be re-evaluated once contracts are in place to understand if there are risks associated with the terms and conditions.

The mitigated risk values and risk contingency amounts are detailed in Section 6.3.

In summary, the Risk Workshops have suitably established the risks associated with this plant and deployment in the UK. The Project Risk Register is a live document and represents the understanding of the Project Team at this stage.

6.3 QUANTITATIVE RISK ASSESSMENT

A Monte Carlo Analysis was performed on the Project Risk Register to produce a quantitative assessment of the overall project risk. This modelling activity produces estimated contingency allowances to various confidence levels based on the residual risk impact and probability of occurrence.

Risk modelling was performed using @RISK software based on the Monte Carlo simulation. Total risk exposure for the identified risks, their probability of occurrence and cost impacts were compounded together as inputs to the Monte Carlo simulation. Total risk exposure was calculated after 5,000 iterations of the model were run during simulation.

6.4 RESIDUAL RISKS

Three of the top ten project risks have been highlighted below for discussion, reflecting a key procurement risk, a key commercial risk and a key site technical risk. Refer to the Project Risk Register to see all residual risks.

[17] 70053760-WSP-00-XX-RG-PM-0002-S0_P03 – Project Risk Register

Risk 2 - Requiring Liquidated Damages on New Technologies

Some equipment suppliers are likely to resist liquidated damage terms on performance guarantees because of the lack of established information on supercritical CO_2. This risk is to be expected with the first of a kind equipment supplies and will require collaboration with the OEMs to: provide data from the La Porte test plant, establish reasonable guaranteed performance values and provide initial monitoring and inspection.

Risk 29 - Flexible CfD and CfD terms

The project team are fully aware of the commercial implications associated with the Contract for Difference (CfD) terms and strike price. At the time of writing, WSP have not witnessed the OPEX data but understand 8 Rivers have modelled various scenarios and are in discussions with BEIS regarding the CfD negotiations – the terms of that agreement are expected in Q1 2021 which will provide clarity on which elements of this risk have been mitigated and what remain. The CfD terms would be known before Financial Investment Decision, so that action can be taken if the CfD terms materially affect the project.

Risk 115 - Unknown buried structures or services

While existing site data may be available, this risk and risk allowance covers the presence of unchartered buried assets. This risk can be planned for and mitigations carried out, such as site-specific geotechnical studies.

It is noted the Feasibility Study has begun work to fully understand the geotechnical risks at the Wilton site by completion of a Geotechnical Desk Study. This has identified the likely ground conditions and existing buried structures and services at Wilton and a Geotechnical Survey Specification has been developed to undertake works to fill the information gaps of the existing site data, ready to inform the FEED. If another site was chosen, this information must be gathered for the site.

The risks due to COVID-19 are now clear to see and could impact various project stages. However, with the implementation of well-established COVID-secure guidelines and working practices, it is believed that both on-site and off-site work may be able to mitigate the majority of this risk. The unknown implications of Brexit have also been considered. The residual impacts are deemed to be higher for early activities, which have less time to respond to new developments, with the residual risk reducing for future project stages which have more time to consider and plan for the implications, which should be better known in future.

The mitigations for both COVID-19 and Brexit implications will need to be managed reactively, considering new information as it becomes available.

It is noted that the lessons learnt from previous AFC Projects has provided evidence of how to mitigate various technical risks associated with the process. Therefore, while various technical risks exist and are present in the Risk Register, in general their residual risk is low provided mitigation measures are implemented as expected.

6.5 SUMMARY – RISK

The risk studies were thorough and analysed technical and project risks to a level of detail beyond that normally seen at Feasibility Stage. The commitment of a detailed suite of mitigation actions, including many which are already complete or in progress, is deemed to effectively reduce project risk to low levels, which is reflected in the Monte Carlo Analysis.

The EPC CAPEX risk amounts should be added to the Pre-FEED EPC CAPEX estimate as this was a Pre-FEED exclusion.

As the project proceeds through future development stages and new information becomes available, the Project Risk Register should be formally reviewed on a regular basis to identify new risks, or changes to existing risks. The risks of the project are likely to change as the project develops, so it is important to continue a strong risk management process to increase the likelihood of project success.

The risk workshops in this this Feasibility Study were site-agnostic, and Wilton specific risks and mitigations were subsequently considered by the team outside of the workshops. We recommend a site-specific risk workshop is conducted early in FEED to re-convene the expertise of the Project Team in a structured risk workshop environment to assess new risks or changes to existing risks based on the site.

7 INDEPENDENT COST VERIFICATION

The cost basis of the Feasibility Study has been analysed to assess whether the predicted CAPEX and OPEX are reasonable and in line with expectations for UK deployment. This cost assessment has been developed using our experience with previous AFC plants, other first of a kind (FOAK) plants and knowledge of deploying UK projects.

7.1 CAPEX

7.1.1 METHODOLOGY

An EPC CAPEX cost breakdown[18] for the Base Case design was provided by McDermott and this was the basis for this cost verification exercise.

The independent cost verification process is as follows:

- The cost breakdown was reviewed line-by-line. Each cost heading was reviewed against cost information obtained from WSP's in house cost data bank.
- A comparable CAPEX estimate was produced to support our cost review.
- Key exclusions, assumptions and variances were discussed and quantified where appropriate.

Table 7-1 shows the CAPEX estimate for each design case, extracted from the Pre-FEED.

Table 7-1 – Summary of EPC CAPEX estimates, extracted from Pre FEED Report, Table 9-1

Parameter	Unit	Base Case	Alternate Case	Optimised Alternate Case
Total EPC Cost	**£m**	**359.6**	**385.8**	**372.1**
Cost per kW	£/kW$_e$	1,287	1,272	1,257
AACE Class		Class IV	Class V	Class V

Note:

- The following CAPEX assessment is on a like-for-like basis with the Base Case design cost estimate. Where WSP believes there are necessary additional costs, these are discussed individually in the subsequent sections.
- The CAPEX increase associated with the Alternate Case and Optimised Alternate Case which should be considered as an addition to this Base Case cost analysis.

[18] NET Power UK Standard Plant BEIS Pre-FEED - Class IV Indicative Estimate Summary - UK East Coast Location - Base Case, 900°C Turbine Inlet Temp, 279 MWe Net Output

7.1.2 CAPEX ASSESSMENT

The McDermott cost appraisal for the Base Case design, at a generic UK location is £359.62m. This is based on an indicative Class IV estimate per AACE 18R-97 and establishes a representative market price for the UK Standard Plant.

This cost estimate was developed using the Pre-FEED design detail and vendor information alongside parametric factoring from similar facilities and the level of detail reflects the Pre-FEED stage of development. Some cost data is confidential and while other data is still being developed, therefore the cost comparison has been carried out in broad terms.

7.1.2.1 WSP have worked with 8 Rivers and McDermott to clarify the key assumptions in the cost build up. CAPEX Discussion

The estimated CAPEX fees are in general agreement with what we would expect for a UK plant of this type and scale and are within the AACE Class IV estimating accuracy for this Pre-FEED stage.

The WSP engineered equipment cost assessment is similar to MDR's estimate, however the WSP estimate for labour and installation of engineered equipment, combined with bulk materials and subcontracts for civil works, is lower when compared to MDR's lump sum estimate for these categories. See Section 7.1.2.2 below.

It is important to note that the Total EPC variance is primarily resultant from the Subcontracts/Bulk Materials variance and carry-on effects of costing factors. Many of the indirects and project fees are calculated as a percentage of construction costs, causing any cost variances to impact other costs.

WSP's assessment for Construction Indirects are similar to MDR's estimate. The variance is likely due to different assumptions around the quantity of engineers required as resources, which is still unconfirmed at this stage.

The estimating factors used included:

- Indirects: We agree that 6% of Direct Costs for Indirects is reasonable.
- Engineering & Project Management: We agree 10% of Construction directs and indirects is a reasonable level.
- Cost Contingency: An allowance of 10% is a reasonable level at Pre-FEED stage.
- EPC Sales, General & Administrative and Direct Operating Expense costs at 2.79% and MDR Fee at 9.25% are reasonable levels

Some cost data for proprietary and first-of-a-kind equipment (such as Recuperative Heat Exchanger and CO_2 Combustion Turbine Generator) is confidential and was not available for review. These costs are subject to further development with the suppliers.

7.1.2.2 Subcontracts and Bulk Materials (Steel & Concrete)

There is a variance between the MDR and WSP estimates for the 'Subcontracts (Erect & Install)' category and the 'Bulk Materials (Structural Steel & Concrete) category:

At Pre-FEED stage, the quantities and specifications for civil and structural elements, and the scope of the subcontracts, are indicative only and require development during FEED. While our analysis shows a variance, this is within +/- 10% which provides confidence that the allowances for these categories are reasonable at Pre-FEED level of detail.

7.1.3 CAPEX KEY ADDITIONS

The Pre-FEED assumptions and exclusions allowed a cost estimate to be developed without a known site location. To support full visibility of expected EPC CAPEX, we have provided indicative estimates where these assumptions carry CAPEX implications, detailed in Table 7-2.

Table 7-2 – Key additional costs from Pre-FEED exclusions and assumptions

	Pre-FEED exclusion / assumption	Estimated cost £m	Comments
1.	No administration building	0.44	Assume administration building at $200m^2$
2.	No warehouse and maintenance buildings included	0.70	Assume warehouse and store building at $540m^2$
3.	Assume 1.2m deep foundations are adequate, assume no piles, no major dewatering necessary, and no soil improvements	5.1	Wilton site expected to require 12 m deep piles
4.	Assume no as-built drawings are necessary.	0.05	Allow £50k for as built drawings
5.	Excludes any spare parts	1.90	Initial spare parts estimated at 1% of direct plant cost
6.	**SUB-TOTAL:**	**£8.19**	
7.	Excludes risk contingency	12.76	See Section 6.3 Quantitative Risk Allowance
8.	**TOTAL:**	**£20.95**	

The total cost of the Pre-FEED exclusions and assumptions is estimated at £20.95 million based on current knowledge. Value engineering opportunities should be pursued in FEED to optimise the above costs.

7.1.3.1 Unquantified CAPEX Additions

The technical review of the Pre-FEED has identified the following items which, depending on the conclusion from further investigative work, may require additional CAPEX to implement. As the items require further design work to firstly determine if they are relevant to the plant design and secondly, the extent of any impact, the cost implications cannot be quantified at this stage:

- A dry or hybrid cooling tower system is likely to be required, which will increase the CAPEX versus the open-loop evaporative cooling tower system which is currently included for.
- The plant design includes instances of lower than expected equipment redundancy. The additional quantity of redundant plant will not be known until further design work is undertaken at FEED.
- Electrical designs, such as equipment ratings, appear to be undersized at this Pre-FEED stage. The equipment ratings should be reviewed and revised. Higher equipment ratings will likely increase equipment cost.

7.1.4 OWNER'S CAPEX KEY ADDITIONS

The McDermott cost estimate considers any items beyond the perimeter fence to be excluded and are to be arranged by others. The Owner will arrange the following services and agreements which will almost certainly include CAPEX implications:

- Putting utilities into service:
    - Oxygen supply
    - CO_2 export
    - Natural gas supply
    - Electrical transmission connection
    - Water supplies
    - Waste-water disposal
- Site construction power, services and potable water
- Owner to provide Builders All-Risk Insurance

7.1.5 KEY REASONABLE ASSUMPTIONS

The cost estimate included the following assumptions which are reasonable, but should be recognised.

- Costs are assessed at Sept 2020 rates - no inflation provision is allowed for.
- All costs exclude VAT.
- Plant entrance road to perimeter fence is by others. This will be a development cost by the Owner.
- Assume adequate flow of service and potable water required for construction are provided as well as locally available power to provide site construction power.
- Cost for off-site CO_2 pipeline inter-connect, including installation, is by others. No costs for scrubbing/cleaning CO_2 are included. CO_2 export pipeline scope ends at plant boundary.
- Assume the owner leases required CO_2 storage tanks and vaporisers.
- Wastewater discharges to the plant boundary without wastewater treatment.
- It is assumed a CO_2 purification skid is not required – this should be confirmed following modelling of GS(M)R specification gas and understanding the CO_2 export specification.

7.1.6 SITE-SPECIFIC COSTS

The Wilton site has a variety of existing assets which will benefit the project and reduce CAPEX versus a site without such assets. These costs are beyond the scope of the EPC contract so were not subject to cost assessment, but are listed below:

- Existing natural gas connection
- Existing water and waste connections
- Existing fire system
- Existing electrical transmission switchyards
- Nearby road, rail and marine infrastructure

The Geotechnical Studies undertaken for the Wilton Site have identified the expected ground conditions such that there is an initial understanding of the scale of required groundworks. This has identified the requirement for piles with an indicative cost of £5.1m, which has been accounted for in Table 7-2 above.

7.2 OPEX

8 Rivers have provided a summary of predicted annual OPEX for a single AFC unit over the plant lifetime. These figures are indicative at this stage, in line with the Pre-FEED level of development, and will be further developed at FEED.

WSP worked with 8 Rivers to clarify the assumptions which built up the OPEX calculations, such as the cost rates and allowances for utilities. These assumptions are reasonable, and the overall OPEX values are in line with expectations for such a plant at this stage of design development.

7.3 SUMMARY – COST

The Pre-FEED presents a reasonable representative market price for the Base Case AFC plant of £359.62 million. WSP's cost assessment estimated a total CAPEX of 3.2% lower than the McDermott estimate, using the same assumptions and exclusions. This low variance at Pre-FEED stage gives confidence that the costing is within the accuracy ranges expected and that the costs are reasonable.

McDermott's CAPEX estimate represents a standard design for deployment at a generic UK site. WSP analysed the assumptions and exclusions from the McDermott CAPEX estimate which would likely be required and have estimated these at £20.95 million. This should be allowed for in the total project CAPEX allowance, which would take the total Base Case EPC CAPEX cost to £380.57 million. It is also important to recognise the other associated CAPEX costs, such as the Owners CAPEX costs and those EPC CAPEX costs which remain unquantified at this stage, such as duplicate plant for redundancy and the unconfirmed cooling tower technology.

8 Rivers have subsequently indicated they intend to pursue the Optimised Alternate Case design, which has not been cost-analysed. McDermott indicatively priced this design case at £372.1 million, and with inclusion of the costs for assumptions and exclusions, this would take the total project CAPEX for the Optimised Alternate plant to £393.05 million.

The predicted annual OPEX allowances appear reasonable for this plant, and the assumptions used to build up these costs did not raise any concerns.

There will be changes to the CAPEX basis for different site locations and particularly where additional plant equipment is expected, such as for the Optimised Alternate Case.

8 CONCLUSION

This Feasibility Study presents a compelling case for the Proposed AFC plant to be deployed in the UK.

Initial data indicates that the AFC plant has competitive performance characteristics to similar scale fossil fuel plants, but with a clear zero-emissions benefit, in alignment with established net-zero and CCUS government policy. There is a clear need for long-duration dispatchable energy to supplement renewable energy in the future of the UK electricity system.

The Pre-FEED design work was focused on the Base Case design but also considered the UK commercial scale deployment at Wilton with the Alternate Cases. The technical reviews have identified five design comments that should be incorporated at FEED, these do not prevent the project from moving to FEED stage. The Pre-FEED design appears feasible for a generic UK site.

The 925 °C alternative cases are a pragmatic design option which increase plant performance and should be pursued further at FEED. Following completion of the McDermott Pre-FEED Report and through additional discussion and analysis with McDermott, 8 Rivers have indicated they intend to take forward the Optimised Alternate Case for the FEED. From review of the information made available, WSP have no technical issues with these modifications. It is acknowledged they have been proven on other plants, though not necessarily with CO_2 as the working fluid.

The Pre-FEED commits to use of appropriate and best-practice UK and EU codes and standards. The Pre-FEED presents a CAPEX-optimised design, and there may be more value to be extracted - plant dispatch modelling should be undertaken to further examine the dispatchability of the Proposed AFC plant and it's cost basis. The design basis will benefit from the learnings of the existing La Porte test plant.

McDermott's EPC CAPEX estimate of £359.62 million for the Base Case plant appears reasonable for deployment at a generic UK site. WSP's cost assessment estimated a total CAPEX of 3.2% lower than the McDermott estimate, and this low variance gives confidence that the costing is within the accuracy ranges expected at this early stage, and that the costs are reasonable. Additional CAPEX costs have been discussed, and these should be further considered at the chosen site and as design development continues.

The Proposed AFC plant requires a number of commercial interfaces to operate, such as oxygen supply and CO2 export. Those negotiations are important to the project cost basis, but have been detailed in the Project Risk Register. Many of these stakeholders are already being engaged with.

Risk has been thoroughly assessed for the Proposed AFC Plant and a comprehensive range of mitigation actions has been agreed. The development of the first-of-a-kind Combustion Turbine Generator inherently includes a technology risk, but this is to be expected with development of new plant equipment, and has been accounted for in the Risk Register. The Monte Carlo Analysis shows the residual risk exposure to be lower than expected for a plant of this type, which is attributable to the extensive mitigations that are planned and in progress.

8.1 FEED STUDY – EARLY PRIORITIES

This report has detailed several items which should be considered as early priorities for the next phase of the project, which are summarised below:

- Early environmental permitting & planning consents work
- Ensure knowledge transfer from La Porte test plant
- Financial studies & plant dispatch modelling
- Geotechnical investigations
- Contracts for Difference negotiations
- Site-specific commercial agreements:
  - CO2 offtake
  - Oxygen supply, including opportunity for ASU heat integration
  - Natural gas supply

8.2 RECOMMENDED NEXT STEPS

The status of each design activity has been detailed in the Pre-FEED Report section 10. Beyond these items, the following key activities should be highlighted for the next project stage:

- Commence FEED
- Site specific work, including:
  - Environmental studies
  - Identify BAT cooling tower system
- Incorporate Pre-FEED review comments into FEED scope
- Incorporate HAZID safeguards and actions into FEED scope
- Further examine the potential cost-benefit of higher plant temperature designs
- Further examine how the plant's market share and value changes with different performance characteristics

APPENDIX TITLE

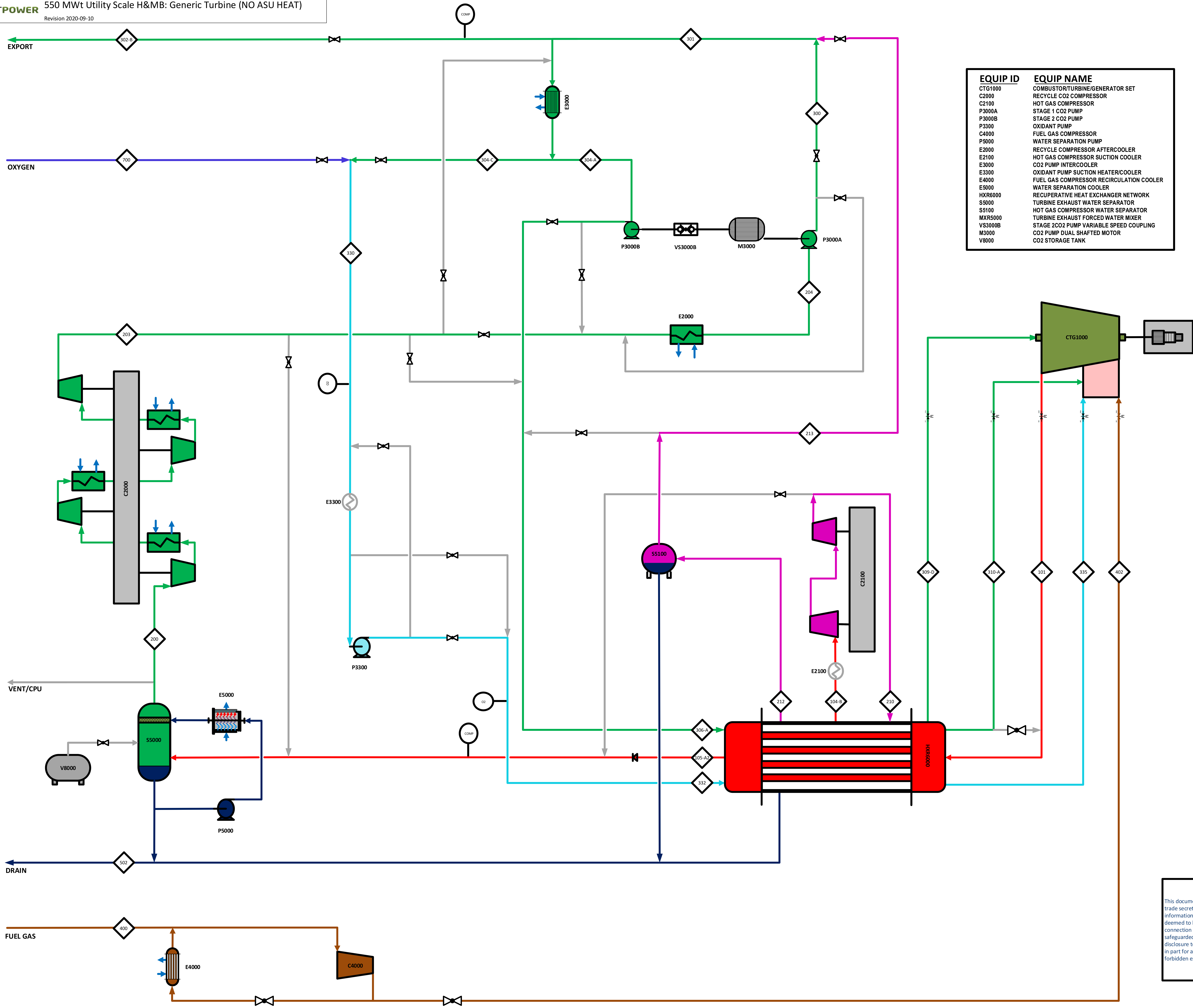
8 First Street
Manchester
M15 4RP

wsp.com

CONFIDENTIAL

NETPOWER 550 MWt Utility Scale H&MB: Generic Turbine (NO ASU HEAT)

Revision 2020-09-10



EQUIP ID	EQUIP NAME
CTG1000	COMBUSTOR/TURBINE/GENERATOR SET
C2000	RECYCLE CO2 COMPRESSOR
C2100	HOT GAS COMPRESSOR
P3000A	STAGE 1 CO2 PUMP
P3000B	STAGE 2 CO2 PUMP
P3300	OXIDANT PUMP
C4000	FUEL GAS COMPRESSOR
P5000	WATER SEPARATION PUMP
E2000	RECYCLE COMPRESSOR AFTERCOOLER
E2100	HOT GAS COMPRESSOR SUCTION COOLER
E3000	CO2 PUMP INTERCOOLER
E3300	OXIDANT PUMP SUCTION HEATER/COOLER
E4000	FUEL GAS COMPRESSOR RECIRCULATION COOLER
E5000	WATER SEPARATION COOLER
HXR6000	RECUPERATIVE HEAT EXCHANGER NETWORK
S5000	TURBINE EXHAUST WATER SEPARATOR
S5100	HOT GAS COMPRESSOR WATER SEPARATOR
MXR5000	TURBINE EXHAUST FORCED WATER MIXER
VS3000B	STAGE 2CO2 PUMP VARIABLE SPEED COUPLING
M3000	CO2 PUMP DUAL SHAFTED MOTOR
V8000	CO2 STORAGE TANK

Stream Chemistry Key

- Transient
- Water
- Oxidant
- Recycle
- Fuel Gas
- HTF
- Oxygen
- Exhaust
- Hot Gas

NETPOWER	CLIENT: Department for Business, Energy & Industrial Strategy					
	PROJECT: NET Power Allam Cycle Power Plant for UK Deployment	REV	DATE	BY	CHK.	APP.
	LOCATION: Sembcorp, Wilton International, Teeside, UK					
			9.28.20	BF	SM	PM

CALCULATION TITLE: Heat and Mass Balance

DESCRIPTION: Heat and material balance output for 550 MWt Turbine Design (925 C TIT)

I

Notes: None.

Stream Name	Units	[redacted]	101	[redacted]	104-B	[redacted]	105-A2
Fluid		[redacted]		[redacted]		[redacted]	
From		[redacted]	SCROLL	[redacted]	HXR	[redacted]	DRN
To		[redacted]	HEADER1	[redacted]	C2100	[redacted]	S5000
[redacted]							
Temperature	C	[redacted]	603.0	[redacted]	175.0	[redacted]	40.8
Pressure	MPa	[redacted]	4	[redacted]	3.85	[redacted]	3.8
Molar Vapor Fraction		[redacted]	1	[redacted]	1	[redacted]	1
Molar Liquid Fraction		[redacted]	0	[redacted]	0	[redacted]	0
[redacted]							
Mass Vapor Fraction		[redacted]	1	[redacted]	1	[redacted]	1
[redacted]							
Mass Density	kg/cum	[redacted]	23.1273	[redacted]	45.8642	[redacted]	77.0272
[redacted]							
Average MW		[redacted]	42.5757	[redacted]	42.5757	[redacted]	43.7985
Mole Flows	kmol/sec	[redacted]	28.1933	[redacted]	7.5160	[redacted]	19.6959
CH4	kmol/sec	[redacted]	1.1885E-32	[redacted]	3.1684E-33	[redacted]	0
C2H6	kmol/sec	[redacted]	0	[redacted]	0	[redacted]	0
C3H8	kmol/sec	[redacted]	0	[redacted]	0	[redacted]	0
C4H10	kmol/sec	[redacted]	0	[redacted]	0	[redacted]	0
C5H12	kmol/sec	[redacted]	0	[redacted]	0	[redacted]	0
O2	kmol/sec	[redacted]	0.241249856	[redacted]	0.064314612	[redacted]	0.176934366
AR	kmol/sec	[redacted]	0.261589919	[redacted]	0.069737054	[redacted]	0.19185207
CO	kmol/sec	[redacted]	2.6552E-07	[redacted]	7.07847E-08	[redacted]	1.94735E-07
H2	kmol/sec	[redacted]	1.09706E-08	[redacted]	2.92464E-09	[redacted]	8.04593E-09
CO2	kmol/sec	[redacted]	26.28738134	[redacted]	7.007932615	[redacted]	19.27872197
H2O	kmol/sec	[redacted]	1.403058217	[redacted]	0.374040203	[redacted]	0.048358282
N2	kmol/sec	[redacted]	0	[redacted]	0	[redacted]	0
Mole Fractions		[redacted]		[redacted]		[redacted]	
CH4		[redacted]	4.21553E-34	[redacted]	4.21553E-34	[redacted]	0
C2H6		[redacted]	0	[redacted]	0	[redacted]	0
C3H8		[redacted]	0	[redacted]	0	[redacted]	0
C4H10		[redacted]	0	[redacted]	0	[redacted]	0
C5H12		[redacted]	0	[redacted]	0	[redacted]	0
O2		[redacted]	0.008556999	[redacted]	0.008556999	[redacted]	0.008983325
AR		[redacted]	0.009278449	[redacted]	0.009278449	[redacted]	0.009740727
CO		[redacted]	9.41784E-09	[redacted]	9.41784E-09	[redacted]	9.8871E-09
H2		[redacted]	3.8912E-10	[redacted]	3.8912E-10	[redacted]	4.08509E-10
CO2		[redacted]	0.932398845	[redacted]	0.932398845	[redacted]	0.978820687
H2O		[redacted]	0.049765697	[redacted]	0.049765697	[redacted]	0.00245525
N2		[redacted]	0	[redacted]	0	[redacted]	0
Mass Flows	kg/sec	[redacted]	1200.348589	[redacted]	320	[redacted]	862.6496855
CH4	kg/sec	[redacted]	1.90668E-31	[redacted]	5.08299E-32	[redacted]	0
C2H6	kg/sec	[redacted]	0	[redacted]	0	[redacted]	0
C3H8	kg/sec	[redacted]	0	[redacted]	0	[redacted]	0
C4H10	kg/sec	[redacted]	0	[redacted]	0	[redacted]	0
C5H12	kg/sec	[redacted]	0	[redacted]	0	[redacted]	0
O2	kg/sec	[redacted]	7.719705896	[redacted]	2.057990411	[redacted]	5.661687398
AR	kg/sec	[redacted]	10.4499941	[redacted]	2.785855826	[redacted]	7.664106504
CO	kg/sec	[redacted]	7.43732E-06	[redacted]	1.98271E-06	[redacted]	5.45461E-06
H2	kg/sec	[redacted]	2.21154E-08	[redacted]	5.89571E-09	[redacted]	1.62196E-08
CO2	kg/sec	[redacted]	1156.902395	[redacted]	308.4177128	[redacted]	848.4526981
H2O	kg/sec	[redacted]	25.27648664	[redacted]	6.73843898	[redacted]	0.871187995
N2	kg/sec	[redacted]	0	[redacted]	0	[redacted]	0
Mass Fractions		[redacted]		[redacted]		[redacted]	
CH4		[redacted]	1.58844E-34	[redacted]	1.58844E-34	[redacted]	0
C2H6		[redacted]	0	[redacted]	0	[redacted]	0
C3H8		[redacted]	0	[redacted]	0	[redacted]	0
C4H10		[redacted]	0	[redacted]	0	[redacted]	0
C5H12		[redacted]	0	[redacted]	0	[redacted]	0
O2		[redacted]	0.00643122	[redacted]	0.00643122	[redacted]	0.006563136
AR		[redacted]	0.008705799	[redacted]	0.008705799	[redacted]	0.008884379
CO		[redacted]	6.19596E-09	[redacted]	6.19596E-09	[redacted]	6.32309E-09
H2		[redacted]	1.84241E-11	[redacted]	1.84241E-11	[redacted]	1.88021E-11
CO2		[redacted]	0.963805352	[redacted]	0.963805352	[redacted]	0.983542581
H2O		[redacted]	0.021057622	[redacted]	0.021057622	[redacted]	0.001009898
N2		[redacted]	0	[redacted]	0	[redacted]	0
Volume Flow	cum/sec	[redacted]	51.90190243	[redacted]	6.977121745	[redacted]	11.19928041

Stream Name	200	203	204	210	212	213	300	301	[redacted]
Fluid									[redacted]
From	S5000	C2000	2000	C2100	HXR	S5100	P3000A	HEADER2	[redacted]
To	C2000	2000	P3000A	HXR	S5100	HEADER2	HEADER2	EXPORT	[redacted]
[redacted]									
Temperature	18.8	33.1	18.8	314.2	40.8	28.6	28.5	36.2	[redacted]
Pressure	3.785	7	6.975	12.5	12.35	12.35	12	12	[redacted]
Molar Vapor Fraction	1	1	0	1	0.954869116	1	0	0	[redacted]
Molar Liquid Fraction	0	0	1	0	0.045130884	0	1	1	[redacted]
[redacted]									
Mass Vapor Fraction	1	1	0	1	0.980793661	1	0	0	[redacted]
[redacted]									
Mass Density	89.1925	225.7289	697.3976	112.1253	410.4521	369.1977	610.7228	652.5817	[redacted]
[redacted]									
Average MW	43.8435	43.8435	43.8435	42.5757	42.5757	43.7950	43.8435	43.8306	[redacted]
Mole Flows	19.6615	19.6615	19.6615	7.5160	7.5160	7.1593	19.6615	26.8209	[redacted]
CH4	0	0	0	3.1684E-33	3.1684E-33	0	0	0	[redacted]
C2H6	0	0	0	0	0	0	0	0	[redacted]
C3H8	0	0	0	0	0	0	0	0	[redacted]
C4H10	0	0	0	0	0	0	0	0	[redacted]
C5H12	0	0	0	0	0	0	0	0	[redacted]
O2	0.176934338	0.176934338	0.176934338	0.064314612	0.064314612	0.06431377	0.176934338	0.241252681	[redacted]
AR	0.191852045	0.191852045	0.191852045	0.069737054	0.069737054	0.069736202	0.191852045	0.261469938	[redacted]
CO	1.94735E-07	1.94735E-07	1.94735E-07	7.07847E-08	7.07847E-08	7.07847E-08	1.94735E-07	2.65529E-07	[redacted]
H2	8.04593E-09	8.04593E-09	8.04593E-09	2.92464E-09	2.92464E-09	2.92462E-09	8.04593E-09	1.09677E-08	[redacted]
CO2	19.27869762	19.27869762	19.27869762	7.007932615	7.007932615	7.006733607	19.27869762	26.2855873	[redacted]
H2O	0.014031331	0.014031331	0.014031331	0.374040203	0.374040203	0.018537943	0.014031331	0.032570499	[redacted]
N2	0	0	0	0	0	0	0	0	[redacted]
Mole Fractions									[redacted]
CH4	0	0	0	4.21553E-34	4.21553E-34	0	0	0	[redacted]
C2H6	0	0	0	0	0	0	0	0	[redacted]
C3H8	0	0	0	0	0	0	0	0	[redacted]
C4H10	0	0	0	0	0	0	0	0	[redacted]
C5H12	0	0	0	0	0	0	0	0	[redacted]
O2	0.008999018	0.008999018	0.008999018	0.008556999	0.008556999	0.008983221	0.008999018	0.008994957	[redacted]
AR	0.009757744	0.009757744	0.009757744	0.009278449	0.009278449	0.009740616	0.009757744	0.009748745	[redacted]
CO	9.90438E-09	9.90438E-09	9.90438E-09	9.41784E-09	9.41784E-09	9.88707E-09	9.90438E-09	9.90007E-09	[redacted]
H2	4.09222E-10	4.09222E-10	4.09222E-10	3.8912E-10	3.8912E-10	4.08505E-10	4.09222E-10	4.08923E-10	[redacted]
CO2	0.980529583	0.980529583	0.980529583	0.932398845	0.932398845	0.978686809	0.980529583	0.980041916	[redacted]
H2O	0.000713644	0.000713644	0.000713644	0.049765697	0.049765697	0.002589343	0.000713644	0.001214371	[redacted]
N2	0	0	0	0	0	0	0	0	[redacted]
Mass Flows	862.0302024	862.0302024	862.0302024	320	320	313.5426982	862.0302024	1175.575212	[redacted]
CH4	0	0	0	5.08299E-32	5.08299E-32	0	0	0	[redacted]
C2H6	0	0	0	0	0	0	0	0	[redacted]
C3H8	0	0	0	0	0	0	0	0	[redacted]
C4H10	0	0	0	0	0	0	0	0	[redacted]
C5H12	0	0	0	0	0	0	0	0	[redacted]
O2	5.661686483	5.661686483	5.661686483	2.057990411	2.057990411	2.057963466	5.661686483	7.719796293	[redacted]
AR	7.664105475	7.664105475	7.664105475	2.785855826	2.785855826	2.785821808	7.664105475	10.4452011	[redacted]
CO	5.45461E-06	5.45461E-06	5.45461E-06	1.98271E-06	1.98271E-06	1.98271E-06	5.45461E-06	7.43756E-06	[redacted]
H2	1.62196E-08	1.62196E-08	1.62196E-08	5.89571E-09	5.89571E-09	5.89569E-09	1.62196E-08	2.21095E-08	[redacted]
CO2	848.4516266	848.4516266	848.4516266	308.4177128	308.4177128	308.3649447	848.4516266	1156.82344	[redacted]
H2O	0.252778349	0.252778349	0.252778349	6.73843898	6.73843898	0.333966229	0.252778349	0.586766658	[redacted]
N2	0	0	0	0	0	0	0	0	[redacted]
Mass Fractions									[redacted]
CH4	0	0	0	1.58844E-34	1.58844E-34	0	0	0	[redacted]
C2H6	0	0	0	0	0	0	0	0	[redacted]
C3H8	0	0	0	0	0	0	0	0	[redacted]
C4H10	0	0	0	0	0	0	0	0	[redacted]
C5H12	0	0	0	0	0	0	0	0	[redacted]
O2	0.006567852	0.006567852	0.006567852	0.00643122	0.00643122	0.006563583	0.006567852	0.006566825	[redacted]
AR	0.008890762	0.008890762	0.008890762	0.008705799	0.008705799	0.008884984	0.008890762	0.008885183	[redacted]
CO	6.32763E-09	6.32763E-09	6.32763E-09	6.19596E-09	6.19596E-09	6.32356E-09	6.32763E-09	6.32674E-09	[redacted]
H2	1.88156E-11	1.88156E-11	1.88156E-11	1.84241E-11	1.84241E-11	1.88035E-11	1.88156E-11	1.88074E-11	[redacted]
CO2	0.984248144	0.984248144	0.984248144	0.963805352	0.963805352	0.983486289	0.984248144	0.984048854	[redacted]
H2O	0.000293236	0.000293236	0.000293236	0.021057622	0.021057622	0.001065138	0.000293236	0.000499132	[redacted]
N2	0	0	0	0	0	0	0	0	[redacted]
Volume Flow	9.664827442	3.818873255	1.236067011	2.853950626	0.779628152	0.84925413	1.411491801	1.801422398	[redacted]

Stream Name	302-B	[redacted]	[redacted]	304-A	304-C	[redacted]	[redacted]	306-A	[redacted]
Fluid		[redacted]	[redacted]			[redacted]	[redacted]		[redacted]
From	EXPORT	[redacted]	[redacted]	HEADER3	HEADER3	[redacted]	[redacted]	305-AV	[redacted]
To	S5200	[redacted]	[redacted]	P3000B	304-CV	[redacted]	[redacted]	HEADER2	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Temperature	36.2	[redacted]	[redacted]	18.8	18.8	[redacted]	[redacted]	41.0	[redacted]
Pressure	12	[redacted]	[redacted]	11.975	11.975	[redacted]	[redacted]	33.042	[redacted]
Molar Vapor Fraction	0	[redacted]	[redacted]	0	0	[redacted]	[redacted]	0	[redacted]
Molar Liquid Fraction	1	[redacted]	[redacted]	1	1	[redacted]	[redacted]	1	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Mass Vapor Fraction	0	[redacted]	[redacted]	0	0	[redacted]	[redacted]	0	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Mass Density	652.5865	[redacted]	[redacted]	810.0367	810.0367	[redacted]	[redacted]	897.0184	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Average MW	43.8306	[redacted]	[redacted]	43.8306	43.8306	[redacted]	[redacted]	43.8306	[redacted]
Mole Flows	0.6674	[redacted]	[redacted]	21.5193	4.6342	[redacted]	[redacted]	21.5193	[redacted]
CH4	0	[redacted]	[redacted]	0	0	[redacted]	[redacted]	0	[redacted]
C2H6	0	[redacted]	[redacted]	0	0	[redacted]	[redacted]	0	[redacted]
C3H8	0	[redacted]	[redacted]	0	0	[redacted]	[redacted]	0	[redacted]
C4H10	0	[redacted]	[redacted]	0	0	[redacted]	[redacted]	0	[redacted]
C5H12	0	[redacted]	[redacted]	0	0	[redacted]	[redacted]	0	[redacted]
O2	0.006003084	[redacted]	[redacted]	0.193565194	0.041684403	[redacted]	[redacted]	0.193565194	[redacted]
AR	0.006506149	[redacted]	[redacted]	0.209786184	0.045177605	[redacted]	[redacted]	0.209786184	[redacted]
CO	6.60714E-09	[redacted]	[redacted]	2.13043E-07	4.58789E-08	[redacted]	[redacted]	2.13043E-07	[redacted]
H2	2.72908E-10	[redacted]	[redacted]	8.79973E-09	1.89503E-09	[redacted]	[redacted]	8.79973E-09	[redacted]
CO2	0.654063539	[redacted]	[redacted]	21.08981663	4.54170713	[redacted]	[redacted]	21.08981663	[redacted]
H2O	0.000810451	[redacted]	[redacted]	0.026132414	0.005627634	[redacted]	[redacted]	0.026132414	[redacted]
N2	0	[redacted]	[redacted]	0	0	[redacted]	[redacted]	0	[redacted]
Mole Fractions		[redacted]	[redacted]			[redacted]	[redacted]		[redacted]
CH4	0	[redacted]	[redacted]	0	0	[redacted]	[redacted]	0	[redacted]
C2H6	0	[redacted]	[redacted]	0	0	[redacted]	[redacted]	0	[redacted]
C3H8	0	[redacted]	[redacted]	0	0	[redacted]	[redacted]	0	[redacted]
C4H10	0	[redacted]	[redacted]	0	0	[redacted]	[redacted]	0	[redacted]
C5H12	0	[redacted]	[redacted]	0	0	[redacted]	[redacted]	0	[redacted]
O2	0.008994957	[redacted]	[redacted]	0.008994957	0.008994957	[redacted]	[redacted]	0.008994957	[redacted]
AR	0.009748745	[redacted]	[redacted]	0.009748745	0.009748745	[redacted]	[redacted]	0.009748745	[redacted]
CO	9.90007E-09	[redacted]	[redacted]	9.90007E-09	9.90007E-09	[redacted]	[redacted]	9.90007E-09	[redacted]
H2	4.08923E-10	[redacted]	[redacted]	4.08923E-10	4.08923E-10	[redacted]	[redacted]	4.08923E-10	[redacted]
CO2	0.980041916	[redacted]	[redacted]	0.980041916	0.980041916	[redacted]	[redacted]	0.980041916	[redacted]
H2O	0.001214371	[redacted]	[redacted]	0.001214371	0.001214371	[redacted]	[redacted]	0.001214371	[redacted]
N2	0	[redacted]	[redacted]	0	0	[redacted]	[redacted]	0	[redacted]
Mass Flows	29.25180533	[redacted]	[redacted]	943.2037933	203.119613	[redacted]	[redacted]	943.2037933	[redacted]
CH4	0	[redacted]	[redacted]	0	0	[redacted]	[redacted]	0	[redacted]
C2H6	0	[redacted]	[redacted]	0	0	[redacted]	[redacted]	0	[redacted]
C3H8	0	[redacted]	[redacted]	0	0	[redacted]	[redacted]	0	[redacted]
C4H10	0	[redacted]	[redacted]	0	0	[redacted]	[redacted]	0	[redacted]
C5H12	0	[redacted]	[redacted]	0	0	[redacted]	[redacted]	0	[redacted]
O2	0.192091477	[redacted]	[redacted]	6.193853932	1.333850884	[redacted]	[redacted]	6.193853932	[redacted]
AR	0.259907649	[redacted]	[redacted]	8.380538481	1.804754969	[redacted]	[redacted]	8.380538481	[redacted]
CO	1.85069E-07	[redacted]	[redacted]	5.96741E-06	1.28509E-06	[redacted]	[redacted]	5.96741E-06	[redacted]
H2	5.5015E-10	[redacted]	[redacted]	1.77392E-08	3.82015E-09	[redacted]	[redacted]	1.77392E-08	[redacted]
CO2	28.78520552	[redacted]	[redacted]	928.1586121	199.8796225	[redacted]	[redacted]	928.1586121	[redacted]
H2O	0.014600498	[redacted]	[redacted]	0.470782756	0.101383404	[redacted]	[redacted]	0.470782756	[redacted]
N2	0	[redacted]	[redacted]	0	0	[redacted]	[redacted]	0	[redacted]
Mass Fractions		[redacted]	[redacted]			[redacted]	[redacted]		[redacted]
CH4	0	[redacted]	[redacted]	0	0	[redacted]	[redacted]	0	[redacted]
C2H6	0	[redacted]	[redacted]	0	0	[redacted]	[redacted]	0	[redacted]
C3H8	0	[redacted]	[redacted]	0	0	[redacted]	[redacted]	0	[redacted]
C4H10	0	[redacted]	[redacted]	0	0	[redacted]	[redacted]	0	[redacted]
C5H12	0	[redacted]	[redacted]	0	0	[redacted]	[redacted]	0	[redacted]
O2	0.006566825	[redacted]	[redacted]	0.006566825	0.006566825	[redacted]	[redacted]	0.006566825	[redacted]
AR	0.008885183	[redacted]	[redacted]	0.008885183	0.008885183	[redacted]	[redacted]	0.008885183	[redacted]
CO	6.32674E-09	[redacted]	[redacted]	6.32674E-09	6.32674E-09	[redacted]	[redacted]	6.32674E-09	[redacted]
H2	1.88074E-11	[redacted]	[redacted]	1.88074E-11	1.88074E-11	[redacted]	[redacted]	1.88074E-11	[redacted]
CO2	0.984048854	[redacted]	[redacted]	0.984048854	0.984048854	[redacted]	[redacted]	0.984048854	[redacted]
H2O	0.000499132	[redacted]	[redacted]	0.000499132	0.000499132	[redacted]	[redacted]	0.000499132	[redacted]
N2	0	[redacted]	[redacted]	0	0	[redacted]	[redacted]	0	[redacted]
Volume Flow	0.044824413	[redacted]	[redacted]	1.164396367	0.250753592	[redacted]	[redacted]	1.051487633	[redacted]

Stream Name		309-D	310-A		330
Fluid	[redacted]			[redacted]	
From	[redacted]	HXR	HXR	[redacted]	MIXER
To	[redacted]	ROTOR	RPD	[redacted]	P3300
[redacted]					
Temperature	[redacted]	375.0	555.0	[redacted]	5.8
Pressure	[redacted]	32.842	32.642	[redacted]	11.965
Molar Vapor Fraction	[redacted]	1	1	[redacted]	0
Molar Liquid Fraction	[redacted]	0	0	[redacted]	1
[redacted]					
Mass Vapor Fraction	[redacted]	1	1	[redacted]	0
[redacted]					
Mass Density	[redacted]	248.5685	188.5473	[redacted]	656.8072
[redacted]					
Average MW	[redacted]	43.8306	43.8306	[redacted]	41.1180
Mole Flows	[redacted]	1.2167	20.3026	[redacted]	6.0187
CH4	[redacted]	0	0	[redacted]	0
C2H6	[redacted]	0	0	[redacted]	0
C3H8	[redacted]	0	0	[redacted]	0
C4H10	[redacted]	0	0	[redacted]	0
C5H12	[redacted]	0	0	[redacted]	0
O2	[redacted]	0.010943997	0.182621197	[redacted]	1.419293365
AR	[redacted]	0.011861117	0.197925067	[redacted]	0.052100263
CO	[redacted]	1.20452E-08	2.00997E-07	[redacted]	4.58789E-08
H2	[redacted]	4.97529E-10	8.30221E-09	[redacted]	1.89503E-09
CO2	[redacted]	1.192398764	19.89741787	[redacted]	4.54170713
H2O	[redacted]	0.001477503	0.024654911	[redacted]	0.005627634
N2	[redacted]	0	0	[redacted]	0
Mole Fractions	[redacted]			[redacted]	
CH4	[redacted]	0	0	[redacted]	0
C2H6	[redacted]	0	0	[redacted]	0
C3H8	[redacted]	0	0	[redacted]	0
C4H10	[redacted]	0	0	[redacted]	0
C5H12	[redacted]	0	0	[redacted]	0
O2	[redacted]	0.008994957	0.008994957	[redacted]	0.235812826
AR	[redacted]	0.009748745	0.009748745	[redacted]	0.008656357
CO	[redacted]	9.90007E-09	9.90007E-09	[redacted]	7.62268E-09
H2	[redacted]	4.08923E-10	4.08923E-10	[redacted]	3.14855E-10
CO2	[redacted]	0.980041916	0.980041916	[redacted]	0.754595788
H2O	[redacted]	0.001214371	0.001214371	[redacted]	0.00093502
N2	[redacted]	0	0	[redacted]	0
Mass Flows	[redacted]	53.32787178	889.8759215	[redacted]	247.477993
CH4	[redacted]	0	0	[redacted]	0
C2H6	[redacted]	0	0	[redacted]	0
C3H8	[redacted]	0	0	[redacted]	0
C4H10	[redacted]	0	0	[redacted]	0
C5H12	[redacted]	0	0	[redacted]	0
O2	[redacted]	0.350194784	5.843659148	[redacted]	45.41568454
AR	[redacted]	0.473827909	7.906710571	[redacted]	2.081301315
CO	[redacted]	3.37392E-07	5.63002E-06	[redacted]	1.28509E-06
H2	[redacted]	1.00296E-09	1.67362E-08	[redacted]	3.82015E-09
CO2	[redacted]	52.47723112	875.681381	[redacted]	199.8796225
H2O	[redacted]	0.026617622	0.444165133	[redacted]	0.101383404
N2	[redacted]	0	0	[redacted]	0
Mass Fractions	[redacted]			[redacted]	
CH4	[redacted]	0	0	[redacted]	0
C2H6	[redacted]	0	0	[redacted]	0
C3H8	[redacted]	0	0	[redacted]	0
C4H10	[redacted]	0	0	[redacted]	0
C5H12	[redacted]	0	0	[redacted]	0
O2	[redacted]	0.006566825	0.006566825	[redacted]	0.183514033
AR	[redacted]	0.008885183	0.008885183	[redacted]	0.008410046
CO	[redacted]	6.32674E-09	6.32674E-09	[redacted]	5.19273E-09
H2	[redacted]	1.88074E-11	1.88074E-11	[redacted]	1.54363E-11
CO2	[redacted]	0.984048854	0.984048854	[redacted]	0.80766625
H2O	[redacted]	0.000499132	0.000499132	[redacted]	0.000409666
N2	[redacted]	0	0	[redacted]	0
Volume Flow	[redacted]	0.214539934	4.719643924	[redacted]	0.376789376

Stream Name	[redacted]	332	335	[redacted]	400	[redacted]	402	[redacted]	[redacted]
Fluid	[redacted]			[redacted]		[redacted]		[redacted]	[redacted]
From	[redacted]	331V	HXR	[redacted]		[redacted]	401V	[redacted]	[redacted]
To	[redacted]	HXR	OXPD	[redacted]	C4000	[redacted]	FPD	[redacted]	[redacted]
[redacted]									
Temperature	[redacted]	38.6	582.0	[redacted]	35.0	[redacted]	209.9	[redacted]	[redacted]
Pressure	[redacted]	33.042	32.642	[redacted]	6	[redacted]	33.685	[redacted]	[redacted]
Molar Vapor Fraction	[redacted]	0	1	[redacted]	1	[redacted]	1	[redacted]	[redacted]
Molar Liquid Fraction	[redacted]	1	0	[redacted]	0	[redacted]	0	[redacted]	[redacted]
[redacted]									
Mass Vapor Fraction	[redacted]	0	1	[redacted]	1	[redacted]	1	[redacted]	[redacted]
[redacted]									
Mass Density	[redacted]	769.9908	171.1543	[redacted]	41.9190	[redacted]	120.9535	[redacted]	[redacted]
[redacted]									
Average MW	[redacted]	41.1180	41.1180	[redacted]	16.0428	[redacted]	16.0428	[redacted]	[redacted]
Mole Flows	[redacted]	6.0187	6.0187	[redacted]	0.6857	[redacted]	0.6857	[redacted]	[redacted]
CH4	[redacted]	0	0	[redacted]	0.685667553	[redacted]	0.685667553	[redacted]	[redacted]
C2H6	[redacted]	0	0	[redacted]	0	[redacted]	0	[redacted]	[redacted]
C3H8	[redacted]	0	0	[redacted]	0	[redacted]	0	[redacted]	[redacted]
C4H10	[redacted]	0	0	[redacted]	0	[redacted]	0	[redacted]	[redacted]
C5H12	[redacted]	0	0	[redacted]	0	[redacted]	0	[redacted]	[redacted]
O2	[redacted]	1.419293365	1.419293365	[redacted]	0	[redacted]	0	[redacted]	[redacted]
AR	[redacted]	0.052100263	0.052100263	[redacted]	0	[redacted]	0	[redacted]	[redacted]
CO	[redacted]	4.58789E-08	4.58789E-08	[redacted]	0	[redacted]	0	[redacted]	[redacted]
H2	[redacted]	1.89503E-09	1.89503E-09	[redacted]	0	[redacted]	0	[redacted]	[redacted]
CO2	[redacted]	4.54170713	4.54170713	[redacted]	0	[redacted]	0	[redacted]	[redacted]
H2O	[redacted]	0.005627634	0.005627634	[redacted]	0	[redacted]	0	[redacted]	[redacted]
N2	[redacted]	0	0	[redacted]	0	[redacted]	0	[redacted]	[redacted]
Mole Fractions	[redacted]			[redacted]		[redacted]		[redacted]	[redacted]
CH4	[redacted]	0	0	[redacted]	1	[redacted]	1	[redacted]	[redacted]
C2H6	[redacted]	0	0	[redacted]	0	[redacted]	0	[redacted]	[redacted]
C3H8	[redacted]	0	0	[redacted]	0	[redacted]	0	[redacted]	[redacted]
C4H10	[redacted]	0	0	[redacted]	0	[redacted]	0	[redacted]	[redacted]
C5H12	[redacted]	0	0	[redacted]	0	[redacted]	0	[redacted]	[redacted]
O2	[redacted]	0.235812826	0.235812826	[redacted]	0	[redacted]	0	[redacted]	[redacted]
AR	[redacted]	0.008656357	0.008656357	[redacted]	0	[redacted]	0	[redacted]	[redacted]
CO	[redacted]	7.62268E-09	7.62268E-09	[redacted]	0	[redacted]	0	[redacted]	[redacted]
H2	[redacted]	3.14855E-10	3.14855E-10	[redacted]	0	[redacted]	0	[redacted]	[redacted]
CO2	[redacted]	0.754595788	0.754595788	[redacted]	0	[redacted]	0	[redacted]	[redacted]
H2O	[redacted]	0.00093502	0.00093502	[redacted]	0	[redacted]	0	[redacted]	[redacted]
N2	[redacted]	0	0	[redacted]	0	[redacted]	0	[redacted]	[redacted]
Mass Flows	[redacted]	247.477993	247.477993	[redacted]	11	[redacted]	11	[redacted]	[redacted]
CH4	[redacted]	0	0	[redacted]	11	[redacted]	11	[redacted]	[redacted]
C2H6	[redacted]	0	0	[redacted]	0	[redacted]	0	[redacted]	[redacted]
C3H8	[redacted]	0	0	[redacted]	0	[redacted]	0	[redacted]	[redacted]
C4H10	[redacted]	0	0	[redacted]	0	[redacted]	0	[redacted]	[redacted]
C5H12	[redacted]	0	0	[redacted]	0	[redacted]	0	[redacted]	[redacted]
O2	[redacted]	45.41568454	45.41568454	[redacted]	0	[redacted]	0	[redacted]	[redacted]
AR	[redacted]	2.081301315	2.081301315	[redacted]	0	[redacted]	0	[redacted]	[redacted]
CO	[redacted]	1.28509E-06	1.28509E-06	[redacted]	0	[redacted]	0	[redacted]	[redacted]
H2	[redacted]	3.82015E-09	3.82015E-09	[redacted]	0	[redacted]	0	[redacted]	[redacted]
CO2	[redacted]	199.8796225	199.8796225	[redacted]	0	[redacted]	0	[redacted]	[redacted]
H2O	[redacted]	0.101383404	0.101383404	[redacted]	0	[redacted]	0	[redacted]	[redacted]
N2	[redacted]	0	0	[redacted]	0	[redacted]	0	[redacted]	[redacted]
Mass Fractions	[redacted]			[redacted]		[redacted]		[redacted]	[redacted]
CH4	[redacted]	0	0	[redacted]	1	[redacted]	1	[redacted]	[redacted]
C2H6	[redacted]	0	0	[redacted]	0	[redacted]	0	[redacted]	[redacted]
C3H8	[redacted]	0	0	[redacted]	0	[redacted]	0	[redacted]	[redacted]
C4H10	[redacted]	0	0	[redacted]	0	[redacted]	0	[redacted]	[redacted]
C5H12	[redacted]	0	0	[redacted]	0	[redacted]	0	[redacted]	[redacted]
O2	[redacted]	0.183514033	0.183514033	[redacted]	0	[redacted]	0	[redacted]	[redacted]
AR	[redacted]	0.008410046	0.008410046	[redacted]	0	[redacted]	0	[redacted]	[redacted]
CO	[redacted]	5.19273E-09	5.19273E-09	[redacted]	0	[redacted]	0	[redacted]	[redacted]
H2	[redacted]	1.54363E-11	1.54363E-11	[redacted]	0	[redacted]	0	[redacted]	[redacted]
CO2	[redacted]	0.80766625	0.80766625	[redacted]	0	[redacted]	0	[redacted]	[redacted]
H2O	[redacted]	0.000409666	0.000409666	[redacted]	0	[redacted]	0	[redacted]	[redacted]
N2	[redacted]	0	0	[redacted]	0	[redacted]	0	[redacted]	[redacted]
Volume Flow	[redacted]	0.321403823	1.445934857	[redacted]	0.262411024	[redacted]	0.09094405	[redacted]	[redacted]

Stream Name	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	502	[redacted]	[redacted]	[redacted]
Fluid	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]		[redacted]	[redacted]	[redacted]
From	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	HEADER1	[redacted]	[redacted]	[redacted]
To	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]		[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Temperature	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	39.5	[redacted]	[redacted]	[redacted]
Pressure	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0.3	[redacted]	[redacted]	[redacted]
Molar Vapor Fraction	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0.001379702	[redacted]	[redacted]	[redacted]
Molar Liquid Fraction	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0.998620298	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Mass Vapor Fraction	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0.003325118	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Mass Density	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	598.5916	[redacted]	[redacted]	[redacted]
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Average MW	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	18.0523	[redacted]	[redacted]	[redacted]
Mole Flows	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	1.3724	[redacted]	[redacted]	[redacted]
CH4	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0	[redacted]	[redacted]	[redacted]
C2H6	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0	[redacted]	[redacted]	[redacted]
C3H8	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0	[redacted]	[redacted]	[redacted]
C4H10	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0	[redacted]	[redacted]	[redacted]
C5H12	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0	[redacted]	[redacted]	[redacted]
O2	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	1.7484E-06	[redacted]	[redacted]	[redacted]
AR	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	1.67257E-06	[redacted]	[redacted]	[redacted]
CO	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	8.36231E-14	[redacted]	[redacted]	[redacted]
H2	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	1.73606E-14	[redacted]	[redacted]	[redacted]
CO2	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0.001950113	[redacted]	[redacted]	[redacted]
H2O	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	1.370488944	[redacted]	[redacted]	[redacted]
N2	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0	[redacted]	[redacted]	[redacted]
Mole Fractions	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]		[redacted]	[redacted]	[redacted]
CH4	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0	[redacted]	[redacted]	[redacted]
C2H6	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0	[redacted]	[redacted]	[redacted]
C3H8	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0	[redacted]	[redacted]	[redacted]
C4H10	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0	[redacted]	[redacted]	[redacted]
C5H12	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0	[redacted]	[redacted]	[redacted]
O2	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	1.27394E-06	[redacted]	[redacted]	[redacted]
AR	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	1.21868E-06	[redacted]	[redacted]	[redacted]
CO	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	6.09301E-14	[redacted]	[redacted]	[redacted]
H2	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	1.26494E-14	[redacted]	[redacted]	[redacted]
CO2	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0.001420907	[redacted]	[redacted]	[redacted]
H2O	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0.9985766	[redacted]	[redacted]	[redacted]
N2	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0	[redacted]	[redacted]	[redacted]
Mass Flows	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	24.77568892	[redacted]	[redacted]	[redacted]
CH4	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0	[redacted]	[redacted]	[redacted]
C2H6	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0	[redacted]	[redacted]	[redacted]
C3H8	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0	[redacted]	[redacted]	[redacted]
C4H10	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0	[redacted]	[redacted]	[redacted]
C5H12	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0	[redacted]	[redacted]	[redacted]
O2	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	5.59468E-05	[redacted]	[redacted]	[redacted]
AR	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	6.68159E-05	[redacted]	[redacted]	[redacted]
CO	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	2.34232E-12	[redacted]	[redacted]	[redacted]
H2	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	3.49969E-14	[redacted]	[redacted]	[redacted]
CO2	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0.085824094	[redacted]	[redacted]	[redacted]
H2O	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	24.68974206	[redacted]	[redacted]	[redacted]
N2	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0	[redacted]	[redacted]	[redacted]
Mass Fractions	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]		[redacted]	[redacted]	[redacted]
CH4	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0	[redacted]	[redacted]	[redacted]
C2H6	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0	[redacted]	[redacted]	[redacted]
C3H8	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0	[redacted]	[redacted]	[redacted]
C4H10	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0	[redacted]	[redacted]	[redacted]
C5H12	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0	[redacted]	[redacted]	[redacted]
O2	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	2.25813E-06	[redacted]	[redacted]	[redacted]
AR	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	2.69683E-06	[redacted]	[redacted]	[redacted]
CO	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	9.45409E-14	[redacted]	[redacted]	[redacted]
H2	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	1.41255E-15	[redacted]	[redacted]	[redacted]
CO2	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0.003464045	[redacted]	[redacted]	[redacted]
H2O	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0.996531	[redacted]	[redacted]	[redacted]
N2	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0	[redacted]	[redacted]	[redacted]
Volume Flow	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0.041389972	[redacted]	[redacted]	[redacted]

Stream Name	[redacted]	[redacted]	[redacted]	[redacted]	**700**
Fluid	[redacted]	[redacted]	[redacted]	[redacted]	
From	[redacted]	[redacted]	[redacted]	[redacted]	
To	[redacted]	[redacted]	[redacted]	[redacted]	MIXER
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Temperature	[redacted]	[redacted]	[redacted]	[redacted]	18.8
Pressure	[redacted]	[redacted]	[redacted]	[redacted]	12
Molar Vapor Fraction	[redacted]	[redacted]	[redacted]	[redacted]	1
Molar Liquid Fraction	[redacted]	[redacted]	[redacted]	[redacted]	0
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Mass Vapor Fraction	[redacted]	[redacted]	[redacted]	[redacted]	1
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Mass Density	[redacted]	[redacted]	[redacted]	[redacted]	165.8377
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Average MW	[redacted]	[redacted]	[redacted]	[redacted]	32.0385
Mole Flows	[redacted]	[redacted]	[redacted]	[redacted]	1.3845
CH4	[redacted]	[redacted]	[redacted]	[redacted]	0
C2H6	[redacted]	[redacted]	[redacted]	[redacted]	0
C3H8	[redacted]	[redacted]	[redacted]	[redacted]	0
C4H10	[redacted]	[redacted]	[redacted]	[redacted]	0
C5H12	[redacted]	[redacted]	[redacted]	[redacted]	0
O2	[redacted]	[redacted]	[redacted]	[redacted]	1.377609
AR	[redacted]	[redacted]	[redacted]	[redacted]	0.006923
CO	[redacted]	[redacted]	[redacted]	[redacted]	0
H2	[redacted]	[redacted]	[redacted]	[redacted]	0
CO2	[redacted]	[redacted]	[redacted]	[redacted]	0
H2O	[redacted]	[redacted]	[redacted]	[redacted]	0
N2	[redacted]	[redacted]	[redacted]	[redacted]	0
Mole Fractions	[redacted]	[redacted]	[redacted]	[redacted]	
CH4	[redacted]	[redacted]	[redacted]	[redacted]	0
C2H6	[redacted]	[redacted]	[redacted]	[redacted]	0
C3H8	[redacted]	[redacted]	[redacted]	[redacted]	0
C4H10	[redacted]	[redacted]	[redacted]	[redacted]	0
C5H12	[redacted]	[redacted]	[redacted]	[redacted]	0
O2	[redacted]	[redacted]	[redacted]	[redacted]	0.995
AR	[redacted]	[redacted]	[redacted]	[redacted]	0.005
CO	[redacted]	[redacted]	[redacted]	[redacted]	0
H2	[redacted]	[redacted]	[redacted]	[redacted]	0
CO2	[redacted]	[redacted]	[redacted]	[redacted]	0
H2O	[redacted]	[redacted]	[redacted]	[redacted]	0
N2	[redacted]	[redacted]	[redacted]	[redacted]	0
Mass Flows	[redacted]	[redacted]	[redacted]	[redacted]	44.35838
CH4	[redacted]	[redacted]	[redacted]	[redacted]	0
C2H6	[redacted]	[redacted]	[redacted]	[redacted]	0
C3H8	[redacted]	[redacted]	[redacted]	[redacted]	0
C4H10	[redacted]	[redacted]	[redacted]	[redacted]	0
C5H12	[redacted]	[redacted]	[redacted]	[redacted]	0
O2	[redacted]	[redacted]	[redacted]	[redacted]	44.08183
AR	[redacted]	[redacted]	[redacted]	[redacted]	0.276546
CO	[redacted]	[redacted]	[redacted]	[redacted]	0
H2	[redacted]	[redacted]	[redacted]	[redacted]	0
CO2	[redacted]	[redacted]	[redacted]	[redacted]	0
H2O	[redacted]	[redacted]	[redacted]	[redacted]	0
N2	[redacted]	[redacted]	[redacted]	[redacted]	0
Mass Fractions	[redacted]	[redacted]	[redacted]	[redacted]	
CH4	[redacted]	[redacted]	[redacted]	[redacted]	0
C2H6	[redacted]	[redacted]	[redacted]	[redacted]	0
C3H8	[redacted]	[redacted]	[redacted]	[redacted]	0
C4H10	[redacted]	[redacted]	[redacted]	[redacted]	0
C5H12	[redacted]	[redacted]	[redacted]	[redacted]	0
O2	[redacted]	[redacted]	[redacted]	[redacted]	0.993766
AR	[redacted]	[redacted]	[redacted]	[redacted]	0.006234
CO	[redacted]	[redacted]	[redacted]	[redacted]	0
H2	[redacted]	[redacted]	[redacted]	[redacted]	0
CO2	[redacted]	[redacted]	[redacted]	[redacted]	0
H2O	[redacted]	[redacted]	[redacted]	[redacted]	0
N2	[redacted]	[redacted]	[redacted]	[redacted]	0
Volume Flow	[redacted]	[redacted]	[redacted]	[redacted]	0.267481