Decarbonisation Readiness - Technical Studies

Carbon Capture Readiness

Department for Business, Energy and Industrial Strategy

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Quality information

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Executive Summary

Since 2009, new build combustion power plants sized over 300MWe in England and Wales have been required to demonstrate they could retrofit carbon capture and storage (CCS) in order to decarbonise. This policy has been known as ‘Carbon Capture Readiness’ (CCR).

In 2009, detailed guidance was produced to support industry, BEIS and the Environment Agency (EA) in assessing the CCR requirements. Due to evolution of gas turbine size and efficiency, variable load profiles for fossil fuel plants, and to recognise the changing landscape of carbon capture and decarbonisation technologies, this guidance has been updated. Plants below 300MWe and new plant types (e.g. combined heat and power, energy from waste and biomass) will now be assessed for carbon capture readiness. The guidance document will also be expanded to cover hydrogen readiness as a means of decarbonisation.

As part of the expansion, BEIS are renaming the policy to ‘Decarbonisation Readiness’. In order to update the guidance BEIS have commissioned two technical studies to update and expand the underpinning evidence base. These technical studies are:

- Lot 1 – Hydrogen readiness
- Lot 2 – Carbon capture readiness

This document reports the findings of the **‘Lot 2 – Carbon capture readiness’** technical study.

Objectives

The aim of this project is to develop an evidence base that is used to define the requirements for demonstrating decarbonisation readiness and inform guidance. The remit of the project is to update and expand the 2009 guidance document to take into consideration:

- Power plants < 300MW
- All relevant technology types (e.g. engine, turbine, boiler, CHP or heat generation)
- All relevant fuel types (e.g. gaseous fuel, liquid fuel, biomass or waste).
- Load factors and operating patterns (if relevant).
- Any new CCS technologies which have been developed since 2009.

It is noted that the basis of the study is limited to new-build power plants built with or without carbon capture and will not apply to existing power stations unless they are subject to significant repowering.

BEIS outlined the following three objectives to be addressed as part of this study:

- **Objective 1:** update the land footprint estimates for addition of a carbon capture site to a power station or other relevant location taking into consideration the expanded scope.
- **Objective 2:** review the 2009 guidance document and checklist and provide recommendations regarding updates to encompass the expanded scope.
- **Objective 3:** make estimates of the additional capital costs (including opportunity costs - e.g. outages whilst retrofitting) and the additional operational costs (e.g. plant machinery, increased costs of leakage monitoring, NOx abatement equipment, increased safety requirements) of implementing post combustion carbon capture

Approach

The approach for the final report comprises the expansion of the interim report with the quantitative analysis of the selected case studies for supporting the updates to the evidence base for Carbon Capture Readiness. This includes Literature Review undertaken to address the study Objectives as well as record of ongoing dialogue with stakeholders and introduction of the case studies to be assessed.

Conclusions and Recommendations

Footprint

The evidence base for demonstrating carbon capture readiness has been developed in this review, according to the three assessments required by BEIS. The footprint for each type of power plant has been calculated as:

Characteristic	Commentary
CCGTs (power and CHP)	$CCP\ area\ (m^2) = 2.53 \times capture\ capacity\ (tpd) + 9600$
OCGTs	$CCP\ area\ (m^2) = 6.68 \times capture\ capacity\ (tpd) + 12600$
Solid fuels	$CCP\ area\ (m^2) = 25.01 \times capture\ capacity(tpd) + 15659$
Reciprocating engine	$CCP\ area\ (m^2) = 16.8 \times capture\ capacity\ (tpd) + 2510$

Checklists

The carbon capture checklists from the 2009 guidance document annexes have been revised to cover power plants < 300MWe; all relevant technology types (e.g. engine, turbine, boiler, CHP or heat generation); as well as all relevant fuel types (e.g. gaseous fuel, liquid fuel, biomass or waste).

Economics

Preliminary estimates have been provided for the parameters which will be needed to model the economics of a plant fitted with CCS:

Characteristic	Commentary
Transportation cost	• Where no direct onshore pipeline option exists, shipping CO_2 port-to-port estimated to be approximately 50% cheaper than offshore pipelines below a certain range of CO_2 throughput – however, opposite is true for larger throughputs • A transportation and storage cost of £18 to £40 per tonne CO_2 on a 2020 basis has been inferred, inclusive of £12/tCO_2 offshore storage costs
Outage period	• Smaller plants may experience outage periods as short as 1 to 3 months during construction and commissioning of capture plant • Large projects with shared services and longer commissioning periods will require longer outage periods
Capital cost estimate	• Relationship between capital cost ratio and capture plant capacity for natural gas power plants is estimated to be: $Cost\ ratio\ \left(\frac{£m_{2022}}{tpd}\right) = 0.594 \times (tpd\ capacity)^{-0.27}$ • Relationship between capital cost ratio and capture plant capacity for solid fuel power plants is estimated to be: $Cost\ ratio\ \left(\frac{£m_{2022}}{tpd}\right) = 0.522 \times (tpd\ capacity)^{-0.2}$

Recommendations

The data calculated in this review presents typical case study data in relation to carbon capture for a variety of combustion technologies. The data is intended to be used for comparison in support of preparing Decarbonisation Readiness proposals, and in the assessment thereof.

The information produced in this review does not remove the requirement for sites to undertake a reasonable level of site-specific design to demonstrate their Decarbonisation Readiness.

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1. Introduction

1.1 Background

Since 2009, new build combustion power plants sized over 300MWe in England and Wales have been required to demonstrate they could retrofit carbon capture and storage (CCS) in order to decarbonise. This policy has been known as 'Carbon Capture Readiness' (CCR).

In 2009, detailed guidance was produced to support industry and BEIS in assessing the CCR requirements. Due to evolution of gas turbine size and efficiency, variable load profiles for fossil fuel plants, and to recognise the changing landscape of carbon capture and decarbonisation technologies, this guidance needs to be updated. Plants below 300MWe and new plant types (e.g. combined heat and power, energy from waste and biomass) will now be assessed for carbon capture readiness. The guidance document will also be expanded to cover hydrogen readiness as a means of decarbonisation.

As part of the expansion, BEIS are renaming the policy to 'Decarbonisation Readiness'. In order to update the guidance BEIS have commissioned two technical studies to update and expand the underpinning evidence base. These technical studies are:

Lot 1 – Hydrogen readiness

Lot 2 – Carbon capture readiness

This document reports the findings of the '**Lot 2 – Carbon capture readiness**' technical study.

1.2 Project Aim

The aim of this study is to update and expand the evidence base which is used to define the requirements for demonstrating carbon capture readiness and inform guidance.

BEIS require carbon capture readiness to be demonstrated through the five different assessments below:

1. that sufficient space is available on or near the site to accommodate carbon capture equipment in the future;
2. that it is likely to be technically feasible to retrofit the applicant's chosen carbon capture technology;
3. that a suitable area of deep geological storage offshore exists for the storage of captured CO_2 from the proposed power station;
4. that it is likely to be technically feasible to transport the captured CO_2 to the proposed storage area; and
5. that it is likely that it will be economically feasible within the power station's lifetime, to link it to a full CCS chain, covering retrofitting of capture equipment, transport and storage.

1.3 Objectives

BEIS require that three of these assessments be based upon supporting evidence and have linked one objective to each of these three assessments, as set out below.

1.3.1 Objective 1

This objective is linked to item 1 in Section 1.2 which is to update and expand the land footprint estimates for a carbon capture site, including:

- Review and update of estimates for Combined Cycle Gas Turbine (CCGT) power plants > 300MWe
- Provide new estimates for CCGT power plants < 300MWe

- Provide new estimates for energy from waste (EfW) and biomass power plants
- Provide new estimates for reciprocating engine-based power and combined heat and power (CHP) plants

1.3.2 Objective 2

This objective is linked to item 2 in Section 1.2 which is to update the relevant checklists in the 2009 guidance document annexes, ensuring that they cover:

- Power plants < 300MWe
- All relevant technology types (e.g. engine, turbine, boiler, CHP or heat generation)
- All relevant fuel types (e.g. gaseous fuel, liquid fuel, biomass or waste).
- Load factors and operating patterns (if relevant).
- Any new CCS technologies which have been developed since 2009.

1.3.3 Objective 3

This objective is linked to item 5 in Section 1.2 which is to make estimates of the parameters which will be needed to model the economics of a plant fitted with CCS. In particular:

- Capital cost associated with CCS equipment in new build and retrofitting to existing;
- Operational expenses associated with transporting and storing CO_2;
- Additional operational costs arising from the operation of CCS equipment.
- Opportunity costs e.g. due to outages whilst retrofitting.

2. Nomenclature

The following nomenclature and abbreviations have been used within this report:

Term	Description
BAT	Best Available Technique
BECCS	Bioenergy with Carbon Capture and Storage
BEIS	Department of Business, Energy & Industrial Strategy
Capacity	Rate of carbon dioxide captured by capture plant, measured in mass per time
CCGT	Combined Cycle Gas Turbine
CCP	Carbon Capture Plant
CCR	Carbon Capture Readiness
CCS	Carbon Capture and Storage
CDM	Construction Design and Management
CHP	Combined Heat and Power
CO_2	Carbon Dioxide
CRI	Commercial Readiness Index
DCC	Direct Contact Cooler
DECC	Department of Energy & Climate Change
EA	Environment Agency
EfW	Energy from Waste
FEED	Front End Engineering Design
GCCSI	Global Carbon Capture and Storage Institute
IEA	International Energy Agency
IED	Industrial Emissions Directive
IGCC	Integrated Gasification Combined Cycle
LHV	Lower Heating Value
MEA	Monoethanolamine
MHI	Mitsubishi Heavy Industries
Mid-merit	A type of flexible operating regime for power plant (not baseload, dispatching after renewables and nuclear but before high-carbon alternatives)

MWe	Megawatts electricity
MWth	Megawatts thermal
N_2	Nitrogen
NCCC	National Carbon Capture Centre
NG	Natural Gas
NOx	Nitrogen Oxides (NO_2, NO_3)
NRW	Natural Resources Wales
OCGT	Open Cycle Gas Turbine
PACT	Pilot-scale Advanced Capture Technology
PCC	Post Combustion Capture
PSA	Pressure Swing Adsorption
RFCC	Residue Fluidised Catalytic Cracking
TCM	Technology Centre Mongstad
Tonnes	1000 kilograms
tpd	Metric tonnes-per-day
TRL	Technology Readiness Level
Two-shift	A type of flexible operating regime for power plant characterised by multiple starts to meet daily peaks with potential to either shut down or run at minimum load during the day (not baseload)
USCPF	Ultra-Supercritical Pulverised Fuel
WHRU	Waste Heat Recovery Unit

3. Technical Approach

3.1 General approach

The following section details the methodology that AECOM utilised to complete the scope of work.

Independent Reviewers from the University of Sheffield and Imperial College London were appointed to conduct an independent senior review of the technical delivery approach, deliverables and supporting technical work to validate that the outputs meet the scope objectives and that appropriate data and methods have been used.

Figure 1 illustrates the approach at a high level, including the timing of key meetings and independent reviewer activities.

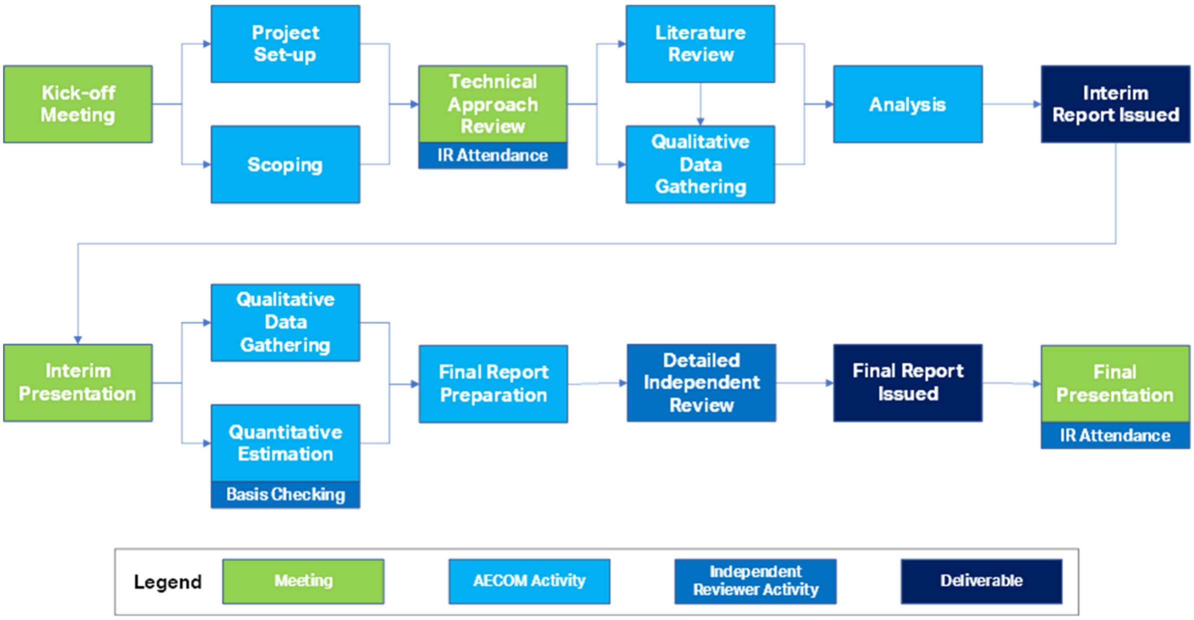


Figure 1. Outline of study approach

3.2 Scoping

The purpose of the scoping exercise was to identify sources of information that may contribute to the evidence base for this study, and include (but not limited to):

- Academic papers, journals and conference presentations;
- Documents for global industry bodies and organisations such as the IEA;
- Vendor publications, technical papers and experience lists;
- Publicly available planning applications; and
- Public domain feasibility and FEED studies.

A full list of the source documents assessed are provided in Appendix A of this report.

3.2.1 Review of Existing Guidance

To address Objective 2, an initial assessment of the 2009 CCR guidance document checklist was completed prior to the Technical Approach Review meeting. The checklist items were converted into a spreadsheet and each item was reviewed and categorised, with updates and areas where additional evidence was required identified. The purpose of this exercise was to structure the following phases of the study and search for evidence.

The record of review of the checklist items is provided in Appendix B.

3.3 Qualitative Assessment

3.3.1 Literature Review

A literature review was completed of the sources identified in the scoping exercise, to extract relevant information to expand and update the existing evidence base.

In completing the literature review the following examples are some of the types of evidence that were sought, and in parentheses are the objectives they look to address:

- State of the art for capture technologies that are in commercial operation, or near commercial deployment (influences Objectives 1, 2 and 3)
- Case studies of existing facilities and demonstration plants (influences Objectives 1,2 and 3);

- Land footprint of carbon capture facilities in operation or in planning phase where significant engineering has been completed (influences Objective 1);
- Land footprint of carbon capture facilities based on academic journals (influences Objective 1);
- Academic papers on performance and operations of carbon capture technologies (influences Objective 2);
- Vendor information regarding performance (influences Objectives 2 and 3); and
- Studies, papers and guidance on CCS plant flexibility (influences Objective 2).

The findings of the literature review are then summarised in Section 4 and a full list of reference documents provided in Appendix A.

3.3.2 Stakeholder Engagement

Delivery of the project is supported and informed by engagement with different groups of stakeholders. At project inception AECOM generated a Stakeholder Engagement Plan, the purpose of which was to define the different groups, the objectives, methods and timings of engagement.

A copy of the Stakeholder Engagement Plan (60677821-TN-001) is provided in Appendix C of this report.

A complete list of the stakeholders engaged is summarised in Appendix A, Section A.2.

3.4 Quantitative Estimation

To address Objective 1 and 3 it was necessary to develop a concept level design of a number of representative configurations as case studies. These were used to produce footprint estimates as well as capital and operating cost estimates for onsite assets with a clear and consistent defined basis.

The case studies provide an evidence base that can be used by examiners during the application process to determine if the acceptance criteria for assessments 1 and 3 defined in Section 1.2 have been addressed appropriately by developers.

3.4.1 Case Studies

These case studies focus on the application of post-combustion capture on a range of different configurations and sizes of power plants, capturing carbon dioxide from a variety of combustion flue gases. The selection of the case studies was discussed with key stakeholders and independent peer reviewers as part of the Technical Approach Review meeting. These discussions and rationale are captured in the ‘Rationale for case study scenarios’ Technical Note (60677821-TN-002) provided in Appendix C of this report.

The case study configurations defined in Table 1 cover a broad range of capture plant throughputs and flue gas compositions. AECOM have provided the CO_2 capture rate and flue gas composition for each configuration to allow for interpolation of plants of different sizes.

Table 1. Case Study Definition

Combustion technology	Sizing Basis	Small	Medium	Large
CCGT (Utility Scale)	Plant nominal gross power output	220 MWe	450 MWe	910 MWe
CCGT (CHP application)	GT nominal gross power output	14 MWe	35 MWe	60 MWe
OCGT	Plant nominal gross power output	145 MWe	290 MWe	N/A
Boiler (EfW)	Plant nominal gross power output	20 MWe	36 MWe	72 MWe
Boiler (Biomass)	Plant nominal gross power output	35 MWth	60 MWth	120 MWth

Combustion technology	Sizing Basis	Small	Medium	Large
Reciprocating Engine	Engine nominal gross power output	1 MWe	5 x 2.5 MWe	50 MWe (5 x 10 MWe units)

3.4.2 Concept Design Basis

To support the development of the case studies and to provide transparency of the assumptions made, AECOM produced an Engineering Basis document for Lot 2 (60677821-TN-004), which is provided in Appendix C of this report.

3.4.3 Basis for Economic Analysis

To support the development of the case studies and to provide transparency of the assumptions made, AECOM produced a Basis for Economic Analysis document (60677821-TN-005), which is provided in Appendix C of this report.

3.4.4 Basis for Layout Development

To support the development of the case studies and to provide transparency of the assumptions made, AECOM produced a Basis for Layout Development document (60677821-TN-006), which is provided in Appendix C of this report.

3.5 Summary Report

The outputs of the Lot 2 – Carbon Capture Readiness Study are summarised in a single report (this document), that is subject to an independent review by both the independent peer reviewers and stakeholders within BEIS, the Welsh Government, the EA and NRW.

4. Analysis

This analysis section presents the outcomes of the Qualitative and Quantitative aspects of the study to address the Objectives stated in Section 1.

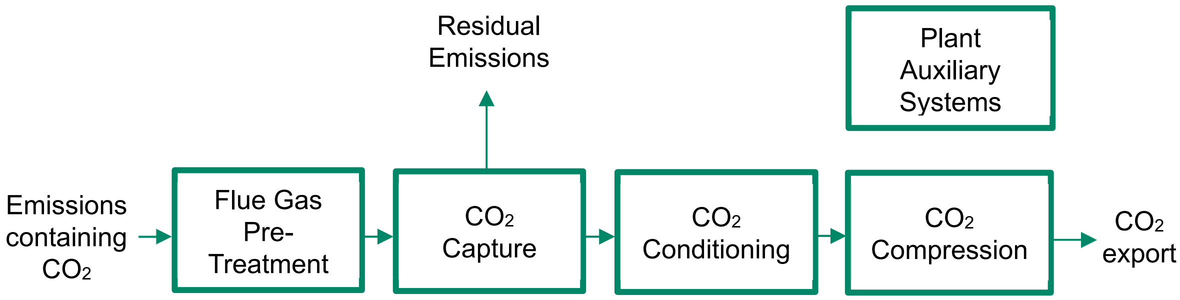
4.1 Objective 1 – Footprint

***Objective 1** is to update and expand the land footprint estimates for a carbon capture site, including review and update of estimates for Combined Cycle Gas Turbine (CCGT power plant > 300MWe; new estimates for CCGT power plants < 300MWe; new estimates for Energy from Waste (EfW) and biomass power plants; new estimates for reciprocating engine-based power plants; and new estimates for Combined Heat and Power (CHP) plants.*

Post-combustion capture has been selected as the benchmark for this review due to the extensive development and general applicability across a variety of sectors. This section provides an introduction to pre-combustion capture and oxy-fuel methods for information which may have certain advantages in individual scenarios in comparison to post-combustion capture. However, post-combustion has been maintained as the benchmark to enable drawing clear comparisons across a wide range of case study technologies and sizes.

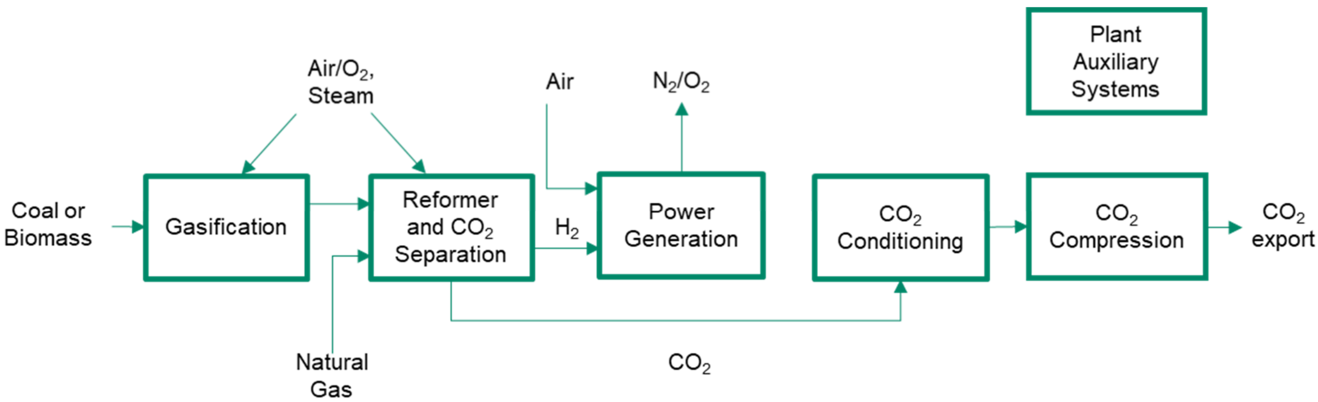
For post combustion processes the carbon capture plant generally comprises flue gas pre-treatment to treat the incoming emission stream to the required specification for the CO_2 capture process, the CO_2 capture process itself, CO_2 conditioning and CO_2 compression. This is illustrated in Figure 2.

Figure 2. Generic Block Diagram for Post Combustion Carbon Capture



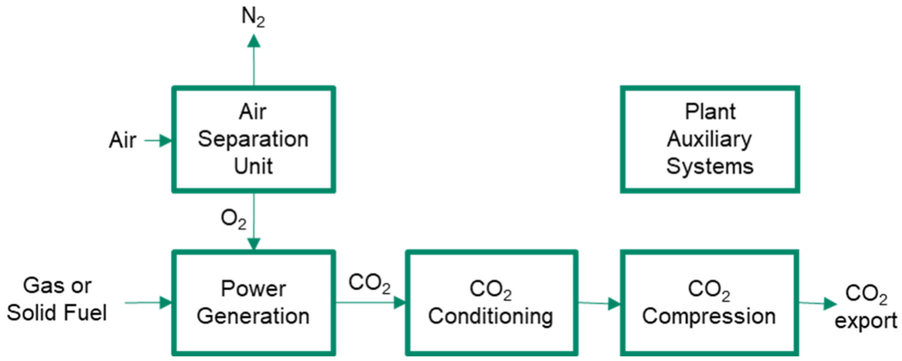
In pre-combustion capture processes, solid fuel such as biomass or coal undergoes gasification to produce syngas which is then separated into H_2 and CO_2. The separated H_2 can be combusted to produce power and CO_2 is conditioned and compressed before export. This process is illustrated in Figure 3.

Figure 3. Generic Block Diagram for Pre-Combustion Carbon Capture



Oxy-combustion involves burning fuels in the presence of pure oxygen as opposed to air to produce a high purity CO_2 stream which can then be conditioned and compressed. Figure 4 illustrates how this would be used in a power generation scenario but oxy-combustion can also be applied to processes such as cement manufacture.

Figure 4. Generic Block Diagram for Oxy-Combustion Carbon Capture



4.1.1 Commercially Viable Technologies

BEIS have recently commissioned AECOM to undertake a comprehensive review and benchmarking of the state-of-the-art and next-generation technologies for carbon capture in industrial, waste, and power applications[1]. The Review split technologies into 3 overall categories:

- Demonstration stage technologies (roughly analogous to Technology Readiness Levels (TRLs) 8-9 or Commercial Readiness Indices (CRIs) 3-4), defined as technologies which have demonstrated successful commercial deployment for at least 12 months, construction has commenced or have received full funding and are likely to be deployable at a large scale (of the order of 1,000 tonnes of CO_2 captured per day (tpd)) by 2030. Demonstration stage technologies are, by definition, those where the greatest degree of certainty is available for parameters, such as site layout and cost requirements, which are relevant to the Objectives.
- Development stage technologies (analogous to TRLs 5-8) are defined as technologies which have operated at least 5 tpd of CO_2 in a similar application and are likely to be deployable at a large scale by 2035.
- Research stage technologies (analogous to TRLs 1-4), defined as technologies which are at an early stage of development, are yet to be proven beyond the laboratory or small testing facility scale and are unlikely to be deployable at larger scale before 2035.

Table 2 contains an extract from this work showing Demonstration stage technologies. The technologies all comprise post-combustion amine-based solvent systems as this represents the most developed technology currently on the market and has the lowest levels of uncertainty with respect to parameters such as equipment size and layout. Each technology in this list has seen at least one deployment at scale and therefore provides some degree of externally verifiable data that is useful for extrapolation.

[1] Next Generation Capture Technologies Review and Benchmarking, Study by AECOM for the Department for Business, Energy & Industrial Strategy, 2022. Available online: https://ukccsrc.ac.uk/next-generation-capture-technologies/#workpackagereports

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Table 2. Demonstration Stage Technologies

Technology Providers	Overview
Mitsubishi Heavy Industries (MHI)	MHI's KS-1 solvent was used at the 4700 tpd Petra Nova project in Texas, USA[2]. MHI's next generation solvent is KS-21. The new solvent, along with process improvements, is anticipated to offer incremental improvements over plants using KS-1[3].
Shell	Shell's Cansolv technology has been demonstrated at scale at the 2740 tpd Boundary Dam site in Canada[4]. The next generation deployment is likely to include EfW applications[5].
Fluor	A previous iteration of Fluor's Econoamine FG Plus technology was deployed at 320-350 tpd scale at Bellingham Gas Power Plant, Massachusetts, USA[6]. The next generation technology will attempt to employ energy improvement features at large scale[7].
Carbon Clean Solutions	Carbon Clean Solutions' proprietary amine has been used at the 160 tpd scale in India on a coal plant[8]. The technology utilises their proprietary APBS advanced solvent. Additionally, Carbon Clean has offerings of bespoke large-scale carbon capture plants and smaller modular carbon capture units.
Aker Carbon Capture	Aker Carbon Capture designed and delivered the 80,000 tpa (~240 tpd) CO_2 capture amine plant at the Technology Centre Mongstad facility which has been in continuous operation since its opening in 2013[9]. Aker's 'Just Catch' technology utilises their proprietary S26 advanced solvent. Aker offers large-scale carbon capture plants termed 'Big Catch' and smaller modular carbon capture units termed 'Just Catch'. Aker has plans for future projects in the EfW and cement sectors[10][11].

Table 3 presents a summary of Development stage technologies. For Development stage technologies there are increased levels of uncertainty in relation to their performance, footprint and cost. Many of the technologies at this stage have potential advantages (such as capital and/or operating cost, energy efficiency, plant reliability, solvent stability[12], plant footprint) over more developed technologies, but it remains to be proven whether the challenges associated with scale-up and the specific technical issues of individual technologies can be overcome. These technologies must first demonstrate sustained commercial operation at scale before proving that cost savings can be made.

For the evaluation of new-build combustion plants' decarbonisation readiness, it is necessary that assessment be made on clearly defined, easily accessed requirements. Therefore, it is recommended that the examination of the footprint (by those assessing projects' carbon capture readiness statements) that has been set aside by projects for carbon capture continues to be assessed against a well-developed generic benchmark such as amine solvent-based capture. In addition to the physical footprint, the technical and economic feasibility checks remain a part of the assessment as before, especially in the case of retrofitting a CCS plant where the full life cycle cost may not have formed part

[2] NRG Petro Nova Case Study, available online: https://www.nrg.com/case-studies/petra-nova.html
[3] MHI press release, available online: https://www.mhi.com/news/210304.html
[4] BD3 Status Update: July 2021, available online: https://www.saskpower.com/about-us/our-company/blog/2021/bd3-status-update-july-2021
[5] DNV GL website: https://www.dnv.com/news/dnv-gl-approves-shell-carbon-capture-technology-to-bring-down-emissions-from-fortum-waste-to-energy-plant--179829
[6] Further Assessment of Emerging CO2 Capture Technologies for the Power Sector and their Potential to Reduce Costs, September 2019, IEAGHG Technical Report
[7] Improvement in power generation with post-combustion capture of CO2, Report Number PH4/33, November 2004, IEAGHG
[8] Carbon Clean Solutions Demonstration Plant Details. Available online: https://www.geos.ed.ac.uk/sccs/project-info/2021
[9] Just Catch – Capture Plants, 18th June 2019, O. Graff, Keynote, TCCS-10, Trondheim
[10] Twence Project Details. Available online: https://www.geos.ed.ac.uk/sccs/project-info/2623
[11] Aker Solutions press release. Available online: https://www.akersolutions.com/news/newsarchive/2020/aker-solutions-awarded-contract-for-the-brevik-carbon-capture-project/
[12] 'Solvent stability' refers to the rate at which the solvent degrades under real operating conditions i.e. in the presence of real flue gas and real solvent management strategy.

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of the baseline design. For projects seeking to deploy technologies towards the Development stage and earlier, some interpretation may be required, leading to one of three main potential scenarios:

1. The land set aside for capture is sufficient to accommodate a technology-neutral amine benchmark. The project's preferred technology requires less footprint than the amine benchmark due to some net advantage (e.g. reduction in pre-treatment requirements with no negative impact elsewhere). Demonstration of the project meeting decarbonisation readiness requirements is the least challenging in this scenario because the uncertainty in layout can be mitigated by changing capture technology basis to that of the benchmark.
2. The land set aside for capture is sufficient to accommodate a technology-neutral amine benchmark. The project's preferred technology requires more footprint than the amine benchmark. Assessment of the site footprint against requirements should be undertaken for the preferred technology and is therefore more challenging to assess in this scenario because of the greater detail required before conclusions can be made that the project has set aside enough land.
3. The land set aside for capture is not sufficient to accommodate a technology-neutral amine benchmark. The project's preferred technology requires less footprint than the amine benchmark due to some net advantage (e.g. reduction in pre-treatment requirements with no negative impact elsewhere). However, the project's decarbonisation readiness relies on the overall feasibility of the preferred technology, without adequate space to change the project basis to that of the benchmark. In this scenario, the project would be subject to the risk of potentially being unable to change capture technology if the option put forward for assessment is later found infeasible. It is expected that this outcome would require the greatest degree of detail from the project and the greatest degree of confidence in the layout put forward for assessment.

In scenarios 2 and 3 where greater rigour may be required to support a decision whether the project has set aside enough land, the following information may be required to enable the assessment:

- Equipment list with sizing of key process equipment items
- Scaled layout drawing with numbering for key process equipment items and any associated ancillaries
- Supporting layout narrative with definition of the preliminary philosophy used to outline items such as:
  - Spacing between equipment items,
  - Grouping of equipment into process areas,
  - Spacing between process areas
  - Spacing for access for construction, maintenance and operation
  - Spacing between site and boundary with outside world

Table 3. Development Stage Technologies

Providers	Overview
Solvent Based Systems	
BASF & Linde	BASF & Linde's technology utilises BASF's proprietary OASE® blue advanced amine solvent with Linde's process engineering developments
C-Capture	An amine and nitrogen free solvent process using a carboxylic acid salt in organic media
CO_2 Capsol (formerly Sargas)	Hot potassium carbonate solvent process with patented heat recovery
CO_2 Solutions (Now owned by SAIPEM)	A carbonic anhydrase enzyme catalysed potassium carbonate solvent process
Baker Hughes CAP (Developed by Alstom, now owned by General Electric)	A non-precipitating chilled ammonia solvent process
ION Clean Energy (formerly ION Engineering)	A water-lean solvent
RTI International	Non-aqueous Solvent
Solid Sorbents	
Kawasaki CO_2 Capture (KCC)	Temperature swing adsorption (TSA) process utilising a granulated amine-coated porous sorbent
Svante (formerly Inventys)	Structured solid sorbent in a rotating absorption bed system
TDA Research	Isothermal process based on a granulated alkalised alumina sorbent
Fuel Cell	
FuelCell Energy	Molten carbonate fuel cell (MCFC)
Membranes	
Membrane Technology and Research (MTR)	Polaris polymeric membrane
Oxy-Combustion	
NET Power	Allam-Fetvedt Cycle
Clean Energy Systems (CES)	Platelet oxy-fuel combustor process
Cryogenics	
Air Liquide	Pressure Swing Adsorption (PSA) plus cryogenic CO_2 separation and purification hybrid process

4.1.2 Case Studies of Existing Facilities & Demonstration Plants

Figure 5 presents a chart of capture plant capacity in terms of metric tonnes per day of CO_2 captured against total site area for capture plant, power island and balance-of-plant. In addition, equivalent area calculated using both the 2009 CCR guidance and the updated, optimised Imperial College guidance published in 2010[13] have been plotted as separate, approximate, trend lines for comparison against

[13] Assessment of the validity of "Approximate minimum land footprint for some types of CO_2 plant" provided as a guide to the Environment Agency assessment of Carbon Capture Readiness in DECC's CCR Guide for Applications under Section 36 of the Electricity Act 1989, Imperial College study for DECC, 2010,

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individual projects. Values for footprint have been derived from public project data or estimated directly using satellite imagery (e.g. Google Earth). A full list of references is presented in Appendix A.

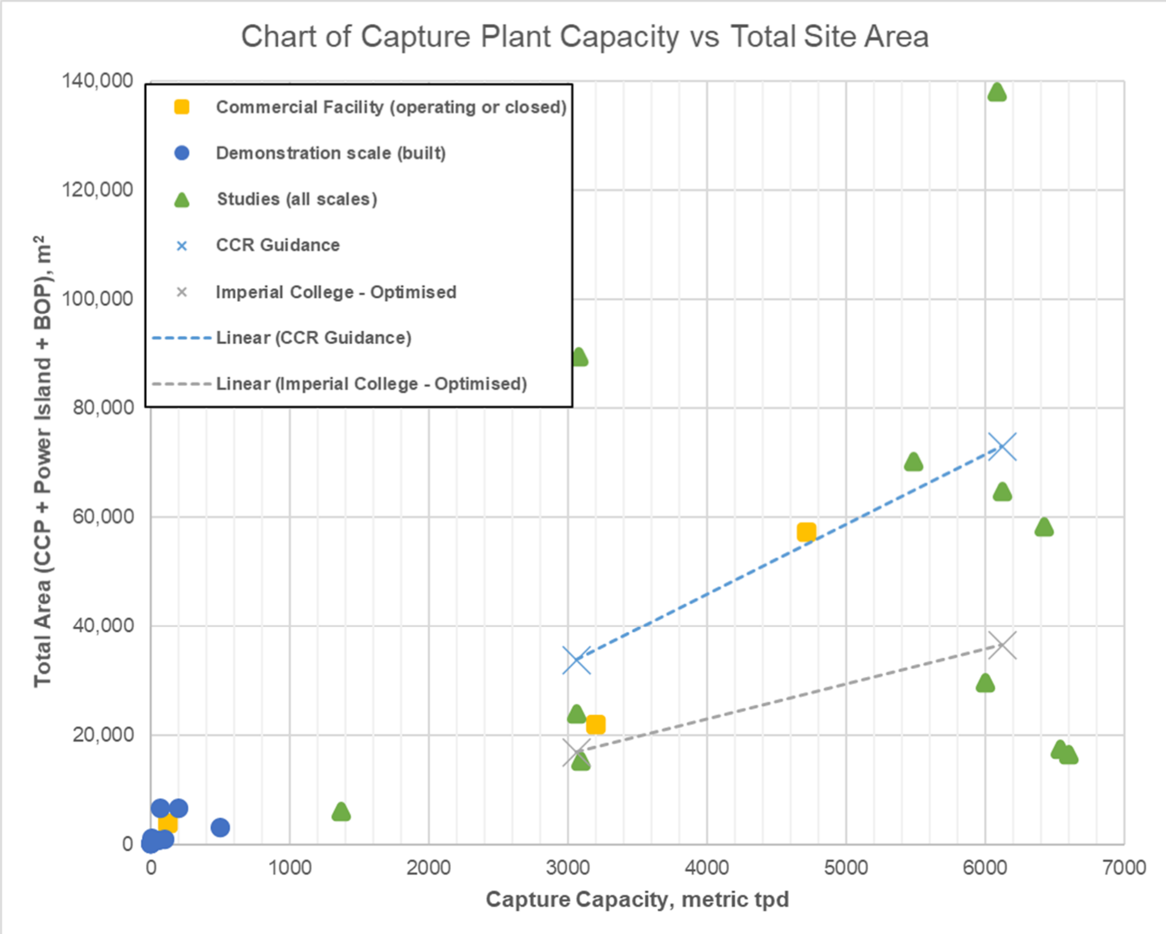

Figure 5. Comparison of Capture Plant Throughput vs Total Plant Footprint

From Figure 5, it is clear that projects that are at a study stage of development (identified by the green triangles in Figure 5) have a much wider spread of footprint than the three major commercial projects that have been deployed (identified by the yellow squares in Figure 5). In particular there are two study phase projects which stand out with significantly greater footprint requirements than from the other projects, namely:

- Net Zero Teesside, at approximately 6,100tpd and 140,000m^2. The footprint set aside by NZT includes space for potential future expansion, as well as additional area set aside for hazardous area separation due to the inclusion of the high-pressure offshore compressor station within the project. Other UK capture projects have generally been undertaken for only a single train of capture and do not include the main offshore compressor station. Therefore, NZT is considered somewhat of an anomaly in the overall data which does not invalidate the general trend.
- The 2014 Peterhead project with Shell, at approximately 3,100tpd and 90,000m^2. This project was based on a challenging brownfield modification to the existing Unit 1 facilities at Peterhead Power Station, seeking to reuse existing infrastructure such as the existing stack, and comprised of multiple dispersed sites for process areas. It also assumed compression on-site for direct offshore injection rather than the less demanding option to export to a gathering network

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/47932/553-imperial-college-review-ccr-guidance.pdf

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operated by a CCUS Cluster. Generally, large scale capture projects seek to deploy on a single contiguous plot where possible and, therefore, the footprint estimated by the 2014 Peterhead project has been deemed to be specific to that project, rather than suggesting general conclusions be extrapolated to other projects.

It is worth noting the wide range of project footprints at the smaller end of the scale occupied by Demonstration projects (blue circles in Figure 5). Figure 6 presents an enlarged view of projects below 600tpd capture rate. Below this capacity, the effect of construction choices (such as modularisation philosophy) and standardised block sizes, e.g. road transport requirements, begin to dominate the overall footprint. Therefore, general trends for these projects may require preliminary evaluation of the mode of equipment transportation to site which may dominate footprint rather than any strong correlation with equipment size.

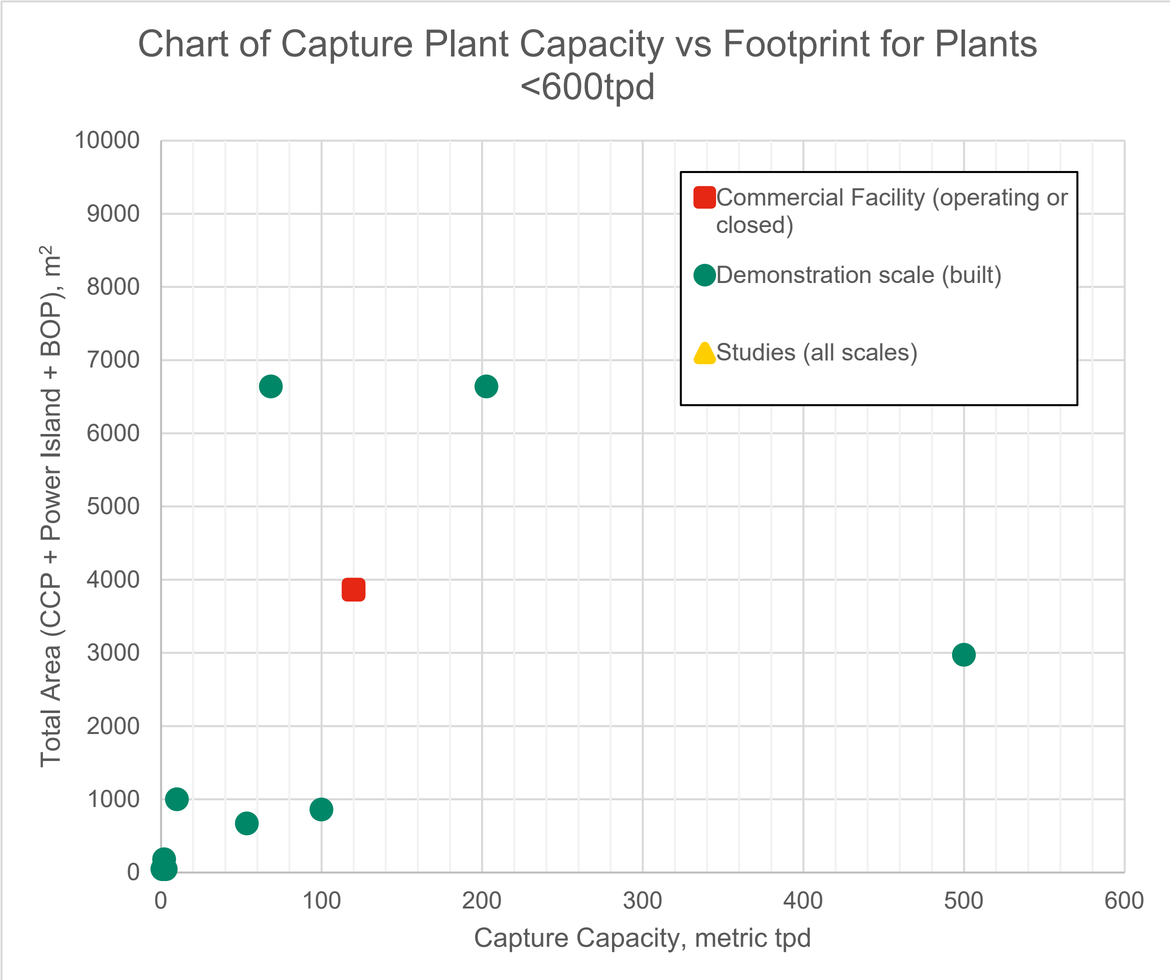

Figure 6. Comparison of Capture Plant Throughput vs Footprint for Projects capturing <600tpd

Table 4 and Table 5 represent the estimated capacity and footprint values for existing plants. Full references for each plant are provided in Appendix A.

Table 4. Existing Large-Scale Plants in Power Generation

Facility Name (feedstock)	Location	Capacity (metric tCO_2/day)	Footprint (m^2)
Boundary Dam 3 (coal)	Canada	3,200	22,000
Petra Nova (coal)	USA	4,700	57,000

Source: AECOM estimate from Google Earth, see Appendix A

Table 5. Main Demonstration Plants

Facility Name (feedstock)	Location	Capacity (metric tCO_2/day)	Footprint (m^2)
Technology Centre Mongstad, TCM (natural gas / RFCC)	Norway	70 / 200	6,600
National Centre for Carbon Capture, NCCC (natural gas / coal)	USA	10	57,000
Pilot-scale Advanced Capture Technology, PACT (various)	UK	1	40
Ferrybridge pilot (coal)	UK	100	900
Fortum pilot (waste)	Norway	3.5	40

Source: AECOM estimate from Google Earth, see Appendix A

4.1.3 Land footprint of carbon capture facilities in operation or in planning phase where significant engineering has been completed

4.1.3.1 CCGT power plants

Multiple projects are currently underway in the UK for large (>300MWe) new-build CCGT with post-combustion capture. These projects include Net Zero Teesside, Keadby 3 and Peterhead Low Carbon. Each of these proposed developments will comprise a H-class CCGT power plant (nominal generating capacity approximately 800MWe) and a post-combustion carbon capture plant using amine-based technology (peak approximately 6000tpd). Table 6 summarises the main projects with information available in the public domain.

Table 6. CCGT Power Plant (>300MWe) Projects

Facility Name (feedstock)	Location	Capacity (metric tCO_2/day)	Footprint (m^2)
Peterhead Low Carbon (NG)	UK	6,400	58,000
Keadby 3 (NG)	UK	6,100	65,000
Net Zero Teesside (NG)	UK	6,100	140,000
Peterhead Shell (NG)	UK	3,100	90,000
Karsto (NG)	Norway	3,100	24,000

Source: Project references in Appendix A

4.1.3.2 CCGT Power Plants < 300MWe & Natural Gas CHP

Reference data for capture projects on CCGT with less than 300MWe capacity is limited. Tata Chemicals presents the main source of data for natural gas combustion at <300MWe scale, as summarised in Table 7.

Table 7. Small-scale CCGT & Natural Gas CHP Projects

Facility name (feedstock)	Location	Capacity (metric tCO_2/day)	Footprint (m^2)
Tata Chemicals (NG)	UK	120	4,000

Source: AECOM estimate from Google Earth

4.1.3.3 EfW & Biomass Power Plants

Reference data for capture projects in biomass and waste applications is limited. Three projects in the public domain are shown in Table 8.

Table 8. Summary of EfW and biomass projects

Facility name (feedstock)	Location	Capacity (metric tCO_2/day)	Footprint (m^2)
Fortum Oslo Varme (waste)	Norway	1,100[1]	6,000
Drax BECCS Pilot (biomass)	UK	1	50
Drax BECCS (biomass)	UK	22,000	39,000

Source: Appendix A

The majority of bioenergy carbon capture and storage (BECCS) projects currently operating globally involve the capture of fermentation CO_2 ethanol plants as discussed within the Global CCS Institute report[14]. No additional biomass or EfW power plant projects were identified within the Global CCS Institute report.

4.1.3.4 Reciprocating Engine Based Power & CHP Plants

No suitable references were found for capture facilities in open literature. Individually, the emissions rate from such plant is likely to be within the sub-600tpd category shown in Figure 5 and therefore, concept layout design will be undertaken to assess individual Case Studies within this category to provide the necessary evidence.

4.1.4 Data from Academic Journals

Within the 2009 CCR Guidance, a summary of the capture plant land footprint for different types of gas and pulverised coal plant using various capture methods was presented (see Table 9). This was based on a published International Energy Agency (IEA) report[15] in 2006 and based on net plant capacities of around 500MW. The 2009 CCR Guidance footprint estimates were based on a defined plant size and subject to interpretation provided by Imperial College[16] in 2010. Note that the 2010 Imperial College review concluded the 2009 CCR Guidance was based on an overly conservative estimate for the footprint of the capture plant (derived from a capture plant processing flue gas from a 785MWe coal power plant) which was directly transcribed to a 500MWe CCGT without evidence of recalculating for the lower flowrate of carbon dioxide from the latter.

Table 9. Approximate Minimum Land Footprint for CO_2 Capture Plants

	CCGT with post-combustion capture	CCGT with pre-combustion capture	CCGT with oxy-combustion	USCPF with post-combustion capture	IGCC with capture	USCPF with oxy-combustion
Site dimensions – generation equipment (m)	170 x 140	170 x 140	170 x 140	400 x 400	475 x 375	400 x 400
Site dimensions – capture equipment (m)	250 x 150	175 x 150	80 x 120	127 x 75		80 x 120
Total site footprint (m^2)	62,000	50,000	34,000	170,000	180,000	170,000

Notes: IGCC – integrated gasification combined cycle, USCPF – ultra-supercritical pulverised fuel

[14] Carbon removal with CCS technologies, Global CCS Institute, 2021
[15] CO_2 capture as a factor in power plant investment decisions, IEA, 2006/8
[16] Assessment of the validity of "Approximate minimum land footprint for some types of CO_2 plant" provided as a guide to the Environment Agency assessment of Carbon Capture Readiness in DECC's CCR Guide for Applications under Section 36 of the Electricity Act 1989, Imperial College study for DECC, 2010, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/47932/553-imperial-college-review-ccr-guidance.pdf

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4.1.5 Case Study Footprints

4.1.5.1 Buffer storage for ship options

Per the Engineering Philosophy, Case Studies with >1200tpd export rate were assumed to be large emitters likely to have a pipeline connection. For cases with captured CO_2 export rates below the threshold (<1200tpd reference), a preliminary assessment has been undertaken to assess the quantity of buffer storage that may be expected for such facilities, as well as the alternatives to pipeline export that may be feasible. The total estimated footprint required for each case study, with on-site liquefaction and storage areas (where applicable), is provided in Appendix H.

The feasibility of shipping large volumes of CO_2 is non-trivial and considered to be outside the scope of the present study. Where the export destination options include a ship option, buffer storage has been provided based on use of refrigerated bullets of standard size, selected to store at least 5 days of CO_2 production at full load for each case study, plus 20% margin. The volume of hold-up stored is an iterative calculation associated with the theoretical ship size intended to service the emitter and therefore, the assumed ship size has also been provided where relevant. The assumptions used in the assessment of export options are summarised in Table 10.

Table 10. Summary of assumptions used in storage and export assessment for ships

Basis	Ships
Ship parameters	– Storage pressure: up to 40barg ship storage condition. (Note that 40barg ships for bulk transport of liquid CO_2 are currently theoretical and may require substantially different tank designs than those at lower pressures) – Payload: min. 5 days at 100% load, rounded up
Nominal vessel sizes considered	– 1000t – 2000t – 3500t
Liquefaction technology	– Ammonia refrigeration package – Entry condition: outlet of compressed CO_2 product, post De-O_2 and De-H_2O – Outlet condition: Liquid CO_2 product at storage condition

The nominal size of ship for each case study was selected from calculated payload requirement, rounded up to the nearest 500t. The range of theoretical ship sizes considered in this review for case studies with shipping spans 1000-3500t, which is consistent with the order of magnitude for ships already in service for shipping CO_2 commercially. It is worth noting that ship design to service the needs of the carbon capture sector is underway including the storage pressure conditions. Therefore, the calculated compression and refrigeration energy for case studies with liquefaction was based on the most conservative difference between inlet CO2 product and outlet at storage conditions. The current carrying capacity of liquid CO_2 ships in operation is on the order of 1000tCO_2 each[17]. Larvik Shipping operate a fleet of four liquid CO_2 tankers, each with a capacity of 1,200 – 1,800 tCO_2[18].

For case studies with ship options, it was assumed that the ship operating regime would seek to minimise empty and part-full journeys. For this regime, the ship would therefore arrive effectively empty and load until effectively full. The actual installed onshore storage volume was increased (from the minimum amount calculated to serve the production rate of CO_2 from the capture plant) to support full loading of the ship. In practice, this resulted in installed onshore storage volumes being greater than

[17] The Costs of CO2 Transport: Post-demonstration CCS in the EU, Zero Emissions Platform, 2011. Available online: https://www.globalccsinstitute.com/archive/hub/publications/119811/costs-co2-transport-post-demonstration-ccs-eu.pdf

[18] Shipping CO_2 – UK Cost Estimation Study, Element Energy Study for BEIS, 2018. Available online: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/761762/BEIS_Shipping_CO2.pdf

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those that would be required to support the CO_2 production rate in isolation. See Figure 7 for an illustration of this basis.

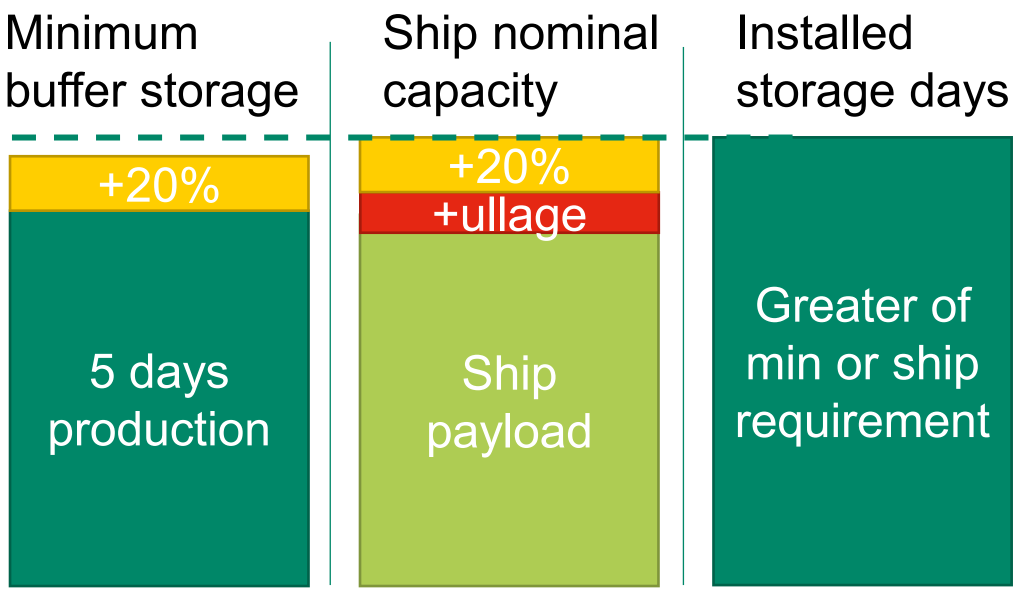

Figure 7. On-shore storage and ships sizing basis

4.1.5.2 Buffer storage for road truck options

An alternative option for truck export was investigated for the smallest case studies, see the summary data in Table 11. The truck option considered the average mass flow production rate of liquefied CO_2 from each case study, as well as a preliminary assessment of the reasonable limit for the dispatch capacity of a 2-bay truck loading station. The limit for the transport capacity was found to be approximately 500 t/day or 20 trucks. It may be possible to apply road truck transportation to larger facilities than those in this review through, for example, optimising the waiting time for trucks, deployment of additional loading bays, or rely on part-load/intermittent operation to schedule truck loading. However, the logistical challenges of organising potentially greater than 20 road truck loading operations per day would be significant and raise the optimise the loading time or rely on intermittent operation to extend the take advantage of part-load The resulting case studies where truck loading options were identified as 4, 5, 15 and 16.

Resizing of the storage volume was not necessary for case studies with trucks because transporting the stored volume from 5 days of full load production would already require multiple road trucks in all cases and therefore the problem of part-full transport was not relevant.

Table 11. Summary of road trucks storage and transport assessment

Basis	Trucks
Truck parameters	– Storage pressure: 20barg cryogenic liquid ('MP') – Net volume: 23.75m³ (25t)
Loading station	– 2 truck bays, available simultaneously – Truck loading cycle: 1h total including movements and loading – Truck loading running hours: 10h per day (0800-1800)
Max average CO_2 throughput	– 20 trucks per day – 475m³/day or 500t/day
Liquefaction technology	– Ammonia refrigeration package – Entry condition: outlet of compressed CO2 product, post De-O_2 and De-H_2O – Outlet condition: Liquid CO_2 product at storage condition

4.1.5.3 Overall footprint for options with storage and liquefaction

For case studies where buffer storage was relevant, the land area for on-site liquefaction of the CO_2 product has been estimated based on the refrigeration duty required to liquefy the CO_2. The space required for these units has been added to the total footprint for the cases studies where applicable.

Table 12 shows the summary of carbon dioxide export options for each case study, as well as the corresponding storage inventory expressed as days of production at full load.

Table 12. Case Studies including Buffer Storage of CO_2 and/or Liquefaction

CS	Case Study Title	Export P, barg	Export destination	Export phase	Liquefaction	Storage, days	Road trucks	Ship size, t
1	Small CCGT	150	National pipeline	Dense	N/A	N/A	N/A	N/A
2	Medium CCGT	150	National pipeline	Dense	N/A	N/A	N/A	N/A
3	Large CCGT	150	National pipeline	Dense	N/A	N/A	N/A	N/A
4	Small CCGT (CHP)	20	Ships / Trucks	Liquid	Included	16	Included	1,000
5	Medium CCGT (CHP)	20	Ships / Trucks	Liquid	Included	11.7	Included	2,000
6	Large CCGT (CHP)	20	Ships	Liquid	Included	9.9	N/A	3,500
7	Small OCGT	150	National pipeline	Dense	N/A	N/A	N/A	N/A
8	Medium OCGT	150	National pipeline	Dense	N/A	N/A	N/A	N/A
9	Small Boiler (EfW)	40	Ships	Liquid	Included	7.5	N/A	2,000
10	Medium Boiler (EfW)	150	National pipeline	Dense	N/A	N/A	N/A	N/A
11	Large Boiler (EfW)	150	National pipeline	Dense	N/A	N/A	N/A	N/A
12	Small Boiler (Biomass)	40	Ships	Liquid	Included	7.1	N/A	2,000
13	Medium Boiler (Biomass)	150	National pipeline	Dense	N/A	N/A	N/A	N/A
14	Large Boiler (Biomass)	150	National pipeline	Dense	N/A	N/A	N/A	N/A
15	Small Recip. Engine	40	Ships / Trucks	Liquid	Included	6.8	Included	N/A
16	Medium Recip. Engine	40	Ships / Trucks	Liquid	Included	12.5	Included	1,000
17	Large Recip. Engine	40	Regional pipeline	Gas	Included	8.8	N/A	3,500

For case studies where buffer storage was relevant, the land area for on-site liquefaction of the CO_2 product has been estimated based on the refrigeration duty required to liquefy the CO_2. The space required for these units has been added to the total footprint for the cases studies where applicable.

Table 12 shows the summary of carbon dioxide export options for each case study, as well as the corresponding storage inventory expressed as days of production at full load.

4.1.5.4 CCGT case studies (power and CHP)

Figure 8 shows the footprint calculated from the layout for each CCGT case study against the corresponding capture plant capacity. The trendline plotted for the CCGT case studies suggests a linear relationship between capture plant capacity footprint and area for CCGT with a simple regression analysis with relatively little variance (R^2 = 0.93). Figure 8 suggests a reasonable rule-of-thumb for extrapolating approximate capture plant footprint in a CCGT application may be shown as:

$$y = 2.53 \times capture\ plant\ capacity + 9600$$

Where y would be the resulting footprint in m^2 and the $capture\ plant\ capacity$ is measured in metric tpd.

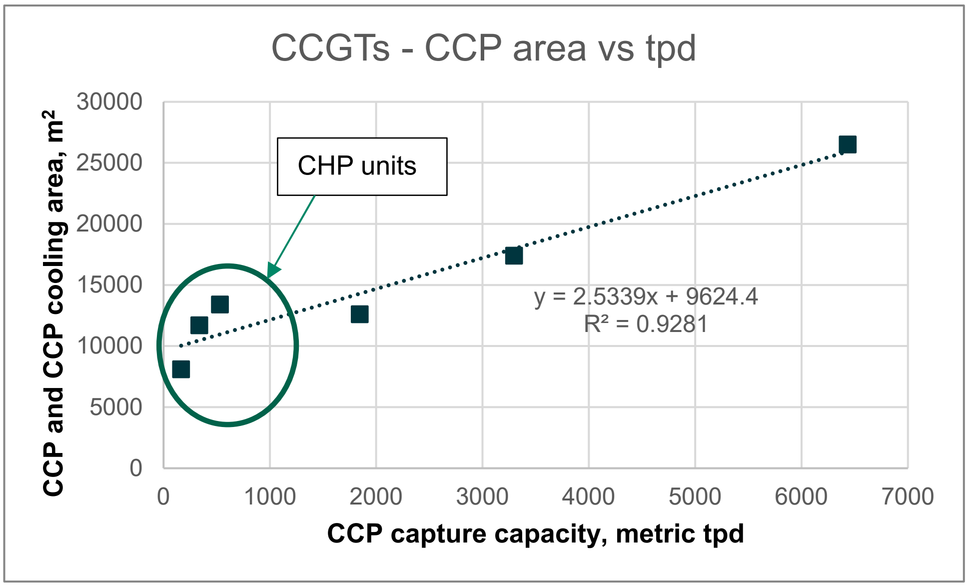

Figure 8. CCGT capture plant areas (including cooling with cooling towers)

An alternative plot of net power generation capacity against resulting capture plant area is shown in Figure 9 which indicates an alternative rule-of-thumb for CCGT applications (R^2 = 0.93). This figure compares the footprint required for capture plant based on the thermal energy input to the plant for the different natural gas case studies:

$$y = 11.9 \times MWth\ (LHV) + 9600$$

Where y would be the resulting footprint in m^2 and $MWth\ (LHV)$ is the thermal energy input to the plant based on the Lower Heating Value (LHV) of natural gas.

Also included in Figure 9 are the corresponding capture plant areas for each CCGT case study calculated using both the current updated guidance of 37.5m^2/MWe based on the Imperial College review[15] and a recent MSc thesis which found a non-linear relationship between capture plant area and net electricity export[19].

[19] Frewin, J. Minimising the Plot Size of CCS Plant: Process Design and Intensification. Imperial College MSc Thesis, 2021

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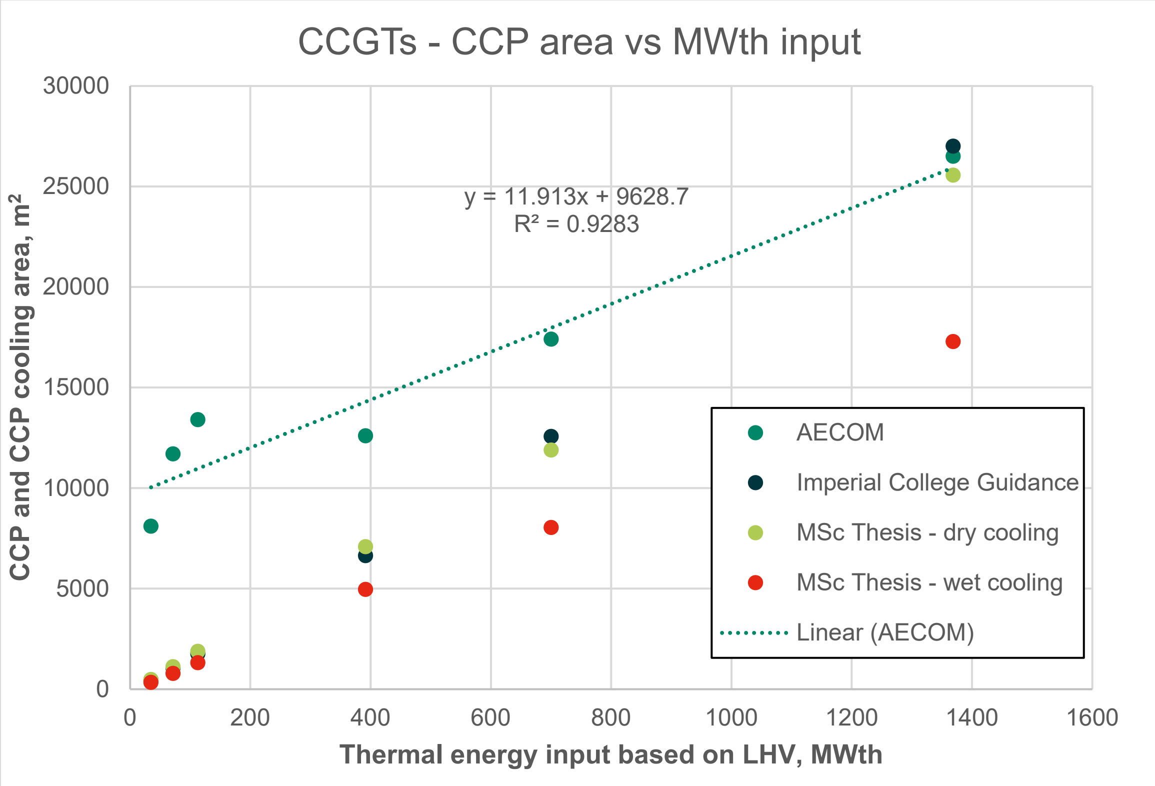

Figure 9. CCGTs capture plant areas (including cooling with cooling towers) against net power output

It is worth noting that, based on the R^2 value of the linear trendline being >0.9, both correlations identified in Figure 8 and Figure 9 appear to give reasonable prediction across the full set of CCGT case studies that have been considered in this review. The case studies were intentionally selected to represent a broad view of the industry from small CHP applications with aeroderivative or industrial units through to units that represent current state-of-the-art H and J Class heavy duty units.

4.1.5.5 OCGT units

Figure 10 shows the impact of deploying post-combustion capture on OCGT in combination with waste heat recovery via a traditional repowering route into CCGT. The OCGT cases are plotted in dark green and correspond to Case Studies 7 and 8, where the conversion has been conservatively assumed to comprise a traditional OCGT-to-CCGT repowering with a topping steam cycle, combined with steam extraction for heat supply to the capture plant. Addition of the topping steam cycle in both Case Studies clearly requires significant area in addition to that required for the capture plant; estimated as approximately 11,700m^2 and 16,600m^2, respectively.

It is worth noting that alternative solutions are under development for post-combustion capture that may use other means for driving the capture process, such as those driven by electricity or those that operate at higher capture temperatures than the typical 40°C-50°C absorber temperature required for effective performance in an amine system. These alternative next-generation capture technologies may encounter their own challenges to overcome prior to wide-scale deployment, as discussed in detail in the Next Generation Capture Technologies Review[20]. Nonetheless, next-generation technologies may

[20] Next Generation Capture Technologies Review and Benchmarking, Study by AECOM for the Department for Business, Energy & Industrial Strategy, 2022. Available online: https://ukccsrc.ac.uk/next-generation-capture-technologies/#workpackagereports

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prove favourable in comparison to OCGT repowering in certain locations where the additional power generation from a steam turbine may not be valued.

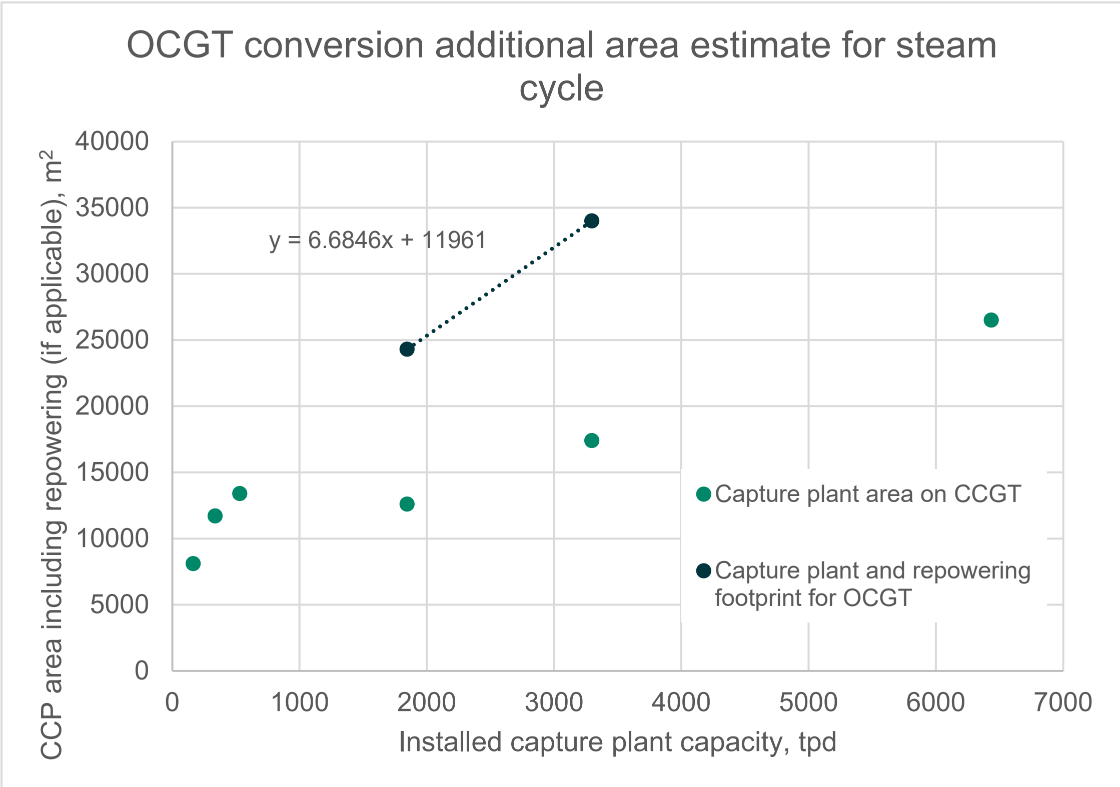

Figure 10. Capture plant capacity vs footprint for OCGT conversion

4.1.5.6 Solid fuels

Figure 11 shows the comparison of capture plant area for thermal waste treatment and biomass Case Studies. The data indicates that carbon capture plants processing waste feedstocks will require larger footprint than equivalent biomass plant. However, part of this difference may be attributed to a minor increase in the space allocated for maintenance and turnaround on the host waste site itself (which has been assumed to burn municipal solid waste) compared to the biomass power plant (which has been assumed to burn clean wood pellets). The difference in assumed requirements for turnaround space on the waste thermal treatment plant has, in turn, been extrapolated to the associated capture plant. Hence, the two solid fuel relationships should be viewed as a bounded area for capture plants processing flue gas from solid fuels.

Figure 11 also shows an apparent decrease in capture plant area requirement from the Small to the Medium cases for both biomass and waste feedstock. This apparent reduction is the result of both ‘Small’ Case Studies including on-site liquefaction and storage of CO_2 in large bullets which represent approximately 12-19% of the capture plant equipment footprint in both scenarios and contributing overall approximately 40% of plant area.

Liquefaction and storage of CO_2 were not part of the ‘Medium’ and ‘Large’ case studies (because the CO2 production rate in each case was greater than the 1200 t/d threshold for assuming pipeline export). Also shown in Figure 11 are the estimated areas of the ‘Small’ cases without area allocated for liquefaction and storage (‘w/o L+S’), which more closely follow the trend implied from the Medium and Large case studies.

It is proposed that the waste footprint correlation be used as a conservative basis for carbon capture plant in biomass and waste service:

$$y = 25.01 \times capture\ capacity + 15659$$

Where y would be the resulting footprint in m^2 and $capture\ capacity$ is measured in metric tonnes per day. The correlation associated with the linear trend line in this case (R^2=0.77) indicates significant divergence particularly with small scale plant that may wish to include on-site liquefaction and buffer storage. For larger plant, it is expected that the calculated trendline would provide a reasonable conservative basis in the absence of site-specific data which may allow a reduction.

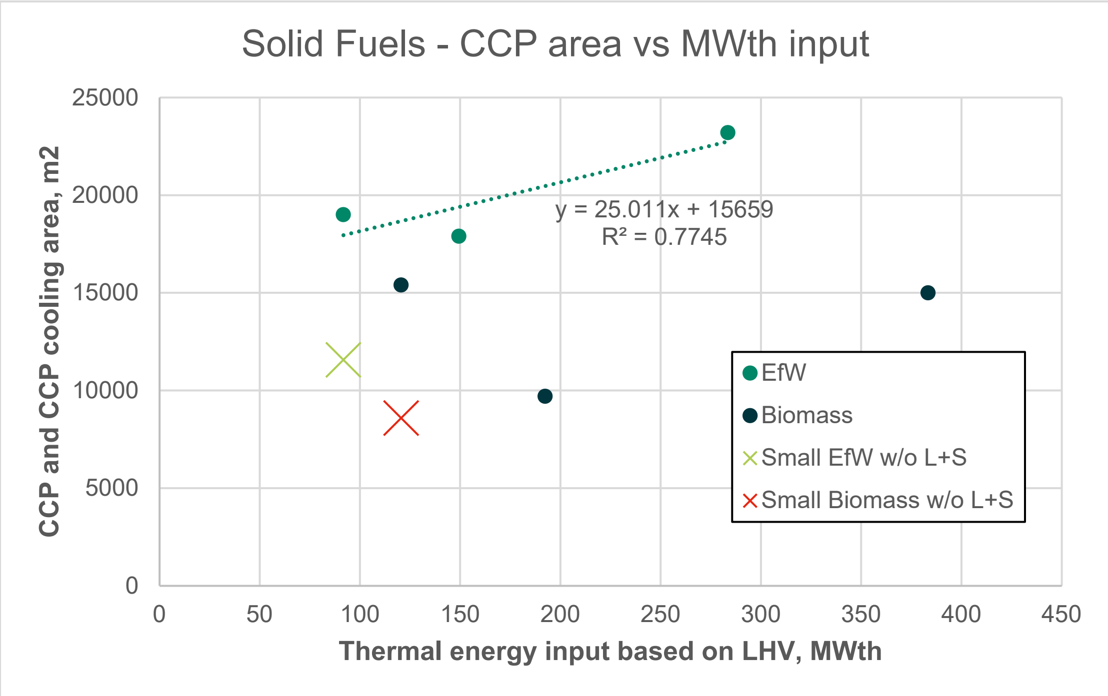

Figure 11. EfW and Biomass capture plant area

4.1.5.7 Reciprocating engines

Figure 12 shows the relationship between the total capture plant area and the installed generating capacity across the three reciprocating engine case studies (with R^2=0.97). The rule-of-thumb for extrapolating reciprocating engine footprint has been calculated as:

$$y = 16.8 \times capture\ capacity + 2510$$

Where y would be the resulting footprint in m^2 and $capture\ capacity$ is measured in metric tonnes per day.

It is worth noting that the scale of reciprocating engines studied range from 1MW installed nominal capacity to an array of 50MW nominal capacity (spanning a range from 12tpd to 529tpd, respectively). Liquefaction and buffer storage of CO_2 has a significant impact on overall footprint in the reciprocating engine case studies, where they comprise up to 25% of the equipment footprint for the Carbon Capture Plant (CCP), or up to 50% of the total CCP footprint.

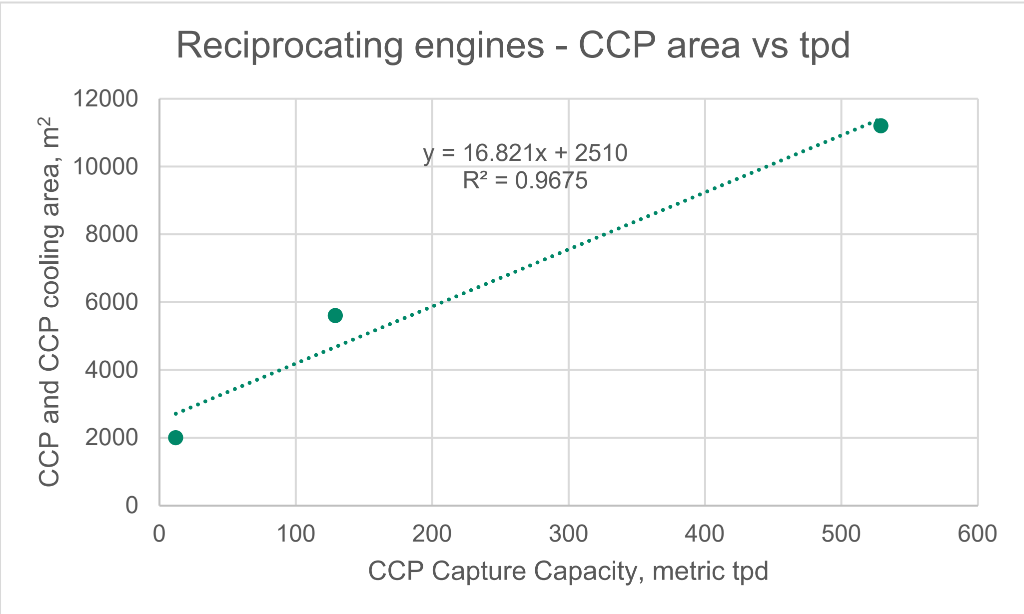

Figure 12. Comparison of CCP capture plant for reciprocating engines

Due to the significant range in capacities between the case studies, a variety of construction methods has been assumed for the reciprocating engine case studies, as summarised below:

- Small case study (1MW x 1 engines): 1 x train for CCP housed within a 40ft shipping container, plus waste heat boiler (including supplementary duct firing to enable 95% capture)
- Medium case study (2.4MW x 5 engines): 2 x 40ft containerised CCP trains per engine (i.e. total 10 off between 5 engines), plus 1 x waste heat boiler per engine (i.e. total 5 off between 5 engines)
- Large case study (10MW x 5 engines): single combined capture plant train (i.e. not containerised), plus 2 x waste heat boilers per engine (i.e. total 10 off between 5 engines). The choice to specify a non-containerised solution for the large reciprocating engine case study was driven by the overall carbon dioxide capture rate for this case study – approximately 529tpd – which corresponds to a relatively large carbon capture plant. For reference, the Tata Chemicals plant discussed in Section 4.1.3 has a nameplate capture capacity of approximately 120tpd i.e. similar to a single train of 10MW reciprocating engine.

4.2 Objective 2 – Checklists

***Objective 2** is to update the relevant checklists in the 2009 guidance document annexes, ensuring that they cover power plants < 300MWe; all relevant technology types (e.g. engine, turbine, boiler, CHP or heat generation); all relevant fuel types (e.g. gaseous fuel, liquid fuel, biomass or waste).*

The 2009 checklists have been reviewed and comments provided to the Environmental Permitting Regulators for review. Qualitative information regarding the background for the comments is provided in this section. For the revised checklists, refer to Appendix B which have incorporated the discussions from the two checklist workshops held in March 2022.

4.2.1 Technologies in commercial operation, or near commercial deployment

Since the 2009 Carbon Capture Readiness regulations were written, the UK energy mix has changed substantially and only three large coal plants remain connected to the electricity grid at the time of writing (of which West Burton A is due to be decommissioned in September 2022, and the remaining plants will be required to close by 2024). Correspondingly, interest in deployment of carbon capture on coal from power generation has decreased substantially, and it is unlikely that any new-build coal plants subject to CCR requirements would be developed in the future. Instead, interest in carbon capture from combustion of solid fuels has changed to biomass and thermal waste treatment applications. Some examples of such projects are shown in Table 13. It is therefore recommended that the two separate post-combustion checklists for coal and natural gas be superseded by a single consolidated checklist that will be used to assess requirements for all post-combustion projects, as well as dedicated sub-sections specific to each individual feedstock type.

Table 13. CCS Projects Operating or under Development in the UK

Project name	Location	Fuel	Capacity, metric tCO_2/day
Drax BECCS	Yorkshire	Biomass	10,000
Tata Chemicals	Northwich	Natural gas	120
Net Zero Teesside	Teesside	Natural gas	6,100
Keadby 3	Lincolnshire	Natural gas	6,400
Peterhead Low Carbon	Aberdeenshire	Natural gas	6,100
Caledonia Clean Energy	Stirlingshire	Natural gas	8,200
Cory	London	Waste	4,500

Source: Appendix A

4.2.2 Existing Facilities & Demonstration Plants

The existing CCR 2009 guidance has been written to assess whether power plants are capable of meeting future requirements to retrofit carbon capture equipment. As such, it is not necessarily adapted to plants that are designed to incorporate capture plant as an integral part of their original design.

In assessing the decarbonisation readiness of a project, the use of the checklists should be sympathetic to the type of project being assessed, such as differences between projects intending to deploy carbon capture from the outset, those intending to be 'Capture Ready' but delay the construction of the capture plant, and those that intend to deploy major refurbishment works of the type that would trigger the requirement for Decarbonisation Readiness.

4.2.3 Academic Papers on Performance and Operation of Carbon Capture Technologies

Requirements for solvent reclaiming have been considered in the BAT Review for Post-Combustion Capture[21]. The checklist assessments should investigate the means proposed by the project for solvent health management, whether through reclaiming or other means.

4.2.4 Vendor Information Regarding Performance

Make-up water may be required by the capture process for a variety of uses, for example for initial fill, or as make-up to water and/or acid wash stages, or others. The make-up water requirement may be satisfied either from dedicated facilities within the capture plant, or from some over-sizing of capacity within the power island feed water and/or make-up water treatment plant to realise some capital cost savings.

Flue gas recirculation is an option for concentrating natural gas-derived flue gas prior to the capture plant, which would allow for a reduction in energy penalty when capturing from natural gas flue gas[22]. Recirculation is expected to be of limited benefit for flue gases with high carbon dioxide concentration such as EfW or biomass. However, while flue gas recirculation is not currently an option offered by any of the main gas turbine manufacturers, it remains a hypothetical option and should be covered in the checklists.

4.2.5 Studies, Papers & Guidance on CCS Plant Flexibility

Potential operational issues related to implementation of flexible CCS cycles were investigated in a BEIS study published in 2020[23]. This study considered the operation of a standard CCGT retrofitted with carbon capture in 3 operating regimes (baseload, two-shift and mid-merit). Residual emissions from the standard configuration were calculated during start-up (hot and cold), as well as shut-down. Options were presented for improving the capture performance during start-up and shut-down. The improvements were selected to enable high capture to be maintained throughout each transient scenario by way of early heat extraction from a start-up bypass and/or maximising the use of solvent inventory for temporarily buffering start-up emissions. The 2020 study outlines a methodology for projects to determine the quantity of additional footprint that may be required to install additional equipment for buffering emissions at start-up, as well as methods for reducing the increment through combinations of improvements. It is proposed that the layouts and concept design in this study be developed with space allocated for additional solvent storage to buffer emissions. The volume of additional solvent storage in these cases has been determined consistent with the methodology outlined in the 2020 study as theoretical space allocation on the site for one additional amine storage tank of the equivalent inventory as the main lean solvent storage tank (or one of the tanks for cases where multiple lean solvent tanks are to be deployed). The allocated space would therefore generally be expected to be provide similar hold-up time for buffering rich amine to the overall process inventory of solvent. Requirements to demonstrate the ability of the proposed capture plant to operate flexibly should also be included in the checklists.

[21] BAT Review for New-Build and Retrofit Post-Combustion Carbon Dioxide Capture Using Amine-Based Technologies for Power and CHP Plants Fuelled by Gas and Biomass as an Emerging Technology under the IED for the UK, Prepared by Jon Gibbins and Mathieu Lucquiaud, July 2021. Available online: https://ukccsrc.ac.uk/wp-content/uploads/2021/06/BAT-for-PCC_V1_0.pdf
[22] Diego, M.E., Akram, M., Bellas, J.-M., Finney, K.N. and Pourkashanian, M. (2017), Making gas-CCS a commercial reality: The challenges of scaling up. Greenhouse Gas Sci Technol, 7: 778-801. https://doi.org/10.1002/ghg.1695
[23] Start-up and Shut-down times of power CCUS facilities, AECOM study for the Department of Business, Energy & Industrial Strategy, May 2020. Available online: https://www.gov.uk/government/publications/start-up-and-shut-down-times-of-power-carbon-capture-usage-and-storage-ccus-facilities

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4.3 Objective 3 – Economics

***Objective 3** is to make estimates of the parameters which will be needed to model the economics of a plant fitted with CCS. In particular: capital cost associated with CCS equipment in new build and retrofitting to existing; operational expenses associated with transporting and storing CO2; additional operational costs arising from the operation of CCS equipment; opportunity costs e.g. due to outages whilst retrofitting.to update the relevant checklists in the 2009 guidance document annexes, ensuring that they cover power plants < 300MWe; all relevant technology types (e.g. engine, turbine, boiler, CHP or heat generation); all relevant fuel types (e.g. gaseous fuel, liquid fuel, biomass or waste).*

4.3.1 Technologies in commercial operation, or near commercial deployment

4.3.1.1 Cost of transport

Carbon dioxide transportation costs by ship and pipeline have been assessed in a study by Element Energy[24]. The cost of both offshore pipeline and shipping port-to-port options were estimated for a case study of 1Mtpa traveling 600km and project lifetime of 20 years as:

- Shipping port-to-port: approximately £$_{2018}$10/metric tonne
- Offshore pipeline: approximately £$_{2018}$20.50/metric tonne

The author's estimate indicates approximately 50% lower cost for shipping carbon dioxide port-to-port than by pipeline. However, it is important to note the assumptions for each option have a significant impact on the cost of each option. The author noted the results of their sensitivity analysis indicated larger throughputs (for example 5Mtpa vs author's 1Mtpa) would favour pipeline transport instead.

A second study for BEIS[25] compared overall costs for combinations of road, rail, ship and/or pipeline from a series of dispersed sites which would not have direct access to clusters. This study illustrated the complexity of the supply chain between capture and compression of CO_2 through to liquefaction and transport to the offshore store. A range of £$_{2020}$18-£$_{2020}$40/tCO_2, inclusive of a £12/tCO_2 for offshore storage costs, has been inferred from this study as a single simplified range for the purposes of preliminary assumptions regarding mixed transport routes across the UK between a variety of sites.

4.3.1.2 Duration of outage

Potential outage durations have been noted by the IEA[26], who suggested that durations as short as 1-3 months may be feasible if host facility operation can continue uninterrupted during construction. 1-3 months may be feasible where the capture plant construction duration is short and/or the capture plant can be kept segregated from its host facility until the commissioning phase. However, for large projects relying on shared services or facing long construction and commissioning schedules, the requirements of operating a construction site in compliance with CDM regulations may require a longer period.

4.3.2 Case Studies of Existing Facilities and demonstration plants

Table 14 shows the significant disparity for reported costs between different facilities. Each individual project has a fundamentally different design basis such as cooling approach, presence of steam extraction, as well as different flue gas pre-treatment requirements. The cost estimates for the larger coal facilities will be used as indicative past project benchmark data for EfW and biomass facilities calculated within this study.

[24] Shipping CO_2 – UK Cost Estimation Study, Element Energy Study for BEIS, 2018. Available online: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/761762/BEIS_Shipping_CO2.pdf
[25] CCS Deployment at dispersed sites, Element Energy Study for BEIS, 2020. Available online: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/929282/BEIS_-_CCUS_at_dispersed_sites_-_Report__1_.pdf
[26] Available online: https://iea.blob.core.windows.net/assets/bf8affe9-9968-4a36-930b-fb3ce7cf0d20/ReadyforCCSRetrofit.pdf

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Tata Chemicals' plant represents a relevant basis for comparing the smaller projects and will be compared (together with engineering study data) against estimates generated for natural gas-derived flue gases from the various emitters in this study.

Table 14. Existing Facility Scale & Cost

Project name	Location	Capacity, tCO_2/day	Cost (£$_{2021}$)
Petra Nova	USA	4,700	880,000,000
Boundary Dam	Canada	3,200	1,200,000,000
Tata Chemicals	UK	120	17,800,000

Source: See Appendix A for estimated capital cost data

4.3.3 Vendor Information Regarding Performance

A technology-neutral benchmark has been maintained throughout the Case Studies to present a consistent assessment of costs at various scales. It is recognised that licensed solvents and competing processes exist which claim significant process improvements. However, for the purposes of assessing the project against its feasibility requirements, it is conservative to maintain a technology-neutral basis for this study.

Overall cost to capture carbon dioxide has recently been presented in a GCCSI report[27], summarised in Table 15. The costs estimated by GCCSI do not include downstream CO_2 compression and include assumptions regarding the cost of fuel (such as \$$_{2021}$2.11/GJ natural gas) which may not be appropriate for the UK at time of writing. Furthermore, the cost rates presented in Table 15 represent levelised values and further interpretation would therefore be required before direct comparisons with the Case Studies considered in Section 4.4 could be made.

Table 15. Total Cost Estimates of Carbon Capture for Power Generation

Power Generation Type	Levelised Cost approximate range (\$$_{2021}$) per tCO_2
CCGT	$70-120
Biomass	$60-80
Waste	$60-80

Source: GCCSI 2021

4.4 Case Study Estimates

Capital and operating cost estimates for on-site assets were developed using representative configurations as case studies with a clear and consistent basis throughout.

The intent is that the results of these case studies provide an evidence base that can be used by examiners during the application process to determine if the acceptance criteria for assessments 1 and 4, defined in Section 1.2, have been addressed appropriately by developers.

4.4.1 Capital Cost Estimates

A summary graph of capital costs associated with CCS equipment across all case studies is shown in Figure 13, with further detail available in Appendix E. These costs have been plotted on a £$_{2022}$ basis as a graph of specific cost (£$_{2022}$/tpd capacity) against installed capture plant capacity (in tpd). Both natural gas case studies (in light green) and solid fuel case studies (in dark green) indicate reasonable correlation with a logarithmic cost reduction with increasing scale. The cost estimates for each case

[27] Technology Readiness and Costs of CCS, GCCSI, 2021. Available online: https://www.globalccsinstitute.com/wp-content/uploads/2021/04/CCS-Tech-and-Costs.pdf

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study have been scaled from other project data and should therefore be viewed with an overall uncertainty of +/-50%. A summary of the uncertainty associated with each equipment item is presented in Appendix F.

The natural gas trendline indicates a reasonable correlation between the case studies (R^2=0.94) and is consistent with the published cost of the Tata Chemicals plant (plotted in red). The natural gas plant cost-capacity rule-of-thumb is therefore suggested to follow the below formula:

$$y = 0.594 \times (tpd\ capacity)^{-0.27}$$

Where y would be the capital cost ratio in terms of £millions/tpd capture plant capacity.

Figure 13 provides an estimate of the cost of fitting post-combustion capture to OCGT as the two light blue points, representing Case Studies 7 and 8, respectively. The OCGT conversion clearly incurs significant incremental cost (corresponding to approximately £30,000/tpd CCP capacity) compared to fitting the post-combustion capture plant to similar CCGT where some heat would already be available for regenerating the solvent. However, addition of the topping steam cycle would enable the generation and export of additional power and/or heat from the prime mover and serve to **increase** overall net thermal generating efficiency for the site compared to the original unabated OCGT plant performance.

In comparison, the solid fuel cases appear to show significantly higher variation (R^2=0.32) shown in Figure 14, reflective of the wide variation in feedstock between the biomass and waste feedstocks. Extra care should be used when extrapolating the cost data for capture on solid fuel cases, with a preliminary rule-of-thumb for capital cost shown below:

$$y = 0.522 \times (tpd\ capacity)^{-0.2}$$

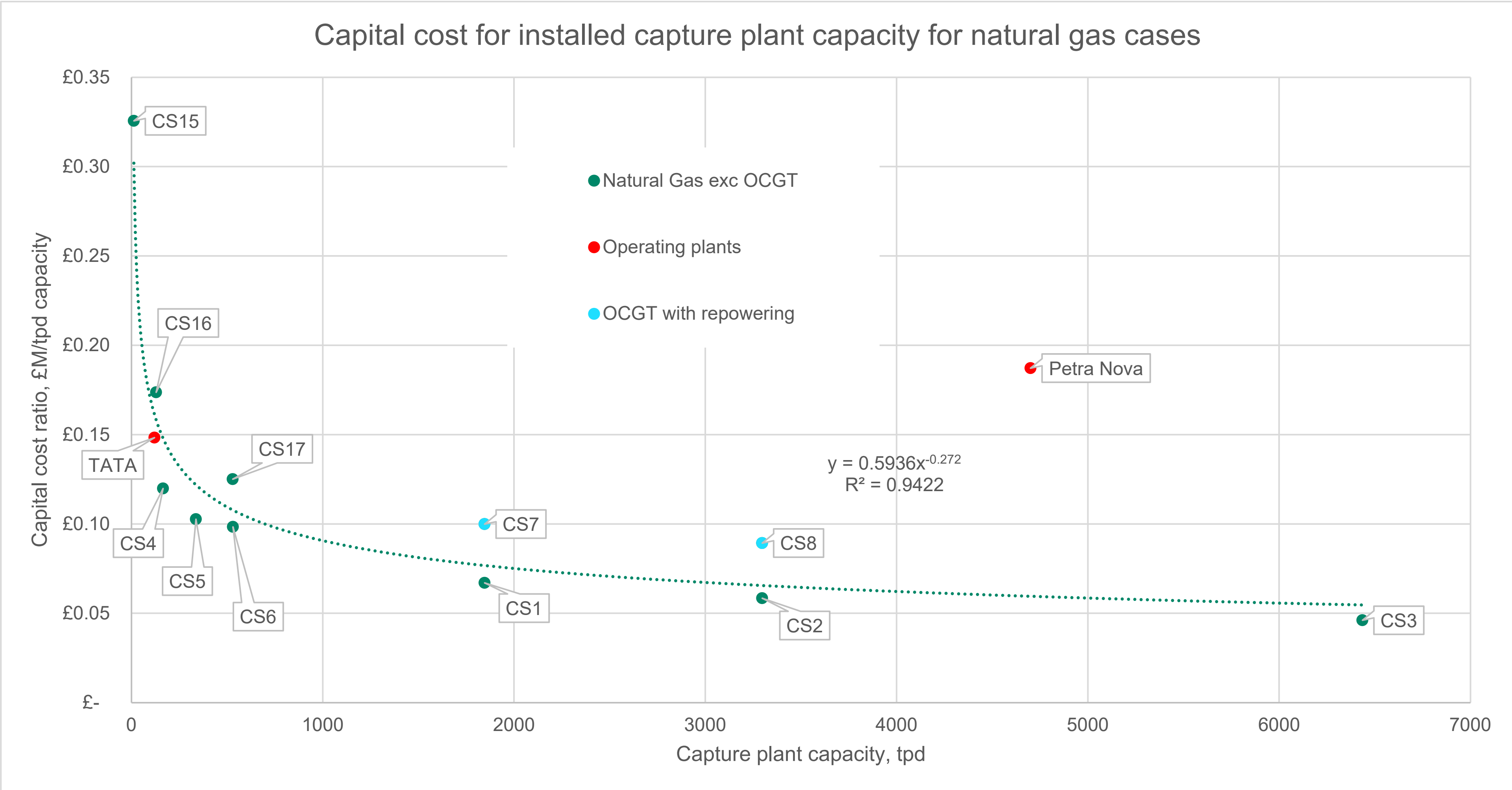

Figure 13. Capital costs for installed capture plant capacities with natural gas type flue gases

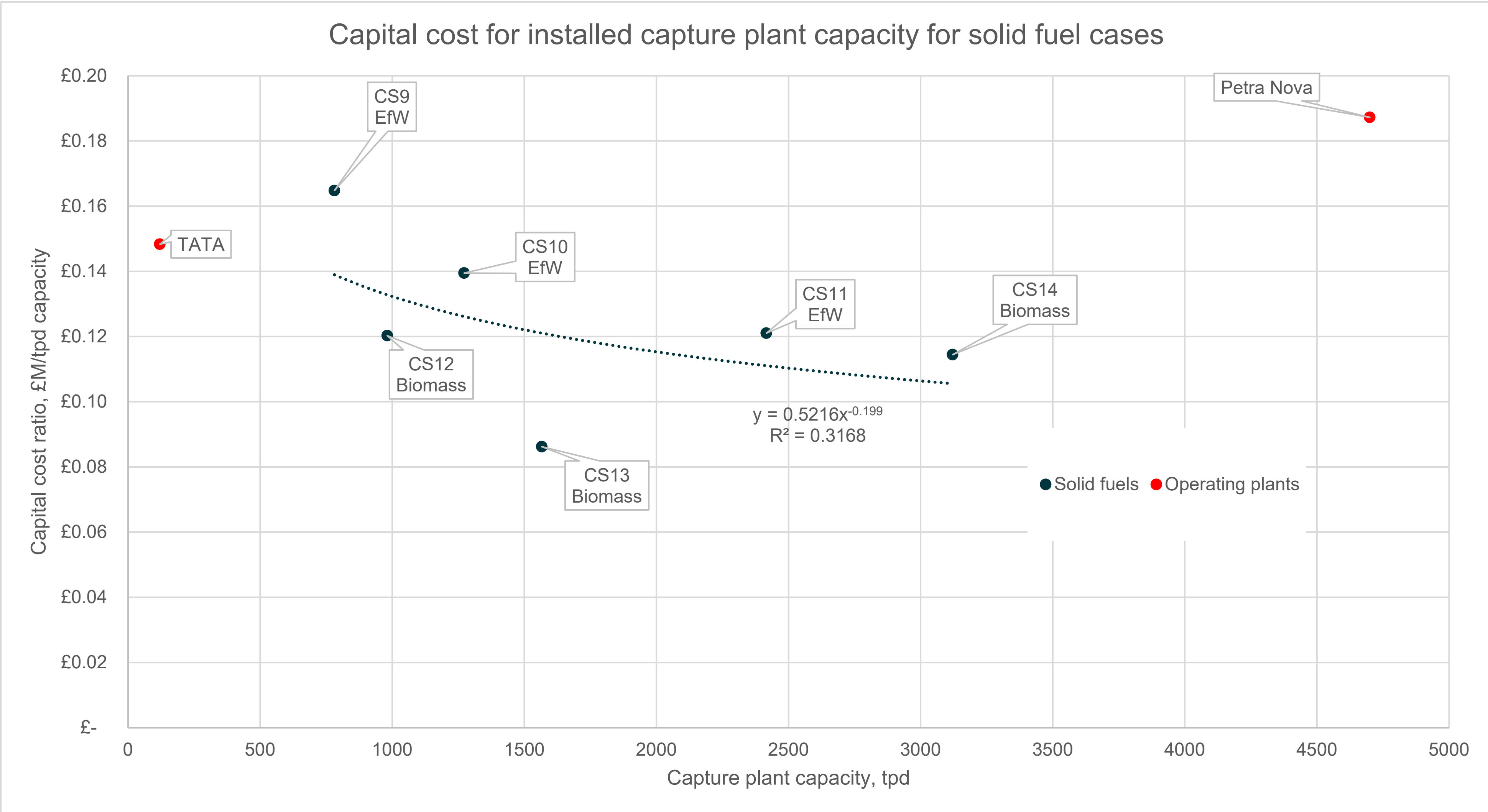

Figure 14. Capital costs for installed capture plant capacities with biomass and waste flue gases

5. Conclusions and Recommendations

5.1 Conclusions

The evidence base for demonstrating carbon capture readiness has been developed in this review, according to the three assessments required by BEIS, summarised below.

5.1.1 Objective 1 – Footprint

Table 16. Summary of main footprint requirements for Carbon Capture Readiness

Characteristic	Commentary
CCGTs (power and CHP)	• Demonstration scale capture plants (<600 tpd CO_2) do not follow a linear trend as closely as larger, commercial projects and may require evaluation of equipment transportation to site to estimate footprint • Relationship between CCP area (including CCP cooling) and thermal energy input to plant is: $CCP\ area\ (m^2) = 2.53 \times capture\ capacity\ (tpd) + 9600$
OCGTs	• Topping steam cycle requires significant additional area – almost equal to CCP area • Relationship between CCP area (including CCP cooling and repowering) and capture capacity of plant is: $CCP\ area\ (m^2) = 6.68 \times capture\ capacity\ (tpd) + 12600$
Solid fuels	• Carbon capture plants with biomass feedstocks appear to require less area than plants with waste feedstock but both datasets are to be used as basis for solid fuel plants • Relationship between CCP area (including CCP cooling) and capture capacity of plant is: $y = 25.01 \times capture\ capacity\ (tpd) + 15659$
Reciprocating engine	• Relationship between CCP area (including CCP cooling) and capture capacity of plant is: $CCP\ area\ (m^2) = 16.8 \times capture\ capacity\ (tpd) + 2510$

5.1.1.1 Liquefaction and on-site buffer storage

Smaller emitters (<1200tpd capture rate) are not assumed to be connected to an export pipeline and therefore may require on-site liquefaction and buffer storage of the captured CO_2 product. Export options for these sites include road trucks or shipping vessels. Sites that adopt either of these export options will require CO_2 storage vessels and on-site liquefaction of the CO_2 product which have a significant impact on footprint (potentially up to 50% of the overall capture plant area).

5.1.2 Objective 2 – Checklists

The final checklists have been issued to BEIS for review and are provided in Appendix B. These represent an updated carbon capture checklist specific to power generators seeking to use carbon capture on site. Items C1 to C15 on the carbon capture checklist constitute requirements which aim to ease the capture retrofit of Natural Gas Combined Cycle power plants with post combustion amine scrubbing technology based CO_2 capture but can also be adapted to other liquid solvent systems.

Table 17. Summary of main checklist conclusions

Characteristic	Commentary
Solid fuels	• It is considered unlikely that new-build coal power plants will be developed in UK in future • Solid fuel power generation now more focused on biomass or waste feedstocks • A consolidated single checklist with sub-sections for each feedstock type is proposed in place of the existing separate checklists for coal and natural gas

Characteristic	Commentary
Retrofit / New-build plants	• Existing guidance has been written based on power plants meeting future requirements to retrofit carbon capture equipment • Assessment of Decarbonisation Readiness should recognise the difference between projects proposing to incorporate capture plant as an integral part of their original design in comparison to those within to delay construction
Flue gas recirculation	• Flue gas recirculation is an option for concentrating natural gas-derived flue gas prior to capture plant and can reduce energy penalty • Limited benefit for EfW or biomass flue gases • Not currently an option provided by gas turbine manufacturers but remains a hypothetical option
Start-up / Shut-down	• Power plants may operate flexibly with frequent starts and stops through their operating lives • Proposed capture plants should demonstrate that they will be able to upgrade to accommodate a more flexible operating regime if flexible operation may become relevant during their operating life.

5.1.3 Objective 3 – Economics

Table 18. Summary of main economic conclusions

Characteristic	Commentary
Transportation cost	• Where no direct onshore pipeline option exists, shipping CO_2 port-to-port estimated to be approximately 50% cheaper than offshore pipelines below a certain range of CO_2 throughput – however, opposite is true for larger throughputs • A transportation and storage cost of £18 to £40 per tonne CO_2 on a 2020 basis has been inferred, inclusive of £12/tCO_2 offshore storage costs
Outage period	• Smaller plants may experience outage periods as short as 1 to 3 months during construction and commissioning of capture plant • Large projects with shared services and longer commissioning periods will require longer outage periods
Capital cost estimate	• Relationship between capital cost ratio and capture plant capacity for natural gas power plants is estimated to be: $Cost\ ratio\ \left(\frac{£m_{2022}}{tpd}\right) = 0.594 \times (tpd\ capacity)^{-0.27}$ • Relationship between capital cost ratio and capture plant capacity for solid fuel power plants is estimated to be: $Cost\ ratio\ \left(\frac{£m_{2022}}{tpd}\right) = 0.522 \times (tpd\ capacity)^{-0.2}$

5.2 Recommendations

The data calculated in this review presents typical case study data in relation to carbon capture for a variety of combustion technologies. The data is intended to be used for:

- As a set of typical data for comparison in support of the wider assessment of Decarbonisation Readiness of projects by the Environmental Permitting Regulators
- As benchmark generic study data demonstrating the level of design information typically used to inform Decarbonisation Readiness by developers wishing to demonstrate their Decarbonisation Readiness

The information produced in this review does not remove the requirement for sites to undertake a reasonable level of site-specific design to demonstrate their Decarbonisation Readiness.

Appendix A Literature Review Document

A.1 Capture Plant Database

Table 19. Carbon capture plants identified in study

Facility Name	Facility Category	Facility Status	Country	Fuel Type	CO_2 Capture Capacity (tCO2/day)	Carbon Capture Plant Footprint (m²)	CAPEX Cost (£-2021)	OPEX Cost (£-2021/yr)	References
Aker Just Catch	Commercial	Operating	-	Various	300	500	-	-	Aker Carbon Capture, "Just Catch" (Webpage), Available: https://akercarboncapture.com/offerings/just-catch/
Aker Just Catch	Commercial	Operating	-	Various	300	500	-	-	Aker Carbon Capture, "Just Catch" (Webpage), Available: https://akercarboncapture.com/offerings/just-catch/
Aker Mobile Testing Unit	Commercial	Operating	-	Gas	1	30	-	-	Graff, O. F., "Aker Clean Carbon - Emission measurement and analysis from Mobile Carbon Capture Test Facility", 2010, Available: http://ieaghg.org/docs/General_Docs/Env_Impacts/13-Emission%20measurement_ACC_Graff.pdf
Aker Mobile Testing Unit	Commercial	Operating	-	Gas	1	30	-	-	Graff, O. F., "Aker Clean Carbon - Emission measurement and analysis from Mobile Carbon Capture Test Facility", 2010, Available: http://ieaghg.org/docs/General_Docs/Env_Impacts/13-Emission%20measurement_ACC_Graff.pdf
Boundary Dam	Commercial	Operating	Canada	Coal	3,200	16,700	1,200,000,000	-	Institute for Energy Economics and Financial Analysis, "Boundary Dam 3 Coal Plant Achieves Goal of Capturing 4 Million Metric Tons of CO2 But Reaches the Goal Two Years Late", 2021, Available: http://ieefa.org/wp-content/uploads/2021/04/Boundary-Dam-3-Coal-Plant-Achieves-CO2-Capture-Goal-Two-Years-Late_April-2021.pdf Giannaris, S. et al., SaskPower's Boundary Dam Unit 3 Carbon Capture Facility - The Journey to Achieving Reliability, Proceedings of the 15th Greenhouse Gas Control Technologies Conference 15-18 March 2021, Available: https://ccsknowledge.com/pub/Publications/PAPER_GHGT15_SaskPowers_BD3_Journey_Achieving_Reliability_Mar2021.pdf

Facility Name	Facility Category	Facility Status	Country	Fuel Type	CO_2 Capture Capacity (tCO2/day)	Carbon Capture Plant Footprint (m^2)	CAPEX Cost (£-2021)	OPEX Cost (£-2021/yr)	References
Caledonia Clean Energy	Commercial	Study	UK	Natural Gas	8,200	-	-	-	University of Edinburgh, "Caledonia Clean Energy Project: Project Details" (Webpage), 2018, Available: https://www.geos.ed.ac.uk/sccs/project-info/98
Cory EfW CCS	Commercial	Study	UK	Waste	4,500	-	-	-	Cory Group, "Cory announces plans for world's biggest energy from waste decarbonisation project" (Webpage), 2021, Available: https://www.corygroup.co.uk/media/news-insights/cory-announces-plans-worlds-biggest-energy-waste-decarbonisation-project/
Drax BECCS	Commercial	Study	UK	Biomass	21,900	38,600	-	-	Drax Power Limited, "Bioenergy with Carbon Capture and Storage (BECCS) at Drax Power Station - Consultation Brochure November - December 2021", 2021, Available: https://beccs-drax.com/wp-content/uploads/2021/10/BECCS-consultation-brochure.pdf
Drax BECCS Pilot	Demonstration	Operating	UK	Biomass	1	40	400,000	-	University of Edinburgh, "Drax BECCS Pilot Plant Details" (Webpage), 2021, Available: https://www.geos.ed.ac.uk/sccs/project-info/2261
ETI GBC TPwCCS (5 trains)	Commercial	Study	UK	Gas	27,400	125,000	2,729,500,000	-	Energy Technologies Institute, "Detailed Report: Plant Performance and Capital Cost Estimating", 2017, Available: https://ukerc.rl.ac.uk/ETI/PUBLICATIONS/AdHoc_CCS_CC1025_1.pdf
ETI GBC TPwCCS (1 train)	Commercial	Study	UK	Gas	5,500	28,000	677,700,000	-	Energy Technologies Institute, "Detailed Report: Plant Performance and Capital Cost Estimating", 2017, Available: https://ukerc.rl.ac.uk/ETI/PUBLICATIONS/AdHoc_CCS_CC1025_1.pdf
Ferrybridge pilot (CCPilot100+)	Demonstration	Closed	UK	Coal	100	900	29,200,000	-	Doosan, "CCPilot100+ Test Results and Operating Experience", IEAGHG PCCC2, 2013, Available: https://ieaghg.org/docs/General_Docs/PCCC2/Secured%20pdfs/7_3_IEAGHG%20PCC2%20Presentation.pdf
Karsto	Commercial	Study	Norway	Natural Gas	3,100	13,200	373,000,000	64,600,000	Bechtel, "CO2 Capture Facility at Karsto, Norway - Front-End Engineering and Design (FEED) Study Report", 2019, Available: https://ukccsrc.ac.uk/8-5-x-11-full-karsto-feed-study-report-redacted-updated_ocr-1/ UKCCSRC, Open Access: Carbon Capture and Storage at Karsto, Norway (Webpage), Available:

Facility Name	Facility Category	Facility Status	Country	Fuel Type	CO_2 Capture Capacity (tCO2/day)	Carbon Capture Plant Footprint (m²)	CAPEX Cost (£-2021)	OPEX Cost (£-2021/yr)	References
									https://ukccsrc.ac.uk/8-5-x-11-full-karsto-feed-study-report-redacted-updated_ocr-1/
Keadby 3	Commercial	Study	UK	Natural Gas	6,100	30,700	519,900,000	291,000,000	AECOM, "Carbon Capture Statement", 2021, Available: https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010114/EN010114-000253-K3%20-%20Document%205.8%20-%20Carbon%20Capture%20Statement.pdf
Kingsnorth E.ON	Commercial	Study	UK	Coal	6,600	16,500	433,300,000	-	BGS, "DECC: Reports from Longannet ScottishPower UK Carbon Capture & Storage (CCS) Consortium Front End Engineering and Design (FEED) Project" (Webpage), Available: https://www2.bgs.ac.uk/ukccs/accessions/projects.html
Klemetsrud Pilot	Demonstration	Operating	Norway	Waste	3	40	-	-	Fagerlund, J et al., "Performance of an amine-based CO2 capture pilot plant at the Fortum Oslo Varme Waste to Energy plant in Oslo, Norway", International Journal of Greenhouse Gas Control, March 2021, Available: https://reader.elsevier.com/reader/sd/pii/S1750583620306678?token=9A828887DA660B689867F2588B3AEBA66C4C5DA1B00410C349395CFD28CCA6CA483BBF042E187C02284F79341BF583CA&originRegion=eu-west-1&originCreation=20220307004858
Klemetsrud Plant - Fortum Oslo Varme	Commercial	Study	Norway	Waste	1,400	6,000	-	-	Fortum Oslo Varme, FEED Study Report DG3 (redacted version), 2020, Available: https://ccsnorway.com/wp-content/uploads/sites/6/2020/07/FEED-Study-Report-DG3_redacted_version_03-2.pdf
Longannet CCS	Commercial	Study	UK	Coal	6,000	29,600	726,600,000	141,300,000	BGS, "DECC: Reports from Kingsnorth E.ON UK Carbon Capture & Storage Front End Engineering and Design (FEED) project" (Webpage), Available: https://www2.bgs.ac.uk/ukccs/accessions/projects.html
Mikawa PCC Pilot Plant	Demonstration	Operating	Japan	Coal	10	1,000	-	-	Saito, S. et al., "Mikawa CO2 Capture Pilot Plant test of New Amine Solvent", September 2015, Available: https://www.ieaghg.org/docs/General_Docs/PCCC3_PDF/4_PCCC3_7_Saito.pdf

Facility Name	Facility Category	Facility Status	Country	Fuel Type	CO_2 Capture Capacity (tCO2/day)	Carbon Capture Plant Footprint (m²)	CAPEX Cost (£-2021)	OPEX Cost (£-2021/yr)	References
Nanko Pilot Test Plant	Demonstration	Operating	Japan	Natural Gas	2	200	-	-	Miyamoto, O. et al., "KM CDR ProcessTM Project Update and the New Novel Solvent Development", Energy Procedia, Available: sciencedirect.com/science/article/pii/S187661021731901X
NCCC (PSTU)	Demonstration	Operating	USA	Coal	100	700	-	-	Carroll, J., "Advanced Technology Testing at the National Carbon Capture Center (FE0022596)", Available: https://www.netl.doe.gov/sites/default/files/2017-12/J-Carroll-Southern-National-Carbon-Capture-Center.pdf
Net Zero Teesside	Commercial	Study	UK	Natural Gas	6,100	39,300	-	-	AECOM, "Document Reference: 5.7 Carbon Capture Readiness Assessment", 2021, Available: https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010103/EN010103-001159-NZT%20DCO%205.7%20-%20Carbon%20Capture%20Readiness%20Assessment.pdf
Peterhead 2	Commercial	Study	UK	Natural Gas	6,400	23,500	435,800,000	259,300,000	SSE Thermal, "Peterhead Low Carbon CCGT Power Station Project Newsletter", 2021, Available: https://www.ssethermal.com/media/3zzbd41m/peterhead-ccs-newsletter_may-2021_final.pdf
Petra Nova	Commercial	Closed	USA	Coal	4,700	17,700	880,000,000	-	NRG Energy, "Petra Nova Case Study" (Webpage), Available: https://www.nrg.com/case-studies/petra-nova.html University of Edinburgh, Petra Nova: Project Details (Webpage), 2017, Available: https://www.geos.ed.ac.uk/sccs/project-info/4
Pilot-scale Advanced CO2 Capture Technology (PACT)	Demonstration	Operating	UK	Coal /Biomass	1	100	-	-	University of Sheffield, "A4 PACT Factsheet", Available: https://itcn-global.org/downloads/factsheets/A4%20PACT%20Factsheet-2.pdf
Plant Barry	Demonstration	Operating	USA	Coal	500	3,000	130,100,000	-	Mitsubishi Heavy Industries, "Plant Barry CO2 Capture Project", October 2015, Available: https://www.cslforum.org/cslf/sites/default/files/documents/tokyo2016/Kamijo-PlantBarryProject-Workshop-Session2-Tokyo1016.pdf

Facility Name	Facility Category	Facility Status	Country	Fuel Type	CO_2 Capture Capacity (tCO2/day)	Carbon Capture Plant Footprint (m²)	CAPEX Cost (£-2021)	OPEX Cost (£-2021/yr)	References
ROAD CCS	Commercial	Operating	Netherlands	Coal	4,100	22,400	204,200,000	26,500,000	ROAD CCS, "Non-confidential FEED study report", 2011, Available: https://www.globalccsinstitute.com/archive/hub/publications/25551/road-non-confidential-feed-study-report-final-high-res-figures.pdf
SaskPower Shand	Commercial	Study	Canada	Coal	6,500	17,400	662,200,000	20,000,000	International CCS Knowledge Centre, "The Shand CCS Feasibility Study - Public Report", November 2018, Available: https://ccsknowledge.com/pub/Publications/Shand_CCS_Feasibility_Study_Public_Report_Nov2018_(2021-05-12).pdf
Shell Peterhead	Commercial	Study	UK	Natural Gas	3,100	54,700	659,700,000	199,500,000	Shell, "Peterhead CCS Project - Basic Design and Engineering Package", 2016, Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/531347/11_003_-__Basic_Design_Engineering_Package.pdf
Sherman FEED	Commercial	Study	USA	Gas	3,100	15,300	406,300,000	-	Elliott, W. et al., "An open-access, detailed description of post-combustion CO2 capture plant", Proceedings of the 15th Greenhouse Gas Control Technologies Conference 15-18 March 2021, Available: https://www.researchgate.net/publication/350517293_An_open-access_detailed_description_of_post-combustion_CO2_capture_plant
Surat Basin CCS Project	Commercial	Study	Australia	Coal	8,000	-	3,309,000,000	271,600,000	Wandoan Power, "Pre-feasibility Study Knowledge Sharing Report", June 2011, Available: https://www.globalccsinstitute.com/archive/hub/publications/20586/wandoan-power-project-pre-feasibility-study-knowledge-sharing-report.pdf
Tata Chemicals Northwich	Commercial	Operating	UK	Gas	120	3,900	17,800,000	-	Tata Chemicals, "Tata Chemicals Europe To Build UK's First Industrial Scale Carbon Capture And Utilisation Plant With £16.7m Investment" (Webpage), 2019, Available: https://www.tatachemicalseurope.com/news-release-tata-chemicals-europe-build-uks-largest-carbon-capture-use-plant#:~:text=In%20a%20unique%20application%20of,industrial%20businesses%20in%20the%20area.

Facility Name	Facility Category	Facility Status	Country	Fuel Type	CO_2 Capture Capacity (tCO2/day)	Carbon Capture Plant Footprint (m²)	CAPEX Cost (£-2021)	OPEX Cost (£-2021/yr)	References
Technology Centre Mongstad	Demonstration	Operating	Norway	Natural Gas	100	6,600	-	-	de Koeijer, G. et al., "CO2 Technology Centre Mongstad - Design, Functionality and Emissions of the Amine Plant", Energy Procedia. 4. 1207-1213, 2011, Available: https://www.researchgate.net/publication/251711742_CO2_Technology_Centre_Mongstad_-_Design_Functionality_and_Emissions_of_the_Amine_Plant
Technology Centre Mongstad	Demonstration	Operating	Norway	Natural Gas	100	6,600	-	-	de Koeijer, G. et al., "CO2 Technology Centre Mongstad - Design, Functionality and Emissions of the Amine Plant", Energy Procedia. 4. 1207-1213, 2011, Available: https://www.researchgate.net/publication/251711742_CO2_Technology_Centre_Mongstad_-_Design_Functionality_and_Emissions_of_the_Amine_Plant

A.2 Stakeholders Contacted

Table 20. Carbon capture technology providers

Manufacturer	Product Type	Date of Initial Contact	Response Received
Aker Carbon Capture	Solvent based	11/03/2022	No
Mitsubishi Heavy Industries	Solvent based	01/03/2022	Yes
Shell Cansolv	Solvent based	11/03/2022	Yes
Fluor	Solvent based	11/03/2022	No
Carbon Clean	Solvent based	11/03/2022	No
C-Capture	Solvent based	11/03/2022	No
Svante	Solid adsorbent on rotating packed bed	11/03/2022	No
Fuel Cell Energy	Fuel Cell	08/03/2022	No
Calix	Indirect calcination for cement production	11/03/2022	No
CO_2 Capsol	Carbonation	11/03/2022	Yes
Origen Power	Carbonation	11/03/2022	No
Carbon8 Systems	Carbonation	11/03/2022	No
Baker Hughes	Chilled ammonia	16/03/2022	Yes
Membrane Technology and Research	Membranes	11/03/2022	No
Net Power/8 Rivers	Allam-Fetvedt cycle	11/03/2022	No

A.3 List of References

The following section lists the documents that have been reviewed in the course of the study:

- Next Generation Capture Technologies Review and Benchmarking, Study by AECOM for the Department for Business, Energy & Industrial Strategy, 2022. Available online: https://ukccsrc.ac.uk/next-generation-capture-technologies/#workpackagereports
- NRG Petro Nova Case Study, available online: https://www.nrg.com/case-studies/petra-nova.html
- MHI press release, available online: https://www.mhi.com/news/210304.html
- BD3 Status Update: July 2021, available online: https://www.saskpower.com/about-us/our-company/blog/2021/bd3-status-update-july-2021
- DNV GL website: https://www.dnv.com/news/dnv-gl-approves-shell-carbon-capture-technology-to-bring-down-emissions-from-fortum-waste-to-energy-plant--179829
- Further Assessment of Emerging CO2 Capture Technologies for the Power Sector and their Potential to Reduce Costs, September 2019, IEAGHG Technical Report
- Improvement in power generation with post-combustion capture of CO2, Report Number PH4/33, November 2004, IEAGHG
- Carbon Clean Solutions Demonstration Plant Details. Available online: https://www.geos.ed.ac.uk/sccs/project-info/2021
- Just Catch – Capture Plants, 18th June 2019, O. Graff, Keynote, TCCS-10, Trondheim
- Twence Project Details. Available online: https://www.geos.ed.ac.uk/sccs/project-info/2623
- Aker Solutions press release. Available online: https://www.akersolutions.com/news/newsarchive/2020/aker-solutions-awarded-contract-for-the-brevik-carbon-capture-project/
- Assessment of the validity of "Approximate minimum land footprint for some types of CO2 plant" provided as a guide to the Environment Agency assessment of Carbon Capture Readiness in DECC's CCR Guide for Applications under Section 36 of the Electricity Act 1989, Imperial College study for DECC, 2010, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/47932/553-imperial-college-review-ccr-guidance.pdf
- Carbon removal with CCS technologies, Global CCS Institute, 2021
- CO2 capture as a factor in power plant investment decisions, IEA, 2006/8
- Assessment of the validity of "Approximate minimum land footprint for some types of CO2 plant" provided as a guide to the Environment Agency assessment of Carbon Capture Readiness in DECC's CCR Guide for Applications under Section 36 of the Electricity Act 1989, Imperial College study for DECC, 2010, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/47932/553-imperial-college-review-ccr-guidance.pdf
- The Costs of CO2 Transport: Post-demonstration CCS in the EU, Zero Emissions Platform, 2011. Available online: https://www.globalccsinstitute.com/archive/hub/publications/119811/costs-co2-transport-post-demonstration-ccs-eu.pdf
- Shipping CO2 – UK Cost Estimation Study, Element Energy Study for BEIS, 2018. Available online: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/761762/BEIS_Shipping_CO2.pdf
- Frewin, J. Minimising the Plot Size of CCS Plant: Process Design and Intensification. Imperial College MSc Thesis, 2021
- Next Generation Capture Technologies Review and Benchmarking, Study by AECOM for the Department for Business, Energy & Industrial Strategy, 2022. Available online: https://ukccsrc.ac.uk/next-generation-capture-technologies/#workpackagereports

- BAT Review for New-Build and Retrofit Post-Combustion Carbon Dioxide Capture Using Amine-Based Technologies for Power and CHP Plants Fuelled by Gas and Biomass as an Emerging Technology under the IED for the UK, Prepared by Jon Gibbins and Mathieu Lucquiaud, July 2021. Available online: https://ukccsrc.ac.uk/wp-content/uploads/2021/06/BAT-for-PCC_V1_0.pdf
- Diego, M.E., Akram, M., Bellas, J.-M., Finney, K.N. and Pourkashanian, M. (2017), Making gas-CCS a commercial reality: The challenges of scaling up. Greenhouse Gas Sci Technol, 7: 778-801. https://doi.org/10.1002/ghg.1695
- Start-up and Shut-down times of power CCUS facilities, AECOM study for the Department of Business, Energy & Industrial Strategy, May 2020. Available online: https://www.gov.uk/government/publications/start-up-and-shut-down-times-of-power-carbon-capture-usage-and-storage-ccus-facilities
- Shipping CO2 – UK Cost Estimation Study, Element Energy Study for BEIS, 2018. Available online: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/761762/BEIS_Shipping_CO2.pdf
- CCS Deployment at dispersed sites, Element Energy Study for BEIS, 2020. Available online: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/929282/BEIS_-_CCUS_at_dispersed_sites_-_Report__1_.pdf
- Available online: https://iea.blob.core.windows.net/assets/bf8affe9-9968-4a36-930b-fb3ce7cf0d20/ReadyforCCSRetrofit.pdf
- Technology Readiness and Costs of CCS, GCCSI, 2021. Available online: https://www.globalccsinstitute.com/wp-content/uploads/2021/04/CCS-Tech-and-Costs.pdf

Appendix B DCR Checklist Recommendations

Table 21. Recommendations for updated CCR checklist

ID	Title	Description	Category	Comments
A5	DeNOx Equipment (Projects with additional DeNOx installed for capture ONLY)	Note A5: A statement is required of the predicted performance of the DeNOx equipment and its compatibility with the relevant solvent mixtures for capture retrofit. This checklist item applies only to separate DeNOx equipment installed for the capture plant in addition to that proposed for the power island, or modifications to the power island DeNOx equipment to provide additional NOx removal upstream of the capture plant.	Amended item	Brought from coal checklist, would not expect to apply to the DeNOx equipment that the power island would install e.g. for its own operation to meet unabated NOx limits.
A6	Particulate Removal Unit e.g. ESP/Bag Filter (Projects with additional particulate removal installed for capture ONLY)	Note A6: A statement describing the expected configuration and anticipated performance of the particulate removal equipment (to maintain effective amine scrubber operation) is required. This checklist item applies only to separate particulate removal equipment installed for the capture plant in addition to that proposed for the power island, or modifications to the power island particulate removal equipment to provide additional particulate removal upstream of the capture plant.	Amended item	Brought from coal checklist, would not expect to apply to natural gas plants and those that already control their particulates below the required level to meet IED requirements.
A7	Flue Gas Desulphurisation Unit (project with FGD ONLY)	Note A7: A statement describing the expected configuration and anticipated performance of the DeSOx equipment after capture retrofit (to maintain effective amine scrubber operation) is required. This checklist item applies only to separate FGD equipment installed for the capture plant in addition to any proposed for the power island, or modifications to the power island FGD equipment to provide additional desulphurisation upstream of the capture plant.	Amended item	Brought from coal checklist, would not expect to apply to plants on natural gas.

ID	Title	Description	Category	Comments
B4	Gas Turbine Combined Cycle unit operation with hydrogen-rich fuel gas (Pre-Combustion Capture project ONLY)	The prime mover must be able to be modified to operate with the proposed hydrogen-rich fuel gas (including achieving any likely environmental restrictions on the emissions of NOx, possibly with the addition of selective catalytic reduction equipment - SCR). Note B4: A statement is required confirming that it will be possible to modify the prime mover to accommodate firing on hydrogen-rich fuel gas in the future and estimating the future performance including expected blending fraction of hydrogen (by % Lower Heating Value).	Valid - Retain Unamended	Brought from pre-combustion capture checklist - to cover modifications for projects wishing to retrofit to pre-combustion capture
B5	Heat recovery steam generator, HRSG, and plant steam cycle with hydrogen-rich fuel gas (Pre-Combustion Capture Project ONLY)	The heat recovery steam generator must be designed to accommodate the changed flue gas composition and temperatures after pre-combustion capture retrofit. The steam cycle as a whole must also be designed to accommodate the needs of the hydrogen production facility, both for providing any additional steam supplies to that facility and for the use of any additional steam production in the hydrogen production facility, to allow reasonable thermal integration and hence overall plant efficiency after retrofit. Note B5: A statement is required describing changes in the requirements for the HRSG and steam cycle after retrofit and how they will be modified to accommodate this.	Valid - Retain Unamended	Brought from pre-combustion capture checklist - to cover modifications for projects wishing to retrofit to pre-combustion capture
B6	Waste Separation and Disposal Facilities (Solid Fuel Capture project ONLY)	Gasification of certain fuels such as coal, petroleum coke, waste or biomass will give rise to by-product residue streams such as sulphur and/or solid ash that do not occur on natural gas plants. Provision for handling such streams on-site and for their satisfactory disposal from the site must be identified. Note B6: A statement is required identifying any additional by-product streams from the plant after pre-combustion capture is retrofitted and describing the appropriate handling and disposal provisions that would be implemented.	Valid - Retain Unamended	Brought from pre-combustion capture checklist - to cover modifications for projects wishing to retrofit to pre-combustion capture
C1	Design, Planning Permissions and Approvals	Note C1: A pre-feasibility-level conceptual capture retrofit study should be supplied for assessment, showing how the proposed CCR features together with an outline level plot plan for the plant retrofitted with capture. The plot plan should label the major items of equipment that comprise the capture plant (with a numbered legend sheet or equivalent), present the scale used for the plan. The plot plan should also indicate the limits of the site to be set aside for the capture plant itself and all associated auxiliaries, indicated by a boundary line and identified on the legend.	Amended item	Added paragraph in red

ID	Title	Description	Category	Comments
		Refer to the standard plans for examples of the level of detail expected from the plot plan.		
C2	Power Plant Location	Note C2a: The work undertaken on CO_2 transport and storage should be referenced; the exit point of gases from the curtilage of the plant and how this affects the configuration of the capture equipment is the important aspect for the Environment Agency. Note C2b: Health and Safety items in this section are outside the Environment Agency remit.	Valid - Retain Unamended	
C3	Space Requirements	Note C3: It is expected that all of the provisions in a-f will be implemented, including the provision of space and access to carry out the necessary works at the time of retrofitting without excessive interruptions to normal plant operation. A statement is required to define the level of formal project development that has been undertaken in support of the space requirement calculations, with reference to a standard methodology such as FEL stages, or equivalent. Alternatively, reference may be made to the standard examples of plant sizes, if appropriate. Further details are requested in the following sections as appropriate. Space will be required for the following: a) CO_2 capture equipment, including any flue gas pre-treatment and CO_2 drying and compression. b) Space for routing flue gas duct to the CO_2 capture equipment. c) Steam turbine island additions and modifications (e.g. space in steam turbine building for routing large low pressure steam pipe to amine scrubber unit). d) Extension and addition of balance of plant systems to cater for the additional requirements of the capture equipment. e) Additional vehicle movement (amine transport etc). f) Space allocation for storage and handling of amines and handling of CO_2 including space for infrastructure to transport CO_2 to the plant boundary.	Amended item	Flue gas recirculation note deleted, new proposed phrasing in red.
C4	Gas Turbine Operation with Increased Exhaust Pressure	Space must be provided for a booster fan, or alternatively, the hot gas path equipment (prime mover, any flue gas ducting, any heat recovery steam generator) must be able to operate with the increased back pressure imposed by the capture equipment. Note C4: A statement is required giving the expected pressure drop required for current commercial capture equipment together with	Amended item	Reordered paragraph to state blowers first, then alternative with back-pressure second for clarity. Added sentence regarding process safety requirements if project

ID	Title	Description	Category	Comments
		identification of the booster fan on the plot plan (as part of C3) and concept sizing (as part of C1). Alternatively, a manufacturer's confirmation that the prime mover as well as all hot gas path equipment design shall incorporate the backpressure from the capture equipment into its design in relation to matters such as performance and safety.		wishes to run with backpressure in HRSG.
C5	Flue Gas System	Space should be available for installing new duct work to enable interconnection of the existing flue gas system with the amine scrubbing plant and provisions in the duct work for tie-ins and addition of items such as bypass dampers and isolation dampers will be required as a minimum. If selective catalytic reduction (SCR) or other flue gas treatment is likely to be added at the time of retrofit then space for this should also be provided. Note C5: A statement is required describing the space and required flue gas system configuration for retrofit requirements and how they will be implemented.	Valid - Retain Unamended	
C6	Steam Cycle	Note C6: A statement is required giving the steam pressure at the steam turbine IP/LP crossover (or other steam extraction point), together with a description of any post-retrofit equipment modifications/additions. If multiple extraction points are to be used, the stated pressure should be for the extraction used to deliver the majority of the heat to the capture process at steady state. It should be stated whether the intended steam extraction design would allow flexibility in adapting the quantity and quality of steam extracted to different solvent systems operating with different heating requirements.	Amended item	Rephrased
C7	Cooling Water System	The amine scrubber, flue gas cooler and CO2 compression plant introduced for CO2 capture increases the overall power plant cooling duty. Note C7: A statement is required of estimated cooling water demands (flows and temperatures) with capture and how these will be met. It is expected that necessary space and tie-ins for cooling water supplies to post-combustion capture equipment will be provided and a description of these should be included.	Valid - Retain Unamended	

ID	Title	Description	Category	Comments
C8	Compressed Air System	The capture equipment addition will call for additional compressed air (both service air and instrument air) requirements. Note C8: A statement is required if intending to rely on existing facilities for compressed air (instrument and/or plant) that sufficient capacity is expected to be provided. In case new facilities are planned, a statement is required that sufficient space has been allocated for equipment, proportionate to the scale of equipment likely to be installed to service the process.	Amended item	Clarification in red
C9	Raw Water Pre-treatment Plant	Space shall be considered in the raw water pre-treatment plant area to add additional raw water pre-treatment streams, as required. It is recognised that raw water requirements for retrofitting capture may be modest and a statement confirming sufficient space is expected to be available within raw water treatment facilities - pending verification during the design phase - would be acceptable. Note C9: A statement is required of estimated treated raw water requirements together with a description of how these will be accommodated.	Amended item	
C10	Demineralisation I Desalination Plant	A supply of reasonably pure water may be required to make up evaporative losses from the flue gas cooler and/or scrubber. Estimates of this water requirement should be made and space allocated for the necessary treatment plant (and an additional water source be identified if necessary). Note C10: A statement is required saying which of the above are needed and in what quantity and also describing how the necessary provisions will be implemented	Valid - Retain Unamended	
C11	Waste Water Treatment Plant	Amine scrubbing plant along with flue gas coolers and FGD polishing unit (if appropriate) provided for post combustion CO_2 capture will result in generation of additional effluents. Note C11: A statement is required giving estimated additional waste water treatment needs and describing how the necessary space and any other provisions will be provided to meet expected demands.	Valid - Retain Unamended	

ID	Title	Description	Category	Comments
C12	Electrical	The introduction of amine scrubber plant along with flue gas coolers, booster fans (if required), and CO_2 compression plant will lead to a number of additional electrical loads (e.g. pumps, compressors). Note C12: A statement is required listing the estimated additional electrical requirements for the capture facilities, as well as a commitment that sufficient space will be retained for any transformers, switchgear and cabling.	Valid - Retain Unamended	Clarification in red
C13	Plant Pipe Racks	Installation of additional pipework after retrofit with capture will be required due to the use of a large quantity of LP steam in the amine scrubbing plant reboiler, return of condensate into the water-steam-condensate cycle, additional cooling water piping and possibly other plant modifications. Note C13: It is expected that provision will be made for space for routing new pipework at the appropriate locations. A statement identifying anticipated significant additional pipework and describing space allocations to accommodate these is required. For sites with long runs of interconnecting ductwork/pipework (e.g. flue gas or LP steam), a statement will be required describing the measures to be taken for managing any condensing droplets of liquid, and also confirmation that the sizing of the booster fan (if present) has fully considered the pressure drop of the ducting.	Amended item	Added clarification in red
~~C14~~	~~Control and Instrumentation~~	~~Note C14: It is expected that space and provisions for additional control equipment and cabling will be implemented. A statement identifying anticipated additional control equipment and describing space and other provisions to accommodate these is required.~~	Deleted (original)	DELETED
C15	Plant Infrastructure	Note C15: It is expected that the provisions below will be implemented. A statement identifying anticipated requirements and describing how they will be met is required. Space at appropriate zones to widen roads and add new roads (to handle increased movement of transport vehicles), space to extend office buildings (to accommodate additional plant personnel after capture retrofit) and space to extend stores building are foreseeable. Commitment from the project to establish a laydown strategy as part of the wider constructability philosophy will be required. The laydown strategy would	Amended item	Reordered paragraph and expanded in red.

ID	Title	Description	Category	Comments
		consider a range of topics in relation to construction of the capture plant such as (but not limited to), how, during a retrofit, vehicles or cranes will access the areas where new equipment will need to be erected, and how the project will ensure sufficient area is available for temporary laydown.		
C16	'Essential' Capture-Ready Requirements: Post Combustion Amine Scrubbing Technology based CO_2 Capture	The capture-ready requirements discussed in this section are the 'essential' requirements which aim to ease the capture retrofit of Natural Gas Combined Cycle power plants with post combustion amine scrubbing technology based CO_2 capture. Note C16: The provisions covered in Notes C1-C15 can be adapted to include other liquid solvent mixtures for CO_2 capture that can be shown to have a reasonable expectation of being commercially available at the time of retrofit and for which reliable performance estimates are already available. A statement on where the requirements for capture readiness for such solvents differ from those for amine capture with respect to all of the relevant sections C1- C15 above is required, together with any additional CCR features or other actions proposed, to be added as addenda to the responses to Notes C1-C15. If making the plant capture ready for other solvents conflicts with the CCR requirements for amine scrubbing then the impact on retrofitting amine scrubbing should be estimated and stated and the reasons for giving the other solvent priority should be listed and justified.	Valid - Retain Unamended	
C##	Solid fuel supply to site (projects using solid fuels ONLY)	For projects intending to generate power from solid fuels (e.g. coal, waste, biomass), fuel delivery and storage facilities are required to be reflected within the equipment list in C1 and the site plot plan presented in C3. Additional evidence is required to show that transport of the fuel to site is feasible, and a statement is required to confirm the plot plan will include space for the fuel vehicle movements (if any).	Amended item	Brought across from Pre-combustion checklist to cover coal, waste and biomass capture. Rewritten B3a.

ID	Title	Description	Category	Comments
C##	Oxy-combustion capture (Project combusting enriched air or oxygen ONLY)	For projects intending to use oxygen-enriched air or full oxy-combustion, the means of oxygen production are expected to be reflected in the equipment list in C1 and the site plot plan presented in C3. A statement is required confirming that the project has considered the impact on footprint, utilities and economics for the oxygen source, and that sufficient space has been allocated for items such as the oxygen generating equipment, interconnecting piping, as well as safety zoning. For projects not intending to generate oxygen on-site (e.g. through purchase of oxygen generated by others), a statement is required to confirm that space has been appropriately allocated for transport of oxygen to site (with appropriate reference to the site plot plan in C3), as well as clarification how the project has considered the energy associated with the generation of the oxygen.	Amended item	Brought across from Pre-combustion checklist to cover oxycombustion. Rewritten B3c.

Appendix C Technical Notes

C.1 Stakeholder Engagement Plan

C.2 Rationale for Case Study Scenarios

C.3 Engineering Basis

C.4 Basis for Layout Development

AECOM

Technical Note

Subject:	Stakeholder Engagement Plan	To:	Project Management Group, AECOM Project Delivery Group, Client Project Delivery Group, Independent Peer Reviewers
Project:	BEIS Decarbonisation Readiness Requirements Review		
Reference:	60677821-TN-001		
Revision:	2		
Date:	04/03/2022		
Author:	Rhys Williams		

1. Introduction

Delivery of the project will be supported and informed by engagement with different groups of stakeholders. The purpose of this document is to define the different groups, and the objectives, methods and timings of engagement.

2. Project management group

The project management group represents the project managers and directors responsible for the day-to-day management of the project and a forum for regular communication between BEIS and AECOM.

All communications relating to the contract, project progress and schedule, performance and invoicing between the respective project managers will be copied to the project management group members.

The project management group members will be invited to a brief progress update call (no more than 30 minutes) held using MS Teams on a weekly basis on Thursdays at 11:00am, unless agreed otherwise. If considered appropriate, meeting frequency may be extended to fortnightly calls.

Table 1 defines the project management group members.

Table 1. Project management group

Name	Organisation	E-mail Address
Ollie Power (Project Manager)	BEIS	Oliver.Power@beis.gov.uk
Richard Lowe (Project Director)	AECOM	richard.lowe@aecom.com
Andy Cross (Project Manager)	AECOM	andy.cross@aecom.com

3. Project delivery group

3.1 AECOM project delivery group

The AECOM project delivery group represents the engineers and consultants responsible for producing the deliverables on the project. The project delivery group may be expanded as the project progresses to incorporate knowledge and experience from other colleagues within AECOM.

All members of the AECOM project delivery group will be provided with access to the shared project drive and will be notified of issue every deliverable and technical document shared with the client.

The project manager and engineering lead are considered mandatory attendees, while all members of the AECOM project delivery group will be invited to the following meetings:

- Kick-off meeting,
- Technical approach review meeting,

- Interim report review meeting, and
- Final report review meeting.

Table 2 defines the AECOM project delivery group members.

Table 2. AECOM project delivery group

Name	Organisation	E-mail Address
Richard Lowe (Project Director)	AECOM	richard.lowe@aecom.com
Andy Cross (Project Manager)	AECOM	andy.cross@aecom.com
Klim Mackenzie (Engineering Lead)	AECOM	klim.mackenzie@aecom.com
Graeme Cook (Lead Verifier)	AECOM	graeme.cook@aecom.com
Rhys Williams (Internal Reviewer)	AECOM	rhys.williams11@aecom.com
Alistair Barclay	AECOM	alistair.barclay@aecom.com
Reece Crawford	AECOM	reece.crawford@aecom.com
Katie Berry	AECOM	katie.berry@aecom.com
Stephen Florence	AECOM	stephen.florence@aecom.com

3.2 Client project delivery group

The client project delivery group represents the engineers and specialists who will review and comment upon AECOM's deliverables.

All deliverables and technical documents issued to the client will be circulated to the client project delivery group. It is anticipated that the client will consolidate comments and return a single comment response sheet to AECOM.

All members of the client project delivery group will be invited to the following meetings:

- Kick-off meeting,
- Technical approach review meeting,
- Interim report review meeting, and
- Final report review meeting.

Table 3 defines the client project delivery group members.

Table 3. Client project delivery group

Name	Organisation	E-mail Address
Ollie Power	BEIS	oliver.power@beis.gov.uk
William Knight	BEIS	william.knight2@beis.gov.uk
Joey Scarf	BEIS	joey.scarf@beis.gov.uk
Alisha Ali	BEIS	alisha.ali@beis.gov.uk
Rhiannon Phillips	Welsh Government	rhiannon.phillips@gov.wales
Lee Guilfoyle	Welsh Government	lee.guilfoyle@gov.wales

4. Independent peer reviewers

Independent peer reviewers from academia have been appointed to review the technical approach, engineering basis and the summary report.

All deliverables and technical documents issued to the client will also be circulated to the independent peer reviewers.

While comments are welcomed from the IPRs on all documents, the first issue of the following documents are subject to mandatory independent peer review:

- Literature review evidence record sheet (Annex B) – focus on categorisation and validity
- DCR checklist recommendations (Annex C)
- Engineering basis for case studies (Annex D)
- Layout estimation summary (Annex H)
- Interim Summary report

The independent reviewers will attend the following meetings:

- Kick-off meeting,
- Technical approach review meeting, and
- Final report review meeting.

Table 4 defines the independent peer reviewers.

Table 4. Independent peer reviewers

Name	Organisation	E-mail Address
Jon Gibbins	University of Sheffield	j.gibbins@sheffield.ac.uk
Mohamed Pourkashanian	University of Sheffield	m.pourkashanian@sheffield.ac.uk
Paul Fennell	Imperial College London	p.fennell@imperial.ac.uk

5. Examining authority engagement

The examining authorities responsible for assessing the compliance of proposed projects with the current carbon capture readiness requirements and future decarbonisation readiness requirements are considered key stakeholders. Their interest in the project is that they seek to ensure that future guidelines are supported by a strong evidence base and provide a practical and clear means for confirming compliance.

The interim and final reports will be shared with the examining authority stakeholders group. Comments from the examining authority are welcome, however, AECOM request that the examining authority comments be consolidated with the client comments before being shared with AECOM.

Table 5 defines the examining authority stakeholders group

Table 5. Examining authority stakeholders group

Name	Organisation	E-mail Address
John Henderson	Environment Agency	john.henderson@environment-agency.gov.uk
Bruce Bethune	Environment Agency	bruce.bethune@environment-agency.gov.uk
Richard Chase	Environment Agency	richard.chase@environment-agency.gov.uk
Karl Shepherd	Natural Resources Wales	Karl.Shepherd@cyfoethnaturiolcymru.gov.uk

6. Industry engagement

In 2021, BEIS engaged with the industry through a call for evidence with the title “Decarbonisation readiness: call for evidence on the expansion of the 2009 Carbon Capture Readiness requirements”. The draft conclusions of this call for evidence have been shared with the project and will represent a large part of engagement with the industry.

Further engagement with the industry and trade bodies within the scope of this review will be limited by the time available to complete the project. AECOM will review the previous responses, identify the gaps in evidence and any relevant parties not previously contacted, and engage with those organisations only to focus on areas where there is limited evidence.

Table 6 lists the organisations contacted by BEIS in the 2021 call for evidence regarding the expansion of Carbon Capture Readiness requirements.

Table 6. Industry organisations engaged by BEIS in 2021

Organisation	Response received
Blue Phoenix UK	
Stop Portland Waste Incinerator	
United Kingdom Without Incineration Network (UKWIN)	
Bioenergy Infrastructure Group	
Siemens Energy	
Scottish Power	
Flexible Generation Group	
Tees Valley Combined Authority	
Drax Group PLC	
The Association for Decentralised Energy	
Progressive Energy	
Uniper UK	
Sembcorp	
Triton Power	
The Association for Renewable Energy & Clean Technologies (REA)	
AMP Clean Energy	
MCS Charitable Foundation	
InterGen	
RWE Generation	
SSE Thermal	
Environmental Services Association	
Carbon Capture & Storage Association	
Energy UK	
Conrad Energy	
EDF Energy	
Viridor	
Centrica	
Baker Hughes	
CISC (Copenhagen Infrastructure Service Co.)	
Statkraft	
NFU	
BP PLC	

Organisation	Response received
Lynemouth Power	
Scottish Government	
Individuals (3)	

7. Equipment manufacturer engagement

To improve the quality of the evidence base produced as part of this project, and to develop the recommendations for the proposed decarbonisation readiness requirement, AECOM will engage equipment manufacturers to verify their current capability and technology development roadmaps.

The terms of reference for engagement with the different categories of OEMs will be developed separately. The list of manufacturers proposed to be contacted as part of this stakeholder engagement is not intended to be exhaustive but is proposed as a representative range of manufacturers across the various relevant technologies and scales of equipment.

The contribution of the evidence provided by equipment manufacturers to this review will inevitably be limited by the manufacturers' ability and willingness to respond to the Request for Information within the timescales of the project.

7.1 Gas turbine manufacturers

Gas turbine manufacturers will be contacted and invited to respond to the following queries:

- Capability of current product offerings to burn hydrogen,
- Capability of current product offerings to burn ammonia,
- Work involved and potential to retrofit/modify installed gas turbines to fire hydrogen, and
- Technology development road map for burning hydrogen.

Table 7 defines a provisional list of potential gas turbine manufacturers to be contacted.

Table 7. Gas turbine manufacturers

Manufacturer	Gas turbine size range
Siemens	2 to 590 MWe
MHI	40 to 570 MWe
GE	34 to 570 MWe
Ansaldo	80 to 540 MWe
Baker Hughes	5 to 170 Mwe
Solar turbines	3 to 16 Mwe
Centrax	3 to 15 Mwe
MAN	6 to 12 Mwe
Kawasaki	< 3 MWe
OPRA	< 3 MWe
Aurelia	< 1 MWe
Capstone	< 1 MWe
Turbotec	< 1 MWe

7.2 Reciprocating engine manufacturers

Reciprocating engine manufacturers will be contacted and invited to respond to the following queries:

- Capability of current product offerings to burn hydrogen,
- Capability of current product offerings to burn ammonia,
- Work involved and potential to retrofit/modify installed reciprocating engines to fire hydrogen, and
- Technology development road map for burning hydrogen.

Table 8 defines a provisional list of potential gas turbine manufacturers to be contacted.

Table 8. Reciprocating engine manufacturers

Manufacturer	Engine size range
Hyuandai Heavy Industry	1 to 26 MWe
MAN	7 to 20 MWe
Jenbacher	0.2 to 10 MWe
Wartsila	1 to 9 MWe
Caterpillar	0.1 to 5 MWe
MTU	0.2 to 3 MWe
Siemens	0.1 to 2 MWe

7.3 Industrial boiler manufacturers

Industrial boiler manufacturers will be contacted and invited to respond to the following queries:

- Capability of current product offerings to burn hydrogen, and
- Capability of current product offerings to burn ammonia.

Table 9 defines a provisional list of potential industrial boiler manufacturers to be contacted.

Table 9. Industrial boiler manufacturers

Organisation	Boiler types
Macchi	Field erected, pre-fabricated
MHPS	Field erected, pre-fabricated
Babcock Wanson	Pre-fabricated, package
HKB	Pre-fabricated, package
Cochran	Package
Bosch	Package
ICI Caldaie	Package
Byworth	Package

7.4 Electrolysers manufacturers

Electrolyser manufacturers will be contacted and invited to respond to the following queries:

- Capability of current product offerings to produce hydrogen,
- Future developments in capacity.

Table 10 defines a provisional list of potential electrolyser manufacturers to be contacted.

Table 10. Electrolyser manufacturers

Organisation	Electrolyser type
Cummins	Alkaline, PEM
Nel.	Alkaline, PEM
ITM Power	PEM
Siemens Silyzer	PEM
Sunpower	Alkaline, SOEC
CPH2	Membrane free
McPhy	Alkaline

7.5 Carbon capture technology providers

AECOM have recently undertaken significant engagement with carbon capture technology providers as part of the BEIS Next Generation Carbon Capture review. It is intended for this project to utilise the evidence collected through the course of that project to update the existing CCS body of evidence. Where gaps are identified AECOM will engage with carbon capture technology providers as necessary.

Table 11 defines a list of the technology providers previously contacted.

Table 11. Carbon capture technology providers

Organisation	Capture technology
Aker Carbon Capture	Solvent based
Mitsubishi Heavy Industries	Solvent based
Shell Cansolv	Solvent based
Fluor	Solvent based
Carbon Clean	Solvent based
C-Capture	Solvent based
Compact Carbon Capture	Solvent on rotating packed bed
Svante	Solid adsorbent on rotating packed bed
Fuel Cell Energy	Fuel Cell
Air Liquide	Cryogenic
Calix	Indirect calcination for cement production
CO_2 Capsol	Carbonation
Origen Power	Carbonation
Carbon8 Systems	Carbonation
Baker Hughes	Chilled ammonia
Membrane Technology and Research	Membranes
NET Power	Allam-Fetvedt cycle

Appendix A Document Log

A.1 Document History

Rev.	Issued Date	Details	Author	Checker	Lead Verifier	Approver
1	09/02/2022	Issued for comment	Rhys Williams	Andy Cross	Graeme Cook	Andy Cross
2	08/04/2022					

A.2 Document Revisions

Rev.	Section	Revisions/Remarks
1	All	First issue, with HOLDS
2	All	Updated

AECOM

Technical Note

Subject:	Rationale for case study scenarios	To:	Project Management Group, AECOM Project Delivery Group, Client Project Delivery Group, Independent Peer Reviewers
Project:	BEIS Decarbonisation Readiness Requirements Review		
Reference:	60677821-TN-002		
Revision:	2		
Date:	30/06/2022		
Author:	Klim MacKenzie		

1. Introduction

This document defines the initial set of case studies proposed by AECOM as discussed at the project inception meeting and Technical Approach Review. The purpose of this document is to define the rationale and decision-making process for the final selection of case studies for both lots.

2. Initial Case Study Basis

2.1 Rationale for Lot 1 Hydrogen Readiness Case Studies

The initial set of case studies presented at the project inception meeting is shown below in Table 1.

Table 1. Lot 1 Hydrogen Readiness initial proposed case studies

#	Combustion technology	Sizing Basis	Small	Medium	Large
1	CCGT (Utility Scale)	Plant nominal gross power output	220 MWe	450 MWe	805 MWe
2	CCGT (CHP application)	GT nominal gross power output	14 MWe	35 MWe	60 MWe
3	OCGT (small scale GTs)	GT nominal gross power output	4 MWe	6 MWe	10 MWe
4	Boiler (CHP)	Boiler Output gross power output	35 MWth	65 MWth	150 MWth
5	Reciprocating Engine	Engine nominal gross power output	4.5 MWe	10 MWe	22.5 MWe (5 x 4.5 MWe units)

Source: Notes of BES DCR Kick-off meeting 2022-02-04

Rationale for CCGT (utility scale) basis: Large represents the largest size of latest H class turbines, similar to that proposed on major UK projects. Medium is representative of the bulk of gas turbines (F class/GT26 turbines) installed in the UK since 2010 and most likely turbines to be considered for retrofits. Small is not a size of plant deployed in the UK at present and is particularly small but was selected to provide a third point on the curve to enable interpolation across a broad range.

Rationale for CCGT (CHP application): used to provide a broad range of sizes based on AECOM's experience of GT CHP plants worldwide. In addition, multiple OEMs market gas turbines in small and large size as 100% hydrogen ready today.

Small scale OCGTs: while not particularly widely utilised, include a number of these smaller units cited as being capable of 100% hydrogen ready. They are also of a size whereby the hydrogen demand is close to that of the current largest electrolysers, whereas for larger turbines the hydrogen demand is orders of magnitude greater than the existing largest green hydrogen plants.

Reciprocating engine: sizes are based on broad range of engine sizes widely available and in service. While units smaller than 4.5MWe are possible, the application of CCS or decarbonisation is more likely to happen on sites where there are greater emission reductions to be achieved.

The table has utilised electrical power output for many size classifications similar to the 2009 CCR guidance.

2.2 Rationale for Lot 2 Carbon Capture Case Studies

The initial set of case studies presented at the project inception meeting is shown below in Table 2.

Table 2. Lot 1 Carbon Capture Readiness initial proposed case studies

#	Combustion technology	Sizing Basis	Small	Medium	Large
1	CCGT (Utility Scale)	Plant nominal gross power output	220 MWe	450 MWe	910 MWe
2	CCGT (CHP application)	GT nominal gross power output	14 MWe	35 MWe	60 MWe
3	Boiler (EfW)	Plant nominal gross power output	20 MWe	45 MWe	80 MWe
4	Boiler (Biomass)	Plant nominal gross power output	35 MWe	65 MWe	120 MWe
5	Reciprocating Engine	Engine nominal gross power output	4.5 MWe	10 MWe	22.5 MWe (5 x 4.5 MWe units)

Rationale for CCGT (utility scale) basis: Large represents the largest size of latest H class turbines, similar to that proposed on major UK projects. Medium is representative of the bulk of gas turbines (F class/GT26 turbines) installed in the UK since 2010 and most likely turbines to be considered for retrofits. Small is not a size of plant deployed in the UK at present and is particularly small but was selected to provide a third point on the curve to enable interpolation across a broad range.

Rationale for CCGT (CHP application): used to provide a broad range of sizes based on AECOM's experience of GT CHP plants worldwide. In addition, multiple OEMs market gas turbines in small and large size as 100% hydrogen ready today.

Boiler: cases are based on providing a broad range to support interpolation with minimum and maximum values guided by the size of existing plants in the UK as per the 2021 Dukes report. Drax Biomass is an outlier in terms of size and scale of biomass plants in the UK with a total net output of 2.6GWe. The other reason for its omission at this stage from a footprint and cost estimate as part of this study is that there is significant information in the public domain on CCS at the site due to the on-going DCO application.

Reciprocating engine: sizes are based on broad range of engine sizes widely available and in service. While units smaller than 4.5MWe are possible, the application of CCS or decarbonisation is more likely to happen on sites where there are greater emission reductions to be achieved.

The table has utilised electrical power output for many size classifications similar to the 2009 CCR guidance.

2.3 Assessment of case study spread and UK power generation industry

The proposed case studies were selected to represent a distribution across a broad range of emitter sizes and support interpolation between specific case studies, see Figure 1 and Figure 2 for a spread in terms of CO2 flows and energy demand.

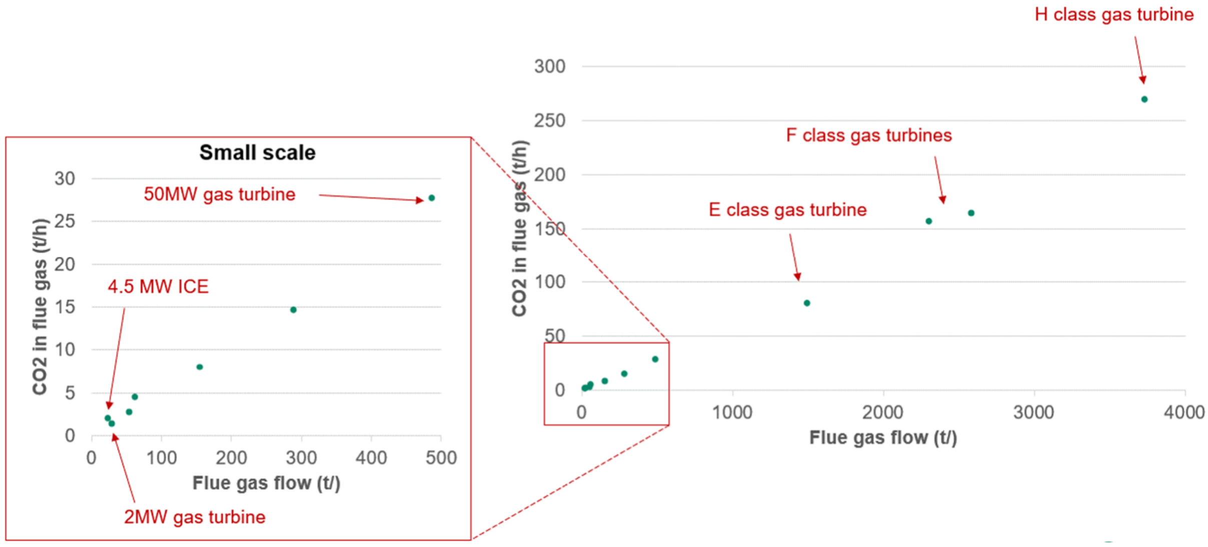

Figure 1. Case study spread in terms of flue gas and CO2 flows

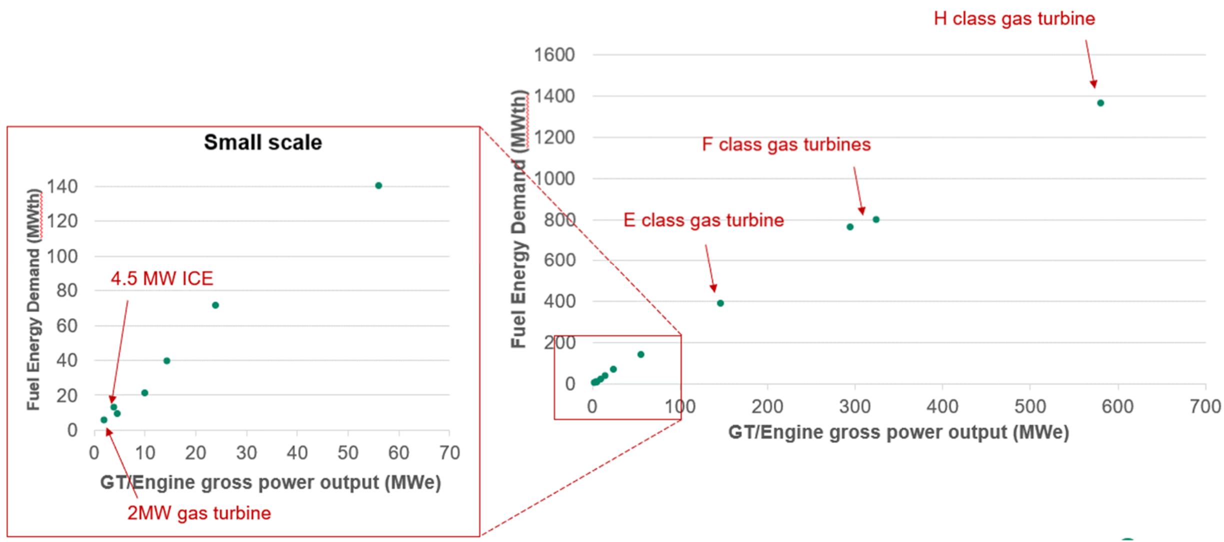

Figure 2. Case study spread in terms of fuel energy demand

2.4 UK CCGT size distribution

All CCGTs in the UK built since 2015 have train sizes between 425MWe and 475MWe. The distribution of proposed plants, in comparison, lies between 575MWe and 975MWe, with a subset between 860MWe and 910MWe being actively progressed through planning. The recommendation is therefore for 910MWe to cover new-build H Class CCGT, 450MWe to cover the existing fleet dominated by F Class CCGT, and a third data point at approximately 220MWe to provide interpolation (based on E Class technology). See Figure 3.

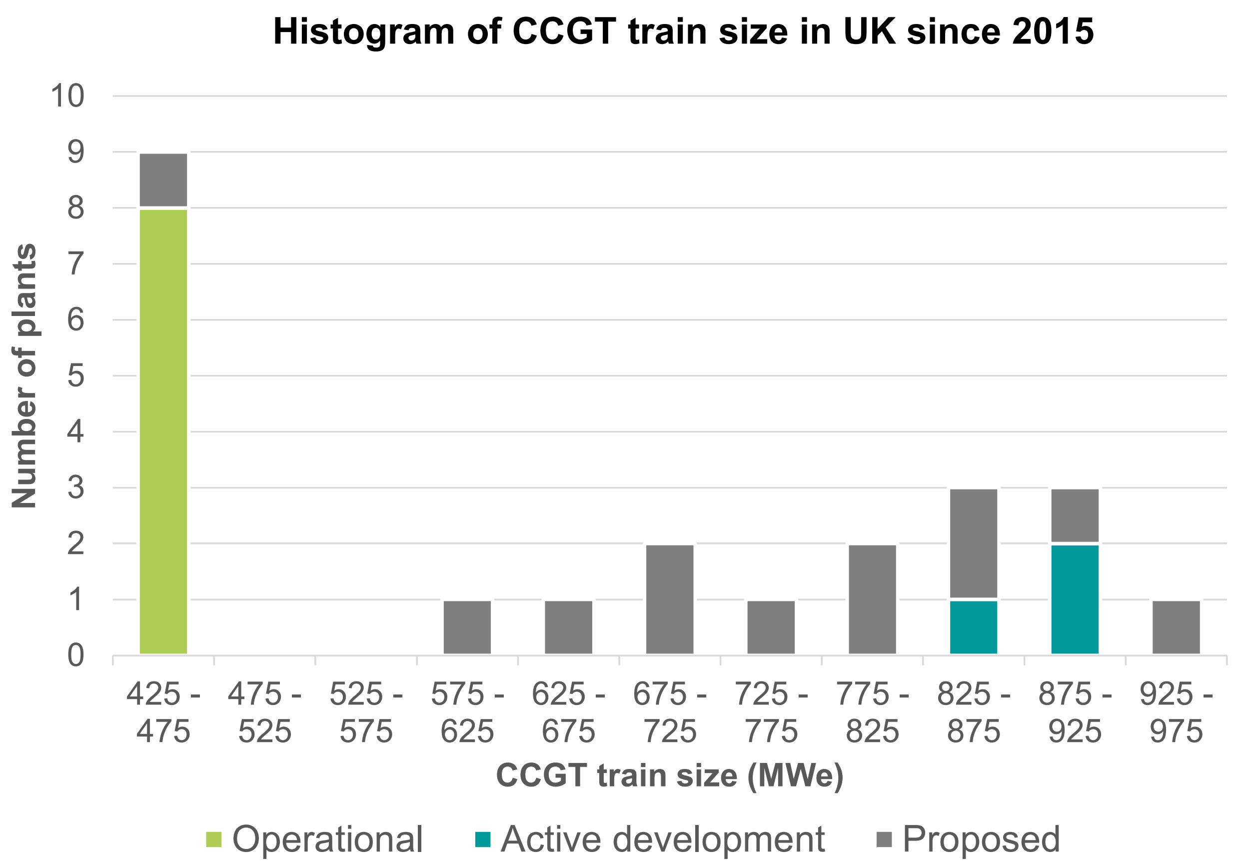

Figure 3. Histogram of CCGT train size in UK since 2015

2.5 UK OCGT size distribution

All OCGTS built in the UK have train sizes less than 150MWe. In comparison, the 10 GT based peaking plants proposed since 2015 have all been proposed at 299MW, at least 6 of which have been awarded or are still live within the PINS process. The 299MW sizing for modern OCGT in the UK appears to be driven by the 2009 Carbon Capture Readiness regulations as this block size does not appear elsewhere in the world.

GTs in the 10-100MW range are well-covered by the CCGT/CHP scope, therefore, AECOM proposed focussing on recent developments and the smaller end of the spectrum <10MW. however, this excludes micro-turbines, see Figure 4.

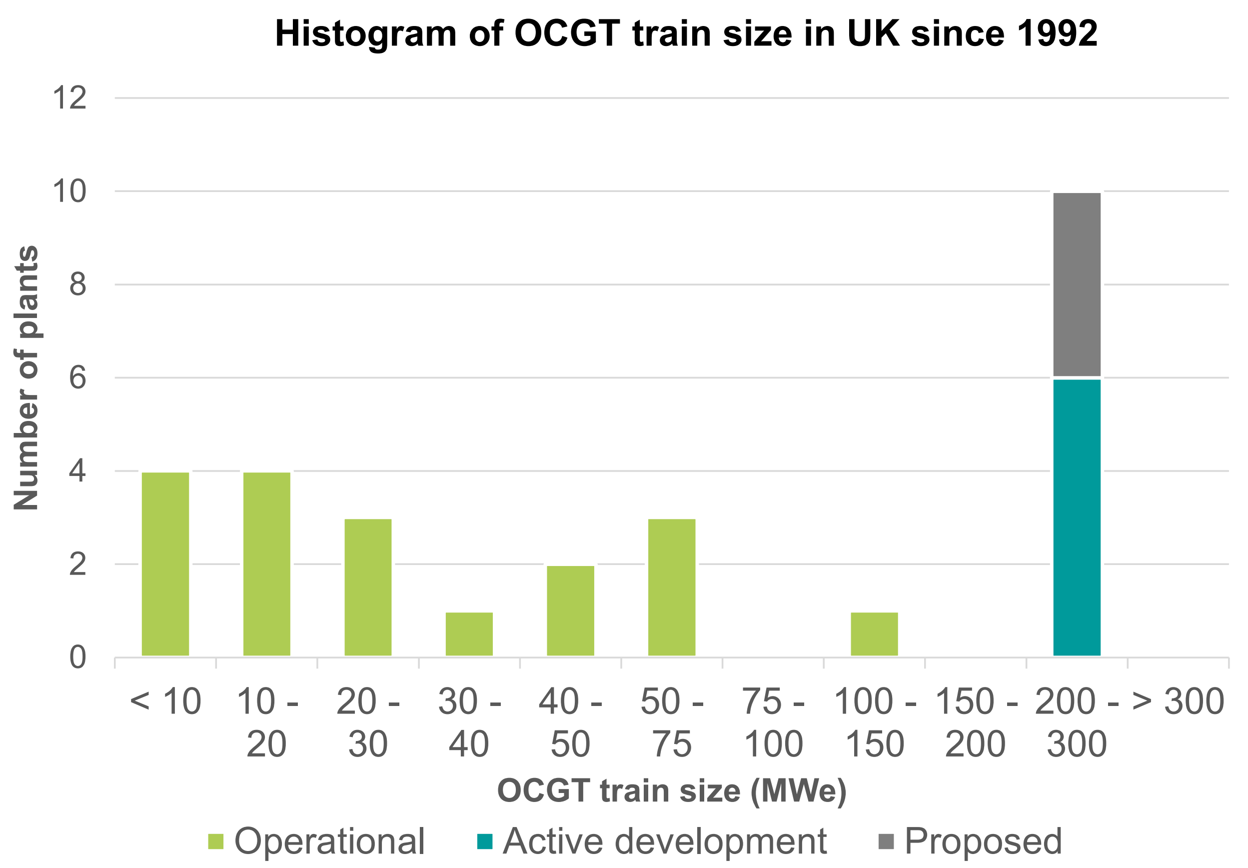

Figure 4. Histogram of OCGT train size in UK since 1992

2.6 UK biomass plant size distribution

The majority of UK biomass plant is below 50MWe with two notable exceptions: Lynemouth and Drax, both of which are relatively unique in their scale. Further, Drax already has a well-publicised carbon capture programme as part of the East Coast Cluster. Therefore, the focus for the study was proposed to consider plants at the 35MWe and 65MWe scale to span the 50MW centre-line, as well as one larger case to represent wider roll-out of BECCS. See Figure 5.

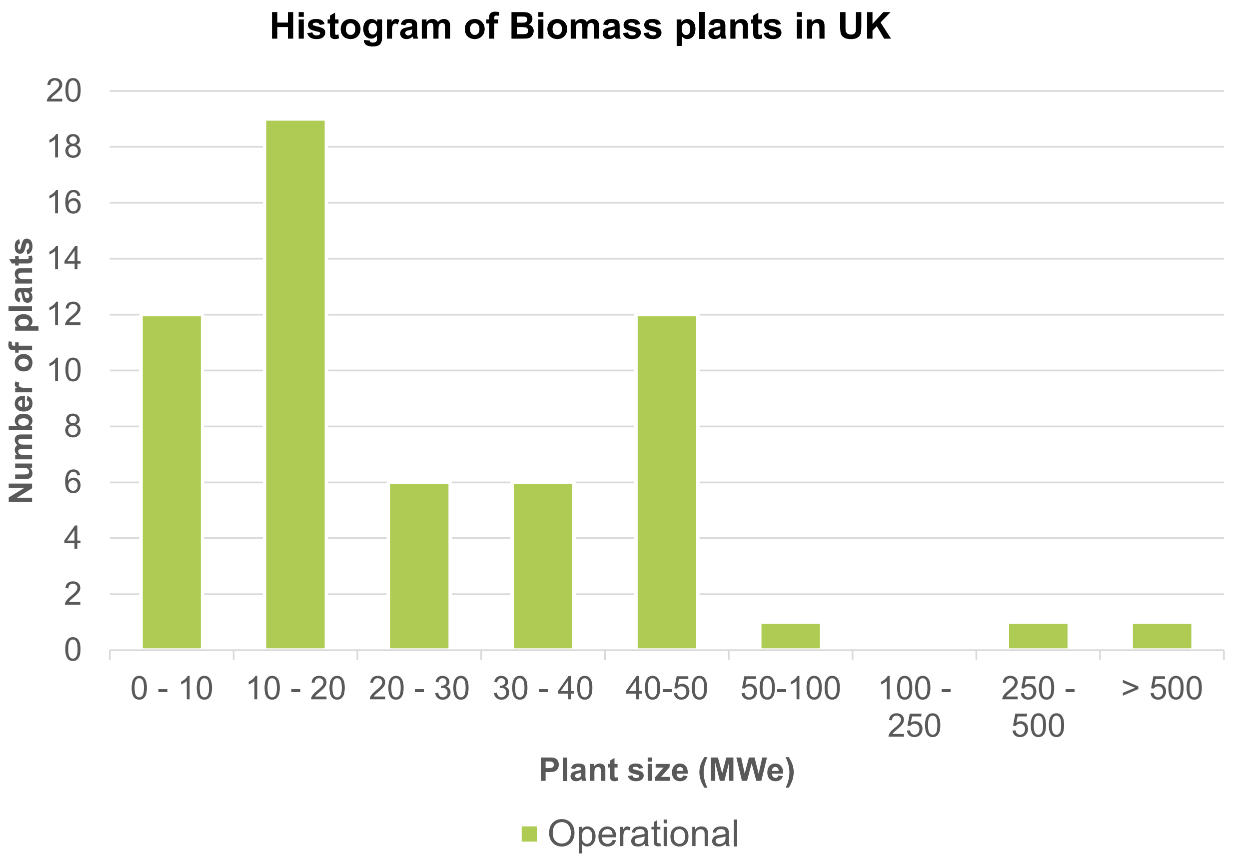

Figure 5. Histogram of biomass plants in the UK

2.7 UK EfW plant size distribution

The selection of EfW plants proposed for the case studies was chosen consistent with the peaks around 20MWe, 45MWe and 80MWe for existing EfW plant in the UK, see Figure 6

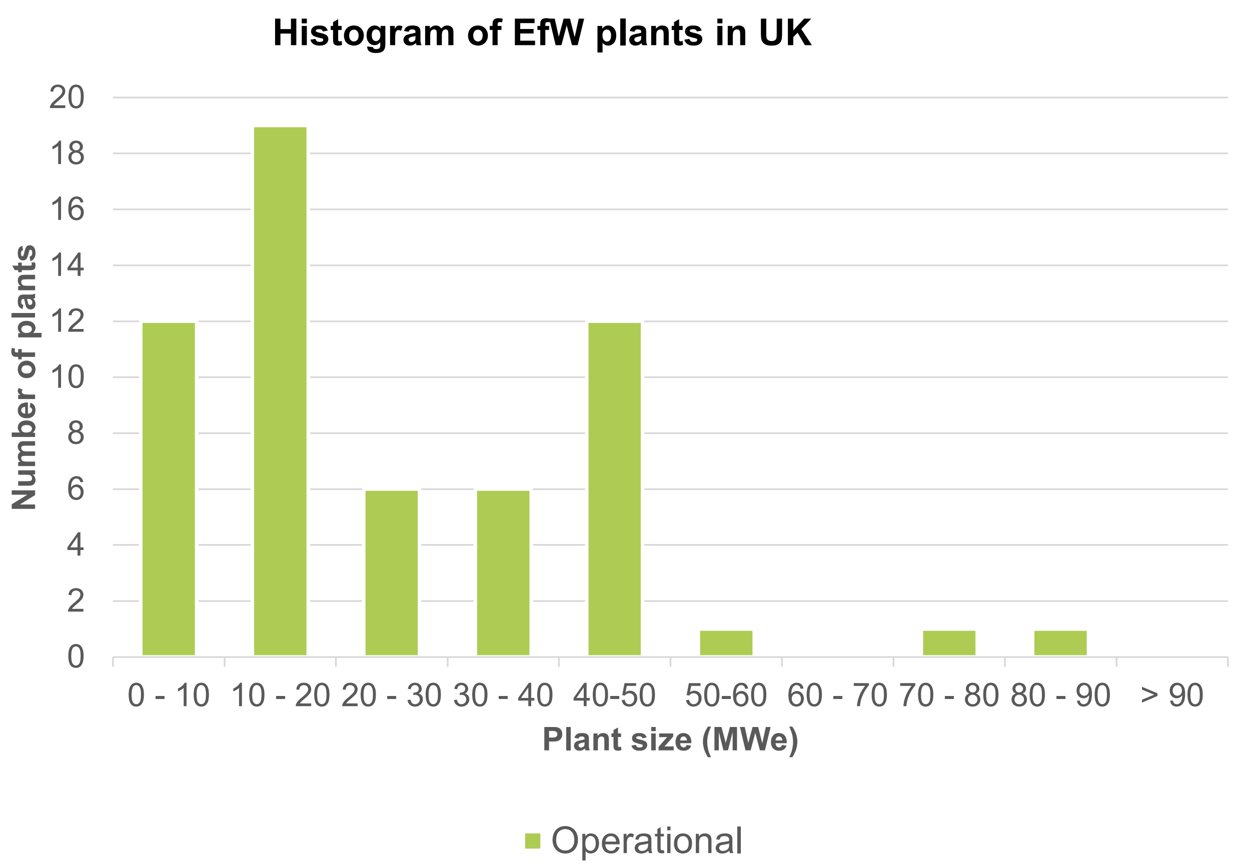

Figure 6. Histogram of EfW plant in the UK

3. Selected Case Studies Basis

The case studies were updated following the Technical Approach Review with BEIS, the Independent Reviewers and the Regulators. The adopted case studies for Lot 1 are shown in Table 3, following request from the EA to consider 2MWe and 4MWe units, as well as the 299MWe case to represent the current set of projects live with PINS. In addition, the reciprocating engine case studies were changed from the original basis.

Table 3. Lot 1 Hydrogen Readiness initial proposed case studies

#	Combustion technology	Sizing Basis	Small	Medium	Large
1	CCGT (Utility Scale)	Plant nominal gross power output	220 MWe	450 MWe	805 MWe
2	CCGT (CHP application)	GT nominal gross power output	14 MWe	35 MWe	60 MWe
3	OCGT (small scale GTs)	GT nominal gross power output	~~4 MWe~~ 2 MWe	~~6 MWe~~ 4 MWe	~~10 MWe~~ 299 MWe
4	Boiler (CHP)	Boiler Output gross power output	35 MWth	65 MWth	150 MWth
5	Reciprocating Engine	Engine nominal gross power output	4.5 MWe	~~10 MWe~~ 12.5 MWe (5 x 2.4 MWe units)	~~22.5 MWe (5 x 4.5 MWe units)~~ 50 MWe (5 x 10MWe units)

For the carbon capture case studies, the EA requested two OCGT-scale units to be added to the scope of the review, summarised in Table 4, as well as a change to the sizes of reciprocating engines studied. These changes were adopted into the selected case studies for the review.

Table 4. Lot 1 Carbon Capture Readiness initial proposed case studies

#	Combustion technology	Sizing Basis	Small	Medium	Large
1	CCGT (Utility Scale)	Plant nominal gross power output	220 MWe	450 MWe	910 MWe
2	OCGT (Utility Scale)	Plant nominal gross power output	145 MWe	290 MWe	-
3	CCGT (CHP application)	GT nominal gross power output	14 MWe	35 MWe	60 MWe
4	Boiler (EfW)	Plant nominal gross power output	20 MWe	45 MWe	80 MWe
5	Boiler (Biomass)	Plant nominal gross power output	35 MWe	65 MWe	120 MWe
6	Reciprocating Engine	Engine nominal gross power output	4.5 MWe	~~10 MWe~~ 12.5 MWe (5 x 2.4 MWe units)	~~22.5 MWe (5 x 4.5 MWe units)~~ 50 MWe (5 x 10MWe units)

Appendix A Document Log

A.1 Document History

Rev.	Issued Date	Details	Author	Checker	Lead Verifier	Approver
1	16/05/2022	Issued for comment	Klim MacKenzie	Andy Cross	Graeme Cook	Andy Cross
2	30/06/2022	Revised	Klim MacKenzie	Andy Cross	Graeme Cook	Andy Cross

A.2 Document Revisions

Rev.	Section	Revisions/Remarks
1	All	First issue
2	H2R H Class	Revised size of H Class CCGT used for H2R lot consistent with data availability for H Class units with hydrogen (CC H Class size unchanged)

AECOM

Technical Note

Subject:	Engineering Basis – CCS	To:	Project Management Group, AECOM Project Delivery Group, Client Project Delivery Group, Independent Peer Reviewers
Project:	BEIS Decarbonisation Readiness Requirements Review		
Reference:	60677821-TN-004		
Revision:	3		
Date:	20/05/2022		
Author:	Klim MacKenzie		

Table of Contents

Introduction

1.1 Document Purpose

This document details the engineering design basis for the case studies supporting the Decarbonisation Readiness Requirements Review project.

These case studies focus on the application of an amine based post combustion carbon capture plant on a range of different configurations of power plants and sizes.

1.2 Project Overview

Since 2009, new build combustion power plants sized over 300MWe in England and Wales have been required to demonstrate they could retrofit carbon capture and storage (CCS) in order to decarbonise. This policy has been known to date as 'Carbon Capture Readiness' (CCR).

In 2009, detailed guidance was produced to support industry and BEIS in assessing the CCR requirements. Due to evolution of gas turbine size and efficiency, variable load profiles for fossil fuel plants, and to recognise the changing landscape of carbon capture and decarbonisation technologies, this guidance needs to be updated, as plants below 300MWe and new plant types (e.g. combined heat and power, energy from waste and biomass) will now be assessed for carbon capture readiness. The guidance document will also be expanded to cover hydrogen readiness as a means of decarbonisation.

As part of the expansion, BEIS are renaming the policy to 'Decarbonisation Readiness'. In order to update the guidance BEIS have commissioned two technical studies to update and expand the underpinning evidence base that was used to develop the guidance documents.

The technical studies are:

1. Lot 1 – Hydrogen readiness
2. Lot 2 – Carbon capture readiness

This document is intended to define the design basis for engineering calculations as part of the '**Lot 2 - Carbon capture readiness'** technical study.

1.3 Case Study Overview

1.3.1 Case Study Aim

The aim of this project is to update and expand the evidence base which is used to define the requirements for demonstrating carbon capture readiness and inform guidance.

BEIS require carbon capture readiness be demonstrated through the five different assessments below:

1. that sufficient space is available on or near the site to accommodate carbon capture equipment in the future;
2. that it is likely to be technically feasible to retrofit their chosen carbon capture technology;
3. that a suitable area of deep geological storage offshore exists for the storage of captured CO_2 from the proposed power station;
4. that it is likely to be technically feasible to transport the captured CO_2 to the proposed storage area; and
5. that it is likely that it will be economically feasible within the power station's lifetime, to link it to a full CCS chain, covering retrofitting of capture equipment, transport and storage.

The purpose of the case studies is to provide an evidence base that can be used by examiners during the application process to determine if the acceptance criteria for assessments 1 and 5 above have been addressed appropriately by developers.

1.3.2 Case Study Definition

Table 1 defines the configurations and sizes of plant that will be subject to case studies.

The proposed configurations cover a broad range of capture plant throughputs and flue gas compositions. AECOM will provide the CO_2 capture rate and flue gas composition for each configuration to allow for interpolation of plants of different sizes.

Table 1. Case Study Definition

Combustion technology	Sizing Basis	Small	Medium	Large
CCGT (Utility Scale)	Plant nominal gross power output	220 MWe	450 MWe	910 MWe
OCGT (Utility Scale)	Plant nominal gross power output	145 MWe	290 MWe	-
CCGT (CHP application)	GT nominal gross power output	14 MWe	35 MWe	60 MWe
Boiler (EfW)	Plant nominal gross power output	20 MWe	36 MWe	72 MWe
Boiler (Biomass)	Plant nominal gross power output	35 MWe	60 MWe	120 MWe
Reciprocating Engine	Engine nominal gross power output	1 MWe	12.5 MWe (5 x 2.4 MWe units)	50 MWe (5 x 10 MWe units)

1.3.3 Case Study Methodology

AECOM propose to use the Thermoflow v30.0 software to undertake process simulation, development of heat and material balances and majority of cost-estimation. For the preliminary sizing of the absorber and stripper column, AECOM will utilise KG-Tower v5.4.3 software.

Thermoflow is an established software suite that has been used in the power industry for over 30 years for fossil fuel, EfW and renewables. In addition to process simulation capability, Thermoflow is supplied with a cost simulation add-on known as PEACE (Plant Engineering And Construction Estimator). In addition to providing cost estimates PEACE completes preliminary equipment sizing and design to generate indicate general arrangement drawings.

KG-Tower is Koch-Glitsch's hydraulic rating software that can be used to develop the specification of mass transfer equipment, including conventional and high performance valve trays, severe service grid packing, and conventional and high performance random and structured packings.

The approach to the case studies proposed is:

- Develop counterfactual (unabated) simulation model
- Verify counterfactual model output against recent experience and publicly available data
- Update counterfactual model to include post carbon capture
- Extract performance output data and cost outputs from the simulation and PEACE
- Verify cost estimate data and supplement with recent AECOM experience and information received from vendors
- Complete economic assessment
- In parallel to the economic assessment, preliminary equipment sizing and equipment specifications will be extracted to generate the layouts and plant footprint estimates

The performance, cost and layout conclusions will be summarised and included in the summary report.

2. Definitions and Acronyms

2.1 Definitions

Table 2 defines the terms used within this document.

Table 2. Acronyms utilised on this project

Term	Description
Power island	Equipment associated with power production from the receipt of the fuel on-site through to the flue gas stack of an unabated plant. Note that power in this case may also mean provision of heat in a Combined Heat and Power or Heat only application. For all cases, power island is used interchangeably across applications to refer to the combustion plant.
Carbon capture plant	Equipment associated with capture of CO_2 from the power plant stack through to the low pressure CO_2 stream exiting the stripper column. MEA has been assumed as the solvent choice for this site, though it is noted that individual projects will use a variety of solvent compositions including other amines or other carbon capture technologies.
Compression and conditioning	Equipment associated with conditioning, dehydration and compression of low pressure CO_2 stream exiting the stripper column through to the high pressure interface with the export gathering pipeline
Utilities units	Equipment associated with cooling, water treatment, waste water treatment, nitrogen and instrument air systems
Solvent storage	Equipment associated with solvent storage for make-up.
Balance of plant	Equipment, electrical equipment and buildings not included in any of the above terms

2.2 Acronyms

Table 3 defines the acronyms and abbreviations used within this document.

Table 3. Acronyms utilised on this project

Acronym	Description
AACE	American Association of Cost Engineers
BoD	Basis of Design
BEDD	Basic Engineering Design Data
CCGT	Combined Cycle Gas Turbine (Gas Turbine + Steam Turbine)
CCP	Carbon Capture Plant
CCS	Carbon Capture and Storage
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CWS	Cooling Water Supply
CWR	Cooling Water Return (discharge in the case of once-through system)
DCC	Direct Contact Condenser
DCO	Development Consent Order
GT	Gas Turbine
HHV	Higher Heating Value
HRSG	Heat Recovery Steam Generator
IP	Intermediate Pressure
LHV	Lower Heating Value
LP	Low Pressure
MEA	Monoethanolamine
MPI	Major Plant Items
NOx	Nitrogen oxides
OEM	Original Equipment Manufacturer
OM	Operating Mode
PCC	Post-combustion Carbon Capture
PEI	Preliminary Environmental Information
PPC	Pollution Prevention and Control
RH	Relative Humidity
SCR	Selective Catalytic Reduction
ST	Steam Turbine
TEG	Triethylene Glycol
WN	Wobbe Number

3. Units of Measure

Table 4 defines the acronyms and abbreviations used within this document.

Table 4. Project units of measure

Parameter	Measuring Unit	Abbreviation
Absolute Viscosity	Centipoise	cP
Concentration (vol.)	Parts per million by volume, parts per million by volume - dry basis (i.e. excluding diluting contribution of water molecules)	ppmv, ppmvd
Concentration (mass)	Percent by weight (mass), percent by mol	%wt
Concentration (molar)	Percent by weight (mass), percent by mol	%mol
Density	Kilogram per cubic meter	kg/m^3
Exported Electricity	Megajoules	MJ
Flowrate (Mass)	Kilogram per second, million metric tons per annum	kg/s, MTPA
Heat transfer rate	Kilowatt thermal, Megawatt thermal	kW.th, MW.th
Length	Meter	m
Mass	Kilograms or metric tons	kg, t
Power	Gigawatt, megawatt or kilowatt	GW, MW, kW
Pressure	Bar gauge, bar atmosphere, millibar	barg, bara, mbar
Temperature	Degree Celsius	ºC
Volume	Cubic meter	m^3
Volume flowrate	Cubic meter per hour, Normal cubic meter per hour (at 20°C and 1.01325bara)	m^3/h, Nm^3/hr
Mass flowrate	Metric tons per hour or kilograms per second	t/h, kg/s

4. Process Description

4.1 Flue Gas Pre-treatment

The flue gas exiting the flue gas treatment area is routed to a bypass or diverter damper, from where it may be directed either directly to a stack (e.g. during start up or fault conditions) or, for normal operation, through the CCP.

This arrangement allows for the CCP and the power island to have a reduced degree of mutual dependency, and to provide enhanced operability in abnormal and fault conditions. In the event of a major equipment fault such as a booster fan trip, the power island can be switched to bypass mode until the fault is corrected. Plant safety issues are also more readily addressed. Safety studies and dynamic analysis of the flue gas path will be necessary at the design stage and will determine such parameters as fan control loops and the type and actuation speed of the bypass dampers. The location of the isolation and bypass damper with respect to the plant will be determined in future studies.

The absorption process requires a flue gas cooler to lower the flue gas temperature to around 45-55°C to enhance the CO_2 chemical absorption and to minimise amine degradation. The flue gas is routed to a direct contact cooler (DCC), which quenches the flue gas to an acceptable temperature for absorption. A small slipstream of the circulating cooling water is routed through the DCC Water Filter to remove particulate build-up. A portion of this particulate free stream is returned to the DCC; the other portion is directed to a wastewater treatment plant.

4.2 Flue Gas Absorption

Quenched flue gas enters the CO_2 Absorber below the lowest section of packing (absorption section). Lean amine at approximately 40°C is injected into the top of the absorption section of packing and contacts the flue gas counter-currently. The acid-base reaction between dissolved CO_2 and MEA causes the absorption of CO_2 into the liquid phase as a temporary salt product. Rich amine (amine-CO_2 salt) drops into the absorber sump while treated flue gas rises into the wash packing section of the absorber.

Two water wash sections are provided in the absorber above the absorption section. These sections circulate water to cool the flue gas, condensing volatile compounds carried up in the flue gas from the absorption section. Both water wash beds bleed excess liquid into the main solvent circulation loop, primarily as a means to return the volatile solvent to the circulation loop.

Conservatively, the two water wash sections comprise:

- Absorber 1st Wash Stage Pump, pumping through Absorber 1st Stage Wash Cooler, bleeding excess water (with dilute solvent) into the solvent line to storage and recycling the rest to the top of the 1st wash stage
- Absorber 2nd Wash Stage Pump, pumping through Absorber 2nd Stage Wash Cooler, bleeding excess water (with dilute solvent) into the solvent line to storage and recycling the rest to the top of the 2nd wash stage

After two stages of recycling water washing, the flue gas has been conservatively assumed to enter a 3rd wash bed where a sulphuric acid solution is contacted counter-currently to reduce ammonia for air emissions control. Ammonia (and any residual solvent in the flue gas not previously recovered by the water washes) is neutralised by the sulphuric acid wash and excess solution removed for off-site disposal via the Acid Drain Drum. Fresh sulphuric acid is supplied to the suction line of the Acid Wash Pump, which circulates acid wash from the acid wash draw tray, through the Acid Wash Cooler and into the liquid distributor at the top of the acid wash section, reducing flue gas ammonia content to below the threshold for either nitrogen deposition or local human health requirements.

Prior to discharge to atmosphere, the flue gas is passed through a mist eliminator device to recover any mist or droplets from the flue gas and then sent to the Flue Gas Reheater. The Reheater uses excess heat from the steam condensate to heat the treated flue gas to approximately 55°C-60°C to assist with dispersion from the CCP absorber stack nozzle.

4.3 Rich Amine Regeneration

Rich solvent leaves the bottom of the Absorber and is routed to the rich to lean amine solution cross heat exchanger which increases the efficiency of the process by heating the rich amine to >100°C using the heat in the lean amine stream from the Stripper. The preheated rich amine enters the Stripper below the wash section of the column through a liquid distributor and flows down through the packed beds counter-current to the vapour from the Reboiler releasing the absorbed CO_2. The lean amine from the bottom of the Stripper is transferred to the rich to lean solution cross heat exchanger, where it is cooled against the rich amine from the absorber train.

To remove impurities from the amine system, ~10% of the cooled amine is routed to the Amine Filter Package. This removes suspended solids and high molecular weight amine degradation products.

The overhead vapour from the Stripper at ~100°C and 0.8 barg is cooled to ~35°C in the overhead Condenser, condensing some of the water content. The two-phase stream enters the separation drum (separating the product gas which is routed to the CO_2 Compression / Dehydration unit).

4.4 CO_2 Compression and Export

The wet CO_2 from the Stripper Reflux Drum is routed to an intercooled CO_2 Compressor. The captured CO_2 is compressed to meet the delivery pressure required for the pipeline.

Free water in a carbon steel pipeline has the potential to severely increase corrosion rates. Therefore, a dehydration package is needed to reduce the water content in the CO_2 stream to 50 ppm (wt.) to ensure that condensation and therefore excessive corrosion of carbon steel components does not occur in the CO_2 pipeline. At this concentration, the dew point is at approximately -46 °C, which makes condensation within the downstream pipeline unlikely.

A glycol-based dehydration package, a mature technology in natural gas dehydration processes, is well suited to be used for this application. For the expected operating temperatures, Triethylene-glycol (TEG) is preferred over other glycol-based absorbents. This package is installed after the second intercooling stage of the CO_2 compression package. That way, the pressure remains below the critical point for the wet CO_2 product stream, dissolving water in the liquid-phase TEG stream. Note that alternative choices such as molsieve dehydration are available. For the purposes of this generic assessment, enhanced TEG has been assumed as the most conservative option.

The conditioned CO_2 product is then compressed, metered and exported to the Transmission & Storage infrastructure. An indicative specification of the export CO_2 is defined in Section 5.3.

4.5 Lean Amine Cooling

Hot lean amine is drawn from the regenerator sump by Lean Amine Booster Pump and pumped through the lean-rich exchanger, cooling the lean amine stream to approximately 50°C. After the cross-exchanger, the lean amine is cooled further for storage to approximately 40°C in Lean Amine Trim Cooler. Lean amine is then sent to the Lean Amine Storage Tank which provides most of the process hold-up for the amine system. Lean amine is to be drained to the storage tank when the plant is shut down for extended outage.

From the lean amine tank, lean amine is pumped by Lean Amine Circulation Pump, with a slip-stream (set as approximately 20%) sent through Lean Amine Filter Package which is to be a Granular Activated Carbon (GAC) type filter for control of those degradation products that are not removed in the reclaimer sludge (mainly volatile compounds that would induce foaming). After the filter, the lean amine is sent to the absorption section for CO_2 capture.

4.6 Amine Reclaiming

The amine-based solution degrades in the presence of different elements that lead to amine oxidation to salts, thus a purification stage is necessary to prevent the accumulation of such heat stable salts. The reclaimer is a kettle-type reboiler where this purification process takes place. There is a feed of steam, water and sodium hydroxide to feed the reactions and processes required to allow for the recovery of part of the degraded amine-based solvent. The reclaimer is expected to operate on an intermittent basis when the content of dissolved salts exceeds a predefined value.

4.7 Steam Extraction

Saturated LP steam for the CCP at approximately 148°C and 3.5 barg is required for:

- the amine reboiler, and
- the de-oxygenation package pre-heater.

Higher pressure steam for the CCP is required for the following at:

- 25barg to the Steam Ejector Steam Generator within the Reclaimer Package
- 25barg to the TEG dehydration reboiler
- 10barg to the Reclaimer Package Solvent Heater

Saturated condensate from all sources is sub-cooled to approximately 99°C and fed to a Condensate Flash Drum, operating at approximately 3.5 barg through separate nozzles for each condensate stream to avoid potential for flashing or condensate hammer from mixing the separate steam pressure levels.

Each technology/configuration will have an optimum location for extraction of steam and return of condensate, which will be identified during the development of each case study.

4.8 Cooling System

There are significant cooling loads associated with the power island, carbon capture plant and CO_2 compression areas.

For the purpose of this study cooling is assumed to be provided by mechanical draft cooling tower and that a desalinated water supply for make-up is readily available.

5. Process Design Basis

5.1 Ambient Conditions

The reference conditions to be used in the study are summarised in Table 5 with International Standards Organization (ISO) conditions (ISO18888:2017) assumed for the site for this study.

Table 5. Reference conditions

Parameter	Value
Temperature, °C	15
Pressure, bara	1.013
Relative Humidity, %RH	60

5.2 Carbon Dioxide Capture Rate

The reference capture rate for the case studies is a minimum of 95% on a steady-state operation basis at full load.

The reference capture rate will not be adjusted to account for ambient CO_2 ingested by the combustion equipment and the carbon capture rate for the purpose of this project is calculated as:

$$CO_2\ Capture\ Rate\ (\%) = \frac{100 \times (Mass\ of\ CO_2\ in\ flue\ gas\ to\ stack - Mass\ of\ CO_2\ from\ absorber\ to\ stack)}{Mass\ of\ CO_2\ in\ flue\ gas\ exiting\ HRSG}$$

5.3 Product CO_2 Specification

The CO_2 product specification is given in Table 6 for the pipeline export connection interface to Transportation & Storage infrastructure. Two export pressure levels have been assumed, with sites producing less than 0.4 MTPA likely to join existing clusters with booster stations, while larger sites are assumed to be cluster anchor projects with CO_2 pressures suitable for export directly to the selected sequestration site.

Table 6. Product CO_2 Expected Quality Achieved

Parameter	Value	Value
CO_2 captured, tph	≤ 50	> 50
Pressure, barg	40	150
Temperature, °C	15 – 35	15 – 35
Carbon Dioxide (CO_2), %vol	99.4	99.4
Water (H_2O), ppmv	<50	<50
Oxygen (O_2), ppmv	<20	<20
Hydrogen (H_2), ppmv	<5,000 (0.5%vol)	<5,000 (0.5%vol)
Sulphur Oxide (Sox), ppmv	<10	<10
Nitrogen Oxide (Nox), ppmv	<10	<10
Hydrogen Sulphide (H_2S), ppmv	<10	<10
Carbon Monoxide (CO), ppmv	<1,000	<1,000

5.4 Fuel Specification

Fuel specifications within this section are typical examples that have been derived from AECOM internal project data.

Table 7. Natural Gas Specification

Parameter	Value
Source	UK natural gas typical
Pressure, barg	50
Temperature, °C	15
LHV at 25°C, kJ/kg	46,516
Molecular weight	17.99
Natural Gas Composition	
Hydrogen, vol%	0.1496
Oxygen, vol%	0.0013
Water, vol%	0
Nitrogen, vol%	0.89
Carbon dioxide, vol%	1.997
Methane, vol%	88.87
Ethane, vol%	6.989
Propane, vol%	0.9985
n-butane, vol%	0.0998
n-pentane, vol%	0.01

Table 8. Solid Fuels Specification

Parameter	Wood Pellets	Municipal Solid Waste
Scenarios used	Biomass 35MW, Biomass 60MW, Biomass 120MW	EfW 20MW, EfW 36MW, EfW 72MW
Fuel supply temperature, °C	25	25
LHV at 25°C, kJ/kg	16784.1	7890.7
Solid Fuels Composition		
Moisture, wt%	8.70	30.00
Ash, wt%	0.50	27.00
Carbon, wt%	45.80	22.50
Hydrogen, wt%	5.50	3.10
Nitrogen, wt%	0.08	0.30
Chlorine, wt%	0.01	0.40
Sulfur, wt%	0.01	0.20
Oxygen, wt%	39.40	16.50

5.5 Flue Gas Specification

The flue gas specification for each case study will be different, Table 9, Table 10, Table 11 and Table 12 define the anticipated flue gas composition for each case.

The flue gas compositions in this section represent reference data for each case study calculated from typical design for the equipment within each case study.

Table 9. Flue Gas Composition – Case Studies 1 to 5

Case Study Number	**1**	**2**	**3**	**4**	**5**
Case Description	Small power CCGT 220MW	Medium power CCGT 450MW	Large power CCGT 910MW	Small CHP CCGT 14MW	Medium CHP CCGT 35MW
Flue Gas Properties					
Mass flowrate, kg/s	416	664	1040	47.1	80.2
Actual volumetric flowrate, Am^3/s	480	696	1094	61.3	103
Stack temperature, °C	127	90	90	179	174
CO_2 mass flow, t/h	81	145	281	7.3	14.8
Flue gas composition					
Carbon Dioxide (CO_2), % mol	3.5	3.9	4.9	2.8	3.3
Water (H_2O), %mol	7.5	8.3	10.0	6.1	7.1
Oxygen (O_2), %mol	13.4	12.5	10.5	14.9	13.8
Nitrogen (N_2), %mol	74.7	74.4	73.7	75.3	74.9
Contaminants					
Sulphur Oxide (SOx), mg/Nm^3	0	0	0	0	0
Nitrogen Oxide (NOx), mg/Nm^3	31	30	30	30	30
Hydrogen Sulphide (H_2S), mg/Nm^3	0	0	0	0	0
Ammonia (NH_3), mg/Nm^3	0	0	0	0	0
Carbon Monoxide (CO), mg/Nm^3	0	0	0	0	0

Table 10. Flue Gas Composition - Case Studies 6 to 10

Case Study Number	**6**	**7**	**8**	**9**	**10**
Case Description	Large CHP CCGT 60MW	Small OCGT 145MW	Medium OCGT 290MW	Small EfW 20MW	Medium EfW 36MW
Flue Gas Properties					
Mass flowrate, kg/s	114	416	664	65.7	107
Actual volumetric flowrate, Am^3/s	141	955	696	71.4	
Stack temperature, °C	156	127	90	94.5	95.6
CO_2 mass flow, t/h	23.2	81	145	34.3	55.8
Flue gas composition					
Carbon Dioxide (CO_2), % mol	3.7	3.5	3.9	9.1	9.1
Water (H_2O), %mol	7.8	7.5	8.3	22.4	22.6
Oxygen (O_2), %mol	13.0	13.4	12.5	6.2	6.2
Nitrogen (N_2), %mol	74.6	74.7	74.4	61.6	61.4
Contaminants					
Sulphur Oxide (SOx), mg/Nm^3	0	0	0	31	31
Nitrogen Oxide (NOx), mg/Nm^3	30	31	30	150	150
Hydrogen Sulphide (H_2S), mg/Nm^3	0	0	0	0	0
Ammonia (NH_3), mg/Nm^3	0	0	0	5	5
Carbon Monoxide (CO), mg/Nm^3	0	0	0	0	0

Table 11. Flue Gas Composition - Case Studies 11 to 14

Case Study Number	**11**	**12**	**13**	**14**
Case Description	EfW 72MW	Biomass 35MW	Biomass 65MW	Biomass 120MW
Flue Gas Properties				
Mass flowrate, kg/s	103.4	61.7	98.3	171.7
Actual volumetric flowrate, Am^3/s	105.3	59.6	94.5	166.0
Stack temperature, °C	96.5	100	99.6	105.1
CO_2 mass flow, t/h	53	43	69	137
Flue gas composition				
Carbon Dioxide (CO_2), % mol	8.8	12.9	12.8	14.7
Water (H_2O), %mol	24.6	11.8	11.8	13.4
Oxygen (O_2), %mol	6.0	5.3	5.3	3.0
Nitrogen (N_2), %mol	59.9	69.2	69.2	68.0
Contaminants				
Sulphur Oxide (SOx), mg/Nm^3	29.9	11.3	11.3	17.0
Nitrogen Oxide (NOx), mg/Nm^3	150	150	150	150
Hydrogen Sulphide (H_2S), mg/Nm^3	0	0	0	0
Ammonia (NH_3), mg/Nm^3	5	5	5	5
Carbon Monoxide (CO), mg/Nm^3	0	0	0	0

Table 12. Flue Gas Composition - Case Studies 15 to 17

Case Study Number	**15**	**16**	**17**
Case Description	Reciprocating engine 1MW	Reciprocating engines 10MW (5 x 2.4MW)	Reciprocating engines 50MW (5 x 10MW)
Flue Gas Properties			
Mass flowrate, kg/s	1.4	19.5	90
Actual volumetric flowrate, Am^3/s	1.6	22.0	104.9
Stack temperature, °C	141.0	119.0	129.7
CO_2 mass flow, t/h	0.5 (NOTE 1)	5.5 (NOTE 1)	23.2 (NOTE 1)
Flue gas composition			
Carbon Dioxide (CO_2), % mol	6.4	5.2	4.6
Water (H_2O), %mol	12.9	10.7	9.6
Oxygen (O_2), %mol	7.3	9.8	11.0
Nitrogen (N_2), %mol	72.6	73.5	73.9
Contaminants			
Sulphur Oxide (SOx), mg/Nm^3	0	0	0
Nitrogen Oxide (NOx), mg/Nm^3	100	100	100
Hydrogen Sulphide (H_2S), mg/Nm^3	0	0	0
Ammonia (NH_3), mg/Nm^3	0	0	0
Carbon Monoxide (CO), mg/Nm^3	0	0	0

Note 1 – Case Studies 15-17 (reciprocating engines) CO_2 mass flow includes additional CO_2 from in-line duct burning to add sufficient heat to the flue gas to enable 95% capture from the overall flue gas.

5.6 Export Power Specification

The export conditions assumed for the purposes of concept design are defined in Table 13. Five export voltage levels have been assumed in order to size the export switchgear and infrastructure.

Table 13. Export Power Reference Conditions

Parameter	Value				
Power plant nominal capacity, MW	≤ 10	10 < M ≤ 50	50 < M ≤ 100	100 < M ≤ 500	> 500
Export Voltage Level, kV	6.6	11	132	275	400

5.7 Utility Specifications

The plant shall be provided with the following utilities:

- Cooling water
- Plant treated make-up water
- Steam
- Electricity

5.7.1 Cooling Water

Heat rejection for the plant shall be by a series of cooling towers. The design duty of the cooling water system is to be determined from the Heat and Material Balance assessment. The operating and design conditions of the cooling water network are shown in Table 14. The general design philosophy for equipment will adjust cooling water flow to maintain 10°C temperature rise across exchangers and within the cooling tower an approach temperature of 4.5°C to wet bulb temperature.

Table 14. Cooling water conditions

Cooling Water Condition	Value
Cooling Water Supply (CWS), °C	15
Cooling Water Return (CWR) °C	25

5.7.2 Plant Treated Make-up Water

Power plants with a steam cycle will typically include a water treatment plant to produce BFW. Provision for an independent parallel supply to the CCP has been included as part of this study as a conservative assumption. Steam condensate or boiler feed-water quality is recommended to minimise introduction of mineral contaminants to the amine loop. A typical minimum specification for the make-up water is shown in Table 15 below.

Table 15. Make-up water quality typical minimum specification

Parameter	Value
Chlorides, ppmw	<2.0
Total Dissolved Solids, ppmw	<50
Total Hardness, ppmw	<2.0
Sodium/Potassium, ppmw	<25
Iron, ppmw	<1.0

5.7.3 Steam

Each technology/configuration will have an optimum location for extraction of steam and return of condensate to the core plant, which will be identified during the development of each case study.

5.7.4 Electricity

Each technology/configuration will have an optimum location for extraction of electricity integration into the power islands electrical network. The tie-in for power for additional infrastructure shall be identified on a case-by-case basis.

6. Equipment Design Criteria

6.1 Design Margin

A design margin of 20% will be applied to the sizing flow rates for pumps, and a margin of 20% will be applied to area calculated for heat exchangers.

Note that 20% represents a relatively large over-design margin compared to normal design practice, however, it is considered reasonable for the Case Studies which shall only comprise a single H&MB case at ISO conditions.

6.2 Sparing Philosophy

The sparing philosophy for critical and high value equipment is specified in Section 6.3. However, the following general principles will be applied for sparing of all other equipment on the plant:

- Static equipment will not be spared
- Heat exchangers will not be spared
- Pumps will require a minimum of N+1
- Compressors and blowers will require space for a minimum of N+1, however, sparing of high value compressors and blowers will be subject to reliability studies

6.3 Equipment Specific Criteria

6.3.1 Flue Gas and Blower Design Basis

The design parameters for the flue gas entering the CCP and the required blower are presented in Table 16, with the value for abated flue gas target temperature defined to ensure adequate buoyancy of the gas exiting the stack. Note that centrifugal fans have been specified for the blower, as a conservative design option. An axial fan technology would be more efficient and if enough space is available on the project site, an axial fan would allow an efficiency of up to 90%.

Table 16. Flue gas and DCC stripping air blower parameters

Design Parameter	Value
Flue gas blower pressure rise, mbar	90
Blower efficiency assuming centrifugal fan, %	83

6.3.2 Absorber Design Basis

Table 17 defines the design parameters relating to the absorber.

Table 17. Absorber temperature and column parameters

Absorber Parameter	Value
Flue gas Temperature from DCC to absorber, °C	39 – 42
Lean amine temperature to absorber, °C	40
Flood, %	80
Structured packing	Sulzer Mellapak® 250.Y metal or equivalent
System factor	0.8
Water wash beds, No.	2 off
Acid wash bed, No.	1 off
Wash beds structured packing	Mellagrid 64.Y or equivalent
Internals metallurgy	All stainless steel or higher

Two water wash sections are provided in the top packed section for maximum recovery of entrained and evaporated solvent from the flow gas, minimising emissions of amine in flue gas and therefore to air. This system is to be set as a circulating flow of water with overflow from both wash beds into the cooled lean solvent rundown to storage.

One further acid wash stage is assumed to be required, the effluent from which is not recovered. The acid wash removes ammonia and further reduces solvent emissions to air.

6.3.3 Stripper Design Basis

The design parameters of the stripper are presented in Table 18, with the reboiler operating temperature to be determined from the modelling simulation from the operating pressure.

Table 18. Stripper temperature and column parameters

Stripper Parameter	Value
Rich Amine approach temperature in cross-exchanger, °C	5
Reboiler Operating Temperature, °C	125
Operating Pressure, barg	1.2
Flood, %	80
Packing type, reflux section	Flexipac HC 700Y or equivalent
Packing type, stripping section	IMTP 50 or equivalent
System Factor	0.8
Internals metallurgy	All stainless or higher

6.3.4 Reclaimer Design Basis

Reclaiming for MEA shall be carried out with a thermal reclaimer running semi-continuously during normal operation, processing a slipstream of the hot lean amine from the stripper bottoms. Reclaimer waste is to be removed in batches for processing off-site. Semi-continuous operation in this study is defined as continuous processing of solvent with batch removal of sludge.

The reclaimer design basis rate is initially set to handle up to 2% of the total lean amine stream mass flow based on typical values recommended by reclaiming vendors. It is expected that this rate is significantly greater than would be normally required for a semi-continuous reclaiming process. Of the processed slipstream, 99.7% is expected to be returned to circulation by an atmospheric still heated with 10 barg IP steam and the vapour driven by a steam ejector.

The residual reclaimer sludge is sent to the amine closed drain drum for disposal off-site.

6.3.5 Heat Exchanger Design Basis

Indicative approach temperatures and heat transfer performance for heat exchangers for preliminary sizing is to be per Table 19 for the shell-and-tube and plate-and-frame types. The values stated offer a realistic preliminary design basis for shell-and-tube and plate-and-frame heat exchanger types.

Table 19. Heat exchanger specification parameters

Heat Exchanger Parameter	Value
F_t correction factor	>0.8
Temperature Approach for Shell-and-tube Type, °C,	10
Temperature Approach for Plate-and-frame Type, °C	5

6.3.6 Pump Design Basis

Preliminary pump duty estimates based on shaft work required with corrections for efficiencies are shown in Table 20.

Table 20. Pump efficiencies

Pump Parameter	Value
Mechanical efficiency, 0 – 2kW	50%
Mechanical efficiency, 2 – 200 kW	65%
Mechanical efficiency, 200 – 1000 kW	75%
Mechanical efficiency, >1000 kW	85%
Electrical efficiency all pumps, typical	99%

6.3.7 Compressor Design Basis

The design parameters for the compressor package are presented in Table 21.

Table 21. Compressor parameters

Compressor Parameter	Value	Value
Compressor train capacity	N+1	N+1
Battery limit export pressure, barg	40	150
Number of Centrifugal Stages	6	7
Average Pressure Ratio	1.85	1.85
Compressor polytropic efficiency, %	83 (typical of vendor data)	83 (typical of vendor data)
Pressure drop in intercoolers and piping, bar	0.4 bar each compressor stage	0.4 bar each compressor stage
Dryer and oxygen packages pressure drop, bar	4	4
Product CO_2 metering pressure drop, bar	1	1

6.3.8 Cooling Tower Design Basis

The design parameters for sizing of the cooling tower package (note that for the H&MB less severe conditions are assumed) are presented in Table 22. The ambient conditions presented below correlates the 0.4th percentile for Herstmonceux (one of the warmest places in the UK) plus an additional 5°C for margin.

Table 22. Cooling tower parameters

Cooling Tower Parameter	Value
Cooling tower type	Mechanical, induced, plume abated
Cooling tower cell sparing	N+1
Approach to wet-bulb temperature, °C	4.5
Design ambient dry-bulb, °C	31
Design ambient wet-bulb, °C	25
Design relative humidity (based on above values), %RH	61
Cooling water return temperature design purposes, °C	29.5
Cooling water supply temperature design temperature, °C	39.5
Cycles of concentration	5

6.3.9 Amine Storage Design Basis

Fresh MEA make-up is required to replace process losses and maintain 35wt% MEA concentration in the process. It is assumed that this will be supplied by road tanker and stored on-site in a make-up tank. The on-site storage inventory is:

- Working volume plus 10%, where working volume is:
  - One standard road truck delivery of 19,000L (max 22t payload), plus 2 days at maximum consumption rate
  - or, 5 days storage at maximum consumption rate

6.3.10 Chemical Storage Design Basis

The CCP requires sodium hydroxide and sulphuric acid for pH control and acid washing. It is assumed these are to be supplied to site as 50wt% solution, to be made up with water where a lower working concentration is required. The general storage philosophy used is the greater of:

- Working volume plus 10%, where working volume is:
  - One standard road truck delivery of 19,000L (max 22t payload), plus 2 days at maximum consumption rate
- or, 5 days storage at maximum consumption rate

Appendix A Document Log

A.1 Document History

Rev.	Issued Date	Details	Author	Checker	Lead Verifier	Approver
1	04/03/2022	Issued for comment	Rhys Williams	Klim MacKenzie	Graeme Cook	Andy Cross
2	05/04/2022	Updated	Klim MacKenzie	Graeme Cook	Graeme Cook	Andy Cross

A.2 Document Revisions

Rev.	Section	Revisions/Remarks
1	All	First issue, with HOLDS
2	All	Updated with BEIS comments

AECOM

Technical Note

Subject:	Basis for Layout Development	To:	Project Management Group, AECOM Project Delivery Group, Client Project Delivery Group, Independent Peer Reviewers
Project:	BEIS Decarbonisation Readiness Requirements Review		
Reference:	60677821-TN-006		
Revision:	1		
Date:	07/03/2022		
Author:	Rhys Williams		

Table of Contents

Introduction

1.1 Document Purpose

This document details the basis for layout development for the case studies supporting the Decarbonisation Readiness Requirements Review project.

1.2 Project Overview

Since 2009, new build combustion power plants sized over 300MWe in England and Wales have been required to demonstrate they could retrofit carbon capture and storage (CCS) in order to decarbonise. This policy has been known to date as 'Carbon Capture Readiness' (CCR).

In 2009, detailed guidance was produced to support industry and BEIS in assessing the CCR requirements. Due to evolution of gas turbine size and efficiency, variable load profiles for fossil fuel plants, and to recognise the changing landscape of carbon capture and decarbonisation technologies, this guidance needs to be updated, as plants below 300MWe and new plant types (e.g. combined heat and power, energy from waste and biomass) will now be assessed for carbon capture readiness. The guidance document will also be expanded to cover hydrogen readiness as a means of decarbonisation.

As part of the expansion, BEIS are renaming the policy to 'Decarbonisation Readiness'. In order to update the guidance BEIS have commissioned two technical studies to update and expand the underpinning evidence base that was used to develop the guidance documents.

The technical studies are:

1. Lot 1 – Hydrogen readiness
2. Lot 2 – Carbon capture readiness

This document is intended to define the basis for layout development for both '**Lot 1 - Hydrogen readiness' and** '**Lot 2 – Carbon capture readiness' technical studies**.

1.3 Document Limitations

This document is designed to support the development of a layout at a concept stage of design and is intended to confirm there is sufficient available plot space at the site and to provide the starting point for future design phases.

The minimum spacing recommendations within this document are a combination of industry guidance documents from *PIP*[1], *GAP*[2]*, and CCPS*[3] and AECOM's experience. The footprint allowances for equipment and buildings are based upon values in literature by *Moran*[4] and AECOM's experience.

The process of developing of a site layout scheme will take many months once the engineering basis has been defined. In developing the site layout, the engineering contractor's multi-discipline team will assess site specific concerns, implement local regulations, solicit input from operations personnel, undertake quantitative risk assessments and apply value engineering principles to minimise the total capital cost.

As such, the footprint determined by applying this basis should provide confidence that there is sufficient footprint available for the proposed development, however there will be opportunities to optimise and reduce the land take with greater levels of engineering and risk assessment. Note, that this guidance has been developed for industrial sites and for the smaller case study sites with footprints less than 500 m² a case-by-case approach will have to be adopted.

1.4 Legislation and Design Codes

This document serves as a guidance note and all local legislative regulations on layout and minimum distance of equipment from site property boundary shall comply with national, state, and local codes and safety regulations. If there is a conflict between different, the more stringent text shall govern.

[1] PIP, 2007, *Process Unit and Offsites Layout Guide*, PNE00003, Construction Industry Institute, USA
[2] GAP, 2001, *Oil and Chemical Plant Layout and Spacing*, GAP.2.5.2, Global Asset Protection Services, USA.
[3] Center for Chemical Process Safety (CCPS), 2018, *Guidelines for Siting and Layout of Facilities*, AIChemE-Wiley, USA
[4] Moran S., 2016, *Process Plant Layout*, 2nd Edition, IChemE-Elsevier, UK

2. Definitions and Acronyms

2.1 Definitions

Table 1 defines the terms used within this document.

Table 1. Acronyms utilised on this project

Term	Description
Battery Limit	The boundary/perimeter of a process unit.
Facility	Generic term used to describe all assets on the Site within the perimeter fence.
Heavy Haulage Road	Road specified to facilitate out of gauge vehicles (i.e. cranes) or items (i.e. columns, pre-fab module) for purposes of construction or maintenance.
In Plant Road	Roads serving one or more Process Units or Sections within a Plot.
Low Occupancy Building	No person is permanently assigned to work in the building and the cumulative occupancy is less than 200 hours per week.
Pedestrian Accessway	Paved area dedicated to pedestrian for access the buildings and Plant.
Pipe Rack	A grouping of piping elevated on a structure.
Pipe Track	A grouping of unburied piping at or slightly below grade level.
Plant	Generic term to describe any one or all the Process Units on a Site.
Plot	An area of the site where a Process Unit or Utilities Area is located.
Process Unit	Multiple equipment items assembled and connected by pipes and ducts to process raw materials and to manufacture either a final or intermediate product.
Major Access Road	Perimeter road and main thoroughfare serving two or more Plots.
Minor Access Road	Road serving up to two Plots.
Section	Part of a Process Unit.
Site	The land owned (or leased) by the Project Owner.
Tank Compound	An area containing one or more tanks.
Utilities	Equipment related to provision of water, effluent treatment, sewage, cooling water, instrument and plant air supply, industrial gases, electrical supply and similar services.

2.2 Acronyms

Table 2 defines the acronyms and abbreviations used within this document.

Table 2. Acronyms utilised on this project

Acronym	Description
ISBL	Inside battery limit(s)
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas(es)
NGL	Natural gas liquid(s)
NPSH	Net positive suction head
OSBL	Outside battery limit(s)
QRA	Quantified risk assessment
SI	Systeme International d'Unites

2.3 Hazard Classification

For the purposes of the concept development layout the hazard classification system set out in GAP 2.5.2A[5] has been adopted. These classifications are intended only to be used in determining concept level spacing requirements and do not replace formal hazard identification or analysis methodology classifications..

Table 3 defines the hazard level classification system adopted for this project, with project relevant examples.

Table 3. Hazard Classification

Hazard Level	Description and examples
High[5]	This category includes processes, operations, or materials having a high explosion hazard and moderate to heavy fire hazard. This class involves highly exothermic or potential runaway reactions and high hazard products handling. Project relevant examples include: – Hydrogen production units, with capacity greater than 1 tonne per hour – Hydrogen storage units, with inventory greater than 5 tonnes – Hydrogen gas compression and heating, with fluid pressures greater than 10 barg – Carbon dioxide compression, with fluid pressures greater than 10 barg
Intermediate[5]	This category includes processes, operations, or materials having an appreciable explosion hazard and a moderate fire hazard. This class generally involves mildly exothermic reactions. Project relevant examples include: – Hydrogen production units, with capacity less than 1 tonne per hour – Hydrogen storage units, with inventory less than 5 tonnes – Hydrogen gas compression and heating, with fluid pressures less than 10 barg – Hydrogenation – Carbon dioxide compression, with fluid pressures less than 10 barg – Amine carbon capture units – Natural gas compression and heating, with fluid pressures greater than 10 barg
Moderate[5]	This category includes processes, operations, or materials having a limited explosion hazard and a moderate fire hazard. This class generally involves endothermic reactions and

[5] GAP, 2001, *Hazard Classification Of Process Operations For Spacing Requirements*, GAP.2.5.2 Appendix A, Global Asset Protection Services, USA.

Hazard Level	Description and examples
	nonreactive operations, such as distillation, absorption, mixing and blending of flammable liquids. Exothermic reactions with no flammable liquids or gases also fit in this hazard group. Typical examples include: Project relevant examples include: – Ammonia production and storage – Urea production and storage – Amine systems (not including significant quantities of high purity CO_2) – Natural gas compression and heating, with fluid pressures less than 10 barg
Low	This category includes processes, operations, or materials having no explosion hazard and a limited fire hazard, however pose a potential risk of harm to life or assets (i.e. high operating pressures or temperatures, toxicity, corrosive, potential for asphyxiation) Project relevant examples include: – High pressure steam and water systems, with fluid pressures greater than 10 barg – Sodium hydroxide handling and storage – Hydrochloric acid handling and storage – Sulphuric acid handling and storage – Non-toxic utilities such as process air and nitrogen

3. Philosophy

The layout development philosophy for the conceptual design phase, adheres to the following heuristics once preliminary equipment and building sizing has been completed:

1. The area for development shall be defined by off-set of a minimum of 5m from the property ownership boundary to permit the installation of security fencing and clear line of sight along the fence line for CCTV.
2. The area for development should be divided into plots, and where possible the plots should be rectangular.
3. The area of each plot should not exceed 20,000 m^2 with no side greater than 200 m.
4. Roads shall separate each plot, with the type of road to be defined in line with the requirements of Section 5.1.
5. The most hazardous process units shall be located towards the interior of the site away from the site boundary to minimise the risk to neighbours and the public. The minimum spacing between plots is specified in Section 7.1.
6. A single plot may contain more than one process unit. The minimum spacing within a plot is specified in Section 7.2.
7. Storage of hazardous materials shall be sited to minimise the risk and consequences of any loss of containment to personnel and equipment. In locating the tank compound consideration to prevailing winds, personnel safety, and nearby population centres shall be considered in selecting the most suitable location. The minimum spacing within the tank compound is specified in Section 7.3.
8. Cooling towers where possible should be located downwind (relative to prevailing wind) of the plant and be orientated so as to minimise the risk of hot air recirculation. The minimum spacing and recommendations for orientation of cooling towers is specified in Section 7.4.
9. Where the is a flow of fluids between units, the layout of the units should be as far is practicable and economical be in a logical order.
10. Utility services should be grouped together as much as is possible.
11. Fire and safety equipment shall be located to minimise exposure to fires, explosions, or releases.
12. High occupancy buildings shall be located as far as practically possible from hazardous process units and such that the route from the main entrance gate minimises the need for employees to drive through the plant.
13. Road layout shall ensure that there are two routes of egress off-site from all locations on site in the event of a fire scenario.

4. General Considerations

4.1 Site Specific Considerations

The following site-specific factors would be typically be considered in developing the layout that cannot be accounted for in the development of these generic case studies:

- Prevailing wind direction
- Meteorology
- Legal boundaries
- Location and extent of fencing
- Adjacent land usage
- Nearby public facilities
- Public roads
- Public utilities such as overhead lines or buried services such as pipelines and/or cables
- Railroads
- Waterways
- Topography and site ground conditions

4.2 Site Access

All case study sites will be assumed to have access on more than one side to permit for a minimum of one main entrance and a secondary emergency/construction access.

This assumption could be significant on plot constrained sites where access and egress routes may be limited due to plot availability and adjacent land usage.

4.3 Maintenance and Laydown Access and Areas

In development of a site layout, consideration should be given to the access and maintenance of equipment. For the purpose of the generic case studies AECOM will utilise their project experience to determine maintenance access requirements.

AECOM shall utilise their project experience to determine preliminary estimates for construction laydown.

4.4 Future Expansion

In development of a site layout, the EPC contractor will typically agree a philosophy for pre-investment and allowances for future expansion. For the purpose of the generic case studies AECOM will not consider future expansion requirements. Allowances of space for future equipment shall be limited to that required to implement hydrogen firing or retro-fitting of carbon capture units.

5. Accessways

5.1 Roads

Table 4 provides recommendations the width, bend radius and minimum clearance for the different type of roads anticipated on site.

Table 4. Road width, bend radius and minimum clearance

Type	Width (m)	Bend Radius (m)	Minimum Clearance (m)
Heavy Haulage Road	10	15	No vertical obstructions
Major Access Road	7.5	12	6.0
Minor Access Road	6.0	6	6.0
In Plant Road	3.5	6	4.5

5.2 Parking

Table 5 provides recommendations for the number of parking bays by type to be provided based on the number of personnel on site.

Table 5. Parking Bay Allowances

Type	Sizing Basis	Minimum No. Spaces
Guardhouse Parking	0.1 spaces / total site personnel	3
Visitor Parking	0.2 spaces / total site personnel	5
Staff Parking	0.7 spaces / total site personnel	10
Accessible Parking	0.15 spaces / total site personnel	3
Motorcycle Parking	0.02 spaces / total site personnel	5
Bicycle Parking	0.05 spaces / total site personnel	10

Table 6 provides recommendations on footprint to provide for each type of parking bay.

Table 6. Parking Bay (Space) Dimensions

Type	Length (m)	Width (m)
Standard Car Parking Bay	6.0	2.75
Accessible Parking Bay	6.0	3.75
Motorcycle Parking Bay	2.5	1.5
Bicycle Parking Bay	2.0	0.5
Maintenance Vehicle Parking Bay	6.0	3.0
Tanker Truck Parking Bay	15.0	3.5

5.3 Pedestrian Accessway

Pedestrian accessways (pavements) should be a minimum of 1.2 m wide, where accessways are anticipated to have high footfall (surrounding offices, canteen, control room, welfare facilities etc) a minimum width of 2.5 m is recommended.

6. Buildings

6.1 Administrative Building

Table 7 defines a basis for estimating the required footprint of the administrative building during concept design phase.

Table 7. Administrative Building Allowances

Area	Sizing Basis	Minimum (m^2)	Maximum (m^2)
Reception	0.3 m^2 / total site personnel	15	40
Office space	8 m^2 / office staff	40	-
Kitchen/eating area	2.5 m^2 / office staff	10	-
Private Office (Large)	45 m^2 / office	45	45
Private Office (Medium)	35 m^2 / office	35	35
Private Office (Small)	25 m^2 / office	25	25
Meeting Room (Large)	85 m^2 / meeting room	85	85
Meeting Room (Medium)	55 m^2 / meeting room	55	55
Meeting Room (Small)	25 m^2 / meeting room	25	25
Facilities/Toilets	0.6 m^2 / office staff	10	-

6.2 Welfare Facilities

Table 8 defines a basis for estimating the required footprint of the welfare facilities during concept design phase. Note that these facilities do not necessarily need to be separate buildings and can be incorporated into the administrative building.

Table 8. Welfare Facilities Allowances

Area	Sizing Basis	Minimum (m^2)	Maximum (m^2)
Canteen/Dining Area/Store	1 m^2 / total site personnel	-	-
Medical Centre	0.15 m^2 / office staff	15	-
Showers/Locker Rooms	0.25 m^2 / total site personnel	15	-

6.3 Control Building

A control building may not be required for smaller sites decarbonising through hydrogen firing rather than carbon capture. Where a control building is required, Table 9 defines a basis for estimating the required footprint of the control building during concept design phase.

Table 9. Control Building Allowances

Area	Sizing Basis	Minimum (m^2)	Maximum (m^2)
Reception	5 m^2 / control staff	15	-
Work station	25 m^2 / control staff	50	-
Kitchen/eating area	2.5 m^2 / control staff	10	-
Private Offices	35 m^2 / office	35	35
Meeting Rooms	85 m^2 / meeting room	85	85

Area	Sizing Basis	Minimum (m^2)	Maximum (m^2)
DCS/electrical Room	0.2 m^2 / equipment item	-	-
Showers/Locker Room	4 m^2 / field eng. & techs	15	-
Permit Office/Key Room	1.2 m^2 / control staff	10	-
Facilities/Toilets	0.6 m^2 / non-admin staff	10	-

6.4 Fire Station

An allowance of 500 m^2 is recommended where a fire station is identified as being required.

6.5 Workshop

An allowance of 20 m^2 per workshop employee is recommended for a workshop and maintenance building. For smaller sites with no permanent workshop employees, a flat area with a footprint of 20 m^2 suitable for a 20ft container type mobile workshop is recommended.

6.6 Stores

An allowance of 1 m^2 per major equipment item (excluding dosing pumps, sewage pumps, drums, vessels and tanks) is recommended for the storage of spare parts. On smaller sites a minimum storage area of 10 m^2 is recommended.

7. Minimum Spacing Recommendations

7.1 Inter-plot Spacing Recommendations

The following section provides a series of figures that outline the minimum spacing recommendations for concept level layout development. As the design is developed and risks can be better assessed there is a potential to reduce the spacing requirements beyond those stated in this document.

Figure 1 defines the minimum spacing recommendations between buildings, infrastructure and process units to be used for concept level layout development.

	PROPERTY LINES WITH OTHERS	ADMINISTRATION BUILDING OR OFFICE	CONTROL BUILDING	LOW OCCUPANCY BUILDING	FIRESTATION & FIRE PUMPS	WORKSHOP	WAREHOUSE/STORAGE	ELECTRICAL OVERHEAD LINES AND TOWERS	MAIN ELECTRICAL SUBSTATION	ELECTRICAL CONTROL & DISTRIBUTION CENTER	MOTOR CONTROL CENTER & INSTRUMENT BUILDING	PROCESS UNIT (HIGH HAZARD)	PROCESS UNIT (INTERMEDIATE HAZARD)	PROCESS UNIT (MODERATE HAZARD)	PROCESS UNIT (LOW/NON-HAZARD)	POWER GENERATION UNIT (FIRED EQUIPMENT)	UTILITIES AREA	COOLING TOWERS	FIN-FAN AIR COOLERS	ATMOSPHERIC STORAGE PLOT (NON-HAZARDOUS)	ATMOSPHERIC STORAGE PLOT (HAZARDOUS)	PRESSURISED STORAGE TANK(S) PLOT	REFRIGERATED STORAGE TANK(S) PLOT
ADMINISTRATION BUILDING OR OFFICE	-																						
CONTROL BUILDING	5	-																					
LOW OCCUPANCY BUILDING	5	-	-																				
FIRESTATION & FIRE PUMPS	5	-	-	-																			
WORKSHOP	5	-	-	-	-																		
WAREHOUSE/STORAGE	10	10	10	5	15	-																	
ELECTRICAL OVERHEAD LINES AND TOWERS	10	10	10	5	15	15	-																
MAIN ELECTRICAL SUBSTATION	-	10	10	5	15	15	15	-															
ELECTRICAL CONTROL & DISTRIBUTION CENTER	10	10	10	B	15	15	15	-	-														
MOTOR CONTROL CENTER & INSTRUMENT BUILDING	10	10	10	B	10	10	10	-	-	-													
PROCESS UNIT (HIGH HAZARD)	10	10	10	B	10	10	5	-	-	-	-												
PROCESS UNIT (INTERMEDIATE HAZARD)	120	120	60	B	100	60	60	30	30	B	B	A											
PROCESS UNIT (MODERATE HAZARD)	60	60	60	B	100	60	60	30	30	B	B	A	A										
PROCESS UNIT (LOW/NON-HAZARD)	30	30	30	B	60	30	30	30	30	B	B	A	A	A									
POWER GENERATION UNIT (FIRED EQUIPMENT)	30	15	15	B	15	15	15	15	15	B	B	A	A	A	A								
UTILITIES AREA	30	30	30	B	60	30	30	15	15	B	B	A	A	A	A	A							
COOLING TOWERS	15	15	15	B	15	15	15	15	15	B	B	15	15	15	15	15	A						
FIN-FAN AIR COOLERS	30	15	15	B	15	15	15	30	30	B	B	15	15	15	15	D	15	C					
ATMOSPHERIC STORAGE PLOT (NON-HAZARDOUS)	30	15	15	B	15	15	15	30	30	B	B	B	B	B	B	D	15	D	D				
ATMOSPHERIC STORAGE PLOT (HAZARDOUS)	30	30	30	B	30	30	30	30	30	15	B	30	30	15	15	15	15	15	15	A			
PRESSURISED STORAGE TANK(S) PLOT	85	85	85	B	85	85	85	85	85	30	B	30	30	30	30	30	30	30	30	E	E		
REFRIGERATED STORAGE TANK(S) PLOT	120	120	120	B	120	120	120	120	120	30	B	120	120	120	120	120	120	120	120	E	E	E	
DISTANCES IN METRES	120	120	120	B	120	120	120	120	120	30	B	120	120	120	120	120	120	120	120	E	E	E	E

NOTES:

- \- NO MINIMUM SPACING REQUIREMENT.
- A. ENGINEERING JUDGEMENT TO BE APPLIED, WITH SUPPORTING QRA.
- B. REFER TO INTRA-UNIT SPACING RECOMMENDATION TABLE (SECTION 7.2).
- C. REFER TO COOLING TOWER SPACING RECOMMENDATIONS (SECTION 7.4).
- D. COOLING TOWERS AND FIN-FAN AIR COOLERS TO BE SEPARATED AS MUCH AS POSSIBLE, AND DOWNWIND OF GAS TURBINE AIR INTAKES. HOT AIR RECIRCULATION STUDY ADVISED.
- E. REFER TO STORAGE TANK SPACING RECOMMENDATION TABLE (SECTION 7.3).

Figure 1. Inter-plot minimum spacing recommendations

An exception to the above figure is units consisting of dense phase CO_2 compression and based on AECOM's recent experience, a separation distance of 200 m from site boundary to CO_2 compressors operating at above 50barg is recommended, rather than 120 m associated with 'Process Unit (High Hazard)'.

7.2 Intra-plot Spacing Recommendations

Figure 2 defines the minimum spacing recommendations within a process unit plot to be used for concept level layout development.

LOW OCCUPANCY BUILDING	ELECTRICAL CONTROL & DISTRIBUTION CENTER	MOTOR CONTROL CENTER & INSTRUMENT BUILDING	UNIT BLOCK VALVE	COMPRESSOR	PUMP (HIGH HAZARD)	PUMP (INTERMEDIATE HAZARD)	PUMP (MODERATE HAZARD)	PUMP (LOW/NON-HAZARD)	GAS TURBINE	STEAM TURBINE	COLUMNS AND DRUMS	FIRED HEATERS AND INCINERATORS	FIN-FAN AIR COOLERS	HEAT EXCHANGERS	MAJOR PIPE RACKS & TRACKS	
-																ELECTRICAL CONTROL & DISTRIBUTION CENTER
5	-															MOTOR CONTROL CENTER & INSTRUMENT BUILDING
5	-	-														UNIT BLOCK VALVE
5	5	5	-													COMPRESSOR
15	15	15	15	2												PUMP (HIGH HAZARD)
15	15	15	15	15	2											PUMP (INTERMEDIATE HAZARD)
15	10	10	15	10	5	2										PUMP (MODERATE HAZARD)
15	10	10	10	10	5	5	-									PUMP (LOW/NON-HAZARD)
15	10	5	5	10	5	5	-	-								GAS TURBINE
15	10	15	15	10	5	2	2	-	-							STEAM TURBINE
15	10	10	10	10	5	2	2	-	-	-						COLUMNS AND DRUMS
15	15	15	15	10	5	2	2	2	15	15	2					FIRED HEATERS AND INCINERATORS
15	15	15	15	10	5	5	5	5	15	15	15	-				FIN-FAN AIR COOLERS
15	5	5	5	10	5	5	2	2	5	5	5	15	-			HEAT EXCHANGERS
15	5	5	5	10	5	5	2	2	5	5	5	15	2	-		MAJOR PIPE RACKS & TRACKS
5	5	5	-	5	5	2	2	2	5	2	2	5	-	2	-	**DISTANCES IN METRES**

NOTES:

- NO MINIMUM SPACING REQUIREMENT.

Figure 2. Intra-plot minimum spacing recommendations

7.3 Storage Tank Spacing Recommendations

Figure 3 defines the minimum spacing recommendations within a tank compound to be used for concept level layout development.

FLOATING & CONE ROOF TANK VOL. < 477 M^3 (3,000 BBL)	FLOATING & CONE ROOF TANK 477 M^3 (3,000 BBL) ≤ VOL. < 1,600 M^3 (10,000 BBL)	FLOATING ROOF TANK 1,600 M^3 (10,000 BBL) ≤ VOL. < 47,700 M^3 (300,000 BBL)	JUMBO FLOATING ROOF TANK VOL. ≥ 47,700 M^3 (300,000 BBL)	CONE ROOF TANK - FLUID FLASH POINT > 60°C 1,600 M^3 (10,000 BBL) ≤ VOL. < 47,700 M^3 (300,000 BBL)	CONE ROOF TANK - FLUID FLASH POINT ≤ 60°C 1,600 M^3 (10,000 BBL) ≤ VOL. < 23,850 M^3 (150,000 BBL)	PRESSURE STORAGE VESSELS SPHERES AND SPHEROIDS	PRESSURE STORAGE VESSELS DRUMS AND BULLETS	REFRIGERATED DOME ROOF TANKS	
½ x D*									FLOATING & CONE ROOF TANK 477 M^3 (3,000 BBL) ≤ VOL. < 1,600 M^3 (10,000 BBL)
½ x D	½ x D								FLOATING ROOF TANK 1,600 M^3 (10,000 BBL) ≤ VOL. < 47,700 M^3 (300,000 BBL)
1 x D	1 x D	1 x D							JUMBO FLOATING ROOF TANK VOL. ≥ 47,700 M^3 (300,000 BBL)
1 x D	1 x D	1 x D	1 x D						CONE ROOF TANK - FLUID FLASH POINT > 60°C 1,600 M^3 (10,000 BBL) ≤ VOL. < 47,700 M^3 (300,000 BBL)
½ x D	½ x D	1 x D	1 x D	½ x D					CONE ROOF TANK - FLUID FLASH POINT ≤ 60°C 1,600 M^3 (10,000 BBL) ≤ VOL. < 23,850 M^3 (150,000 BBL)
1 x D	1 x D	1 x D	1 x D	1 x D	1 x D				PRESSURE STORAGE VESSELS SPHERES AND SPHEROIDS
1½ x D 30M MIN	1½ x D 30M MIN	1½ x D 30M MIN	2 x D 30M MIN	1½ x D 30M MIN	1½ x D 30M MIN	1 x D 15M MIN			PRESSURE STORAGE VESSELS DRUMS AND BULLETS
1½ x D 30M MIN	1½ x D 30M MIN	1½ x D 30M MIN	2 x D 30M MIN	1½ x D 30M MIN	1½ x D 30M MIN	1 x D 30M MIN	1 x D		REFRIGERATED DOME ROOF TANKS
2 x D 60M MIN	2 x D 60M MIN	2 x D 60M MIN	2 x D 60M MIN	2 x D 60M MIN	2 x D 60M MIN	1 x D 30M MIN	1 x D 30M MIN	1 x D 30M MIN	**DISTANCES IN METRES**

NOTES:

- NO MINIMUM SPACING REQUIREMENT.

* FOR STORAGE CONTAINING NON-HAZARDOUS FLUIDS OR FLUIDS WITH A FLASH POINT > 60°C STORED AT AMBIENT TEMPERATURE, 2M SPACING IS ACCEPTABLE.

D = LARGEST TANK DIAMETER

Figure 3. Storage tank minimum spacing recommendations

7.4 Cooling Tower Spacing Recommendations

Figure 4 and Figure 5 defines the siting and spacing of multiple cooling towers as recommended by *Hensley*[6].

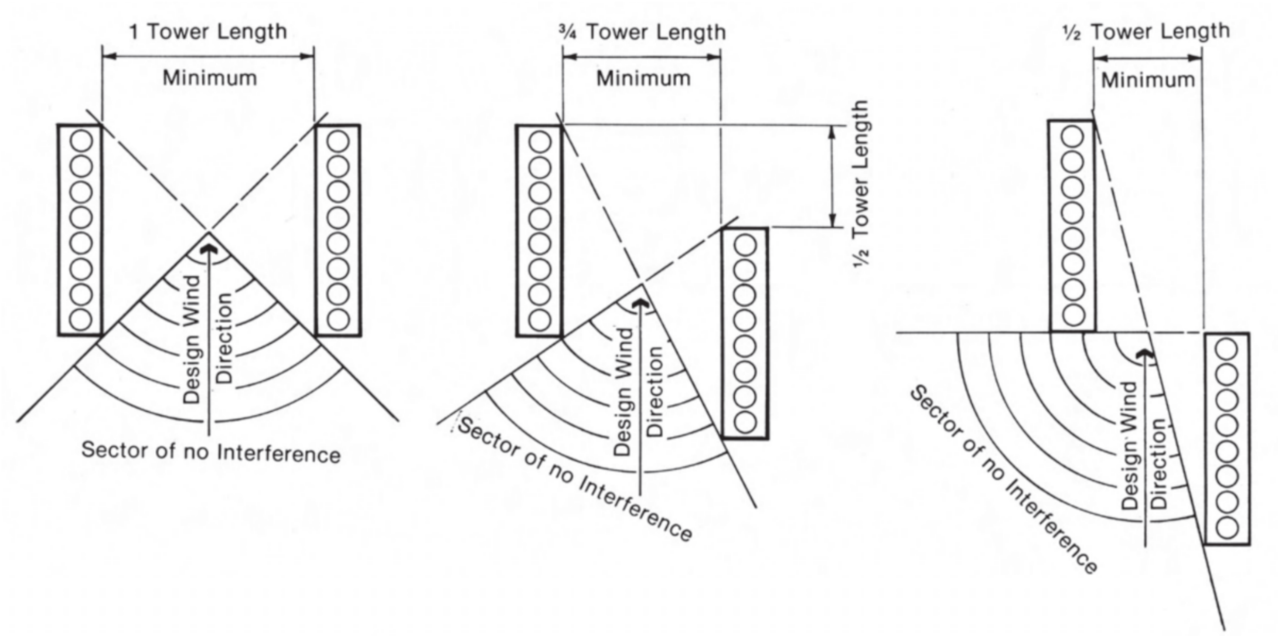

Figure 4. Recommended orientation of towers in a prevailing longitudinal wind

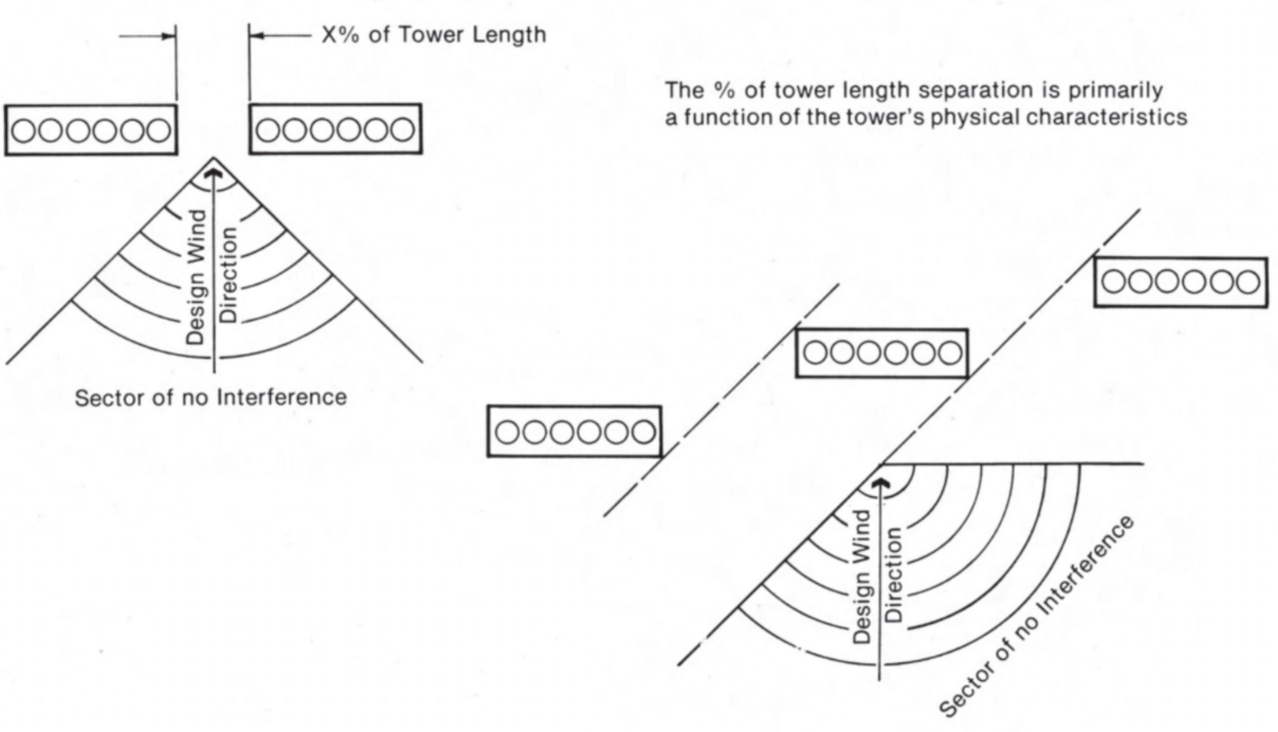

Figure 5. Recommended orientation of towers in a prevailing broadside wind

[6] Hensley J. C., 2009, *Cooling Tower Fundamentals*, 2nd Edition, SPX Cooling Technologies, USA.

Appendix A Document Log

A.1 Document History

Rev.	Issued Date	Details	Author	Checker	Lead Verifier	Approver
1	07/03/2022	Issued for comment	Rhys Williams	Klim MacKenzie	Graeme Cook	Andy Cross

A.2 Document Revisions

Rev.	Section	Revisions/Remarks
1	All	First issue

Appendix D Concept Design Summaries

Appendix E Capital Cost Summaries

Table 22. Capital cost estimates in millions of £2022

Case Study Type MW nameplate	CS1 CCGT 220	CS2 CCGT 450	CS3 CCGT 910	CS4 CCGT 14	CS5 CCGT 35	CS6 CCGT 60	CS7 OCGT 145	CS8 OCGT 290	CS9 EfW 20	CS10 EfW 36	CS11 EfW 72	CS12 Biom. 35	CS13 Biom. 60	CS14 Biom. 120	CS15 Recip. 1	CS16 Recip. 12.5	CS17 Recip. 50
CCS Case Study Data																	
Prime movers x steam x capture plants	1x1x1	1x1x1	1x1x1	1x1x1	1x1x1	1x1x1	1x1x1	1x1x1	1x1x1	1x1x1	2x1x1	1x1x1	1x1x1	2x1x1	1x1x1	5x5x5	5x5x1
Plant thermal energy input (MWth LHV)	382	700	1369	35	71	113	382	700	92	149	284	121	192	383	2.3	27	112
Net plant output (MWe)	177	335	720	12	28	47	177	335	12	23	46	26	46	91	0.93	11.6	45
Net plant efficiency (%)	46	48	53	34	39	42	46	48	13	15	16	22	24	24	40	43	40
Capture plant size (tpd)	1846	3297	6435	165	337	531	1846	3297	781	1272	2416	981	1566	3121	12	129	529
EPC Costs (all units where applicable, £2022 millions)																	
Flue Gas Pre-Treatment	£18.3	£27.5	£43.9	£3.4	£5.6	£7.7	£18.3	£27.5	£8.0	£11.3	£17.7	£9.4	£13.0	£21.1	£0.5	£2.8	£7.6
CO_2 Capture Technology	£18.0	£32.1	£62.6	£1.6	£3.3	£5.2	£18.0	£32.1	£19.5	£31.8	£60.4	£24.5	£39.1	£78.0	£1.1	£5.8	£15.6
CO_2 Conditioning	£1.4	£2.1	£3.4	£0.3	£0.4	£0.6	£1.4	£2.1	£1.1	£1.5	£2.3	£1.2	£1.7	£2.8	£-	£0.2	£0.6
CO_2 Compression	£19.3	£28.9	£25.2	£0.9	£1.5	£2.1	£19.3	£28.9	£11.2	£59.9	£93.7	£13.1	£9.4	£112.2	£0.1	£0.8	£2.1
Auxiliaries Total	£17.3	£26.4	£42.9	£3.2	£5.3	£7.2	£17.3	£26.4	£34.3	£10.5	£17.3	£12.1	£14.8	£20.7	£0.5	£2.3	£6.4
- Cooling (assuming CTs)	£3.2	£5.2	£9.0	£0.6	£1.0	£1.3	£3.2	£5.2	£1.6	£2.2	£4.3	£5.2	£5.2	£5.2	£0.1	£0.1	£0.5
Civils	£22.4	£33.6	£53.7	£4.1	£6.8	£9.4	£22.4	£33.6	£17.0	£23.9	£37.5	£19.9	£27.7	£44.8	£0.6	£3.5	£9.3
Liquefaction	£-	£-	£-	£-	£0.2	£0.3	£-	£-	£0.2	£-	£-	£0.3	£-	£-	£-	£0.2	£0.2
Buffer Storage & Loading Infrastructure	£-	£-	£-	£2.0	£3.9	£8.4	£-	£-	£9.4	£-	£-	£11.8	£-	£-	£0.1	£1.5	£9.1
WHRU	£-	£-	£-	£-	£-	£-	£-	£-	£-	£-	£-	£-	£-	£-	£-	£0.3	£0.8
Repowering	£-	£-	£-	£-	£-	£-	£47.7	79.8	£-	£-	£-	£-	£-	£-	£-	£-	£-
Total EPC	**£96.7**	**£150.7**	**£231.8**	**£15.5**	**£27.0**	**£40.8**	**£144.4**	**£230.5**	**£100.8**	**£138.9**	**£229.0**	**£92.5**	**£105.7**	**£279.7**	**£3.1**	**£17.5**	**£51.8**
Project Development Costs																	
Land Requirements	£0.2	£0.4	£0.8	£0.0	£0.1	£0.1	£0.2	£0.4	£0.1	£0.1	£0.2	£0.1	£0.1	£0.2	£0.0	£0.1	£0.1
Utility & Infrastructure Connections	£1.0	£1.5	£2.3	£0.2	£0.3	£0.4	£1.4	£2.3	£1.0	£1.4	£2.3	£0.9	£1.1	£2.8	£0.0	£0.2	£0.5

Case Study Type MW nameplate	CS1 CCGT 220	CS2 CCGT 450	CS3 CCGT 910	CS4 CCGT 14	CS5 CCGT 35	CS6 CCGT 60	CS7 OCGT 145	CS8 OCGT 290	CS9 EfW 20	CS10 EfW 36	CS11 EfW 72	CS12 Biom. 35	CS13 Biom. 60	CS14 Biom. 120	CS15 Recip. 1	CS16 Recip. 12.5	CS17 Recip. 50
Consultancy Services	£1.0	£1.5	£2.3	£0.2	£0.3	£0.4	£1.4	£2.3	£1.0	£1.4	£2.3	£0.9	£1.1	£2.8	£0.0	£0.2	£0.5
Planning & Other Regulatory	£1.9	£3.0	£4.6	£0.3	£0.5	£0.8	£2.9	£4.6	£2.0	£2.8	£4.6	£1.8	£2.1	£5.6	£0.1	£0.3	£1.0
Developers Costs	£6.8	£10.5	£16.2	£1.1	£1.9	£2.9	£10.1	£16.1	£7.1	£9.7	£16.0	£6.5	£7.4	£19.6	£0.2	£1.2	£3.6
Commissioning & Start-Up	£4.8	£7.5	£11.6	£0.8	£1.4	£2.0	£7.2	£11.5	£5.0	£6.9	£11.4	£4.6	£5.3	£14.0	£0.2	£0.9	£2.6
Total Project Development	**£15.7**	**£24.5**	**£37.9**	**£2.5**	**£4.4**	**£6.6**	**£23.3**	**£37.3**	**£16.2**	**£22.3**	**£36.8**	**£14.9**	**£17.0**	**£45.0**	**£0.5**	**£2.9**	**£8.4**
Capital Costs, £$_{2022}$ millions																	
Total Capital Cost	£112.5	£175.2	£269.7	£18.0	£31.4	£47.5	£167.7	£267.8	£117.0	£161.2	£265.8	£107.4	£122.7	£324.7	£3.6	£20.4	£60.2
Contingency	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
Grand Total CAPEX	**£123.7**	**£192.8**	**£296.7**	**£19.8**	**£34.6**	**£52.2**	**£184.5**	**£294.6**	**£128.7**	**£177.4**	**£292.4**	**£118.1**	**£135.0**	**£357.2**	**£3.9**	**£22.4**	**£66.2**
Carbon Capture Plant Cost Ratios, £$_{2022}$ millions																	
Plant thermal energy input (MWth LHV)	382	700	1369	35	71	113	382	700	92	149	284	121	192	383	2.3	27	112
Net plant efficiency (%)	46	48	53	34	39	42	46	48	13	15	16	22	24	24	40	43	40
Net plant output (MWe)	177	335	720	12	28	47	177	335	12	23	46	26	46	91	0.93	11.6	45
Capture plant size (tpd)	1846	3297	6435	165	337	531	1846	3297	781	1272	2416	981	1566	3121	12	129	529
Total CAPEX thermal ratio (£/MWth)	**£0.32**	**£0.28**	**£0.22**	**£0.57**	**£0.49**	**£0.46**	**£0.48**	**£0.42**	**£1.40**	**£1.19**	**£1.03**	**£0.98**	**£0.70**	**£0.93**	**£1.70**	**£0.83**	**£0.59**
Total CAPEX electrical ratio (£/MWe)	**£0.70**	**£0.58**	**£0.41**	**£1.65**	**£1.24**	**£1.11**	**£1.04**	**£0.88**	**£10.72**	**£7.71**	**£6.36**	**£4.54**	**£2.94**	**£3.93**	**£4.20**	**£1.93**	**£1.47**
Total CAPEX capture ratio (£/tpd)	**£0.07**	**£0.06**	**£0.05**	**£0.12**	**£0.10**	**£0.10**	**£0.10**	**£0.09**	**£0.16**	**£0.14**	**£0.12**	**£0.12**	**£0.09**	**£0.11**	**£0.33**	**£0.17**	**£0.13**

Appendix F Capital Cost Uncertainty

Item	Remarks	Cost source type	Uncertainty
EPC Costs			
– Flue Gas Pre-Treatment	System-level cost scaled from previous project data on CO_2 captured rate	Previous AECOM project	+/-50%
– Capture Technology			
– CO_2 Conditioning			
– CO_2 Compression			
– Auxiliary Systems	Scaled except cooling which is calculated separately on CO_2 captured rate	Previous AECOM project	+/-40%
▪ Cooling System – Cooling Towers	Estimated directly per Design Basis and cooling MW.th	Preliminary equipment design	+/-40%
– Civil Works	System-level cost scaled from previous project data on CO_2 captured rate	Previous AECOM project	+/-100%
– Liquefaction	System-level cost scaled from MW.th refrigeration required	Literature	+/-100%
– Buffer Storage & Loading Infrastructure	System-level cost scaled from calculated storage inventory	Literature	+/-100%
– Waste Heat Recovery Unit	System-level cost scaled from waste heat 'package' cost plus installation margin	Scaled vendor quote	+/-40%
– CCGT Repowering		PEACE	+/-50%
Land requirements; utility & infrastructure connections; consultancy services; planning & other regulatory; developer's costs; commissioning & start-up	Estimated from previous project data to support various Pre-FEED projects	Previous AECOM project	+/-50%
Total Capital Cost			**+/-50%**

Appendix G Operating Cost Summaries

Table 23. Operating cost estimates for the capture plant (and capture-associated auxiliaries) in millions of £2022 per year

Case Study Type MW nameplate	CS1 CCGT 220	CS2 CCGT 450	CS3 CCGT 910	CS4 CCGT 14	CS5 CCGT 35	CS6 CCGT 60	CS7 OCGT 145	CS8 OCGT 290	CS9 EfW 20	CS10 EfW 36	CS11 EfW 72	CS12 Biom. 35	CS13 Biom. 60	CS14 Biom. 120	CS15 Recip. 1	CS16 Recip. 12.5	CS17 Recip. 50
CCS Case Study Data																	
Prime movers x steam x capture plants	1x1x1	1x1x1	1x1x1	1x1x1	1x1x1	1x1x1	1x1x1	1x1x1	1x1x1	1x1x1	2x1x1	1x1x1	1x1x1	2x1x1	1x1x1	5x5x5	5x5x1
Plant thermal energy input (MW.th LHV)	382	700	1369	35	71	113	382	700	92	149	284	121	192	383	2.3	27	112
Net plant output (MW.e)	177	335	720	12	28	47	177	335	12	23	46	26	46	91	0.93	11.6	45
Net plant efficiency (%)	46	48	53	34	39	42	46	48	13	15	16	22	24	24	40	43	40
Capture plant size (tpd)	1846	3297	6435	165	337	531	1846	3297	781	1272	2416	981	1566	3121	12	129	529
Fixed Costs																	
Labour	£0.8	£0.9	£1.3	£0.5	£0.5	£0.5	£0.8	£0.9	£0.8	£0.8	£1.2	£0.8	£0.8	£1.6	£0.5	£0.5	£0.5
Administration & Other Overheads	£1.9	£2.9	£4.5	£0.3	£0.5	£0.8	£2.8	£4.4	£1.9	£2.7	£4.4	£1.8	£2.0	£5.4	£0.1	£0.3	£1.0
Maintenance	£3.1	£4.8	£7.4	£0.5	£0.9	£1.3	£4.6	£7.4	£3.2	£4.4	£7.3	£3.0	£3.4	£8.9	£0.1	£0.6	£1.7
Total Fixed OPEX	**£5.7**	**£8.7**	**£13.2**	**£1.3**	**£1.9**	**£2.6**	**£8.1**	**£12.7**	**£6.0**	**£7.9**	**£12.9**	**£5.5**	**£6.2**	**£15.9**	**£0.6**	**£1.4**	**£3.2**
Variable Costs (£2022 millions)																	
Electricity	£6.7	£10.1	£16.8	£0.8	£1.4	£2.0	£6.7	£10.1	£2.1	£1.4	£2.8	£0.9	£1.5	£3.0	£0.0	£0.3	£1.4
Towns Water	£0.0	£0.0	£0.0	£0.0	£0.0	£0.0	£0.0	£0.0	£-	£-	£-	£-	£-	£-	£0.0	£0.0	£0.0
Demin Water	£0.0	£0.0	£0.0	£0.0	£0.0	£0.0	£0.0	£0.0	£0.0	£0.0	£0.0	£0.0	£0.0	£0.0	£0.0	£0.0	£0.0
Steam	£8.3	£14.8	£28.8	£0.7	£1.5	£2.4	£8.3	£14.8	£3.5	£5.7	£10.8	£4.4	£7.0	£14.0	£0.1	£0.6	£2.5
Other Chemicals & Consumables	£0.9	£1.4	£2.7	£0.1	£0.1	£0.2	£1.0	£1.4	£0.8	£1.5	£2.8	£0.9	£1.6	£2.8	£0.0	£0.5	£0.2
Wastes	£1.8	£2.9	£5.6	£0.1	£0.3	£0.5	£1.8	£2.9	£0.8	£1.3	£2.4	£1.0	£1.6	£3.1	£0.0	£0.1	£0.5
CO_2 Atmospheric Emissions	£0.6	£1.1	£2.2	£0.1	£0.1	£0.2	£0.6	£1.1	£0.3	£0.4	£0.8	£0.3	£0.5	£1.1	£0.0	£0.0	£0.5
CO_2 to Road Truck	£-	£-	£-	£0.1	£-	£0.4	£-	£-	£0.5	£-	£-	£0.6	£-	£-	£0.0	£0.0	£0.4
CO_2 to T&S Network	£12.5	£22.4	£43.7	£-	£-	£-	£12.5	£22.4	£-	£8.6	£16.4	£-	£10.6	£21.2	£-	£-	£-
Plant Auxiliary Systems	£0.1	£0.2	£0.3	£0.0	£0.0	£0.0	£0.1	£0.2	£0.2	£0.3	£0.5	£0.2	£0.3	£0.6	£0.0	£0.0	£0.0
Total Variable OPEX	**£31.0**	**£52.8**	**£100.2**	**£2.0**	**£3.5**	**£5.7**	**£31.0**	**£52.9**	**£8.1**	**£19.2**	**£36.5**	**£8.3**	**£23.1**	**£45.9**	**£0.1**	**£1.5**	**£5.4**

Case Study Type MW nameplate	CS1 CCGT 220	CS2 CCGT 450	CS3 CCGT 910	CS4 CCGT 14	CS5 CCGT 35	CS6 CCGT 60	CS7 OCGT 145	CS8 OCGT 290	CS9 EfW 20	CS10 EfW 36	CS11 EfW 72	CS12 Biom. 35	CS13 Biom. 60	CS14 Biom. 120	CS15 Recip. 1	CS16 Recip. 12.5	CS17 Recip. 50
Total Operating Cost, £2022 millions																	
Total Operating Cost	£36.7	£61.5	£113.4	£3.3	£5.4	£8.3	£39.2	£65.6	£14.1	£27.1	£49.5	£13.8	£29.3	£61.8	£0.7	£2.9	£8.6
Contingency	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
Grand Total OPEX	**£40.4**	**£67.6**	**£124.7**	**£3.6**	**£6.0**	**£9.2**	**£43.1**	**£72.1**	**£15.5**	**£29.8**	**£54.4**	**£15.2**	**£32.3**	**£68.0**	**£0.8**	**£3.2**	**£9.5**
Cost Per Electricity Unit																	
Plant Thermal Energy Input (MWth)	392	700	1369	35	71	113	390	699	2	27	112	92	149	284	121	192	383
Net Plant Output (MWe)	177	335	720	12	28	47	177	335	12	23	46	26	46	91	0.9	11.6	45.0
Annual electricity production (GWh)	1,300	2,500	5,400	90	210	350	1,300	2,500	90	170	340	190	340	680	7	90	340
Fixed OPEX (£/MWh)*	£4.3	£3.5	£2.5	£15.0	£9.3	£7.5	£6.2	£5.1	£66.7	£46.2	£37.7	£28.6	£18.1	£23.5	£88.3	£16.7	£9.5
Variable OPEX (£/MWh)*	£23.5	£21.2	£18.7	£21.9	£16.7	£16.3	£23.5	£21.2	£90.6	£112.2	£106.7	£42.8	£67.5	£67.7	£14.8	£17.4	£16.2
Total OPEX (£/MWh)*	£30.6	£27.1	£23.3	£40.6	£28.6	£26.2	£32.7	£28.9	£173.0	£174.2	£158.8	£78.5	£94.2	£100.3	£113.4	£37.5	£28.3

*These values are provided in £2022 rather than millions of £2022 as with the rest of the values in the table, assuming a single year of full load operation with capacity factor 0.85. These costs do not account for fuel or other OPEX associated with the host site.

Appendix H Layout Estimate Summaries

Table 24. Summary of estimated plant footprints

CS	Case Study Title	Power Island Footprint (m^2)	Capture Plant Footprint (m^2)	Liquefaction Footprint (m^2)	*Storage Footprint (m^2)	Total Footprint (m^2)
1	Small CCGT	20,200	12,600	N/A	N/A	46,000
2	Medium CCGT	26,300	17,400	N/A	N/A	60,000
3	Large CCGT	35,500	26,500	N/A	N/A	97,000
4	Small CCGT (CHP)	6,800	8,100	3	1,320	22,800
5	Medium CCGT (CHP)	10,300	11,700	3	1,320	29,600
6	Large CCGT (CHP)	12,000	13,400	6	2,340	34,200
7	Small OCGT	13,200	24,300	N/A	N/A	46,000
8	Medium OCGT	16,400	34,000	N/A	N/A	60,000
9	Small Boiler (EfW)	21,300	19,000	6	2,350	51,100
10	Medium Boiler (EfW)	28,700	17,900	N/A	N/A	59,500
11	Large Boiler (EfW)	38,000	23,200	N/A	N/A	79,400
12	Small Boiler (Biomass)	17,600	15,400	6	2,860	50,400
13	Medium Boiler (Biomass)	25,700	9,700	N/A	N/A	60,000
14	Large Boiler (Biomass)	43,500	15,000	N/A	N/A	95,900
15	Small Recip. Engine	1,100	2,000	2	550	4,500
16	Medium Recip. Engine	2,400	5,600	3	770	8,300
17	Large Recip. Engine	5,000	11,200	5	1,330	18,500

*Where applicable, storage footprint includes area allocated for a road truck receiving facility.

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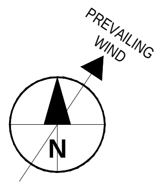

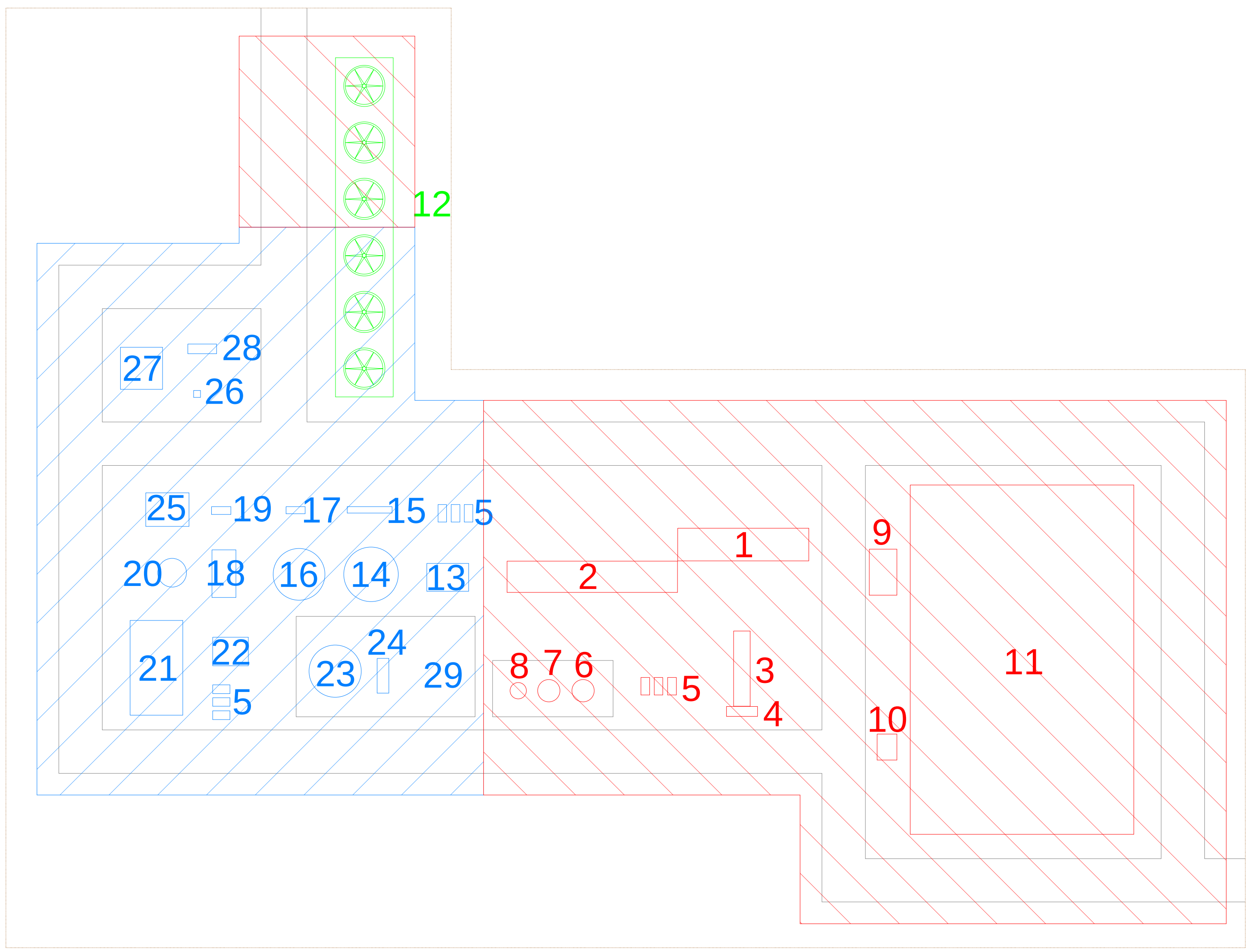

ITEM No.	DESCRIPTION
1	GAS TURBINE
2	HEAT RECOVERY STEAM GENERATOR
3	STEAM TURBINE
4	CONDENSER
5	PUMPS (VARIOUS)
6	DEMINERALISED WATER TANK
7	RAW WATER TANK
8	NEUTRALISED WATER TANK
9	GT TRANSFORMER
10	ST TRANSFORMER
11	SWITCHYARD
12	COOLING TOWERS
13	FLUE GAS BLOWER
14	DIRECT CONTACT COOLER
15	DCC CIRCULATING WATER COOLER
16	ABSORBER
17	WATER WASH COOLER
18	THERMAL RECLAIMER PACKAGE
19	LEAN TRIM COOLER
20	CO2 STRIPPER COLUMN
21	CO2 STRIPPER REBOILER
22	CO2 STRIPPER CONDENSER
23	LEAN AMINE STORAGE TANK
24	FRESH AMINE STORAGE TANK
25	LEAN-RICH CROSS-EXCHANGER
26	DE-OXYGENATION PACKAGE
27	COMPRESSOR STAGES
28	CO2 PRODUCT METERING PACKAGE
29	FLEX-CCS EQUIPMENT AREA (FUTURE)

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PROJECT

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LEGEND

- POWER ISLAND
- COOLING SYSTEM
- CAPTURE PLANT
- SITE FENCELINE

NOTES

1. DRAWING IS FOR INDICATIVE PURPOSES ONLY
2. FOOTPRINT OF THE OVERALL SITE IS APPROX. 46,000M^2
3. FOOTPRINT OF THE POWER ISLAND EQUIPMENT IS APPROX. 20,200M^2
4. FOOTPRINT OF THE CAPTURE PLANT EQUIPMENT IS APPROX. 12,600M^2
5. FACILITY NET EXPORT CAPACITY = 177MWe @ ISO WITH COOLING TOWERS

0 18.75 37.5 m
1:750

APPROVED FOR ISSUE

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A	JC	KM	KM

ISSUE/REVISION

I/R	DATE	DESCRIPTION
A	28/03/22	FIRST ISSUE

PROJECT NUMBER

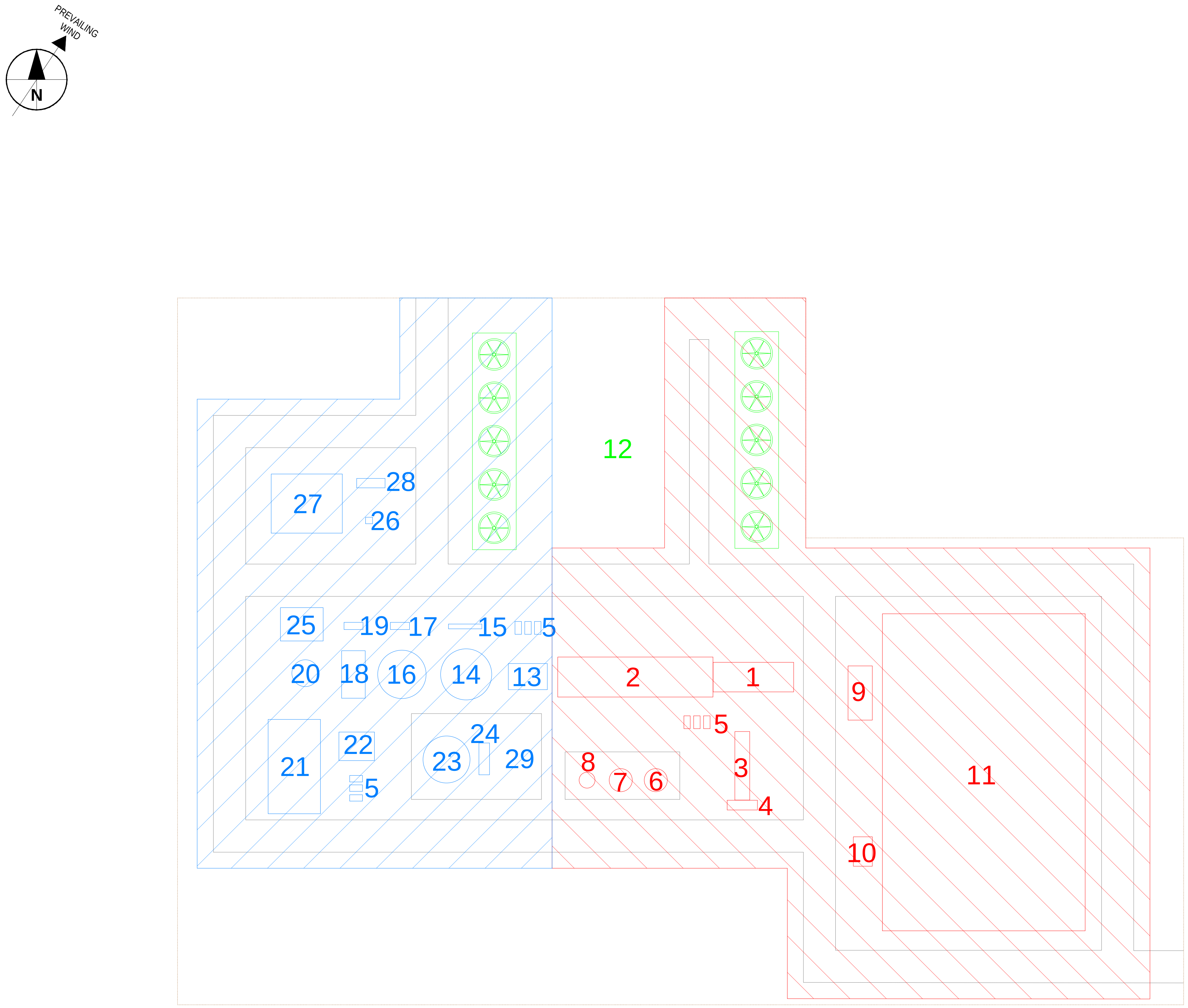
60677821

SHEET TITLE

CCS CASE STUDY 1 - SMALL CCGT LAYOUT

SHEET NUMBER

60677821-CC-DR-011



ITEM No.	DESCRIPTION
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3	STEAM TURBINE
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6	DEMINERALISED WATER TANK
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8	NEUTRALISED WATER TANK
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20	CO2 STRIPPER COLUMN
21	CO2 STRIPPER REBOILER
22	CO2 STRIPPER CONDENSER
23	LEAN AMINE STORAGE TANK
24	FRESH AMINE STORAGE TANK
25	LEAN-RICH CROSS-EXCHANGER
26	DE-OXYGENATION PACKAGE
27	COMPRESSOR STAGES
28	CO2 PRODUCT METERING PACKAGE
29	FLEX-CCS EQUIPMENT AREA (FUTURE)

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LEGEND

- POWER ISLAND
- COOLING SYSTEM
- CAPTURE PLANT
- SITE FENCELINE

NOTES

1. DRAWING IS FOR INDICATIVE PURPOSES ONLY
2. FOOTPRINT OF THE OVERALL SITE IS APPROX. 60,000M^2
3. FOOTPRINT WITHOUT THE POWER ISLAND EQUIPMENT IS APPROX. 26,300M^2
4. FOOTPRINT OF CAPTURE PLANT EQUIPMENT IS APPROX. 17,400M^2
5. FACILITY NET EXPORT CAPACITY = 335MWe @ ISO WITH COOLING TOWERS

0 18.75 37.5 m
1:750

APPROVED FOR ISSUE

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A	JC	KM	KM

ISSUE/REVISION

I/R	DATE	DESCRIPTION
A	28/03/22	FIRST ISSUE

PROJECT NUMBER

60677821

SHEET TITLE

CCS CASE STUDY 2 - MEDIUM CCGT LAYOUT

SHEET NUMBER

60677821-CC-DR-012

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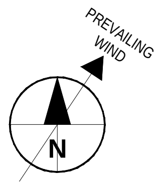
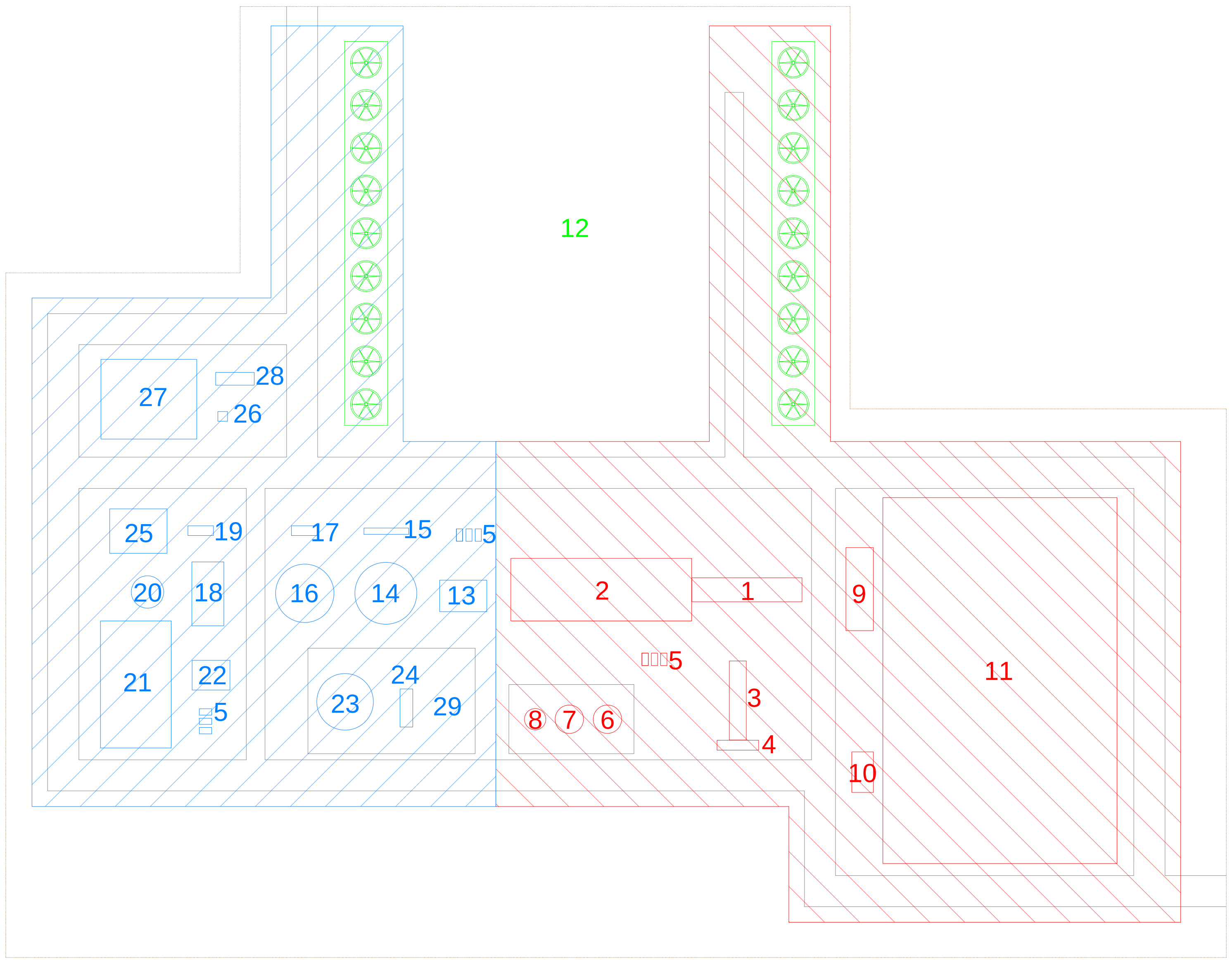




ITEM No.	DESCRIPTION
1	GAS TURBINE
2	HEAT RECOVERY STEAM GENERATOR
3	STEAM TURBINE
4	CONDENSER
5	PUMPS (VARIOUS)
6	DEMINERALISED WATER TANK
7	RAW WATER TANK
8	NEUTRALISED WATER TANK
9	GT TRANSFORMER
10	ST TRANSFORMER
11	SWITCHYARD
12	COOLING TOWERS
13	FLUE GAS BLOWER
14	DIRECT CONTACT COOLER
15	DCC CIRCULATING WATER COOLER
16	ABSORBER
17	WATER WASH COOLER
18	THERMAL RECLAIMER PACKAGE
19	LEAN TRIM COOLER
20	CO2 STRIPPER COLUMN
21	CO2 STRIPPER REBOILER
22	CO2 STRIPPER CONDENSER
23	LEAN AMINE STORAGE TANK
24	FRESH AMINE STORAGE TANK
25	LEAN-RICH CROSS-EXCHANGER
26	DE-OXYGENATION PACKAGE
27	COMPRESSOR STAGES
28	CO2 PRODUCT METERING PACKAGE
29	FLEX-CCS EQUIPMENT AREA (FUTURE)

NOT FOR CONSTRUCTION

FOR INFORMATION ONLY

AECOM

PROJECT

DECARBONISATION READINESS

CLIENT

BEIS

CONSULTANT

AECOM
Portwall Place
Bristol BS1 6NA
+44 (0) 117 001 7000 tel 7099 fax
www.AECOM.com

LEGEND

- POWER ISLAND
- COOLING SYSTEM
- CAPTURE PLANT
- SITE FENCELINE

NOTES

1. DRAWING IS FOR INDICATIVE PURPOSES ONLY
2. FOOTPRINT OF THE OVERALL SITE IS APPROX. 97,000M^2
3. FOOTPRINT OF THE POWER ISLAND EQUIPMENT IS APPROX. 35,500M^2
4. FOOTPRINT OF THE CAPTURE PLANT EQUIPMENT IS APPROX. 26,500M^2
5. FACILITY NET EXPORT CAPACITY = 720MW @ISO WITH COOLING TOWERS

0 25 50 m
1:1000

APPROVED FOR ISSUE

A	JC	KM	KM
I/R	DRAWN BY	CHECKED	APPROVED

ISSUE/REVISION

A	28/03/22	FIRST ISSUE
I/R	DATE	DESCRIPTION

PROJECT NUMBER

60677821

SHEET TITLE

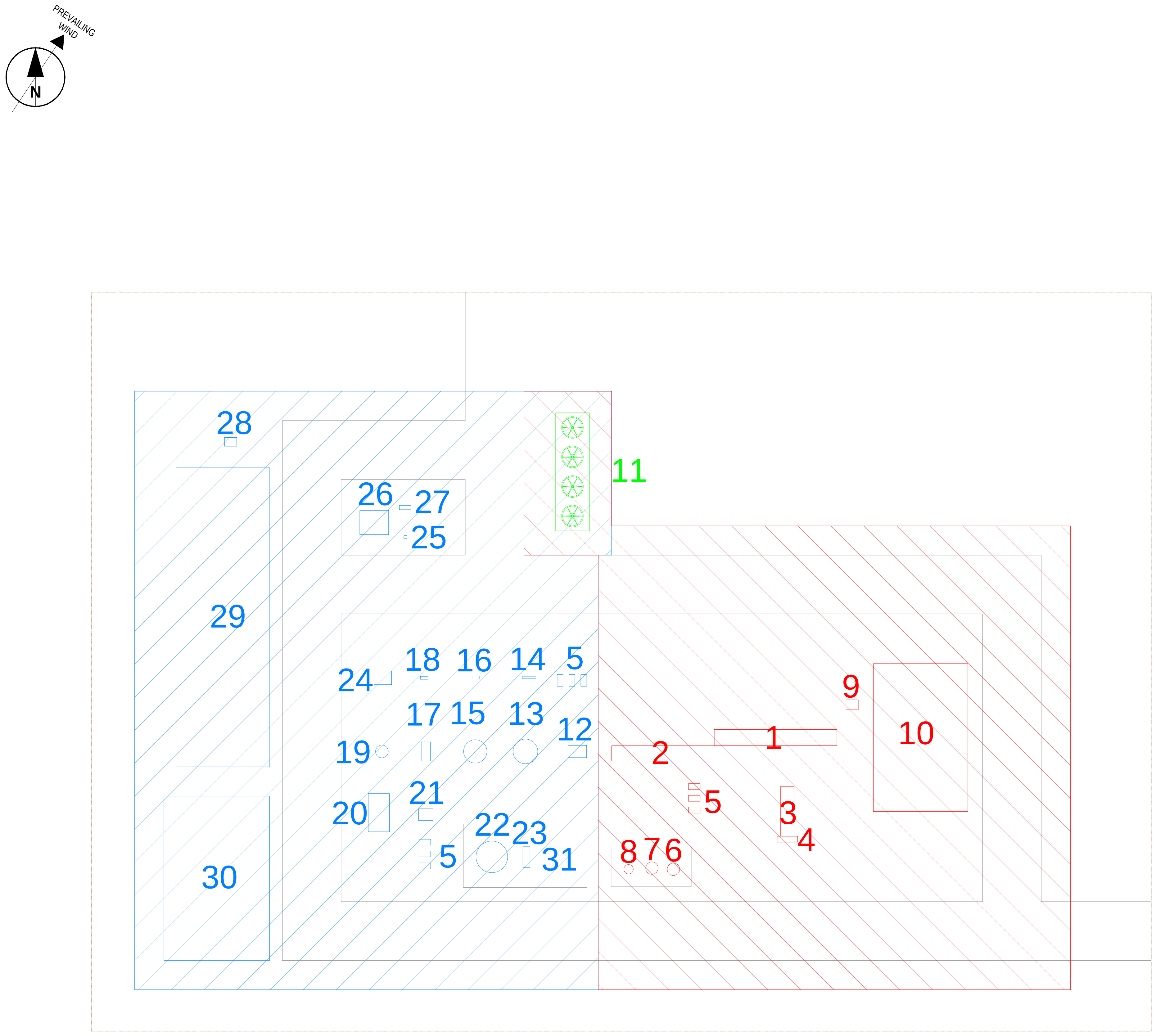
CCS CASE STUDY 3 - LARGE CCGT LAYOUT

SHEET NUMBER

60677821-CC-DR-013

Last saved by: JAMIE.CALVERT(2022-04-04) Last Plotted: 2022-04-07 AutoCAD Version: 23.1S (LMS TECH)
Filename: C:\USERS\JAMIE.CALVERT\AECOM\BEIS - DECARBONISATION READINESS - DOCUMENTS\GENERAL\400_TECHNICAL\409 DRAWINGS\LOT 2 - CC DRAWINGS\60677821-CC-DR-013 - CS3 LARGE CCGT LAYOUT - REV A.DWG

Project Management Initials: Designer: Checked: Approved:



ITEM No.	DESCRIPTION
1	GAS TURBINE
2	HEAT RECOVERY STEAM GENERATOR
3	STEAM TURBINE
4	CONDENSER
5	PUMPS (VARIOUS)
6	DEMINERALISED WATER TANK
7	RAW WATER TANK
8	NEUTRALISED WATER TANK
9	LV TRANSFORMER
10	SWITCHYARD
11	COOLING TOWERS
12	FLUE GAS BLOWER
13	DIRECT CONTACT COOLER
14	DCC CIRCULATING WATER COOLER
15	ABSORBER
16	WATER WASH COOLER
17	THERMAL RECLAIMER PACKAGE
18	LEAN TRIM COOLER
19	CO2 STRIPPER COLUMN
20	CO2 STRIPPER REBOILER
21	CO2 STRIPPER CONDENSER
22	LEAN AMINE STORAGE TANK
23	FRESH AMINE STORAGE TANK
24	LEAN-RICH CROSS-EXCHANGER
25	DE-OXYGENATION PACKAGE
26	COMPRESSOR STAGES
27	CO2 PRODUCT METERING PACKAGE
28	LIQUEFACTION PACKAGE
29	STORAGE BULLETS
30	ROAD TRUCK RECEIVING FACILITY
31	FLEX-CCS EQUIPMENT AREA (FUTURE)

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FOR INFORMATION ONLY

AECOM

PROJECT

DECARBONISATION READINESS

CLIENT

BEIS

CONSULTANT

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Portwall Place
Bristol BS1 6NA
+44 (0) 117 001 7000 tel 7099 fax
www.AECOM.com

LEGEND

- POWER ISLAND
- COOLING SYSTEM
- CAPTURE PLANT
- SITE FENCELINE

NOTES

1. THIS GENERAL ARRANGEMENT DRAWING IS PRELIMINARY, INFORMED BY FEL 1 LEVEL DEFINITION. INDIVIDUAL PROJECTS SHOULD UNDERTAKE THEIR OWN STUDIES TO INFORM THEIR SPECIFIC REQUIREMENTS
2. FOOTPRINT OF THE OVERALL SITE IS APPROX. 22,800M^2
3. FOOTPRINT OF THE POWER ISLAND EQUIPMENT IS APPROX. 6,800M^2
4. FOOTPRINT OF THE CAPTURE PLANT EQUIPMENT IS APPROX. 8,100M^2
5. FACILITY NET EXPORT CAPACITY = 12MW @ ISO WITH COOLING TOWERS

0 10 20 m

1:400

APPROVED FOR ISSUE

A	JC	KM	KM
I/R	DRAWN BY	CHECKED	APPROVED

ISSUE/REVISION

A	04/04/2022	FIRST ISSUE
I/R	DATE	DESCRIPTION

PROJECT NUMBER

60677821

SHEET TITLE

CCS CASE STUDY 4 - SMALL CCGT CHP LAYOUT

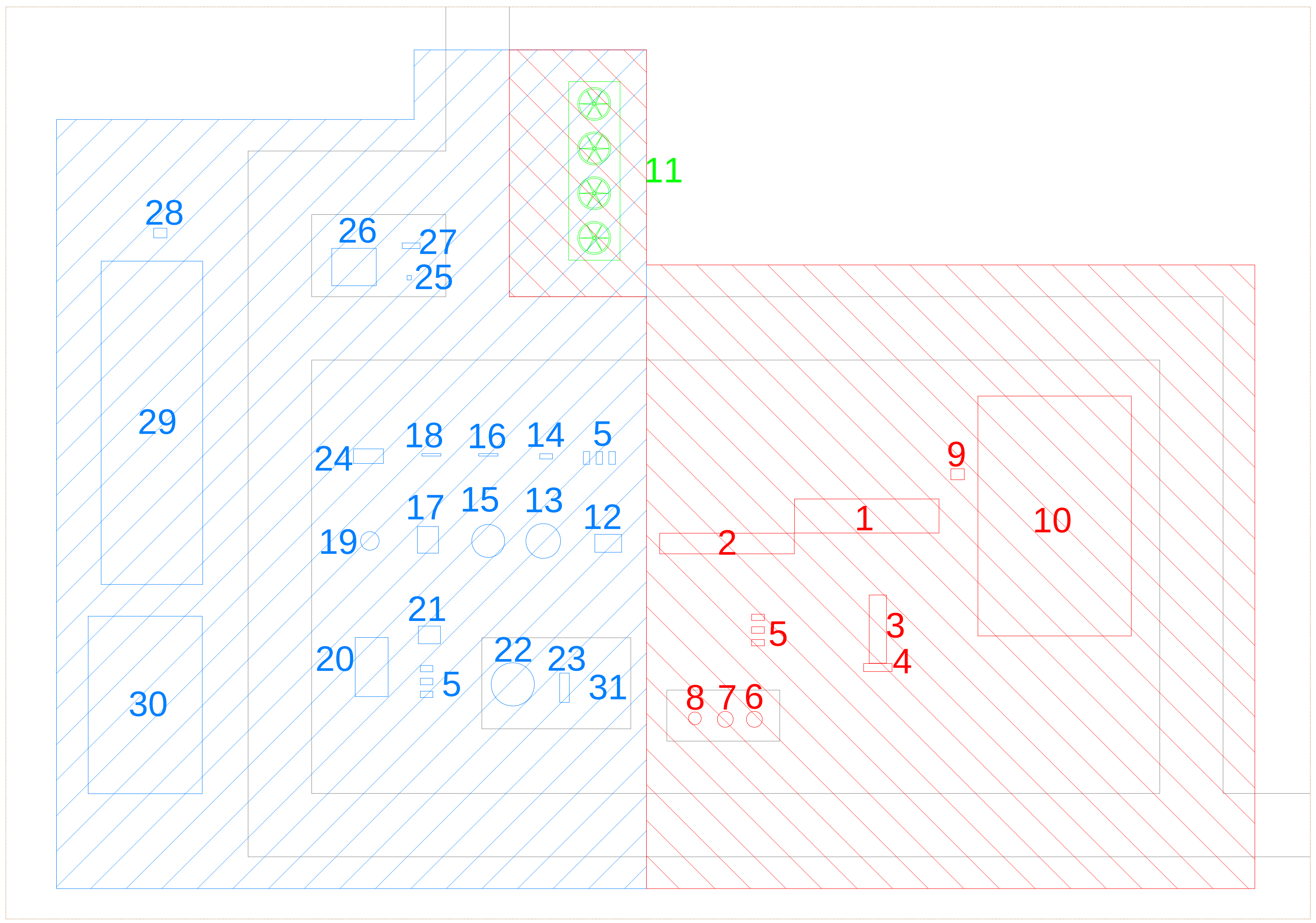
SHEET NUMBER

60677821-CC-DR-021

Last saved by: JAMIE.CALVERT(2022-04-05) Last Plotted: 2022-04-05
Filename: C:\USERS\JAMIE.CALVERT\AECOM\BEIS - DECARBONISATION READINESS - DOCUMENTS\GENERAL\400_TECHNICAL\409 DRAWINGS\LOT 2 - CC DRAWINGS\60677821-CC-DR-021 - CS4 SMALL CCGT CHP LAYOUT - REV A.DWG
AutoCAD Version: 23.1S (LMS TECH)
Project Management Initials: Designer: Checked: Approved:

PREVAILING WIND

N



ITEM No.	DESCRIPTION
1	GAS TURBINE
2	HEAT RECOVERY STEAM GENERATOR
3	STEAM TURBINE
4	CONDENSER
5	PUMPS (VARIOUS)
6	DEMINERALISED WATER TANK
7	RAW WATER TANK
8	NEUTRALISED WATER TANK
9	LV TRANSFORMER
10	SWITCHYARD
11	COOLING TOWERS
12	FLUE GAS BLOWER
13	DIRECT CONTACT COOLER
14	DCC CIRCULATING WATER COOLER
15	ABSORBER
16	WATER WASH COOLER
17	THERMAL RECLAIMER PACKAGE
18	LEAN TRIM COOLER
19	CO2 STRIPPER COLUMN
20	CO2 STRIPPER REBOILER
21	CO2 STRIPPER CONDENSER
22	LEAN AMINE STORAGE TANK
23	FRESH AMINE STORAGE TANK
24	LEAN-RICH CROSS-EXCHANGER
25	DE-OXYGENATION PACKAGE
26	COMPRESSOR STAGES
27	CO2 PRODUCT METERING PACKAGE
28	LIQUEFACTION PACKAGE
29	STORAGE BULLETS
30	ROAD TRUCK RECEIVING FACILITY
31	FLEX-CCS EQUIPMENT AREA (FUTURE)

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PROJECT

DECARBONISATION READINESS

CLIENT

BEIS

CONSULTANT

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www.AECOM.com

LEGEND

- POWER ISLAND
- COOLING SYSTEM
- CAPTURE PLANT
- SITE FENCELINE

NOTES

1. THIS GENERAL ARRANGEMENT DRAWING IS PRELIMINARY, INFORMED BY FEL 1 LEVEL DEFINITION. INDIVIDUAL PROJECTS SHOULD UNDERTAKE THEIR OWN STUDIES TO INFORM THEIR SPECIFIC REQUIREMENTS
2. FOOTPRINT OF THE OVERALL SITE IS APPROX. 29,600M^2
3. FOOTPRINT OF THE POWER ISLAND EQUIPMENT IS APPROX. 10,300M^2
4. FOOTPRINT OF THE CAPTURE PLANT EQUIPMENT IS APPROX. 11,700M^2
5. FACILITY NET EXPORT CAPACITY = 28MW @ ISO WITH COOLING TOWERS

0 12.5 25 m

1:500

APPROVED FOR ISSUE

A	JC	KM	KM
I/R	DRAWN BY	CHECKED	APPROVED

ISSUE/REVISION

A	04/04/22	FIRST ISSUE
I/R	DATE	DESCRIPTION

PROJECT NUMBER

60677821

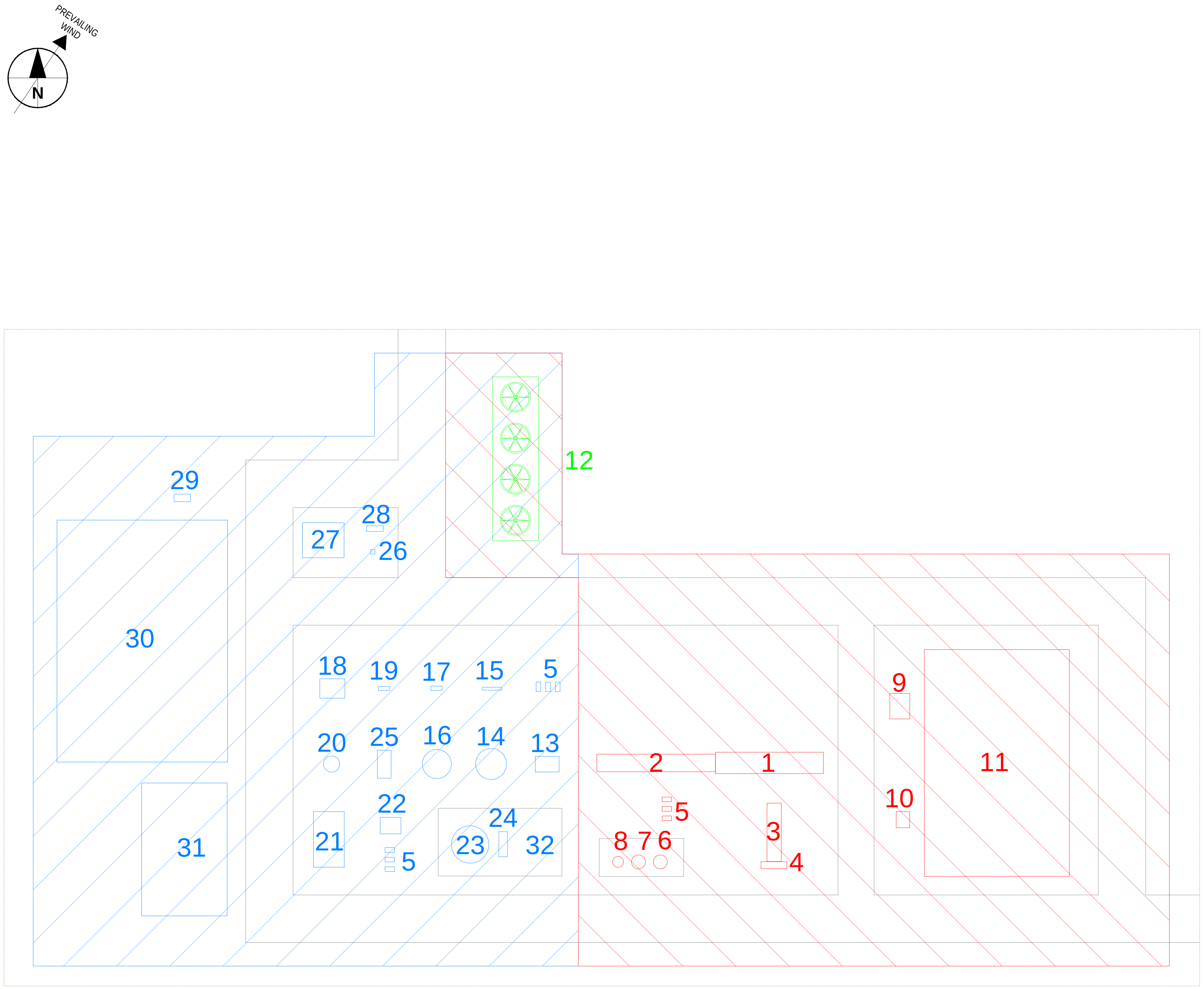
SHEET TITLE

CCS CASE STUDY 5 - MEDIUM CCGT CHP LAYOUT

SHEET NUMBER

60677821-CC-DR-022

Last saved by: JAMIE.CALVERT(2022-04-05) Last Plotted: 2022-04-05 AutoCAD Version: 23.1S (LMS TECH)
Filename: C:\USERS\JAMIE.CALVERT\AECOM\BEIS - DECARBONISATION READINESS - DOCUMENTS\GENERAL\400_TECHNICAL\409 DRAWINGS\LOT 2 - CC DRAWINGS\60677821-CC-DR-022 - CS5 MEDIUM CCGT CHP LAYOUT - REV A.DWG
Project Management Initials: Designer: ____ Checked: ____ Approved: ____



ITEM No.	DESCRIPTION
1	GAS TURBINE
2	HEAT RECOVERY STEAM GENERATOR
3	STEAM TURBINE
4	CONDENSER
5	PUMPS (VARIOUS)
6	DEMINERALISED WATER TANK
7	RAW WATER TANK
8	NEUTRALISED WATER TANK
9	GT TRANSFORMER
10	ST TRANSFORMER
11	SWITCHYARD
12	COOLING TOWERS
13	FLUE GAS BLOWER
14	DIRECT CONTACT COOLER
15	DCC CIRCULATING WATER COOLER
16	ABSORBER
17	WATER WASH COOLER
18	LEAN-RICH CROSS-EXCHANGER
19	LEAN TRIM COOLER
20	CO2 STRIPPER COLUMN
21	CO2 STRIPPER REBOILER
22	CO2 STRIPPER CONDENSER
23	LEAN AMINE STORAGE TANK
24	FRESH AMINE STORAGE TANK
25	THERMAL RECLAIMER PACKAGE
26	DE-OXYGENATION PACKAGE
27	COMPRESSOR STAGES
28	CO2 PRODUCT METERING PACKAGE
29	LIQUEFACTION PACKAGE
30	STORAGE BULLETS
31	ROAD TRUCK RECEIVING FACILITY
32	FLEX-CCS EQUIPMENT AREA (FUTURE)

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AECOM

PROJECT

DECARBONISATION READINESS

CLIENT

BEIS

CONSULTANT

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+44 (0) 117 001 7000 tel 7099 fax
www.AECOM.com

LEGEND

- POWER ISLAND
- COOLING SYSTEM
- CAPTURE PLANT
- SITE FENCELINE

NOTES

1. THIS GENERAL ARRANGEMENT DRAWING IS PRELIMINARY, INFORMED BY FEL 1 LEVEL DEFINITION. INDIVIDUAL PROJECTS SHOULD UNDERTAKE THEIR OWN STUDIES TO INFORM THEIR SPECIFIC REQUIREMENTS
2. FOOTPRINT OF THE OVERALL SITE IS APPROX. 34,200M²
3. FOOTPRINT OF THE POWER ISLAND EQUIPMENT IS APPROX. 12,000M²
4. FOOTPRINT OF THE CAPTURE PLANT EQUIPMENT IS APPROX. 13,400M²
5. FACILITY NET EXPORT CAPACITY = 47MW @ ISO WITH COOLING TOWERS

0 12.5 25 m
1:500

APPROVED FOR ISSUE

I/R	DRAWN BY	CHECKED	APPROVED
A	JC	KM	KM

ISSUE/REVISION

I/R	DATE	DESCRIPTION
A	05/04/22	FIRST ISSUE

PROJECT NUMBER

60677821

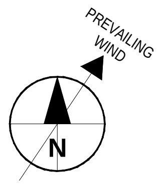
SHEET TITLE

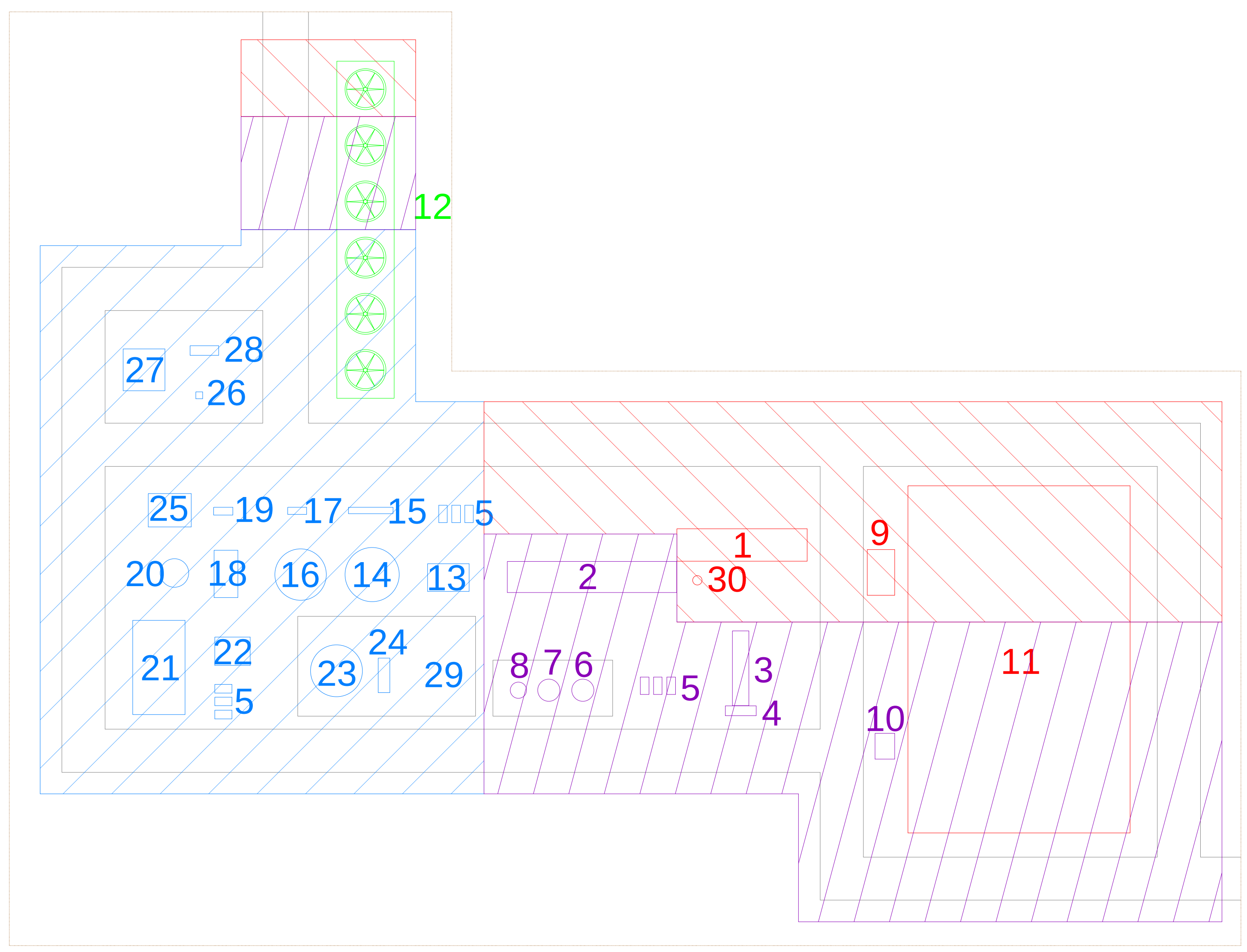
CCS CASE STUDY 6 - LARGE CCGT CHP LAYOUT

SHEET NUMBER

60677821-CC-DR-023

Last saved by: JAMIE.CALVERT(2022-04-06) Last Plotted: 2022-04-06 AutoCAD Version: 23.1S (LMS TECH) Project Management Initials: Designer: Checked: Approved:
Filename: C:\USERS\JAMIE.CALVERT\AECOM\BEIS - DECARBONISATION READINESS - DOCUMENTS\GENERAL\400_TECHNICAL\409 DRAWINGS\LOT 2 - CC DRAWINGS\60677821-CC-DR-023 - CS6 LARGE CCGT CHP LAYOUT - REV A.DWG





ITEM No.	DESCRIPTION
1	GAS TURBINE
2	HEAT RECOVERY STEAM GENERATOR
3	STEAM TURBINE
4	CONDENSER
5	PUMPS (VARIOUS)
6	DEMINERALISED WATER TANK
7	RAW WATER TANK
8	NEUTRALISED WATER TANK
9	GT TRANSFORMER
10	ST TRANSFORMER
11	SWITCHYARD
12	COOLING TOWERS
13	FLUE GAS BLOWER
14	DIRECT CONTACT COOLER
15	DCC CIRCULATING WATER COOLER
16	ABSORBER
17	WATER WASH COOLER
18	THERMAL RECLAIMER PACKAGE
19	LEAN TRIM COOLER
20	CO_2 STRIPPER COLUMN
21	CO_2 STRIPPER REBOILER
22	CO_2 STRIPPER CONDENSER
23	LEAN AMINE STORAGE TANK
24	FRESH AMINE STORAGE TANK
25	LEAN-RICH CROSS-EXCHANGER
26	DE-OXYGENATION PACKAGE
27	COMPRESSOR STAGES
28	CO_2 PRODUCT METERING PACKAGE
29	FLEX-CCS EQUIPMENT AREA (FUTURE)
30	OCGT STACK (ORIGINAL)

NOT FOR CONSTRUCTION

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PROJECT

DECARBONISATION READINESS

CLIENT

BEIS

CONSULTANT

AECOM
Portwall Place
Bristol BS1 6NA
+44 (0) 117 001 7000 tel 7099 fax
www.AECOM.com

LEGEND

- OCGT PLANT
- CCGT REPOWERING, WASTE HEAT RECOVERY UNIT & STEAM CYCLE
- COOLING SYSTEM
- CAPTURE PLANT
- SITE FENCELINE

NOTES

1. THIS GENERAL ARRANGEMENT DRAWING IS PRELIMINARY, INFORMED BY FEL 1 LEVEL DEFINITION. INDIVIDUAL PROJECTS SHOULD UNDERTAKE THEIR OWN STUDIES TO INFORM THEIR SPECIFIC REQUIREMENTS
2. FOOTPRINT OF THE OVERALL SITE IS APPROX. 46,000M^2
3. FOOTPRINT OF THE OCGT EQUIPMENT IS APPROX. 8,500M^2
4. FOOTPRINT OF THE CCGT REPOWERING EQUIPMENT IS APPROX. 11,700M^2
5. FOOTPRINT OF THE CAPTURE PLANT EQUIPMENT IS APPROX. 12,600M^2
6. FACILITY NET EXPORT CAPACITY = 177MWe @ ISO WITH COOLING TOWERS

0 18.75 37.5 m
1:750

APPROVED FOR ISSUE

I/R	DRAWN BY	CHECKED	APPROVED
A	JC	KM	KM

ISSUE/REVISION

I/R	DATE	DESCRIPTION
A	05/04/22	FIRST ISSUE

PROJECT NUMBER

60677821

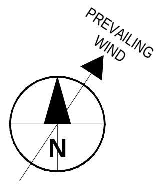
SHEET TITLE

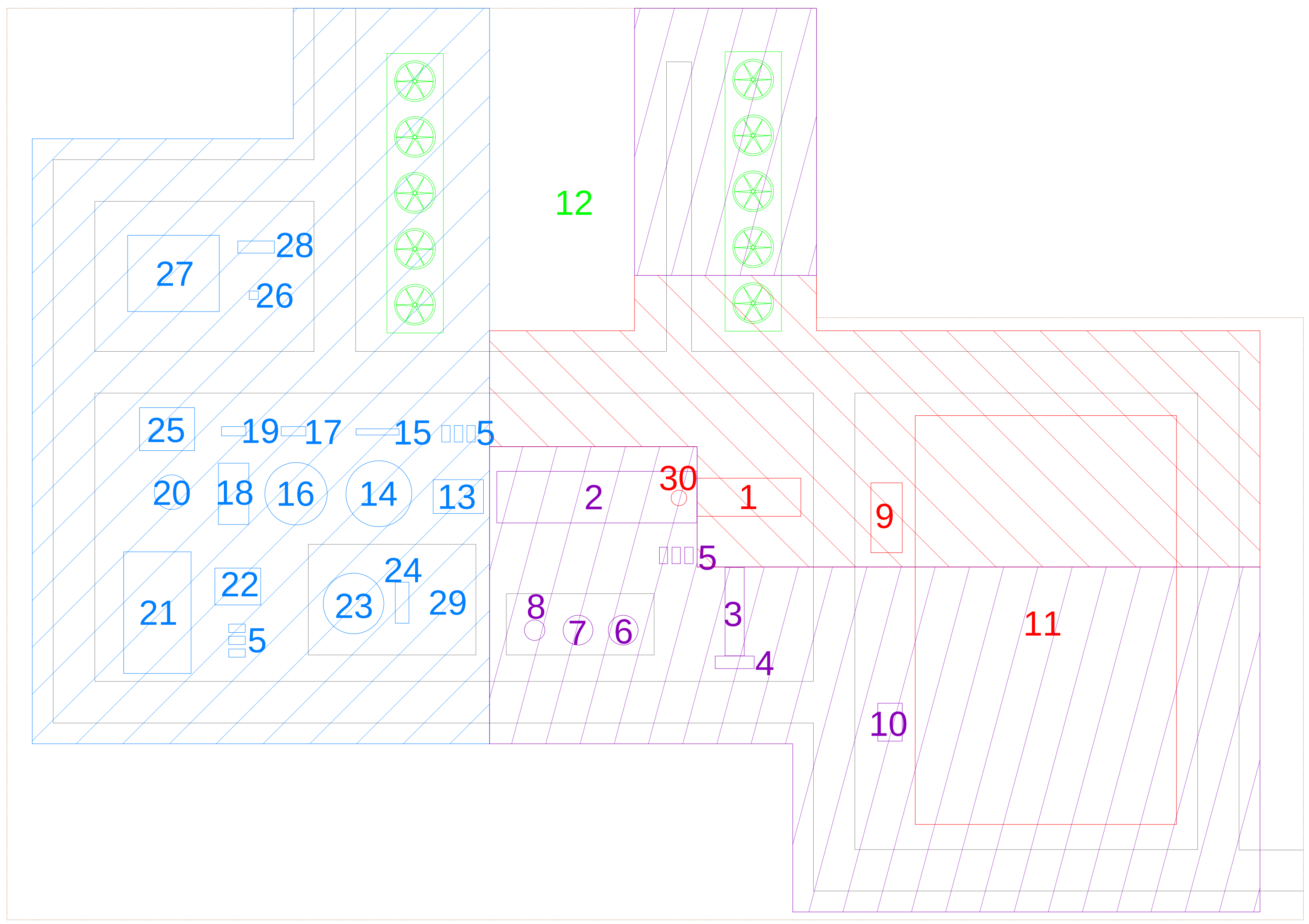
CCS CASE STUDY 7 - SMALL OCGT LAYOUT

SHEET NUMBER

60677821-CC-DR-031

Last saved by: JAMIE.CALVERT(2022-04-05) Last Plotted: 2022-04-05
Filename: C:\USERS\JAMIE.CALVERT\AECOM\BEIS - DECARBONISATION READINESS - DOCUMENTS\GENERAL\400_TECHNICAL\409 DRAWINGS\LOT 2 - CC DRAWINGS\60677821-CC-DR-031 - CS7 SMALL OCGT LAYOUT - REV A.DWG
AutoCAD Version: 23.1S (LMS TECH)
Project Management Initials: Designer: Checked: Approved:





ITEM No.	DESCRIPTION
1	GAS TURBINE
2	HEAT RECOVERY STEAM GENERATOR
3	STEAM TURBINE
4	CONDENSER
5	PUMPS (VARIOUS)
6	DEMINERALISED WATER TANK
7	RAW WATER TANK
8	NEUTRALISED WATER TANK
9	GT TRANSFORMER
10	ST TRANSFORMER
11	SWITCHYARD
12	COOLING TOWERS
13	FLUE GAS BLOWER
14	DIRECT CONTACT COOLER
15	DCC CIRCULATING WATER COOLER
16	ABSORBER
17	WATER WASH COOLER
18	THERMAL RECLAIMER PACKAGE
19	LEAN TRIM COOLER
20	CO2 STRIPPER COLUMN
21	CO2 STRIPPER REBOILER
22	CO2 STRIPPER CONDENSER
23	LEAN AMINE STORAGE TANK
24	FRESH AMINE STORAGE TANK
25	LEAN-RICH CROSS-EXCHANGER
26	DE-OXYGENATION PACKAGE
27	COMPRESSOR STAGES
28	CO2 PRODUCT METERING PACKAGE
29	FLEX-CCS EQUIPMENT AREA (FUTURE)
30	OCGT STACK (ORIGINAL)

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PROJECT

DECARBONISATION READINESS

CLIENT

BEIS

CONSULTANT

AECOM
Portwall Place
Bristol BS1 6NA
+44 (0) 117 001 7000 tel 7099 fax
www.AECOM.com

LEGEND

- OCGT PLANT
- CCGT REPOWERING, WASTE HEAT RECOVERY UNIT & STEAM CYCLE
- COOLING SYSTEM
- CAPTURE PLANT
- SITE FENCELINE

NOTES

1. THIS GENERAL ARRANGEMENT DRAWING IS PRELIMINARY, INFORMED BY FEL 1 LEVEL DEFINITION. INDIVIDUAL PROJECTS SHOULD UNDERTAKE THEIR OWN STUDIES TO INFORM THEIR SPECIFIC REQUIREMENTS
2. FOOTPRINT OF THE OVERALL SITE IS APPROX. 60,000M^2
3. FOOTPRINT OF THE OCGT EQUIPMENT IS APPROX. 9,600M^2
4. FOOTPRINT OF THE CCGT REPOWERING EQUIPMENT IS APPROX. 16,600M^2
5. FOOTPRINT OF CAPTURE PLANT EQUIPMENT IS APPROX. 17,400M^2
6. FACILITY NET EXPORT CAPACITY = 335MWe @ ISO WITH COOLING TOWERS

0 18.75 37.5 m
1:750

APPROVED FOR ISSUE

I/R	DRAWN BY	CHECKED	APPROVED
A	JC	KM	KM

ISSUE/REVISION

I/R	DATE	DESCRIPTION
A	05/04/22	FIRST ISSUE

PROJECT NUMBER

60677821

SHEET TITLE

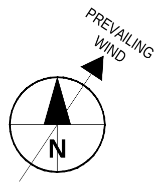
CCS CASE STUDY 8 - MEDIUM OCGT LAYOUT

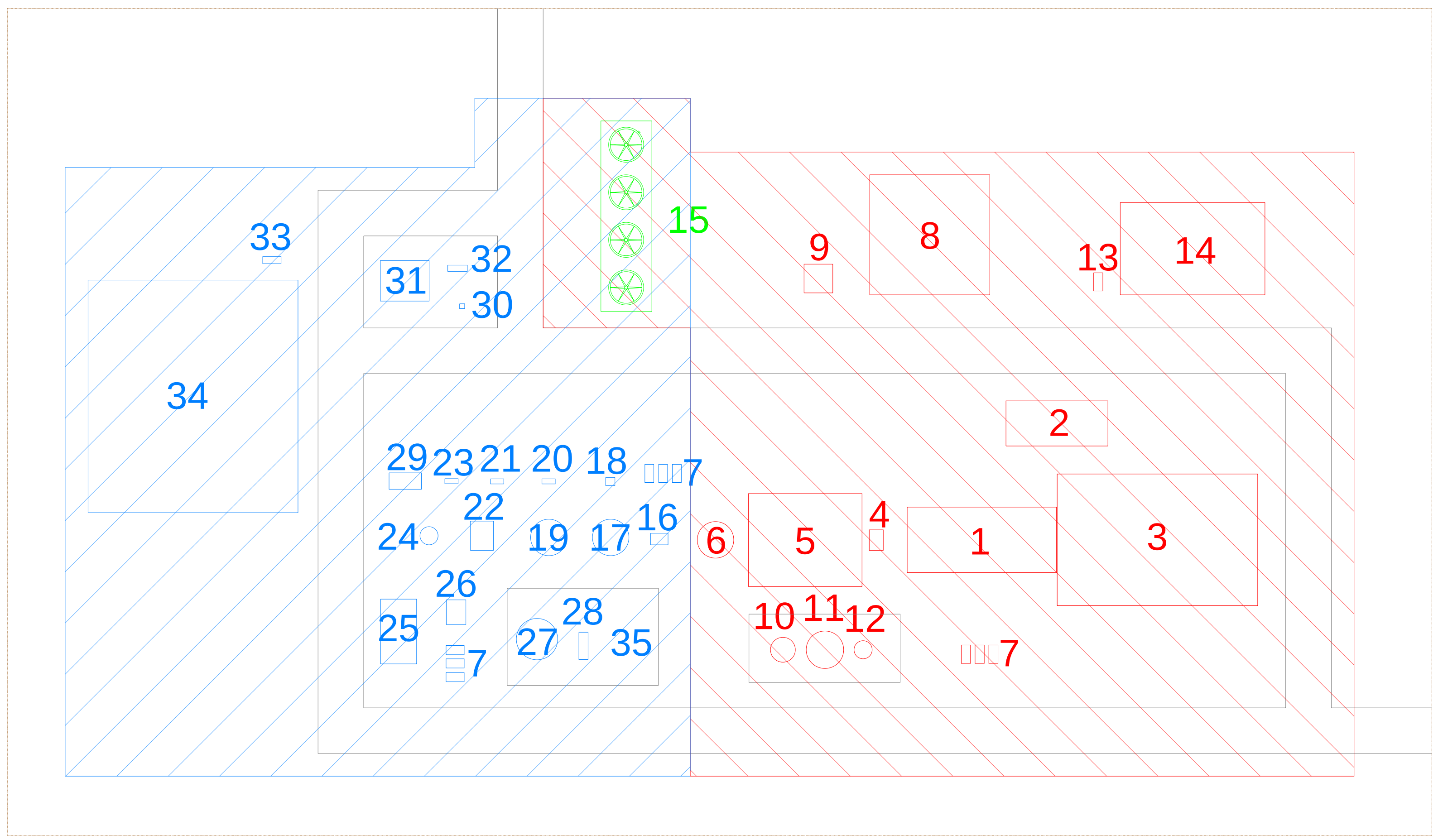
SHEET NUMBER

60677821-CC-DR-032

Project Management Initials: Designer: Checked: Approved:

Last saved by: JAMIE.CALVERT(2022-04-05) Last Plotted: 2022-04-05
Filename: C:\USERS\JAMIE.CALVERT\AECOM\BEIS - DECARBONISATION READINESS - DOCUMENTS\GENERAL\400_TECHNICAL\409 DRAWINGS\LOT 2 - CC DRAWINGS\60677821-CC-DR-032 - CS8 MEDIUM OCGT LAYOUT - REV A.DWG
AutoCAD Version: 23.1S (LMS TECH)





ITEM No.	DESCRIPTION
1	BOILER
2	STEAM TURBINE + CONDENSER AREA
3	FUEL RECEIVING AREA
4	ID FAN
5	FLUE GAS DESULFURISATION
6	STACK
7	PUMPS (VARIOUS)
8	COMBUSTION WASTE STORAGE
9	REAGENT STORAGE
10	DEMINERALISED WATER TANK
11	RAW WATER TANK
12	NEUTRALISED WATER TANK
13	TRANSFORMERS
14	SWITCHYARD
15	COOLING TOWERS
16	FLUE GAS BLOWER
17	DIRECT CONTACT COOLER
18	DCC CIRCULATING WATER COOLER
19	ABSORBER
20	WATER WASH COOLER
21	ABSORBER INTERSTAGE COOLER
22	THERMAL RECLAIMER PACKAGE
23	LEAN TRIM COOLER
24	CO2 STRIPPER COLUMN
25	CO2 STRIPPER REBOILER
26	CO2 STRIPPER CONDENSER
27	LEAN AMINE STORAGE TANK
28	FRESH AMINE STORAGE TANK
29	LEAN-RICH CROSS-EXCHANGER
30	DE-OXYGENATION PACKAGE
31	COMPRESSOR STAGES
32	CO2 PRODUCT METERING PACKAGE
33	LIQUEFACTION PACKAGE
34	STORAGE BULLETS
35	FLEX-CCS EQUIPMENT AREA (FUTURE)

NOT FOR CONSTRUCTION
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DECARBONISATION READINESS

CLIENT
BEIS

CONSULTANT
AECOM
Portwall Place
Bristol BS1 6NA
+44 (0) 117 001 7000 tel 7099 fax
www.AECOM.com

LEGEND
- POWER ISLAND
- COOLING SYSTEM
- CAPTURE PLANT
- SITE FENCELINE

NOTES
1. DRAWING IS FOR INDICATIVE PURPOSES ONLY
2. FOOTPRINT OF THE OVERALL SITE IS APPROX. 56,500M^2
3. FOOTPRINT OF THE POWER ISLAND EQUIPMENT IS APPROX. 21,500M^2
4. FOOTPRINT OF THE CAPTURE PLANT EQUIPMENT IS APPROX. 19,000M^2
5. FACILITY NET EXPORT CAPACITY = 12MW @ ISO WITH COOLING TOWERS

0   18.75   37.5 m
1:750

APPROVED FOR ISSUE

A	JC	KM	KM
I/R	DRAWN BY	CHECKED	APPROVED

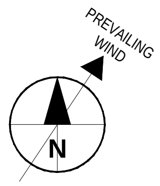
ISSUE/REVISION

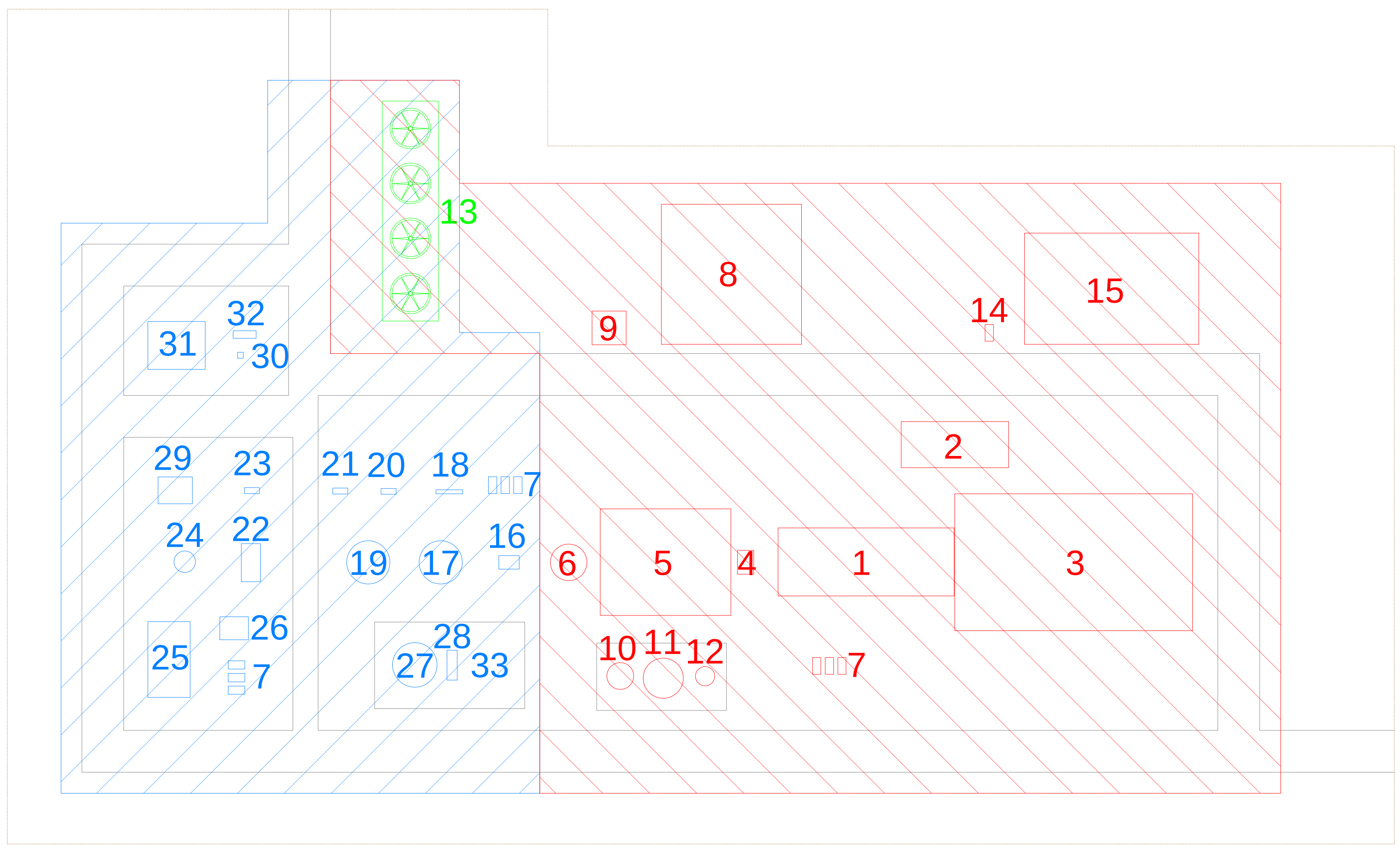
A	04/04/22	FIRST ISSUE
I/R	DATE	DESCRIPTION

PROJECT NUMBER
60677821

SHEET TITLE
CCS CASE STUDY 9 -
SMALL BOILER EFW LAYOUT

SHEET NUMBER
60677821-CC-DR-041





ITEM No.	DESCRIPTION
1	BOILER
2	STEAM TURBINE + CONDENSER AREA
3	FUEL RECEIVING AREA
4	ID FAN
5	FLUE GAS DESULFURISATION
6	STACK
7	PUMPS (VARIOUS)
8	COMBUSTION WASTE STORAGE
9	REAGENT STORAGE
10	DEMINERALISED WATER TANK
11	RAW WATER TANK
12	NEUTRALISED WATER TANK
13	TRANSFORMERS
14	SWITCHYARD
15	COOLING TOWERS
16	FLUE GAS BLOWER
17	DIRECT CONTACT COOLER
18	DCC CIRCULATING WATER COOLER
19	ABSORBER
20	WATER WASH COOLER
21	ABSORBER INTERSTAGE COOLER
22	THERMAL RECLAIMER PACKAGE
23	LEAN TRIM COOLER
24	CO2 STRIPPER COLUMN
25	CO2 STRIPPER REBOILER
26	CO2 STRIPPER CONDENSER
27	LEAN AMINE STORAGE TANK
28	FRESH AMINE STORAGE TANK
29	LEAN-RICH CROSS-EXCHANGER
30	DE-OXYGENATION PACKAGE
31	COMPRESSOR STAGES
32	CO2 PRODUCT METERING PACKAGE
33	FLEX-CCS EQUIPMENT AREA (FUTURE)

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PROJECT

DECARBONISATION READINESS

CLIENT

BEIS

CONSULTANT

AECOM
Portwall Place
Bristol BS1 6NA
+44 (0) 117 001 7000 tel 7099 fax
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LEGEND

- POWER ISLAND
- COOLING SYSTEM
- CAPTURE PLANT
- SITE FENCELINE

NOTES

1. THIS GENERAL ARRANGEMENT DRAWING IS PRELIMINARY, INFORMED BY FEL 1 LEVEL DEFINITION. INDIVIDUAL PROJECTS SHOULD UNDERTAKE THEIR OWN STUDIES TO INFORM THEIR SPECIFIC REQUIREMENTS
2. FOOTPRINT OF THE OVERALL SITE IS APPROX. 59,500M^2
3. FOOTPRINT OF THE POWER ISLAND EQUIPMENT IS APPROX. 28,600M^2
4. FOOTPRINT OF THE CAPTURE PLANT EQUIPMENT IS APPROX. 16,600M^2
5. FACILITY NET EXPORT CAPACITY = 23MW @ ISO WITH COOLING TOWERS

0 18.75 37.5 m
1:750

APPROVED FOR ISSUE

I/R	DRAWN BY	CHECKED	APPROVED
A	JC	KM	KM

ISSUE/REVISION

I/R	DATE	DESCRIPTION
A	06/04/22	FIRST ISSUE

PROJECT NUMBER

60677821

SHEET TITLE

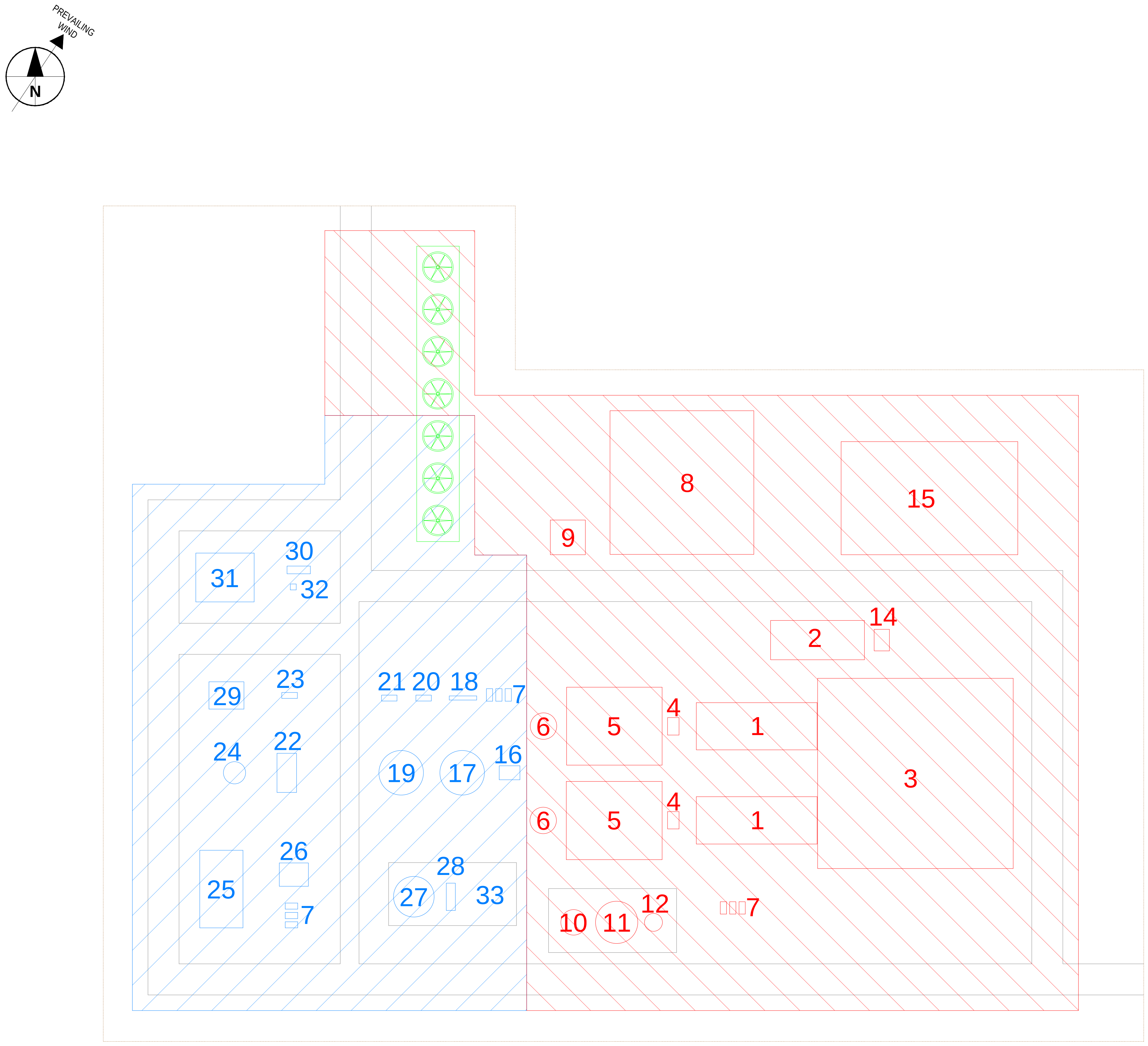
CCS CASE STUDY 10 - MEDIUM BOILER EFW LAYOUT

SHEET NUMBER

60677821-CC-DR-042

Last saved by: JAMIE.CALVERT(2022-04-07) Last Plotted: 2022-04-07 AutoCAD Version: 23.1S (LMS TECH)
Filename: C:\USERS\JAMIE.CALVERT\AECOM\BEIS - DECARBONISATION READINESS - DOCUMENTS\GENERAL\400_TECHNICAL\409 DRAWINGS\LOT 2 - CC DRAWINGS\60677821-CC-DR-042 - CS10 MEDIUM BOILER EFW LAYOUT - REV A.DWG

Project Management Initials: Designer: Checked: Approved:



ITEM No.	DESCRIPTION
1	BOILER
2	STEAM TURBINE + CONDENSER AREA
3	FUEL RECEIVING AREA
4	ID FAN
5	FLUE GAS DESULFURISATION
6	STACK
7	PUMPS (VARIOUS)
8	COMBUSTION WASTE STORAGE
9	REAGENT STORAGE
10	DEMINERALISED WATER TANK
11	RAW WATER TANK
12	NEUTRALISED WATER TANK
13	TRANSFORMERS
14	SWITCHYARD
15	COOLING TOWERS
16	FLUE GAS BLOWER
17	DIRECT CONTACT COOLER
18	DCC CIRCULATING WATER COOLER
19	ABSORBER
20	WATER WASH COOLER
21	ABSORBER INTERSTAGE COOLER
22	THERMAL RECLAIMER PACKAGE
23	LEAN TRIM COOLER
24	CO2 STRIPPER COLUMN
25	CO2 STRIPPER REBOILER
26	CO2 STRIPPER CONDENSER
27	LEAN AMINE STORAGE TANK
28	FRESH AMINE STORAGE TANK
29	LEAN-RICH CROSS-EXCHANGER
30	DE-OXYGENATION PACKAGE
31	COMPRESSOR STAGES
32	CO2 PRODUCT METERING PACKAGE
33	FLEX-CCS EQUIPMENT AREA (FUTURE)

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LEGEND

- POWER ISLAND
- COOLING SYSTEM
- CAPTURE PLANT
- SITE FENCELINE

NOTES

1. THIS GENERAL ARRANGEMENT DRAWING IS PRELIMINARY, INFORMED BY FEL 1 LEVEL DEFINITION. INDIVIDUAL PROJECTS SHOULD UNDERTAKE THEIR OWN STUDIES TO INFORM THEIR SPECIFIC REQUIREMENTS
2. FOOTPRINT OF THE OVERALL SITE IS APPROX. 79,400M^2
3. FOOTPRINT OF THE POWER ISLAND EQUIPMENT IS APPROX. 38,900M^2
4. FOOTPRINT OF THE CAPTURE PLANT EQUIPMENT IS APPROX. 22,200M^2
5. FACILITY NET EXPORT CAPACITY = 46MW @ ISO WITH COOLING TOWERS

0 18.75 37.5 m
1:750

APPROVED FOR ISSUE

I/R	DRAWN BY	CHECKED	APPROVED
A	JC		

ISSUE/REVISION

I/R	DATE	DESCRIPTION
A	28/03/22	FIRST ISSUE

PROJECT NUMBER

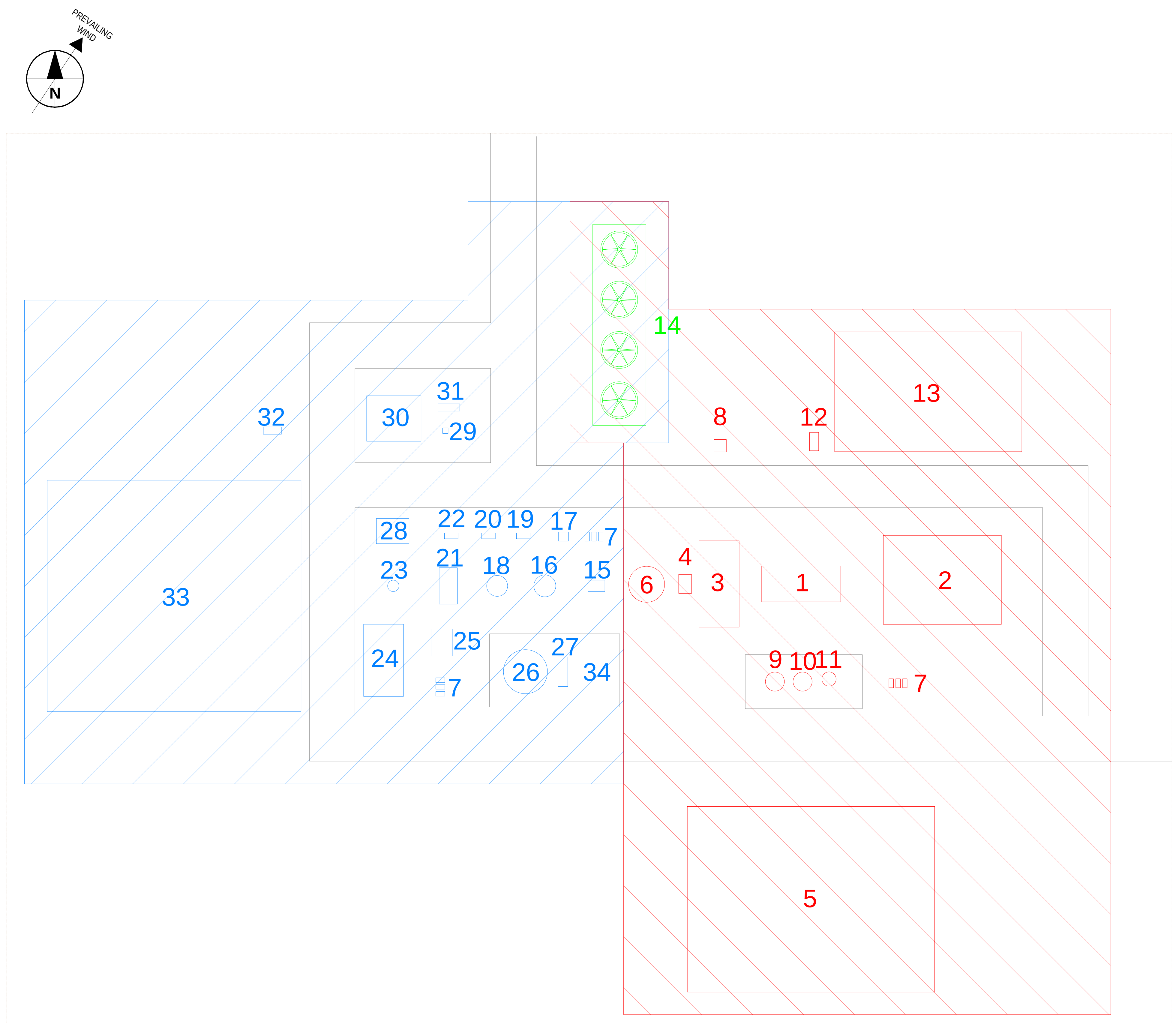
60677821

SHEET TITLE

CCS CASE STUDY 11 - LARGE BOILER EFW LAYOUT

SHEET NUMBER

60677821-CC-DR-043



ITEM No.	DESCRIPTION
1	BOILER
2	STEAM TURBINE + CONDENSER AREA
3	FABRIC FILTER
4	ID FAN
5	BIOMASS STORAGE AREA
6	STACK
7	PUMPS (VARIOUS)
8	COMBUSTION WASTE STORAGE
9	DEMINERALISED WATER TANK
10	RAW WATER TANK
11	NEUTRALISED WATER TANK
12	TRANSFORMERS
13	SWITCHYARD
14	COOLING TOWERS
15	FLUE GAS BLOWER
16	DIRECT CONTACT COOLER
17	DCC CIRCULATING WATER COOLER
18	ABSORBER
19	WATER WASH COOLER
20	ABSORBER INTERSTAGE COOLER
21	THERMAL RECLAIMER PACKAGE
22	LEAN TRIM COOLER
23	CO2 STRIPPER COLUMN
24	CO2 STRIPPER REBOILER
25	CO2 STRIPPER CONDENSER
26	LEAN AMINE STORAGE TANK
27	FRESH AMINE STORAGE TANK
28	LEAN-RICH CROSS-EXCHANGER
29	DE-OXYGENATION PACKAGE
30	COMPRESSOR STAGES
31	CO2 PRODUCT METERING PACKAGE
32	LIQUEFACTION PACKAGE
33	STORAGE BULLETS
34	FLEX-CCS EQUIPMENT AREA (FUTURE)

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PROJECT

DECARBONISATION READINESS

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LEGEND

- POWER ISLAND
- COOLING SYSTEM
- CAPTURE PLANT
- SITE FENCELINE

NOTES

1. THIS GENERAL ARRANGEMENT DRAWING IS PRELIMINARY, INFORMED BY FEL 1 LEVEL DEFINITION. INDIVIDUAL PROJECTS SHOULD UNDERTAKE THEIR OWN STUDIES TO INFORM THEIR SPECIFIC REQUIREMENTS
2. FOOTPRINT OF THE OVERALL SITE IS APPROX. 50,400M^2
3. FOOTPRINT OF THE POWER ISLAND EQUIPMENT IS APPROX. 17,600M^2
4. FOOTPRINT OF THE CAPTURE PLANT EQUIPMENT IS APPROX. 15,400M^2
5. FACILITY NET EXPORT CAPACITY = 26MW @ ISO WITH COOLING TOWERS

0   12.5   25 m
1:500

APPROVED FOR ISSUE

I/R	DRAWN BY	CHECKED	APPROVED
A	JC	KM	KM

ISSUE/REVISION

I/R	DATE	DESCRIPTION
A	06/04/22	FIRST ISSUE

PROJECT NUMBER

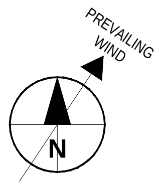
60677821

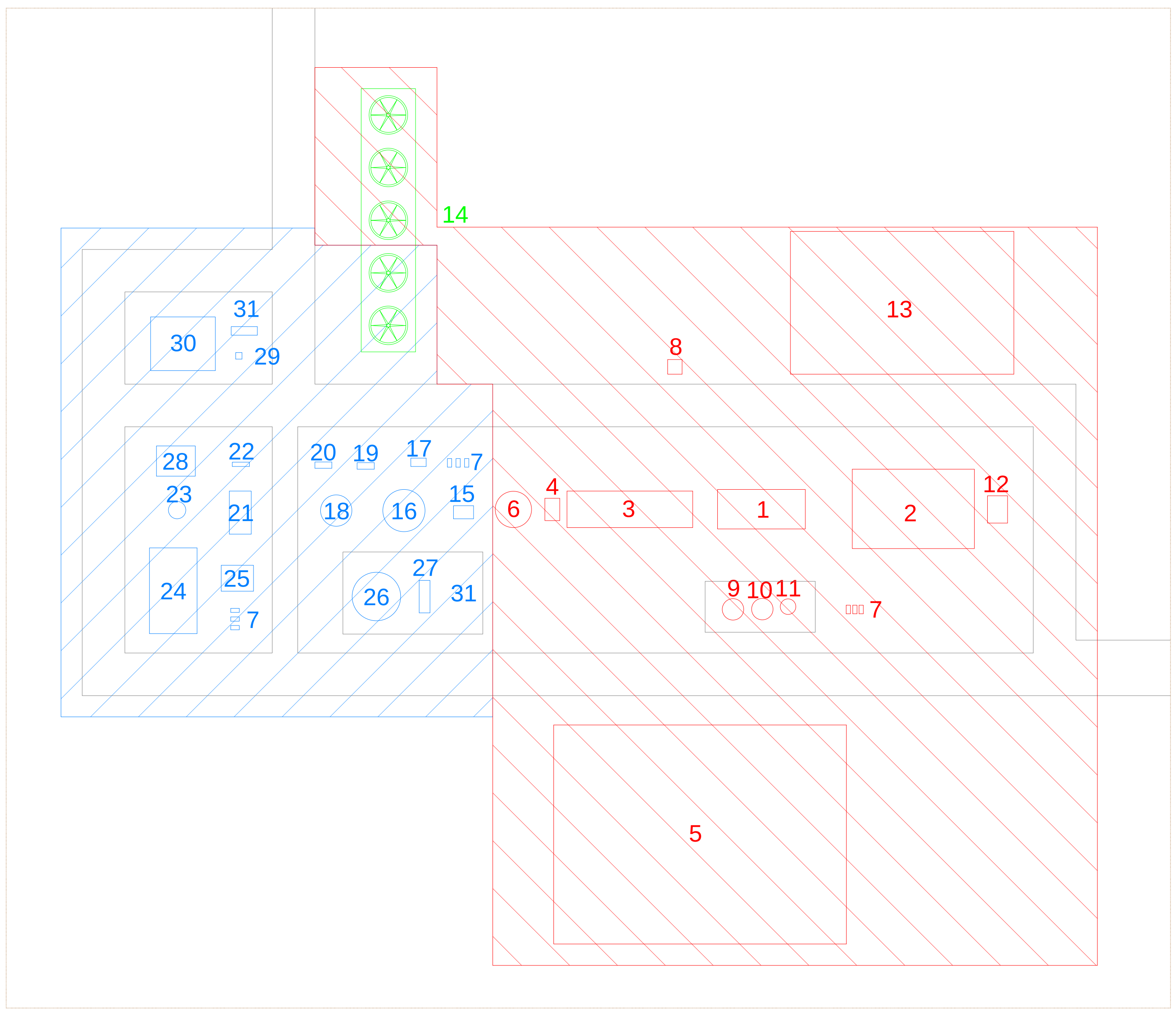
SHEET TITLE

CCS CASE STUDY 12 -
SMALL BOILER BIOMASS LAYOUT

SHEET NUMBER

60677821-CC-DR-051





ITEM No.	DESCRIPTION
1	BOILER
2	STEAM TURBINE + CONDENSER AREA
3	FABRIC FILTER
4	ID FAN
5	BIOMASS STORAGE AREA
6	STACK
7	PUMPS (VARIOUS)
8	COMBUSTION WASTE STORAGE
9	DEMINERALISED WATER TANK
10	RAW WATER TANK
11	NEUTRALISED WATER TANK
12	TRANSFORMERS
13	SWITCHYARD
14	COOLING TOWERS
15	FLUE GAS BLOWER
16	DIRECT CONTACT COOLER
17	DCC CIRCULATING WATER COOLER
18	ABSORBER
19	WATER WASH COOLER
20	ABSORBER INTERSTAGE COOLER
21	THERMAL RECLAIMER PACKAGE
22	LEAN TRIM COOLER
23	CO2 STRIPPER COLUMN
24	CO2 STRIPPER REBOILER
25	CO2 STRIPPER CONDENSER
26	LEAN AMINE STORAGE TANK
27	FRESH AMINE STORAGE TANK
28	LEAN-RICH CROSS-EXCHANGER
29	DE-OXYGENATION PACKAGE
30	COMPRESSOR STAGES
31	CO2 PRODUCT METERING PACKAGE
32	FLEX-CCS EQUIPMENT AREA (FUTURE)

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BEIS

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LEGEND

- POWER ISLAND
- COOLING SYSTEM
- CAPTURE PLANT
- ANCILLARY AREAS (OFF-SITE)
- SITE FENCELINE

NOTES

1. THIS GENERAL ARRANGEMENT DRAWING IS PRELIMINARY, INFORMED BY FEL 1 LEVEL DEFINITION. INDIVIDUAL PROJECTS SHOULD UNDERTAKE THEIR OWN STUDIES TO INFORM THEIR SPECIFIC REQUIREMENTS
2. FOOTPRINT OF THE OVERALL SITE IS APPROX. 64,000M^2
3. FOOTPRINT OF THE POWER ISLAND EQUIPMENT IS APPROX. 26,200M^2
4. FOOTPRINT OF THE CAPTURE PLANT EQUIPMENT IS APPROX. 11,000M^2
5. FACILITY NET EXPORT CAPACITY = 46MW @ ISO WITH COOLING TOWERS

0 18.75 37.5 m
1:750

APPROVED FOR ISSUE

I/R	DRAWN BY	CHECKED	APPROVED
A	JC	KM	KM

ISSUE/REVISION

I/R	DATE	DESCRIPTION
A	06/04/22	FIRST ISSUE

PROJECT NUMBER

60677821

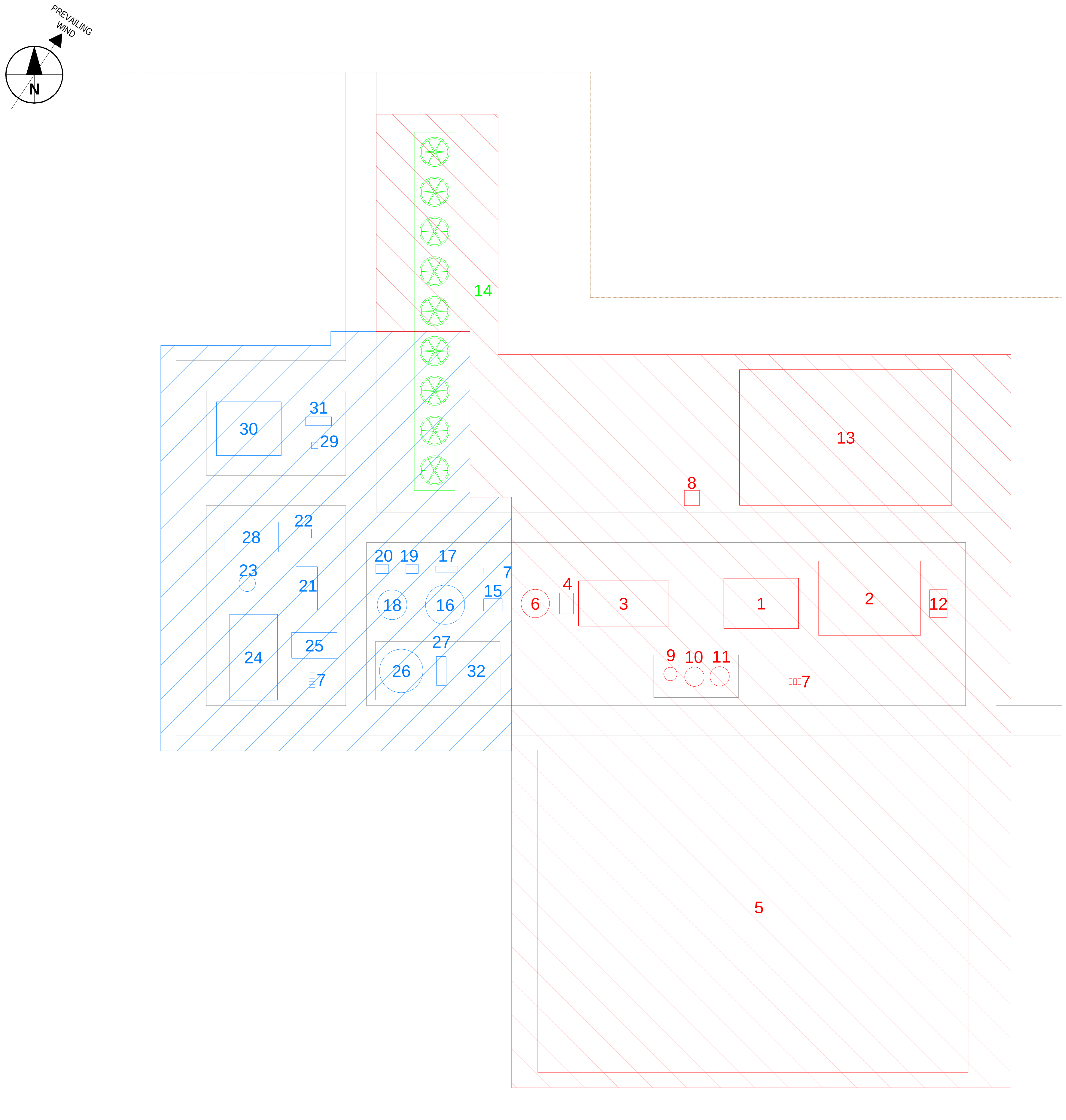
SHEET TITLE

CCS CASE STUDY 13 - MEDIUM BOILER BIOMASS LAYOUT

SHEET NUMBER

60677821-CC-DR-052

Last saved by: JAMIE.CALVERT(2022-04-07) Last Plotted: 2022-04-07 AutoCAD Version: 23.1S (LMS TECH) Project Management Initials: Designer: ____ Checked: ____ Approved: ____
Filename: C:\USERS\JAMIE.CALVERT\AECOM\BEIS - DECARBONISATION READINESS - DOCUMENTS\GENERAL\400_TECHNICAL\409 DRAWINGS\LOT 2 - CC DRAWINGS\60677821-CC-DR-052 - CS13 MEDIUM BOILER BIOMASS LAYOUT - REV A.DWG



ITEM No.	DESCRIPTION
1	BOILER
2	STEAM TURBINE + CONDENSER AREA
3	FABRIC FILTER
4	ID FAN
5	BIOMASS STORAGE AREA
6	STACK
7	PUMPS (VARIOUS)
8	COMBUSTION WASTE STORAGE
9	DEMINERALISED WATER TANK
10	RAW WATER TANK
11	NEUTRALISED WATER TANK
12	TRANSFORMERS
13	SWITCHYARD
14	COOLING TOWERS
15	FLUE GAS BLOWER
16	DIRECT CONTACT COOLER
17	DCC CIRCULATING WATER COOLER
18	ABSORBER
19	WATER WASH COOLER
20	ABSORBER INTERSTAGE COOLER
21	THERMAL RECLAIMER PACKAGE
22	LEAN TRIM COOLER
23	CO2 STRIPPER COLUMN
24	CO2 STRIPPER REBOILER
25	CO2 STRIPPER CONDENSER
26	LEAN AMINE STORAGE TANK
27	FRESH AMINE STORAGE TANK
28	LEAN-RICH CROSS-EXCHANGER
29	DE-OXYGENATION PACKAGE
30	COMPRESSOR STAGES
31	CO2 PRODUCT METERING PACKAGE
32	FLEX-CCS EQUIPMENT AREA (FUTURE)

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PROJECT

DECARBONISATION READINESS

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LEGEND

- POWER ISLAND
- COOLING SYSTEM
- CAPTURE PLANT
- SITE FENCELINE

NOTES

1. THIS GENERAL ARRANGEMENT DRAWING IS PRELIMINARY, INFORMED BY FEL 1 LEVEL DEFINITION. INDIVIDUAL PROJECTS SHOULD UNDERTAKE THEIR OWN STUDIES TO INFORM THEIR SPECIFIC REQUIREMENTS
2. FOOTPRINT OF THE OVERALL SITE IS APPROX. 95,900M²
3. FOOTPRINT OF THE POWER ISLAND EQUIPMENT IS APPROX. 43,500M²
4. FOOTPRINT OF THE CAPTURE PLANT EQUIPMENT IS APPROX. 15,000M²
5. FACILITY NET EXPORT CAPACITY = 91MW @ ISO WITH COOLING TOWERS

0 18.75 37.5 m

1:750

APPROVED FOR ISSUE

I/R	DRAWN BY	CHECKED	APPROVED
A	JC	KM	KM

ISSUE/REVISION

I/R	DATE	DESCRIPTION
A	06/04/22	FIRST ISSUE

PROJECT NUMBER

60677821

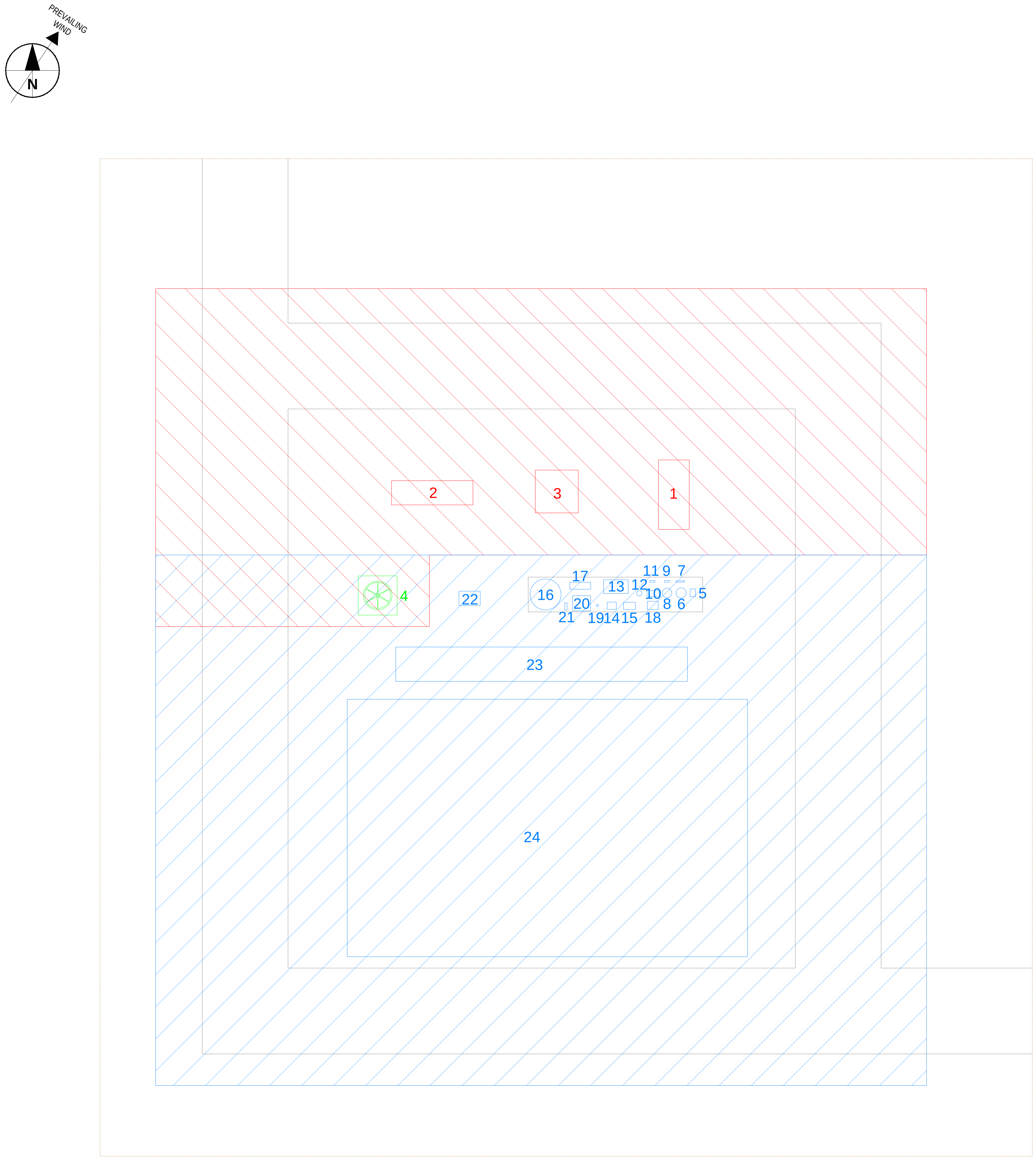
SHEET TITLE

CCS CASE STUDY 14 - LARGE BOILER BIOMASS LAYOUT

SHEET NUMBER

60677821-CC-DR-053

Last saved by: JAMIE.CALVERT(2022-04-07) Last Plotted: 2022-04-07 AutoCAD Version: 23.1S (LMS TECH) Project Management Initials: Designer: Checked: Approved:
Filename: C:\USERS\JAMIE.CALVERT\AECOM\BEIS - DECARBONISATION READINESS - DOCUMENTS\GENERAL\400_TECHNICAL\409 DRAWINGS\LOT 2 - CC DRAWINGS\60677821-CC-DR-053 - CS14 LARGE BOILER BIOMASS LAYOUT - REV A.DWG



ITEM No.	DESCRIPTION
1	RECIPROCATING ENGINE (INC. GENERATOR)
2	WASTE HEAT RECOVERY UNIT
3	ELECTRICAL & CONTROL UNIT
4	COOLING TOWERS
5	FLUE GAS BLOWER
6	DIRECT CONTACT COOLER
7	DCC CIRCULATING WATER COOLER
8	ABSORBER
9	WATER WASH COOLER
10	THERMAL RECLAIMER PACKAGE
11	LEAN TRIM COOLER
12	CO2 STRIPPER COLUMN
13	CO2 STRIPPER REBOILER
14	CO2 STRIPPER CONDENSER
15	PUMPS
16	LEAN AMINE STORAGE TANK
17	FRESH AMINE STORAGE TANK
18	LEAN-RICH CROSS-EXCHANGER
19	DE-OXYGENATION PACKAGE
20	COMPRESSOR STAGES
21	CO2 PRODUCT METERING PACKAGE
22	LIQUEFACTION PACKAGE
23	STORAGE BULLET
24	ROAD TRUCK RECEIVING FACILITY

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LEGEND

- POWER ISLAND
- COOLING SYSTEM
- CAPTURE PLANT
- SITE FENCELINE

NOTES

1. THIS GENERAL ARRANGEMENT DRAWING IS PRELIMINARY, INFORMED BY FEL 1 LEVEL DEFINITION. INDIVIDUAL PROJECTS SHOULD UNDERTAKE THEIR OWN STUDIES TO INFORM THEIR SPECIFIC REQUIREMENTS
2. FOOTPRINT OF THE OVERALL SITE IS APPROX. 4,500M^2
3. FOOTPRINT OF THE POWER ISLAND EQUIPMENT IS APPROX. 1,100M^2
4. FOOTPRINT OF THE CAPTURE PLANT EQUIPMENT IS APPROX. 2,000M^2
5. FACILITY NET EXPORT CAPACITY = 1MW @ ISO WITH COOLING TOWERS
6. CAPTURE PLANT IS LOCATED WITHIN A 40FT ISO CONTAINER

0 3.75 7.5 m

1:150

APPROVED FOR ISSUE

I/R	DRAWN BY	CHECKED	APPROVED
A	JC	KM	KM

ISSUE/REVISION

I/R	DATE	DESCRIPTION
A	05/04/22	FIRST ISSUE

PROJECT NUMBER

60677821

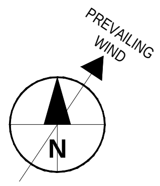
SHEET TITLE

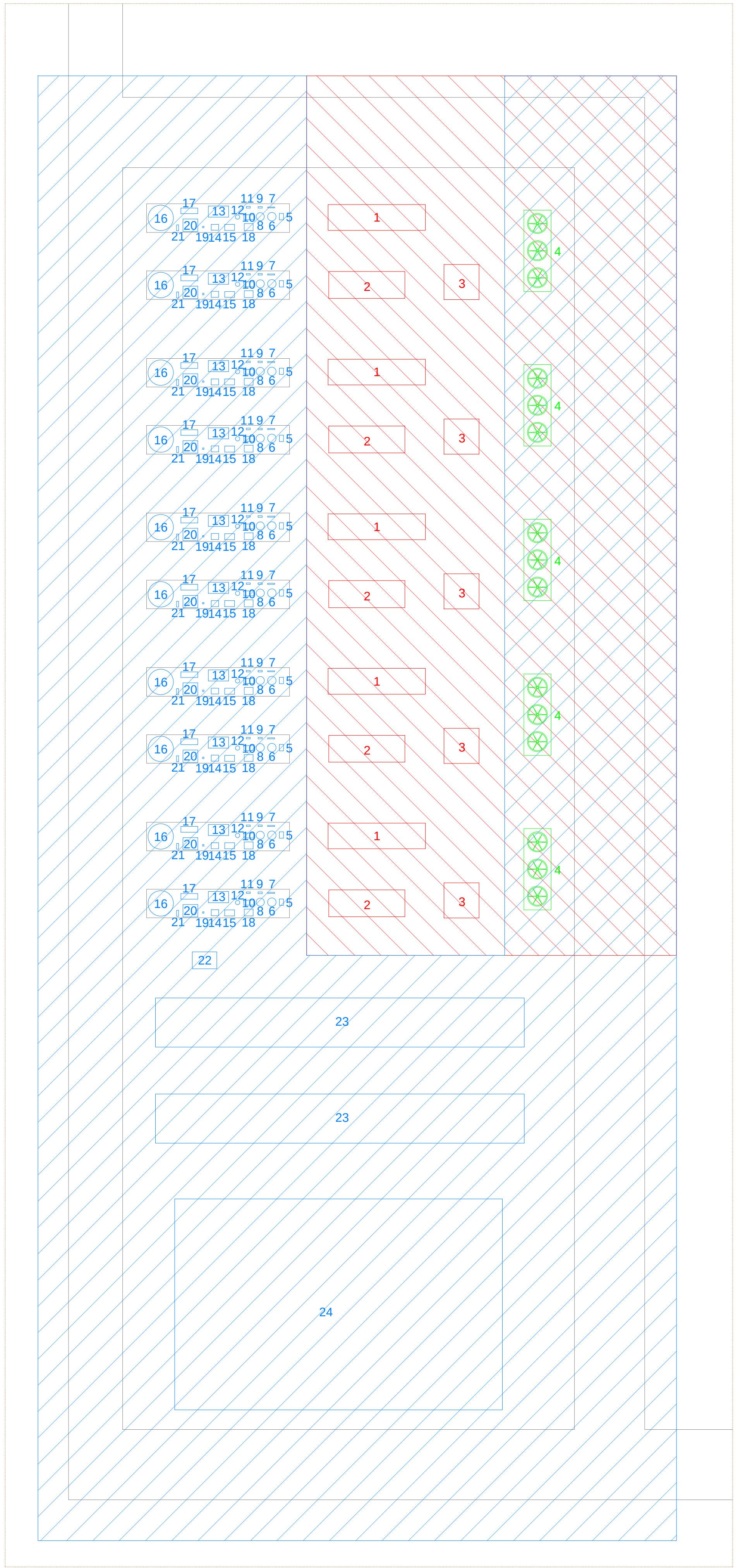
CCS CASE STUDY 15 - SMALL RECIPROCATING ENGINE LAYOUT

SHEET NUMBER

60677821-CC-DR-061

Last saved by: JAMIE.CALVERT(2022-04-05) Last Plotted: 2022-04-05 AutoCAD Version: 23.1S (LMS TECH) Project Management Initials: Designer: Checked: Approved:
Filename: C:\USERS\JAMIE.CALVERT\AECOM\BEIS - DECARBONISATION READINESS - DOCUMENTS\GENERAL\400_TECHNICAL\409 DRAWINGS\LOT 2 - CC DRAWINGS\60677821-CC-DR-061 - CS15 SMALL RECIP ENGINE LAYOUT - REV A.DWG





ITEM No.	DESCRIPTION
1	RECIPROCATING ENGINE (INC. GENERATOR)
2	WASTE HEAT RECOVERY UNIT
3	ELECTRICAL & CONTROL UNIT
4	COOLING TOWERS
5	FLUE GAS BLOWER
6	DIRECT CONTACT COOLER
7	DCC CIRCULATING WATER COOLER
8	ABSORBER
9	WATER WASH COOLER
10	THERMAL RECLAIMER PACKAGE
11	LEAN TRIM COOLER
12	CO2 STRIPPER COLUMN
13	CO2 STRIPPER REBOILER
14	CO2 STRIPPER CONDENSER
15	PUMPS
16	LEAN AMINE STORAGE TANK
17	FRESH AMINE STORAGE TANK
18	LEAN-RICH CROSS-EXCHANGER
19	DE-OXYGENATION PACKAGE
20	COMPRESSOR STAGES
21	CO2 PRODUCT METERING PACKAGE
22	LIQUEFACTION PACKAGE
23	STORAGE BULLET
24	ROAD TRUCK RECEIVING FACILITY

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LEGEND

- POWER ISLAND
- COOLING SYSTEM
- CAPTURE PLANT
- SITE FENCELINE

NOTES

1. THIS GENERAL ARRANGEMENT DRAWING IS PRELIMINARY, INFORMED BY FEL 1 LEVEL DEFINITION. INDIVIDUAL PROJECTS SHOULD UNDERTAKE THEIR OWN STUDIES TO INFORM THEIR SPECIFIC REQUIREMENTS
2. FOOTPRINT OF THE OVERALL SITE IS APPROX. 8,300M^2
3. FOOTPRINT OF THE POWER ISLAND EQUIPMENT IS APPROX. 2,400M^2
4. FOOTPRINT OF THE CAPTURE PLANT EQUIPMENT IS APPROX. 5,600M^2
5. FACILITY NET EXPORT CAPACITY = 11.6MW @ ISO WITH COOLING TOWERS
6. EACH CAPTURE PLANT UNIT IS LOCATED WITHIN TWO 40FT ISO CONTAINERS

0 6.25 12.5 m

1:250

APPROVED FOR ISSUE

I/R	DRAWN BY	CHECKED	APPROVED
A	JC	KM	KM

ISSUE/REVISION

I/R	DATE	DESCRIPTION
A	05/04/22	FIRST ISSUE

PROJECT NUMBER

60677821

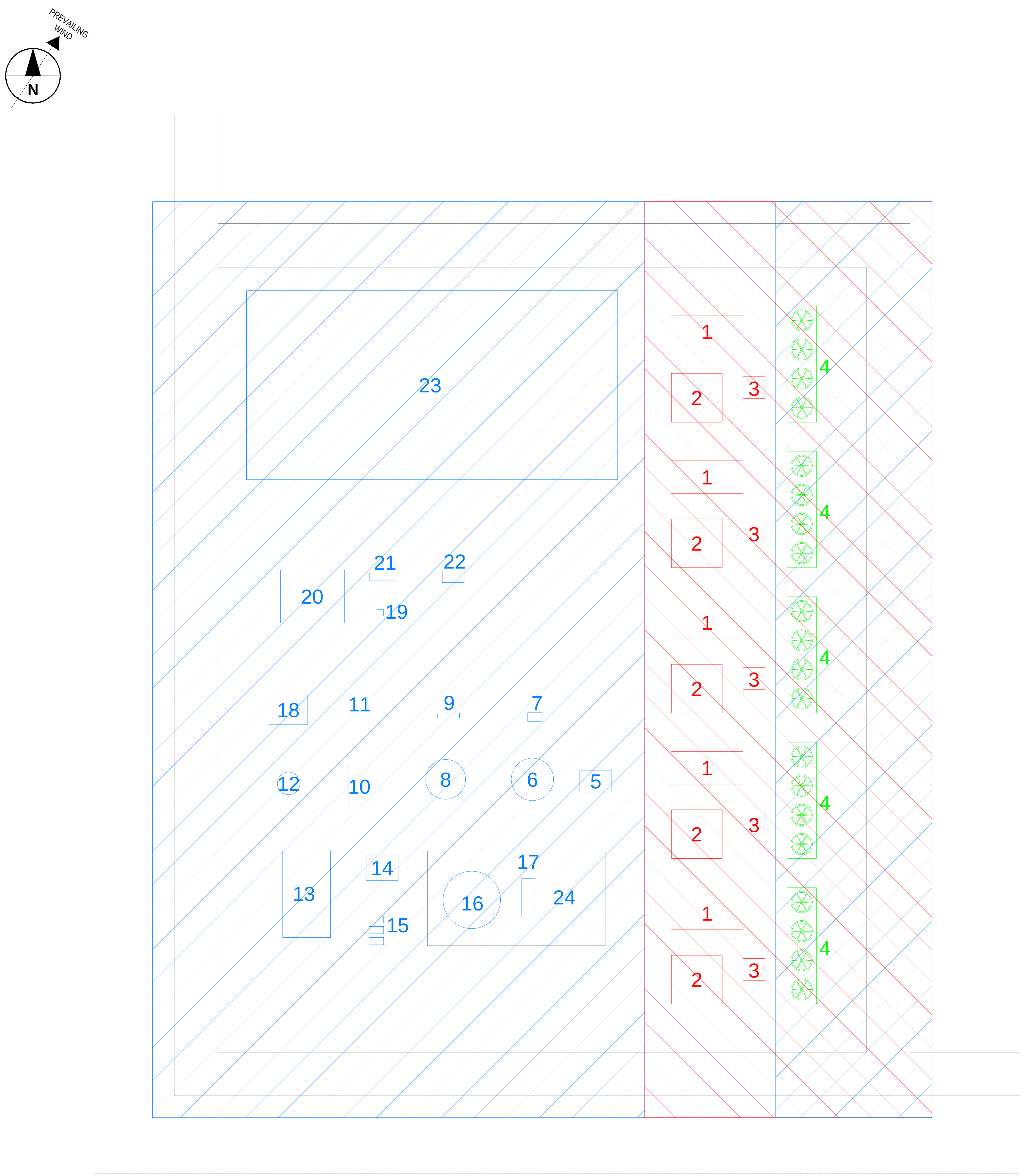
SHEET TITLE

CCS CASE STUDY 16 - MEDIUM RECIPROCATING ENGINE LAYOUT

SHEET NUMBER

60677821-CC-DR-062

Last saved by: JAMIE.CALVERT(2022-04-05) Last Plotted: 2022-04-05
Filename: C:\USERS\JAMIE.CALVERT\AECOM\BEIS - DECARBONISATION READINESS - DOCUMENTS\GENERAL\400_TECHNICAL\409 DRAWINGS\LOT 2 - CC DRAWINGS\60677821-CC-DR-062 - CS16 MEDIUM RECIP ENGINE LAYOUT - REV A.DWG
AutoCAD Version: 23.1S (LMS TECH)
Project Management Initials: Designer: Checked: Approved:



ITEM No.	DESCRIPTION
1	RECIPROCATING ENGINE (INC. GENERATOR)
2	WASTE HEAT RECOVERY UNIT
3	ELECTRICAL & CONTROL UNIT
4	COOLING TOWERS
5	FLUE GAS BLOWER
6	DIRECT CONTACT COOLER
7	DCC CIRCULATING WATER COOLER
8	ABSORBER
9	WATER WASH COOLER
10	THERMAL RECLAIMER PACKAGE
11	LEAN TRIM COOLER
12	CO2 STRIPPER COLUMN
13	CO2 STRIPPER REBOILER
14	CO2 STRIPPER CONDENSER
15	PUMPS
16	LEAN AMINE STORAGE TANK
17	FRESH AMINE STORAGE TANK
18	LEAN-RICH CROSS-EXCHANGER
19	DE-OXYGENATION PACKAGE
20	COMPRESSOR STAGES
21	CO2 PRODUCT METERING PACKAGE
22	LIQUEFACTION PACKAGE
23	STORAGE BULLET
24	FLEX-CCS EQUIPMENT AREA (FUTURE)

AECOM

PROJECT
DECARBONISATION READINESS

CLIENT
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LEGEND
- POWER ISLAND
- COOLING SYSTEM
- CAPTURE PLANT
- SITE FENCELINE

NOTES
1. THIS GENERAL ARRANGEMENT DRAWING IS PRELIMINARY, INFORMED BY FEL 1 LEVEL DEFINITION. INDIVIDUAL PROJECTS SHOULD UNDERTAKE THEIR OWN STUDIES TO INFORM THEIR SPECIFIC REQUIREMENTS
2. FOOTPRINT OF THE OVERALL SITE IS APPROX. 18,500M^2
3. FOOTPRINT OF THE POWER ISLAND EQUIPMENT IS APPROX. 5,000M^2
4. FOOTPRINT OF THE CAPTURE PLANT EQUIPMENT IS APPROX. 11,200M^2
5. FACILITY NET EXPORT CAPACITY = 48MW @ ISO WITH COOLING TOWERS

0 7.5 15 m
1:300

APPROVED FOR ISSUE

A	JC	KM	KM
I/R	DRAWN BY	CHECKED	APPROVED

ISSUE/REVISION

A	06/04/22	FIRST ISSUE
I/R	DATE	DESCRIPTION

PROJECT NUMBER
60677821

SHEET TITLE
CCS CASE STUDY 17 - MEDIUM RECIPROCATING ENGINE LAYOUT

SHEET NUMBER
60677821-CC-DR-063

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