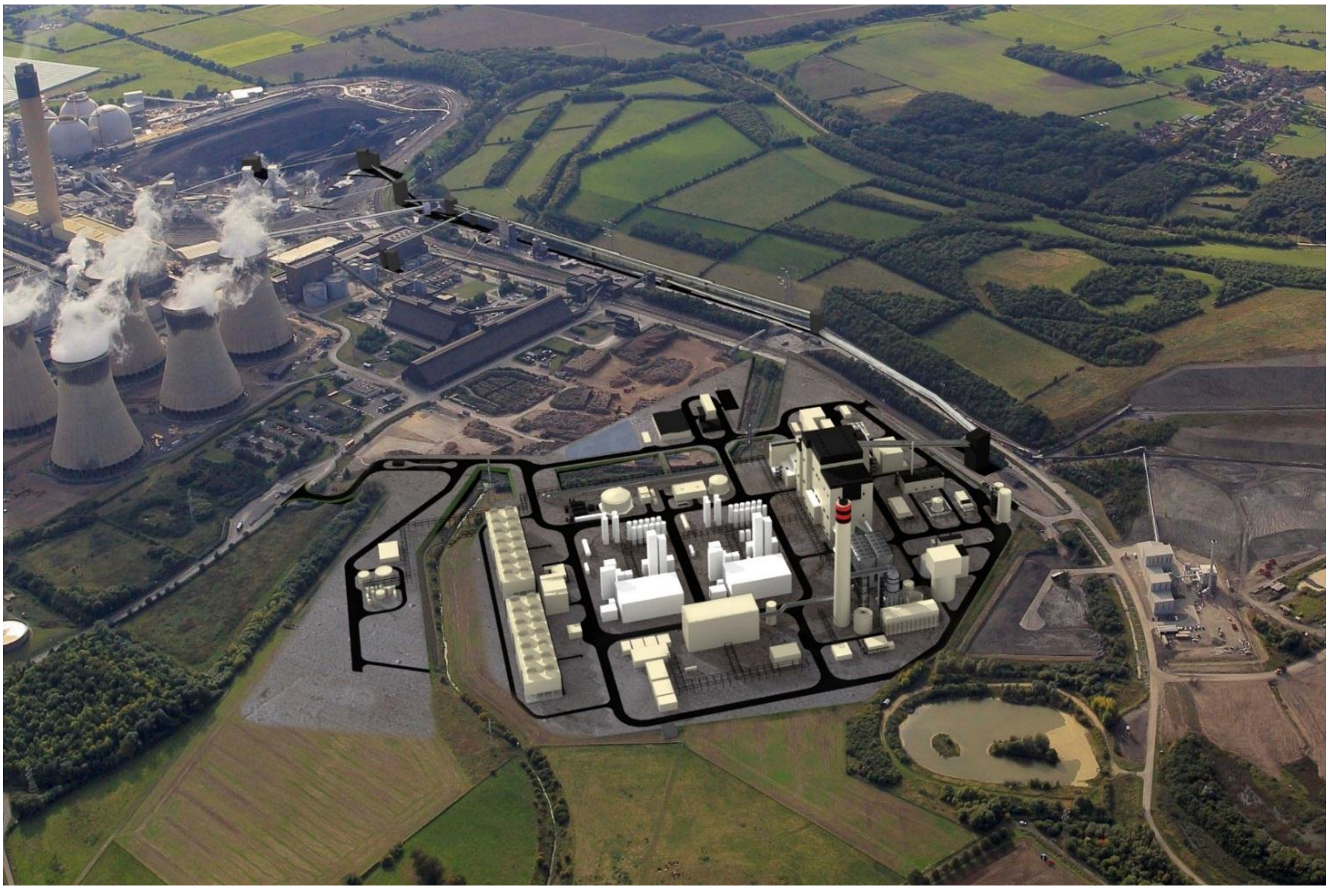
White Rose Carbon Capture and Storage (CCS) Project

Land Adjacent to and within the Drax Power Station Site, Drax, Near Selby, North Yorkshire

Environmental Permit
Chapter XII – Energy Efficiency



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Glossary of Abbreviations and Definitions

AOD	Above Ordinance Datum
ASU	Air Separation Unit
BS	British Standard
CCS	Carbon Capture and Storage
CEMP	Construction Environmental Management Plan
CPL	Capture Power Limited
dB	Decibel
EA	Environment Agency
EIA	Environmental Impact Assessment
ES	Environmental Statement
ESP	Electrostatic Precipitators
FGD	Flue Gas Desulphurisation
FRA	Flood Risk Assessment
GGH	Gas to Gas Heater
GPU	Gas Processing Unit
HGV	Heavy Goods Vehicle
IED	Industrial Emissions Directive
LWS	Local Wildlife Site
MSA	Molecular Sieve Adsorber
MWe	Megawatt
NERC	Natural Environment and Rural Communities (Act 2006)
NSIP	Nationally Significant Infrastructure Project
PEIR	Preliminary Environmental Information Report
SAC	Special Area of Conservation
SINC	Site of Importance for Nature Conservation
SPA	Special Protection Area
SSSI	Site of Special Scientific Interest
VFD	Variable Frequency Drives
WFD	Water Framework Directive
WHO	World Health Organisation
WSI	Written Scheme of Investigation

CONTENTS

1.0 BACKGROUND TO THE WHITE ROSE CARBON CAPTURE AND STORAGE

1.1 Capture Power Ltd (CPL) plans to construct and operate a new 448 MWe (gross output) ultra-critical coal fired power station. The Project will have the capacity to provide electricity sufficient for 630,000 households whilst capturing two million tonnes of carbon dioxide (CO_2) per year arising from the combustion process (approximately 90% of CO_2 emissions). The generating station and the means to capture CO_2 together comprise the White Rose Carbon Capture and Storage (CCS) Project (the ‘Project’).

1.2 The application has been submitted to the Planning Inspectorate (PINs) in accordance with the requirements of the Planning Act 2008 (“the 2008 Act”) and the Infrastructure Planning (Environmental Impact Assessment) Regulations 2009 (’the EIA Regulations’ for the purposes of this EIA). On the 17 December 2014, the application was accepted by PINs and the project now enters a period of examination before the Secretary of State decides whether to grant consent for the application.

1.3 The Project is a key part of the UK’s development / commercialisation of CCS, which the Government is supporting through over £1billion of capital and research and development funding. Additionally, the Project will support the development of a CO_2 transmission pipeline (a separate project developed by National Grid Carbon Ltd (NGCL)) which it is hoped will, in the future, be used by other industries and power stations in the Yorkshire and Humber area to transport their CO_2 emissions for permanent storage in the North Sea in geological features.

1.4 The application site (henceforth the ‘Project site’) is located on land adjoining the existing Drax Power Station in North Yorkshire, England. CO_2 captured will not be stored on site as the Project will link to a CO_2 transport and storage solution as noted above. The Project is in line with Government strategies (for instance the CCS Roadmap) for controlling the construction / operation of new electrical generation infrastructure whilst meeting carbon reduction targets for the energy sector in the UK.

ENVIRONMENTAL PERMIT AND PROCESS

1.5 This Environmental Permit application is associated with the White Rose Carbon Capture and Storage Project. A Development Consent Order has been submitted to The Planning Inspectorate and was ‘Accepted’ on 17 December 2015. Due the proposed activities of White Rose Carbon Capture and Storage it is envisaged that the current Drax Power Limited Environment Permit (VP3530LS) can be varied to accommodate the White Rose Carbon Capture and Storage project.

1.6 This Environmental Permit application is made in order to make a variation of the existing Drax Power limited Environment Permit (VP3530LS). The application forms and the application chapters form the Environmental Permit which will seek to add the activities of the White Rose Carbon Capture and Storage project to the Drax Power Limited Environmental Permit.

2.0 INTRODUCTION

2.1 The White Rose Carbon Capture and Storage project (White Rose CCS) has the capability of operating in both air mode and oxy mode. Air mode utilises atmospheric air for the combustions process and standard flue gas abatement technology to generate a flue gas which is compliant with the requirements of the Industrial Emissions Directive (IED). In Oxy mode (carbon capture mode), the additional pieces of infrastructure are operating which requires additional works power to be consumed and inevitably effects the overall efficiency of the plant when comparing the efficiency of the plant in air mode to the efficiency of the plant in Oxy mode.

2.2 Due to the operation of both the ASUs and the GPU whilst operating in Oxy mode, the net efficiency will decrease. Both the ASU and the GPU are cryogenic systems which function through serial compression and expansion of the gas to generate a final product. In the case of the ASUs this product is oxygen, in the case of the GPU, this product is carbon dioxide. The serial compression and expansion of gas is an energy intensive process in order to reduce the temperature of the gas to the distillation point of the requisite product. However, the energy which has been used to generate the requisite gas also results in the remaining gases which can be utilised where possible. In addition, compression of gas results in the generation of heat which may also be utilised in other integrated cycles and systems for the OPP.

2.3 The fundamental concept of oxy-firing is to use oxygen instead of air (as per conventional coal combustion) for the combustion process in order to obtain a CO_2 rich flue gas mainly composed of CO_2 + H_2O (and some inert gases) more “easily” cleaned and compressed to the required pipeline CO_2 specification for onward transport and storage.

2.4 As a result oxy-firing requires the addition of two units to the conventional coal fired power plant:

- The Air Separation Unit (ASU) to provide the oxygen; and
- The Gas Processing Unit (GPU) where the CO_2 is further purified and compressed.

2.5 In addition, some modifications of the power plant itself are necessary to ensure stable combustion and a CO_2 product which meets the required specifications, mainly:

2.6 Partial recirculation of the flue gas in order to maintain appropriate temperature and heat absorption in the furnace and convection pass;

  - Removal of the water from the flue gas before treatment in the GPU in the Flue Gas Condenser;
  - Minimisation of leakage of air into flue gas ducts and equipment, (e.g. Boiler, Flue Gas Desulphurisation (FGD), Electrostatic Precipitator (ESP));
  - Sizing of auxiliary equipment, taking into account the additional needs of ASU and GPU; and
  - Injection/mixing of oxygen in the flue gas path.

2.7 Whilst the additional and modified units increase the parasitic load versus an unabated plant, as a new build plant White Rose benefits from being able to select modern high efficiency boiler technology and auxiliary units as well as design for heat integration between the components in order to reduce the impact of CO_2 capture on overall efficiency.

2.8 Please see Appendix B for details of the Combined Heat and Power report produced for the White Rose Carbon Capture and Storage Project

3.0 OVERVIEW OF HIGH EFFICIENCY SYSTEMS SELECTED FOR THE PLANT

3.1 High efficiency systems have been selected throughout the plant:

- Ultra super critical boiler design with reheat
- High efficiency steam turbine designed for high pressures and temperatures to improve efficiency
- BFW Variable frequency drives (VFD) have been fitted to the boiler feedwater pumps in order to reduce feedwater pumps electrical consumption at partial load.
- Water (rather than air) cooled condenser to achieve a lower pressure (higher power recovery) at the steam turbine exit
- Mechanical draft cooling towers to have low cooling water temperature
  - Higher power from ST
  - Lower power for large compressors in ASU & GPU
- Hydrogen cooling in generator to optimize winding cooling and thereby improve efficiency of the generator
- ASU cycle selection and machine selection for minimum power consumption
- Selection of high efficiency centrifugal compressors in GPU
- ASU & GPU cold boxes design to minimise heat losses from cryogenic processes
- Liquid oxygen is contained in highly insulated storage vessels in order to minimise heat in leak and thus minimise product boil off and loss.
- Equipment location: as far as possible, electrical building located close to electrical consumers to minimize losses in cable, and equipment arrangement to minimize pressure drop in the pipes or ducts

Water Stream Cycle Purpose and Basic Design

3.2 The water and steam cycle is the central element between the steam generator and the turbo-generator. The purpose of the water and steam cycle is to heat the water and feed this to the boiler, to transfer the steam produced by the Boiler to the ST and to condense the steam in a condenser at the turbine exhaust to enable re-start of a new cycle. A number of features are aimed to maximise efficiency:

3.3 In order to increase the plant efficiency, the condensate and boiler feed water streams (excluding the portion heated in the ASU) are heated-up through six low pressure heaters and three high pressure heaters by steam from the appropriate turbine section.

3.4 Reheating of high pressure turbine exhaust - the “cold reheat steam” returns to the boiler re-heater to reheat the steam to maximise efficiency in the later stages of expansion.

3.5 In the turbine, the steam expansion provides mechanical energy to the ST shaft, which is directly coupled with the turbo-generator (all turbine sections and generator on the same shaft, so no gearbox losses).

3.6 The steam from the low pressure turbine section is then directed to the condenser where it condenses at vacuum conditions. To obtain the maximum of expansion in the turbine, the main driver for the steam cycle efficiency, non-condensable gases that collect in the condenser are removed using the vacuum pumps, to ensure highest achievable vacuum level is maintained.

Ultra Supercritical Boiler

3.7 The boiler is a sliding pressure, supercritical, once-through type. In normal operation the water and steam generated in the furnace waterwalls passes through only once (there is no separation in a steam drum with water recycled back to the waterwalls), and operation is at supercritical conditions (above the critical pressure of 221.2 bar where two phase mixtures of water and steam cease to exist, and are replaced by a single supercritical fluid).

3.8 Developments in metallurgy have allowed the use of higher operating pressure and temperatures. Chrome-nickel based super alloys are used in the components of the steam generator, turbine and piping systems that are exposed to high temperature steam. At USC conditions the thermodynamics of the Rankine cycle are improved by expanding higher pressure and temperature steam through the turbine, and as a result a supercritical steam generating unit is more efficient than a subcritical unit.

3.9 For White Rose steam from the outlet of the boiler superheater is sent to the high pressure turbine at about 260 bar and 600°C. The steam exhausting the high pressure steam is re-heated to about 620°C to further improve the efficiency, and sent to the intermediate pressure turbine. The typical improvement in efficiency versus subcritical thermal power is shown in the graph below (the star indicates the White Rose conditions expected):

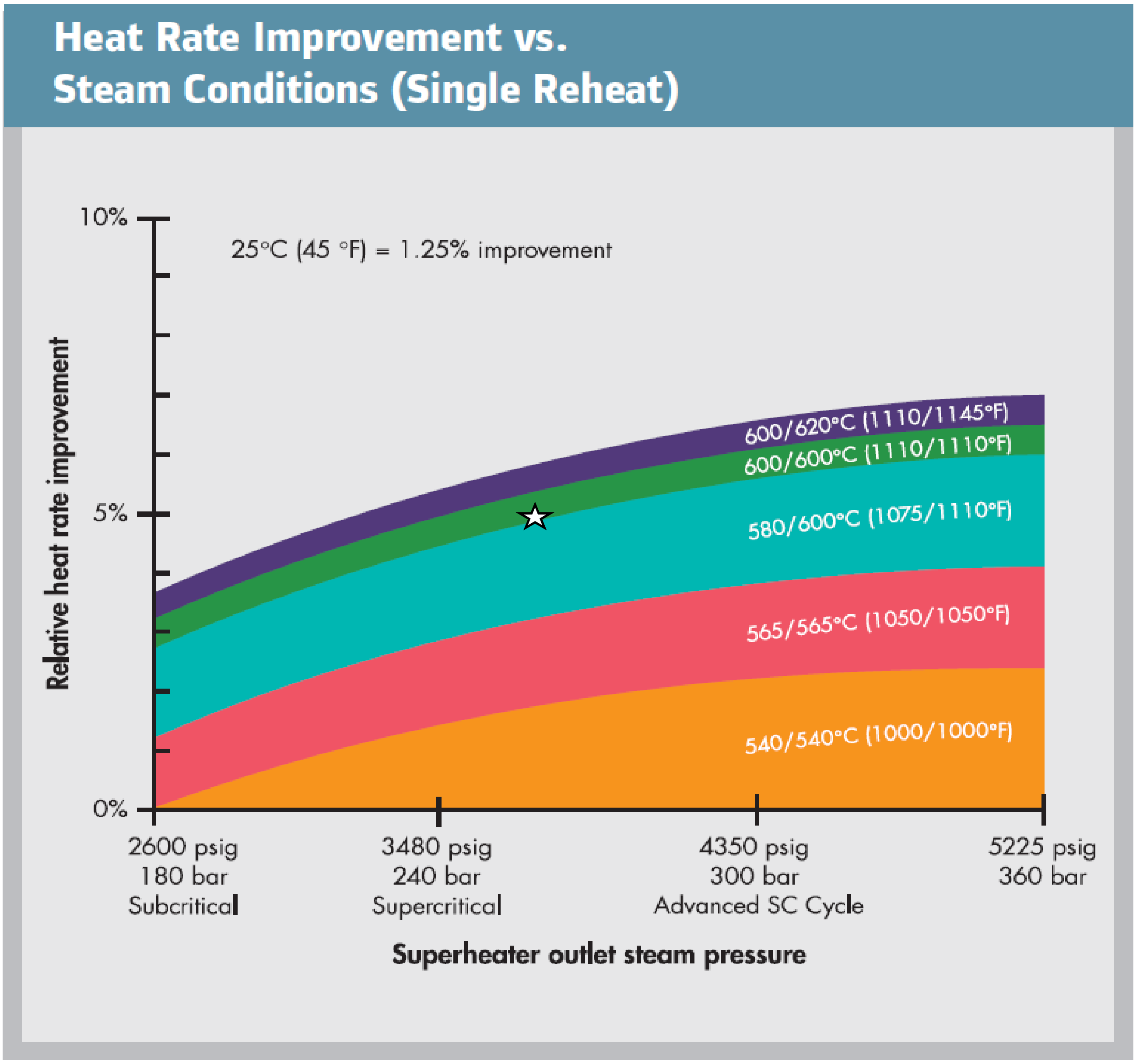


Figure provided by Alstom.

3.10 The increased efficiency reduces fuel consumption, CO_2 emissions, reagent consumption (ammonia, limestone etc.), solid waste, water use and operating costs. The once through cycle eliminates the need for water/steam separation in drums during operation, and allows a simpler separator to be employed during start-up conditions allowing quicker and more efficient start-ups.

3.11 In turndown, the boiler operates in the sliding pressure mode, where pressure is reduced with load. This gives more flexibility in load changes and controlling the power output to the grid.

3.12 Other key features of the boiler in terms of efficiency:

- oxygen supply lines and control valves;
- oxygen mixing devices;
- a low leakage “air” heater or gas to gas heater (GGH);
- an SO_3 mitigation system; and
- ductwork and dampers to connect the inlets of the PA and FD fans to the recirculated flue gas sources.

Air Separation Units

3.13 The main energy input to the ASU is the power to drive the main air compressor. While a high efficiency machine with a typical isothermal efficiency of ~ 75% is selected, the main air compressor is still the biggest source of losses in the ASU. This loss can be reduced by recovering the heat of compression into the steam cycle by direct transfer to cold condensate from the steam turbine condenser.

3.14 From a thermodynamic perspective, the ideal is to heat as much feed water as possible to as high temperature as possible while minimising the compressor power consumption. In order to achieve this an axial compressor (i.e. with no intercooling between stages) was selected. This approach is complementary to the main ASU cycle design, with a very low MAC delivery pressure to minimise ASU power consumption, meaning that the relative inefficiency of not having intercooling between the stages of the main air compressor is offset by the removal of the intercooler’s pressure drop. This allows heating of the condensate feed water to temperatures of around 120-140°C with minimal increase of compressor power consumption.

3.15 In order to maximise the heat recovery a heat exchanger with a small temperature difference and low pressure drop must be specified, different from a conventional ASU inter- or after cooler. To achieve this a spirally wound exchanger has been selected (such as typically used in LNG applications). Around 35 MW of heat is recovered to the steam cycle and this is converted within the steam cycle to around 7% of the ASU power consumption.

3.16 Since the ASU generates both a cold stream of gas, mainly nitrogen and also generates a cooling demand due to the compression systems operating, there are a number of opportunities for integration of systems in an attempt to reduce the site’s overall power consumption. Currently the design include integration of the following:

- Condensate from steam turbine condenser passes through a heat exchanger associated with the main compression systems associated with the ASU. The condensate passes through the heat exchanger before being returned to the main water steam cycle. This results in an improvement in overall cycle efficiency by raising the condensate from around 30 degrees Celsius to over 100 degrees Celsius.

- Low operating oxygen delivery pressures to reduce power consumption, e.g. pumping costs

- The ASUs are located as close as possible to the consumer in order to minimise pressure drop on high gas flows.

- The ASU main process itself is integrated in terms of recovering energy through effective heat exchange and utilisation of waste gas generated within the plant

- Liquid oxygen is contained in highly insulated storage vessels in order to minimise heat in leak and thus minimise product boil off and loss.

- The ASU could produce clean dry air for instrument use thus saving power by not running the other compressors.

4.0 EFFICIENCY DATA FOR THE POWER PLANT

4.1 Whilst preparing this chapter, cognisance has been taken of the current horizontal guidance regarding energy efficiency:

> *Horizontal Guidance Note IPPC H2 - Integrated Pollution Prevention and Control (IPPC) Energy Efficiency, Version 3, February 2002*

4.2 There are a number of concepts and statements within the guidance document which, for a carbon capture plant, simply do not hold and are incorrect, for example the overarching statement that:

> *"The primary indicator in the assessment of energy efficiency is emission of carbon dioxide generated through the production of energy from fuels"*

4.3 For the carbon capture plant, this statement is clearly not correct, moving from air mode to oxy mode results in a decrease in efficiency, however, a significant reduction in carbon dioxide emissions is also achieved. Hence it is not possible to link energy efficiency with carbon dioxide emissions whilst operating in oxy mode. The plant will be captured by the Emissions Performance Standard which constrains the plant to operate at an annual average of 450g/kWh following an initial 3 year commissioning window where the EPS is not applied. The data below therefore needs to be considered in the context of a carbon capture plant rather than a standard power station and the Horizontal Guidance note.

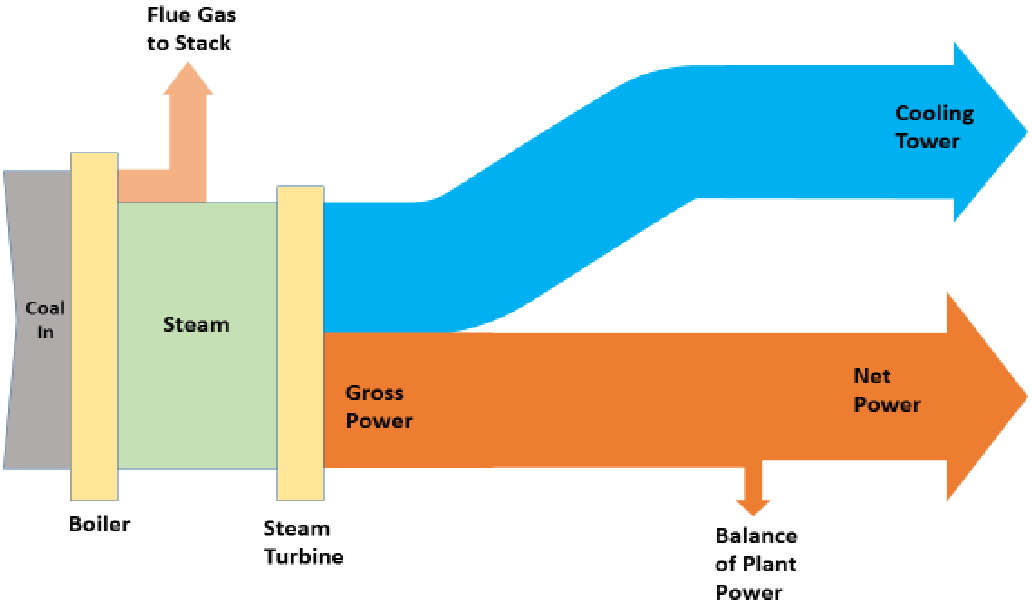
Oxy mode (11°C / 85% RH): Net Efficiency: around 33% LHV
Air mode (11°C / 85% RH): Net Efficiency: around 43.5% LHV

4.4 Therefore a reduction in net efficiency of the order of 10% can be expected when moving from air mode to oxy mode.

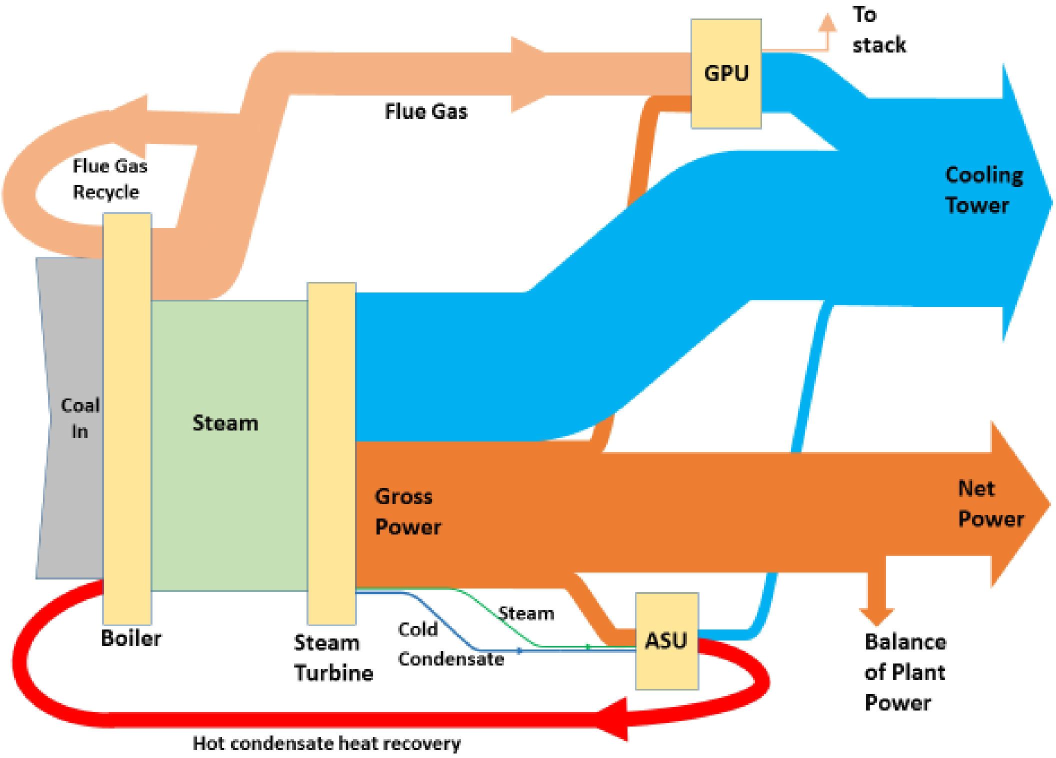
5.0 PARASITIC LOADS AND FLOW OF ENERGY

5.1 The ASU & the GPU have the greatest impact on parasitic load, together contributing ~ 95 MW additional power demand from the large compressors in each unit. As a result there cooling demand and this is further compounded by the Flue Gas Condenser within the GPU which condenses a large portion of the water vapour in the flue gas (in air mode this goes directly to atmosphere) and the heat of condensation must be removed via the cooling system.

5.2 After the ASU and GPU the other large parasitic loads are the cooling system (fans and pumps) and the boiler feed water pumps. However, these loads are synonymous with a standard power station. Indicative Sankey diagrams are included to illustrate the additional loads in oxy-mode operation and the heat recovery between the ASUs and the boiler.



White Rose OPP – Air Mode Operation Sankey Diagram



White Rose OPP – Oxy Mode Operation Sankey Diagram

5.3 For the OPP the two “new” parasitic loads are the ASU and the GPU. The process has been designed to minimise their impact.

6.0 POWER DEMAND OF THE ASU

6.1 The power consumption of the ASU is dependent on a number of factors:

- Oxygen purity
- Oxygen pressure
- Choice of ASU cycle
- Use of Co-products

6.2 For the OPP the oxygen purity also has an impact on the performance of the GPU. As the oxygen purity is reduced from the typical 99.5% the amount of inerts (nitrogen and argon) increases. These in turn have to be removed by the GPU to obtain the necessary CO_2 specification and increased quantities result in a higher power consumption in the GPU. As a result an oxygen purity of 96.3% was selected to minimise the combined power consumption of the ASUs and GPU.

6.3 The oxyfuel process combusts coal at just above atmospheric pressure so very low pressure oxygen (~0.3 bar) is supplied in order to minimise the ASU power consumption. Gas buffers are provided to smooth any pressure fluctuations and allow a minimum pressure to be used.

6.4 The ASU cycle chosen was designed to minimise the power consumption by decoupling the main air supply pressure from the oxygen production pressure resulting in a lower pressure (less power) from the MAC.

6.5 There is no requirement for nitrogen use within the OPP. All the nitrogen co-produced in separating the oxygen from the air is re-used within the ASU cycle either to produce chilled water by evaporative cooling or to regenerate the Molecular Sieve Adsorber (MSA) Units remove Moisture and CO_2 to prevent ice and dry ice from forming later in the process. The chilled water is used to cool the air after the MAC in a direct contact cooler. This reduces the regeneration requirements (steam usage) for the MSA units and reduces the air temperature to the booster air compressor thereby reducing its power consumption. Both these minimize the loss of the overall efficiency of the OPP.

7.0 POWER DEMAND OF GPU

7.1 The GPU cycle chosen was designed to minimise the power consumption through efficient heat integration within the cycle, equipment selection and minimising heat losses from a cryogenic system.

Standard Integration methods and Efficiency benefits

7.2 Air for the process is filtered by a high efficiency filtration system and is then compressed to the required process pressure by a multistage, electrically driven axial compressor. The compressed air is then cooled by an after cooler which simultaneously heats the condensate return to the boiler thus maximising process efficiency.

7.3 Heat integration between the ASUs and the Oxy Boiler allows for the recovery of a large portion of the heat of compression from the ASUs' main air compressors back into the water steam cycle loop. Cold condensate from the ST condenser passes to the condensate pumps and is then divided into two streams. The first stream goes to the first LP heater within the boiler for reheating, while a second stream, around 30% of the total cold condensate flow, goes to the ASUs for reheating before being returned upstream of the last LP heater. This approach reduces the amount of steam extracted from the ST to heat-up the cold condensate, thereby improving the cycle efficiency.

7.4 In order to maximise the amount and temperature of the heat recovered, an axial flow main air compressor is selected with no intercooling and the heat is recovered in a spirally heat exchanger in order to achieve a close approach temperature and low pressure drop. The cold condensate is heated from around 30°C to about 145°C in the ASU exchangers and the heat integration recovers around 35 MW of thermal heat.

7.5 The compressed air is further cooled and washed in a direct contact air cooler in counter current flow with water injected at two levels. In the lower section the air is pre-cooled with process cooling water. In the upper section, the air is further cooled by chilled water produced from evaporative cooling using dry nitrogen gas from the ASU.

Flexible Operation / 'Energy Storage'

7.6 In order to maximise the export of power from the OPP at periods of high market demand, it is possible to reduce the power consumed by the ASUs whilst still maintaining full GO_X output to the boiler. LO_X is re-injected back into the ASU process which both releases GO_X and allows the energy contained within the LOX to be recovered and further used within the separation process itself. The LO_X is produced by the ASUs during periods of low energy cost and can be stored until required. The liquid oxygen is pumped from the cryogenic storage tanks via a cryogenic transfer pump system.

8.0 WATER USE AND EFFICIENCY

8.1 When oxy-mode (CCS operation) the raw water consumption of the OPP is around 1400 m3/h. This is an increase of 30% above the consumption in air mode (ASU and GPU not in operation). The increase is due to the higher cooling water demand, and concomitant evaporation and drift losses in the cooling tower, arising from the GPU and to a much lesser extent the ASU. The GPU has a large CW demand arising from both its compressor cooling requirements and a direct contact cooler to dehydrate the flue gas before is purification and compression. The DCC recovers water from the flue gas and the majority is reused to provide ~ 70% of the water make-up demand for the Flue Gas Desulphurisation unit. In air mode all the FGD demand must be supplied by raw water.

8.2 The ASU cooling water demand is small for the size of unit, as the majority of its cooling is achieved by pre-heating condensate being returned to the steam cycle.