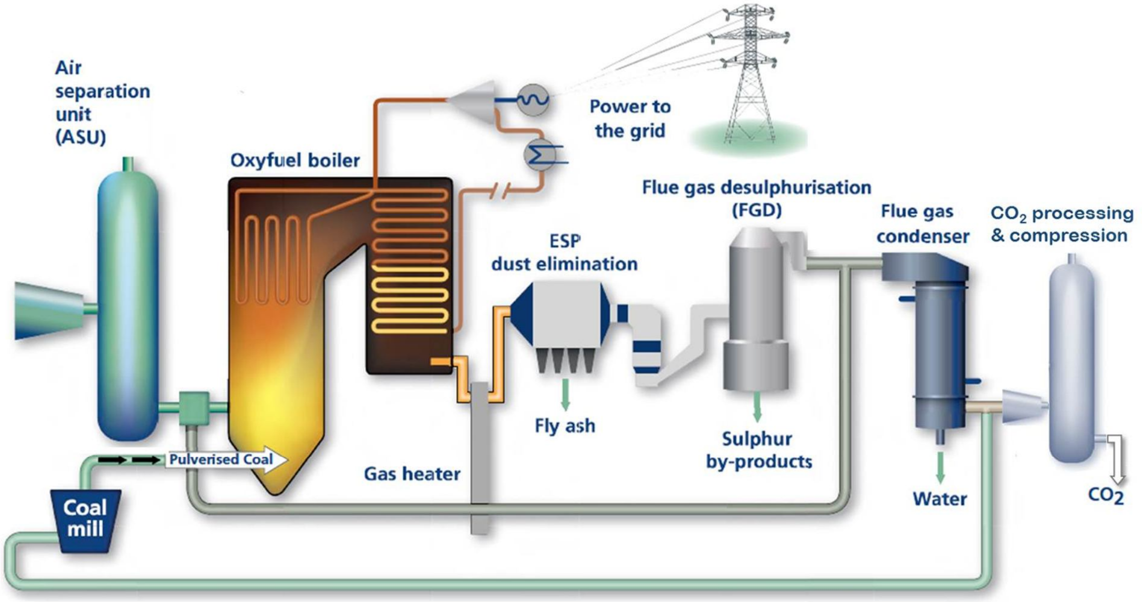
March 2015

WHITE ROSE

K27: Oxy Power Plant Process Description

Technical: Oxy Power Plant



CAPTURE POWER drax BOC A Member of The Linde Group ALSTOM nationalgrid

Disclaimer

IMPORTANT NOTICE

The information provided further to UK CCS Commercialisation Programme (the Competition) set out herein (the Information) has been prepared by Capture Power Limited and its sub-contractors (the Consortium) solely for the Department of Energy and Climate Change in connection with the Competition. The Information does not amount to advice on CCS technology or any CCS engineering, commercial, financial, regulatory, legal or other solutions on which any reliance should be placed. Accordingly, no member of the Consortium makes (and the UK Government does not make) any representation, warranty or undertaking, express or implied, as to the accuracy, adequacy or completeness of any of the Information and no reliance may be placed on the Information. In so far as permitted by law, no member of the Consortium or any company in the same group as any member of the Consortium or their respective officers, employees or agents accepts (and the UK Government does not accept) any responsibility or liability of any kind, whether for negligence or any other reason, for any damage or loss arising from any use of or any reliance placed on the Information or any subsequent communication of the Information. Each person to whom the Information is made available must make their own independent assessment of the Information after making such investigation and taking professional technical, engineering, commercial, regulatory, financial, legal or other advice, as they deem necessary.

Contents

Key Words

Key Word	Description
Air Quality Control System	Technology used to remove impurities, particulates SOx and NOx from waste gases in order to comply with environmental standards
Air Separation Unit	A unit whose function is to separate oxygen from the air for use in the oxyfuel process
Biomass	Sustainable plant based material used for low carbon combustion, an option for White Rose fuel supply
Carbon Dioxide	A greenhouse gas produced during the combustion process
Carbon Capture and Storage	A technology which reduces carbon emissions from the combustion based power generation process and stores it in a suitable location
Coal	The fossilised fuel used in the combustion process for White Rose
Control System	A device, or set of, that manages the behaviour of items of plant equipment
Co-firing	Use of more than one fuel type (typically coal and biomass) in the combustion process
Emissions Monitoring	Systems used to measure and monitor emissions to the environment
Flue Gas	The waste gas stream from the combustion process
Gas Processing Unit	Unit in which the processing and compressing of CO_2 gas takes place before transportation to storage
Generator	The unit that converts mechanical energy from the turbine into electrical energy for transfer to the power grid
Heat integration	The recovery of waste heat in parts of the power generation process in order to improve the overall power plant efficiency
Interconnections	Links for supply between existing Drax and OPP facilities
Operating Mode	The method of operation of the OPP, which can operate in air or oxy-firing mode
Oxy-firing	The use of oxygen (instead of air) in the combustion process
Oxyfuel	The technology where combustion of fuel takes place with oxygen replacing air as the oxidant for the process, with resultant flue gas being high in CO_2
Oxygen	The gas used as the oxidant for the Oxy-fuel process
Oxy Boiler	The boiler within the Oxy Power Plant capable of producing full load in either the air or oxy-fired mode of operation
Oxy Power Plant	A power plant using oxyfuel technology
OPP Process	The flow of input and output streams through the Oxy Power Plant
Steam Turbine	The rotating machine that converts the thermal energy from the steam heated during combustion to provide mechanical output used in the generator to generate electricity
White Rose	The White Rose Carbon Capture and Storage project

Executive Summary

The Oxy Power Plant (OPP) Process Description was generated as part of the Front End Engineering Design (FEED) contract with the Department of Energy and Climate Change (DECC) for White Rose, an integrated full-chain Carbon Capture and Storage (CCS) Project. This document is one of a series of Key Knowledge Deliverables (KKD) from White Rose to be issued by DECC for public information.

White Rose comprises a new coal-fired ultra-supercritical OPP of up to 448 MW_e (gross) and a Transport and Storage (T&S) network that will take the carbon dioxide from the OPP and transport it by pipeline for permanent storage under the southern North Sea. The OPP captures around 90% of the carbon dioxide emissions and has the option to co-fire biomass.

Delivery of the project is through Capture Power Limited (CPL), an industrial consortium formed by Alstom, BOC and Drax, and National Grid Carbon Limited (NGC), a wholly owned subsidiary of National Grid.

This report provides a description of the OPP process, covering all main components: Air Separation Unit (ASU), Oxy-Boiler, Turbine-Generator, Water and Steam Cycle, Air Quality Control Systems (AQCS) and Gas Processing Unit (GPU). The report also provides information on the Interconnections to the existing Drax Power Station, control and performance monitoring systems, plant operating modes and CCS deployment specifics.

This document should be read in conjunction with the following documents:

- K.22 - Full Chain Process Flow Diagrams; and
- K.23 - Full Chain Heat and Material Balances.

Separate reports provide process descriptions for the CO_2 T&S elements of the project:

- K.29 - Transport - Process Description; and
- K.30 - Storage - Process Description.

1 Introduction

1.1 Background

The White Rose Carbon Capture and Storage (CCS) Project (White Rose) is an integrated full-chain CCS project comprising a new coal-fired Oxy Power Plant (OPP) and a transport and storage (T&S) network that will take the carbon dioxide from the OPP and transport it by pipeline for permanent storage under the southern North Sea.

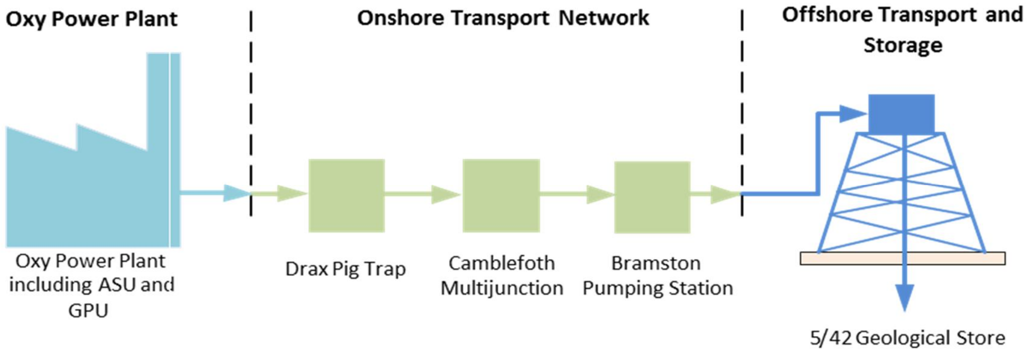
The OPP is a new ultra-supercritical power plant with oxyfuel technology of up to 448 MWe gross output that will capture around 90% of carbon dioxide emissions and also have the option to co-fire biomass.

One of the first large scale demonstration plants of its type in the world, White Rose aims to prove CCS technology at commercial scale as a competitive form of low-carbon power generation and as an important technology in tackling climate change. The OPP will generate enough low carbon electricity to supply the equivalent needs of over 630,000 homes.

White Rose is being developed by Capture Power Limited, a consortium of Alstom, BOC and Drax. The project will also establish a CO_2 transportation and storage network in the region through the Yorkshire and Humber CCS pipeline being developed by National Grid Carbon Ltd (NGC).

The full chain and its component parts (see Figure 1.1) are designed to be operated such that the target of two million tonnes of CO_2 per year can be safely stored.

Figure 1.1: Key Elements within the Full Chain



Source: CPL

The standalone OPP will be located to the northeast of the existing Drax Power Station site near Selby, North Yorkshire (see Figure 1.2) within the Drax Power Ltd (DPL) landholding and benefits from fuel import and power transmission infrastructure currently in place. The plant will generate electricity for export to the Electricity Transmission Network while capturing approximately 2 million tonnes of CO_2 per year, some 90% of all CO_2 emissions produced by the plant. The CO_2 will be transported by pipeline for permanent undersea storage beneath the North Sea.

Figure 1.2: White Rose CCS Project Artist Impression

Source: CPL

The power plant technology, known as oxy-fuel combustion, burns fuel in a modified combustion environment with the resulting combustion gases having a high CO_2 concentration. This allows the CO_2 produced to be captured without the need for additional chemical separation, before being transported for storage.

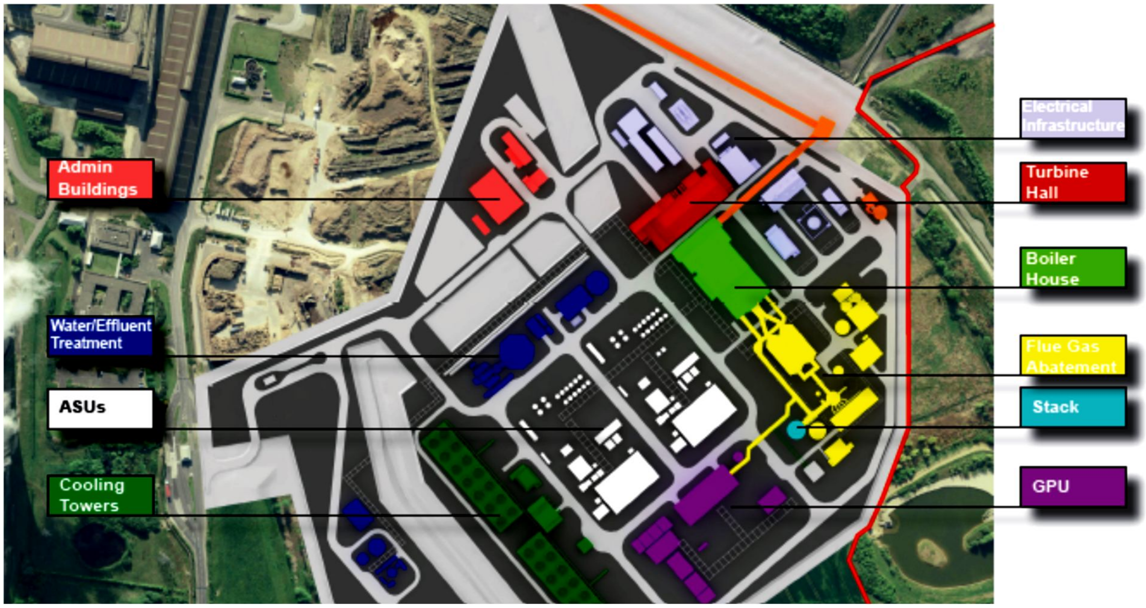
A new company, Capture Power Limited (CPL), has been formed by the consortium partners to develop, implement and operate the White Rose CCS Project. Alstom will have responsibility for construction of the power plant together with the CO_2 gas processing unit (GPU) and BOC will have responsibility for the construction of the air separation unit (ASU) that supplies oxygen for combustion. Drax will have responsibility for the operation and maintenance (O&M) of the power plant including the GPU, while BOC will have responsibility for the O&M of the ASU.

For the T&S elements of the project, NGC will construct and operate the CO_2 transport pipeline and, with partners, the permanent CO_2 undersea storage facilities at a North Sea site.

The general plant layout (see Figure 1.3) has been optimised to take into consideration the location of:

- Boiler, turbine hall, and power generation and transformers close to the coal / biomass delivery point;
- Air Quality Control Systems (AQCS) in line with the power block axis to simplify duct routing;
- ASU as close as possible to boiler in order to minimize the oxygen duct length and pressure drop;
- The existing High Voltage (HV) line and associated corridor;
- The interconnection points with existing DPL facilities; and
- The common cooling towers (power block, ASU, GPU) installed south of the site.

Figure 1.3: Plant Layout



Source: DCO Application

Coal for the new plant will be delivered by rail and biomass by road, using the existing Drax power station's facilities.

White Rose will benefit the UK and continued development of CCS technology by:

- Demonstrating oxy-fuel CCS technology as a cost effective and viable low-carbon technology;
- Reducing CO_2 emissions in order to meet future environmental legislation and combat climate change;

- Improving the UK’s security of electricity supply by providing a new, flexible and reliable coal-based low-carbon electricity generation option;
- Generating enough low-carbon electricity to supply the energy needs of the equivalent of over 630,000 households; and
- Acting as an anchor project for the development of a CO_2 transportation and storage network in the UK’s most energy intensive region thereby facilitating decarbonisation and attracting new investment.

1.2 Scope

The scope of this report is to provide an overall process narrative to a level of detail appropriate to accompany the OPP Process Flow Diagrams (PFDs) as listed in the K.22.- Full Chain Process Flow Diagrams report

This report is structured as followed:
- Section 1– Introduction;
- Section 2 – OPP Process Description;
- Section 3 – Interconnections with Exiting Drax Facilities Process Description;
- Section 4 – Control and Performance Monitoring Systems;
- Section 5 – Power Plant Operating Modes; and
- Section 6 – CCS Deployment Specifics.

2 Oxy Power Plant Process Description

2.1 Overview

This chapter details the processes involved in the OPP, focusing on the carbon capture aspects.

2.1.1 Oxy-Firing Principle

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.

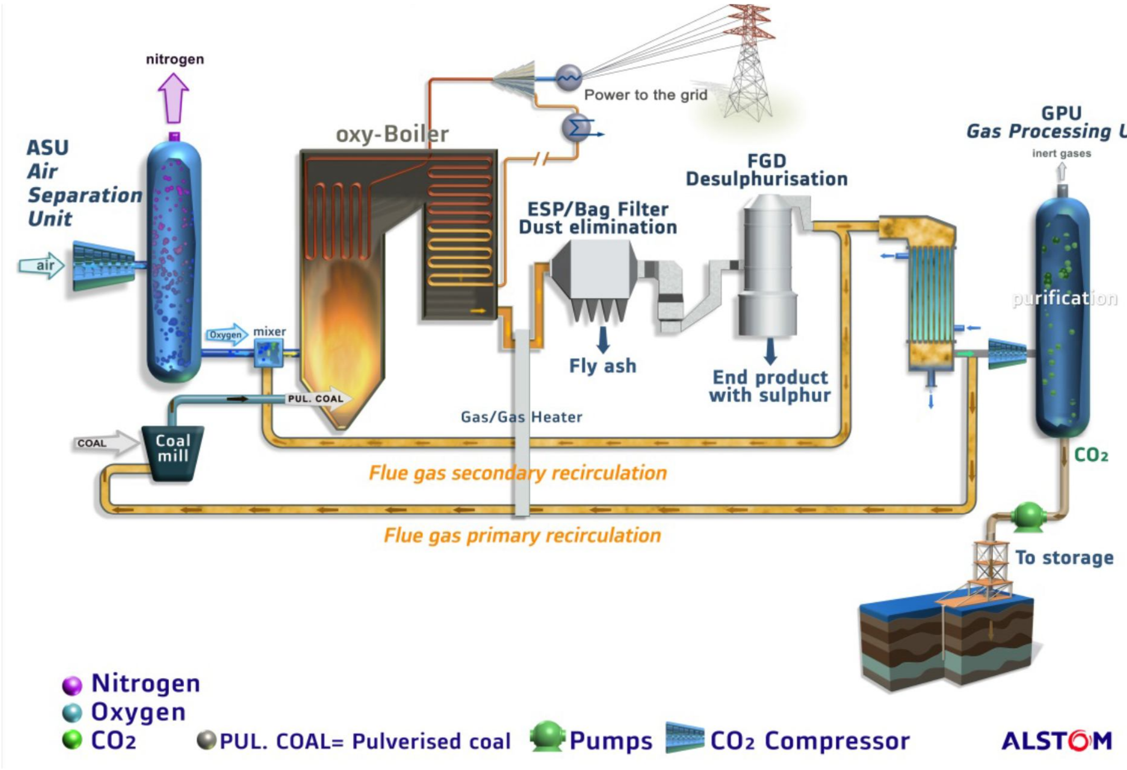
Oxy-firing requires the addition of two units to the conventional coal fired power plant:
- the ASU; and
- the GPU.

In addition, some modifications of the power plant itself are necessary, mainly:
- 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 (FGC);
- 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.

2.1.2 Oxy Power Plant

A schematic of the main components of the OPP is shown in Figure 2.1:
- ASU which separates oxygen from air, considerably reducing the content of nitrogen entering the boiler, and in turn resulting in a CO_2 rich flue gas which can then be processed and captured;
- Oxy-fired boiler, steam turbine generator and other power block components;
- AQCS that clean the flue gas to reduce atmospheric pollutants arising from combustion. The main components are the ESP and FGD unit; and
- GPU to process and compress the CO_2 rich flue gas to achieve the required CO_2 specifications and pressure for onward transport and storage.

Figure 2.1: Oxy Power Plant Diagram



Source: Alstom

As shown in Figure 2.1, the flue gas is recirculated from two locations. The primary recirculated flue gas (FGR) is taken after the FGC where most of the water has been condensed. The primary FGR stream is used to dry the coal during pulverisation and to transport the pulverised coal to the burners for combustion. The secondary FGR is taken downstream of the FGD system to accommodate a range of coals, some of which have a relatively high sulphur content. The oxygen is mixed with the primary and secondary FGR streams just upstream of the Primary Air (PA) and Forced Draft (FD) fans and injected into the furnace through the furnace windboxes. A third oxygen stream is injected directly at the windboxes.

In oxy-firing mode a high CO_2 content flue gas stream is provided to the GPU. The GPU is used for further processing and compression in order to produce a relatively pure CO_2 stream meeting the T&S specification.

In air firing mode the flue gases generated are discharged to the atmosphere via the OPP main stack.

2.1.3 Oxygen Firing Process Considerations

Burning coal in pure oxygen would result in a much lower flue gas flows and excessive furnace temperature, so sufficient flue gas must be recycled to moderate the furnace gas temperature and to provide sufficient gas flow for effective convection section heat absorption. This allows the furnace temperature to be maintained low enough to avoid ash slagging, fouling and corrosion, and the heat flux to furnace walls to be maintained within the limits imposed to prevent overheating of the tubes.

The location of the gas recycle take-off from the flue gas path also has a significant impact on the design and operation of the boiler and ancillary equipment. As the gas recycle is taken closer to the boiler outlet, more of the downstream gas cleaning equipment can be reduced in size and cost; however the concentration of impurities returned to the boiler increases and the boiler design must allow for the impacts on ash deposition, corrosion and pollutant levels. The final balance between boiler impacts and downstream equipment savings are generally controlled by fuel characteristics (e.g. sulphur & ash content) as well as site-specific factors (e.g. emission levels).

New equipment added within the boiler scope to allow oxy-firing capability includes:

- 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.

The FGR ducts also include isolation dampers and inlets for primary and secondary air, which are used during air firing, start-up, and during the transition between air and oxygen firing.

Additionally, sizing of the fans and ducts can be different than for an air-fired design due to the higher density of the recirculated flue gas as compared to air.

The windbox is also modified in order to accommodate the use of a stream of nearly pure oxygen provided from the ASU. About a third of the total oxygen produced in the ASU is introduced directly in the windbox. This is done in order to keep the oxygen content in the primary and secondary streams at a similar concentration to air in order to remove the need for the use of more costly alloys for the ducts and other equipment downstream of the oxygen mixing locations. The oxygen mixing locations for these streams are just upstream of the PA and FD fans. The main advantages of mixing oxygen in these locations are to minimise ASU power requirements (lower O_2 pressure required by mixing before the fans) and to improve the GGH preheater performance (lower sink temperature and higher sink mass flow) thus providing a boiler efficiency improvement without the addition of a separate oxygen heater in the flue gas stream. Another requirement is to achieve a safe mixing of oxygen in the recirculated flue gas stream before the GGH preheater to avoid the risks associated with areas of high oxygen concentration in the presence of dust.

Other changes to allow for oxy-firing in the boiler include SO_3 mitigation, duct lining, fan protection, quad-sector versus tri-sector air heater for leakage reduction, air heater enamelled section, O_2 control, and material selection depending on O_2 temperature.

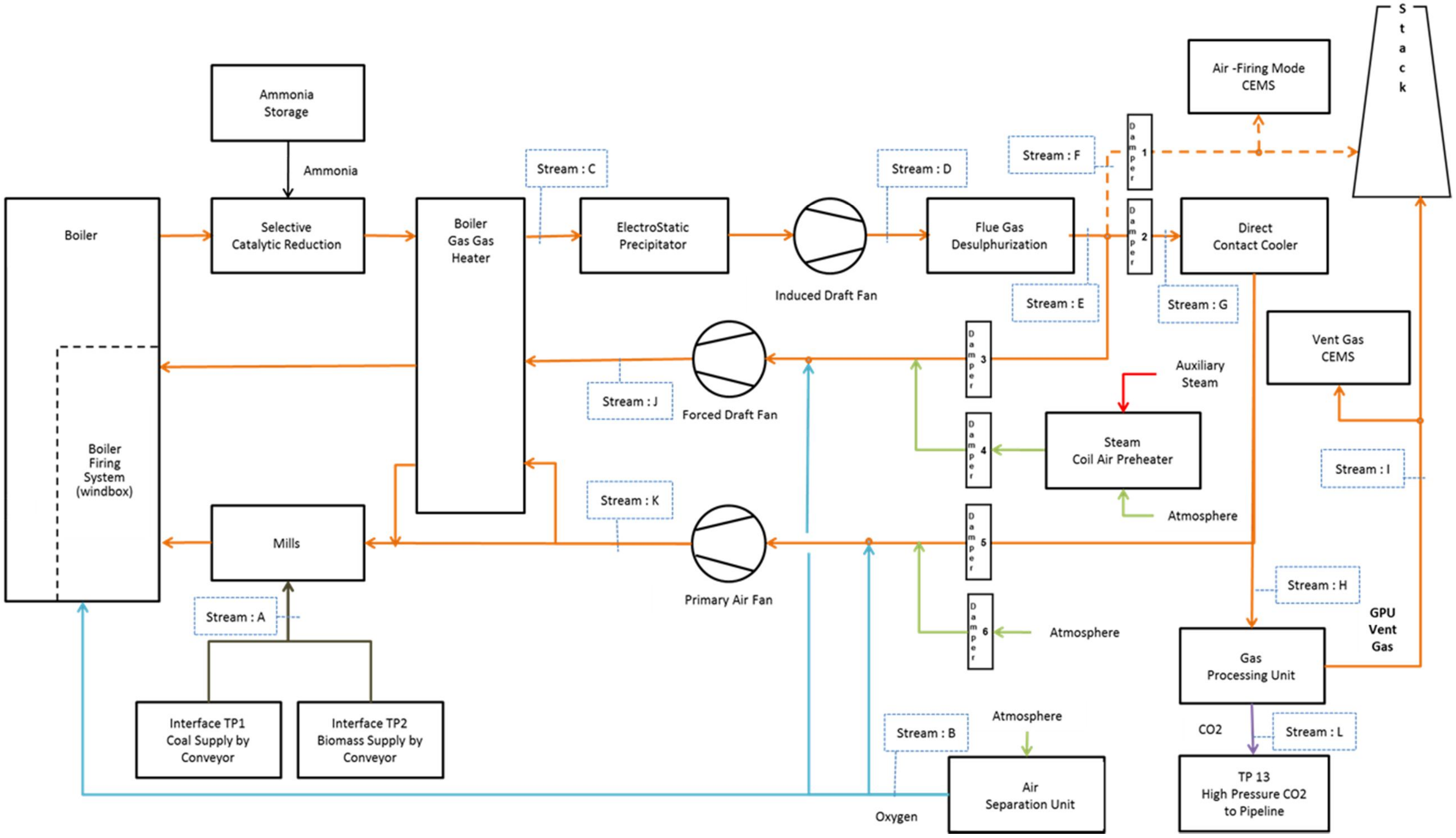
2.2 Process Description

This section provides an overall process narrative for the OPP that includes the following major facilities:

- ASU;
- Oxy Boiler; and
- AQCS.

The OPP Block Flow Diagram is presented in Figure 2.2 and details of the main feed and product stream specifications are provided in Table 2.1.

Figure 2.2: OPP Block Flow Diagram



Source: Alstom

Table 2.1: Feed and Product Stream Specifications (oxy-fuel mode)

Stream Number	Stream	Temperature (ºC)	Pressure(bara)	Mass Flow (kg/h)
A	Raw Coal	18	close to atmosphere	140,000
B	Oxygen from ASU	22	close to atmosphere	270,000
C	Flue gas to ESP	160	close to atmosphere	1,480,000
D	Flue gas from ID Fan	165	close to atmosphere	1,490,000
E	Flue gas from FGD	70	close to atmosphere	1,550,000
F	Flue gas to Stack	-	close to atmosphere	0
G	Flue gas to DCC	70	close to atmosphere	865,000
H	Flue gas to GPU	25	close to atmosphere	355,000
I	GPU vent to Stack	65	close to atmosphere	80,000
J	Secondary air	60	close to atmosphere	720,000
K	Primary air	30	close to atmosphere	270,000
L	CO_2	20	135	269,000

Source: Alstom

2.3 Air Separation Unit

2.3.1 Introduction

Gaseous oxygen (GOX) for consumption in the OPP boiler, as well as nitrogen for use within the air separation process itself, are produced by cryogenic distillation of air.

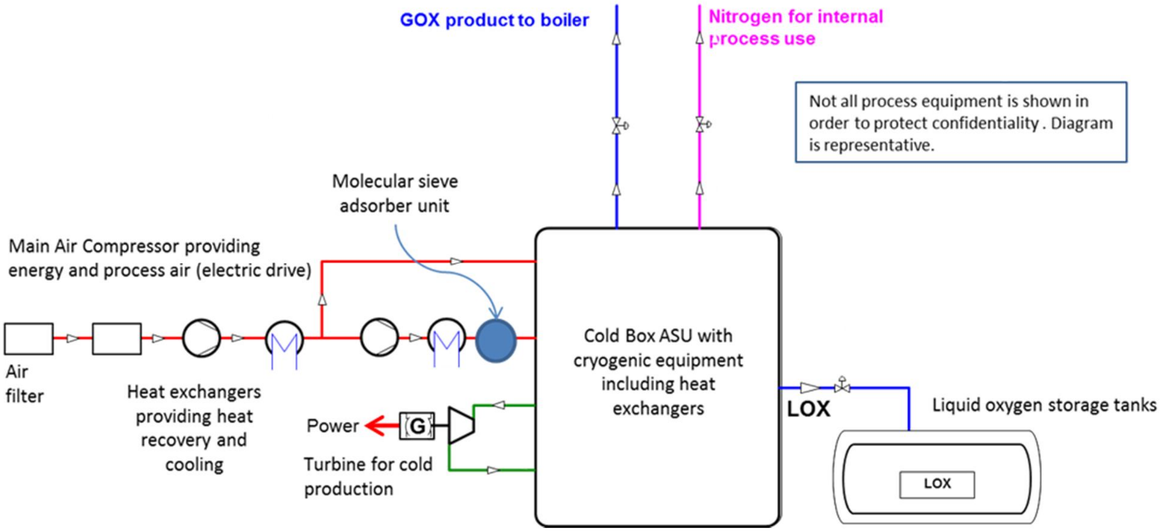
The ASU is centrally located within the OPP site (as shown in Section 1, Figure 1.3) and is designed to be able to operate independently from OPP provided that utilities are available.

The two ASU trains are identical, each sized for 50% of the oxygen requirement. For clarity, only one train is shown in Figure 2.4.

Figure 2.3: Linde ASU

Source: Linde

Figure 2.4: Schematic Diagram ASU (one train)



Source: BOC

The ASU operation is flexible, within limits, adjusting its output in order to match the load of the OPP.

Liquid oxygen (LOX) is also produced for back up storage as described in Section 2.3.6**Error! Reference source not found.**.

2.3.2 Air Compression, Precooling and Purification

Figure 2.5: Main Air Compressor

Source: Linde

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, turbo compressor. The compressed air is then cooled by an after cooler which simultaneously heats the condensate return to the boiler thus maximising process efficiency.

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.

The cooling water in the direct contact air cooler also scrubs the water-soluble chemical impurities from the process air.

Remaining contaminants such as water vapour, CO_2 and hydrocarbons in the air flow are removed while passing through an adsorber vessel filled with molecular sieve material, the Molecular Sieve Adsorber Unit. Moisture and CO_2 must be removed to prevent ice and dry ice from forming later in the process. One vessel is always on line to the process, while the other vessel undergoes a low pressure regeneration cycle using waste nitrogen form the ASU. For the regeneration cycle, the waste nitrogen is heated before entering the adsorber vessel, where it then desorbs water and CO_2 from the molecular sieve. The vessel is then cooled with cool dry waste nitrogen before being re-pressurised.

2.3.3 Main Heat Exchanger

The main process air downstream of the Molecular Sieve Adsorber Unit is then fed to the Main Heat Exchanger (see Figure 2.6). This is an aluminium plate and fin heat exchanger which cools the incoming air against warming the cold product streams from the distillation system, which are warmed in the same process.

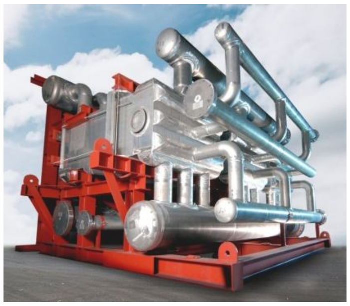
The Main Heat Exchangers are located within the cold box.

2.3.4 Auxiliary Process Equipment

Auxiliary equipment required for the ASU to operate includes compressors and turbine expanders. The compressors provide additional energy and turbine expanders improve efficiency in order to maintain and optimise the overall heat balance for a cryogenic process. Pumps for transferring cryogenic liquids to and from process related vessels are also included.

The ASU plant is supplied with cooling water from the main circulating system common to the OPP and thus has no separate cooling tower.

Figure 2.6: Main Heat Exchanger



Source: Linde

2.3.5 Air Separation

In the distillation columns, contained within the cold boxes, the low pressure air stream is separated into pure gaseous nitrogen liquid oxygen enriched liquid at the bottom. The cold streams then exit via the Main Heat Exchanger as described above.

2.3.6 Liquid Product Storage

To meet the oxygen requirement of the OPP during periods when demand exceeds the ASU production, as well as during short duration shut downs of the ASU, a liquid storage back up system will be provided (see Figure 2.7). Liquid oxygen drawn from the air separation plant will be stored in a vacuum insulated, horizontal pressure tank. Liquid pumps will be provided to feed liquid oxygen from this tank, either back into the ASU as liquid oxygen injection, or into the backup storage, which consist of 4 parallel connected vacuum insulated vertical pressure tanks. In case of a short term ASU shutdown, liquid oxygen from the backup storage can be vaporised in a steam heated water bath vaporiser and fed to the boiler.

2.3.7 Liquid Reinjection

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 GOX output to the boiler. LOX is re-injected back into the ASU process which both releases GOX and allows the energy contained within the LOX to be recovered and further used within the separation process itself. The LOX 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.

2.3.8 Buffer Storage for Gaseous Product

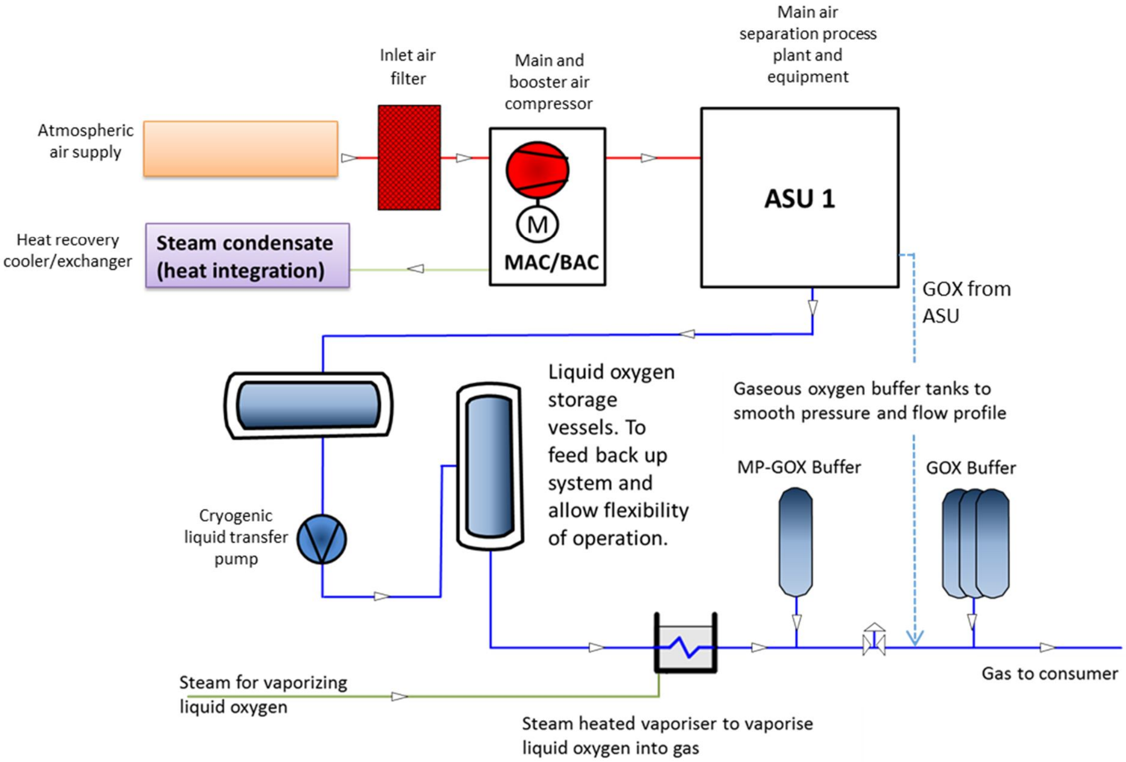
Buffer storage vessels are fitted on the gaseous oxygen supply to the boiler in order to smooth out the pressure fluctuations and ensure oxygen supply pressure is maintained. The liquid oxygen backup system has an additional medium pressure (MP) buffer vessel in order to give a faster response time to provide instantaneous supply to the boiler.

2.3.9 Oxygen Gas Flow to the Oxy Boiler

The flow of oxygen gas to the Oxy Boiler is controlled by the supervisory control system. Each ASU train feeds into a common supply header at a constant pressure. If the pressure and or flow from the plants exceed the demand then the excess is fed into the gas buffer vessels or if these are full, vented back to the atmosphere until equilibrium is established. Similarly if the demand exceeds the instantaneous supply capability then there is a means to vaporise liquid oxygen to match the short term shortfall.

This provides a high degree of control flexibility in operation.

Figure 2.7: Schematic Diagram ASU Back-up System (one train)



Source: BOC

2.4 Oxy Boiler

2.4.1 Introduction

The boiler is a balanced draft, sliding pressure, supercritical, once-through type, utilizing a low NOx firing system. The boiler operates either in air mode (without CO_2 capture) or in oxy mode (with CO_2 capture). The air mode is primarily foreseen for start-up

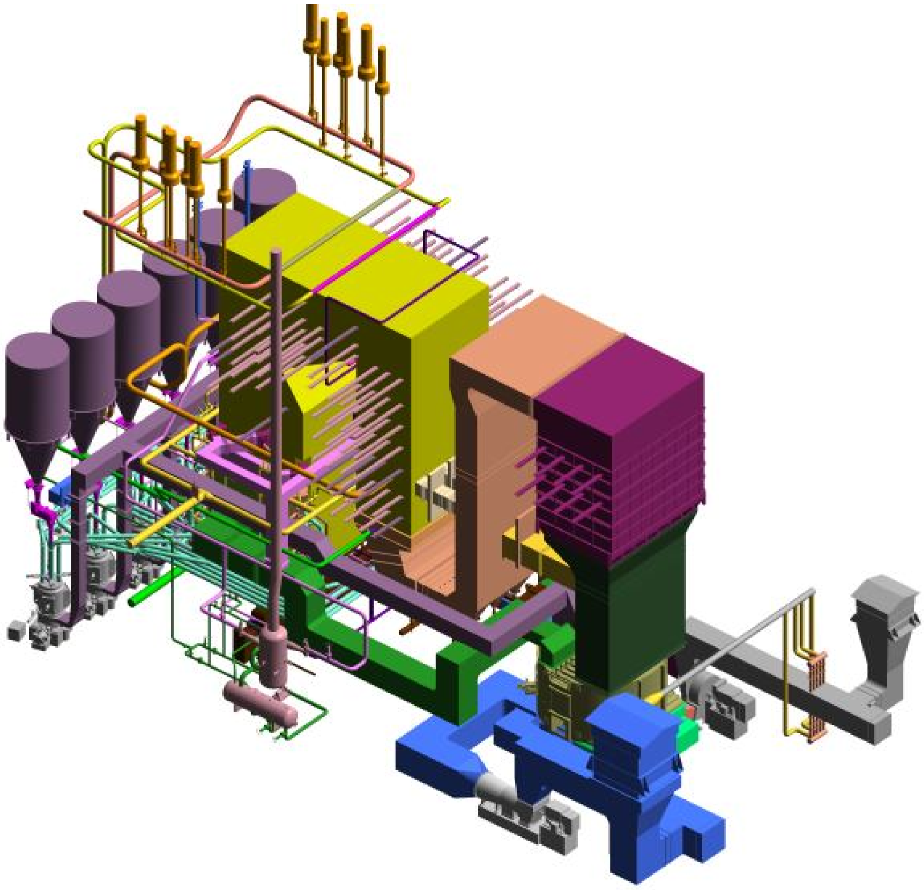
The boiler is capable of producing full load in either the air or oxy-fired mode of operation from a wide range of pulverised coals and is designed with the option to co-fire biomass along with the coal.

The boiler provides steam (both high pressure and reheat pressure streams) to the steam turbine (ST) at the specified flow rate, temperature and pressure.

In oxy-firing mode a high CO_2 content flue gas stream is provided to the GPU. The GPU is used for further processing and compression in order to produce a relatively pure CO_2 stream meeting the T&S specification.

In air firing mode the flue gas generated is discharged to the atmosphere via the OPP main stack.

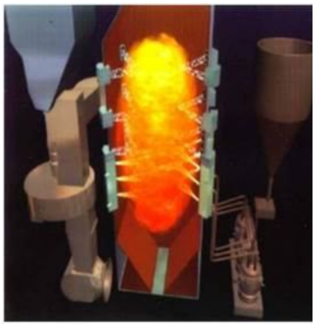
Figure 2.8: 3D model of Oxy-Boiler



Source: Alstom

2.4.2 Boiler Firing System

Figure 2.9: Firing System



Source: Alstom

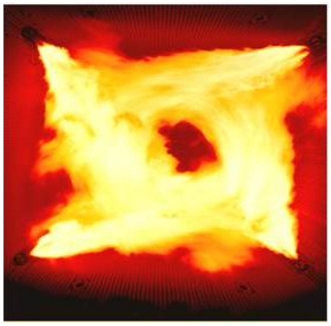
The fuel firing system consists of:

- four tangential fired windboxes;
- the Separated Over Fire Air (SOFA) windboxes,
- the ignition system; and
- the flame scanners.

The unique feature of titling tangential nozzles allows for complete combustion of the fuel and for simple and reliable steam temperature control. In addition, the corner windbox firing method results in low NOx emissions with a variety of fuels, uniform furnace heat absorption patterns, and high boiler turndown capability.

2.4.2.1 Tangential Firing System Operation

Figure 2.10: Top view: Tangential Firing

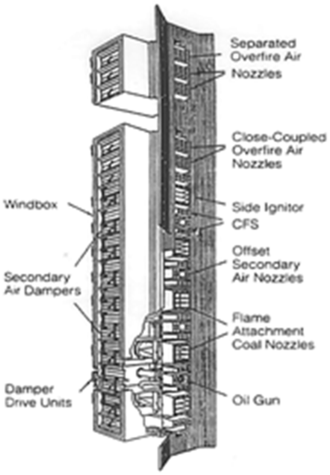


Source: Alstom

Figure 2.10 shows a Low NOx Tangential Firing System (LNTFS) with two levels for over fire air. Both the fuel and air are directed towards the tangent of an imaginary circle in the centre of the furnace, thus, the name "Tangential Firing".

A typical tangential firing flame pattern can be seen in photo in Figure 2.9. During the operation, a horizontally swirling flame pattern is formed with a vortex in the centre of the furnace. This unique mixing technique forms a large single flame envelope, forcing the fuel and air from each corner to take the maximum path length through the furnace before it exits at the furnace outlet. Both in theory and in practice, any imbalance between windboxes is quickly "averaged out" within the horizontal flame pattern providing for strong mixing which does not depend on precision control of air and fuel admission

Figure 2.11: Typical Windbox arrangement



Source: Alstom

The fuel and air/oxidant (are introduced to the furnace through a device called a windbox assembly. The windbox is a vertical stack of alternating fuel and air/oxidant compartments with dampers associated with each compartment. One windbox is located in each of the four corners of the furnace. Figure 2.11 shows a typical tilting tangential windbox design arranged vertically with alternating levels of oxidant and fuel. The dampers at each compartment are controlled to vary the distribution of oxidant over the height of the windbox, making it possible to change the velocities of the secondary oxidant streams for ignition point adjustment.

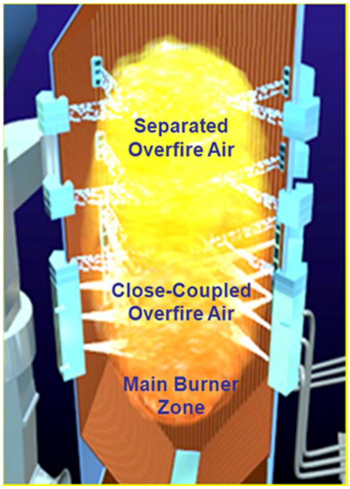
The overall oxy-firing system design includes the flexibility to vary the quantity and location of oxygen supplied to the furnace for combustion. The design allows the oxygen to be injected and premixed into the recycle before being divided into over fire, windbox auxiliary and windbox fuel compartments flows. The design also allows the local addition of additional oxygen through lances directly into the individual auxiliary and fuel compartments.

2.4.2.2 *Separated Over Fire Air System*

Separated Over Fire Air (SOFA) is a portion of the total combustion air (or oxidant) which is discharged through two discrete levels of windboxes (high and low level SOFA) located in the furnace corners between the top of the main windboxes and the furnace outlet plane.

Each SOFA windbox contains Over Fire Air (OFA) compartments with nozzle tips having adjustable yaw (rotation around vertical axis) and tilt (rotation around horizontal axis) positioning capability.

Figure 2.12: SOFA



Source: Alstom

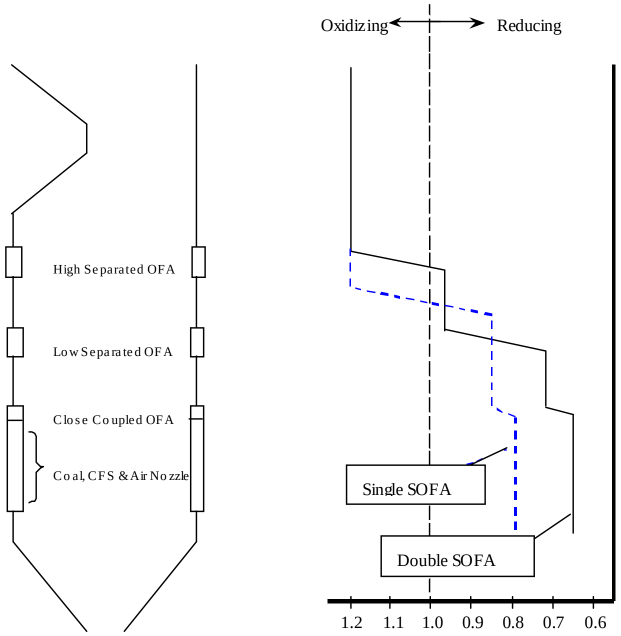
The use of air staging, OFA, to control NOx production in tangentially fired units has been extensively demonstrated. With the multiple-firing zone concept, OFA is injected to the furnace at several different levels.

This, in effect, divides the furnace volume into three discrete zones:

- the primary firing zone;
- the NOx reduction zone; and
- the final burnout zone.

The stoichiometric ratio in each zone is defined and controlled by the total OFA flow, the Close Coupled Over Fired Air (CCOFA) versus SOFA flow distribution, and the final excess air ratio. This advanced air staging approach provides better control of NOx production through optimisation of the stoichiometric ratio in each firing zone as shown in Figure 2.13. These principles also apply during oxy-firing by varying the amount of oxygen carried in the oxidant stream to each furnace zone to control the stoichiometric ratio.

Figure 2.13: Stoichiometry vs Elevation

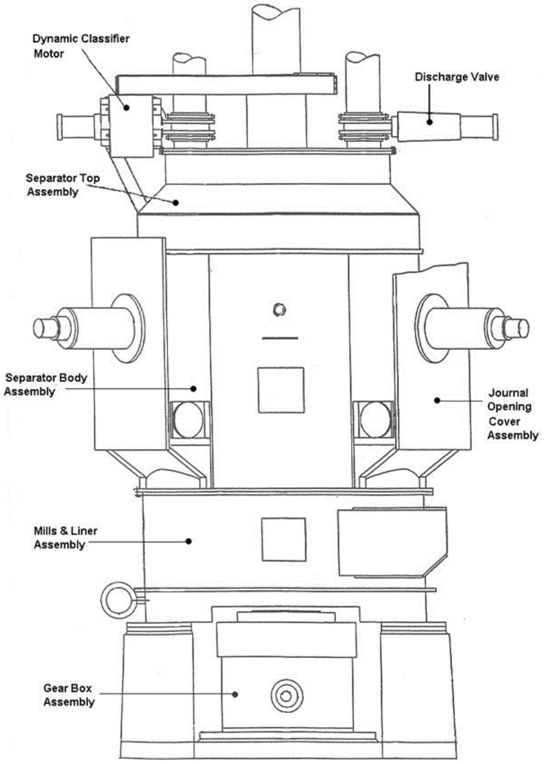


Source: Alstom

2.4.3 Coal Firing System - Coal Pulverisers and Feeders

Pulverisers are used to prepare and deliver the fuel to the steam generator. The coal pulveriser dries, grinds, and transports coal to the furnace. Properly prepared coal insures complete combustion of fuel that results in low unburned carbon in the ash and high boiler efficiencies.

Figure 2.14: Coal Pulveriser



Source: Alstom

As illustrated in Figure 2.14, coal is fed from a gravimetric coal feeder to the pulveriser through a centre feed pipe onto a revolving bowl. Centrifugal force causes the coal to travel outward toward the outer perimeter of the bowl. As the coal travels across the bowl, it passes through the grinding zone between the grinding ring and grinding rolls. Grinding force is imparted on the coal bed through a pivoting roller journal assembly with the grinding force controlled by externally adjustable springs. As the partially pulverized coal passes beyond the roller the coal continues outward toward the edge of the bowl.

The drying and transport oxidant for the coal pulverising process is the oxygenated primary flue gas recycle stream. The oxygen is mixed upstream of the primary recycle fan, to a concentration similar to the concentration of oxygen in air, before a portion of this stream is pre-heated in the GGH. The hot oxidant enters the mill-side housing below the bowl and is directed upward around the bowl through vanes attached to the circumference of the bowl. As it passes upward around the bowl, it entrains the partially pulverised coal and the drying and product sizing or classification process begins.

The coal/oxidant mixture then enters the primary classifier where heavier coal particles strike the deflector and intermediate liners and are returned to the bowl for further grinding. The lighter particles are carried up and through the deflector openings where secondary classification occurs.

Any tramp iron, or dense difficult-to-grind foreign material in the coal feed, is carried over the outer edge of the bowl where it drops to the mill bottom. Pivoted scrapers attached to the bowl hub sweep the tramp iron and other material to the tramp iron discharge opening and out of the pulveriser.

2.4.4 Biomass Firing System

The biomass firing system allows the option to co-fire biomass with the coal fuel. Vertical hammer type mills are provided for the biomass. The biomass system will use a pneumatic transport system, using recirculated flue gas for transport media instead of air.

2.4.5 Oil Firing System

The boiler ignition system is designed for light fuel oil (LFO). The LFO flow is regulated by a control station skid and controlled by the burner management system (BMS). Air is used to atomise the oil into the furnace.

2.4.6 Light Fuel Oil System

The LFO system stores and provides the LFO needed by various systems of the power plant. In addition to the use in the boiler during start-up and shut-down phases, the light fuel oil is used as primary fuel for the emergency diesel generator, the firefighting diesel pump and the auxiliary boiler.

The LFO is supplied to the plant by road tanker. The fuel is unloaded into the storage tank, using the unloading pumps, at a flow rate of about 40 t/h. The fuel tank has a storage capacity of 660m^3.

The fuel oil is pumped from the storage tank by mean of Boiler transfer pumps, at flow rate of 30 t/h, to the boiler fuel oil firing system, where it is atomised in the oil gun using air. The non-burned fuel oil is sent back to the storage tank.

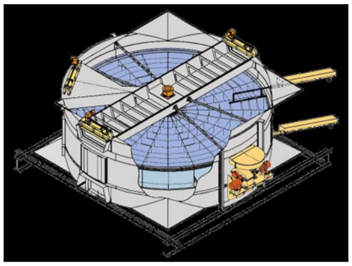
Another part of the LFO is transferred by the auxiliary transfer pumps at a flow rate of about 10 t/h to the buffer oil tanks of the emergency diesel generator (used in case of total blackout), the firefighting diesel pump and the auxiliary boiler (which produces auxiliary steam during plant start-up).

2.4.7 Air, Oxygen, CO_2 and Flue Gas Systems

The power plant has two operating mode: the air-firing mode which is the conventional mode for a fossil fuel power plant and an oxy-firing mode where the air is replaced by the oxygen produced by the ASU.

The air and fuel gas systems are designed to provide combustion air, cooling air, sealing air, and to remove the flue gases resulting from the combustion.

Figure 2.15: Air Fan



Source: Alstom

One primary air fan provides the primary oxidant stream to the mills for drying and transporting the coal or biomass to the furnace. A portion of the primary oxidant stream is heated in a rotary GGH against the boiler exhaust flue gas. From the mills, the primary oxidant stream transports the pulverized coal to the furnace.

In air mode, the primary oxidant stream is the air coming from the atmosphere, and damper no.6 is open and damper no. 5 is closed (see Figure 2.2).

In oxy mode, the flue gas stream is recirculated from downstream of the direct contact cooler (DCC) in order to limit the water concentration. Damper no.5 is open and damper no.6 is closed. Oxygen is mixed with the recirculated flue gas upstream of the PA Fan. This mix of recirculated flue gas and oxygen constitutes the primary oxidant stream.

Raw coal, fed to coal mills, is dried and transported to the furnace by the heated primary oxidant stream.

The raw coal flow to the mills is about 140 t/h. The total primary oxidant stream flow used to dry the coal is around 395 t/h.

One FD fan supplies the secondary oxidant stream for combustion.

In air mode, the secondary oxidant stream comes from the atmosphere through the steam coil air pre-heater; damper no.4 is open while damper no.3 is closed (see Figure 2.2).

In oxy mode, the secondary oxidant stream is drawn from downstream of the FGD system to keep SO_3 concentration as low as possible. The pure oxygen is mixed with the recirculated flue gas upstream of the fan. The secondary oxidant stream is heated in the GGH and led to the boiler firing system.

The total secondary oxidant stream entering the windbox is approximately 755 t/h.

About a third of the total oxygen need is introduced directly in the windbox. This is done in order to keep oxygen content in the primary and secondary streams below a threshold value, above which would require the use of more costly alloys for the ducts and other equipment downstream of the oxygen mixing locations.

The total oxygen flow to the boiler is about 270 t/h.

For both air and oxy mode the flue gas stream leaving the boiler is cleaned by reducing the NOx content in the SCR system and by reducing the SO_3 in the flue gas by the use of an SO_3 mitigation system. The flue gas, transported by the induced draft fan is cooled in the GGH, cleaned of particulate matter in the ESP, and cleaned of sulphur compounds in the FGD.

In air mode the flue gas is discharged through the stack; damper no.1 is open and damper no.2 is closed. A Control Emission Monitoring System (CEMS) is installed to monitor the emission level.

The flue gas leaving the FGD system is saturated with water which needs to be reduced before entering the GPU. This is accomplished in the DCC flue gas condenser. Cooling water is distributed through the incoming flue gas thanks to multiple stages of sprays. The water condensed is partly recirculated and cooled by main cooling water from cooling towers. The main part of the excess condensate is discharged to the FGD as make-up water with the remaining part discharged to the Waste Water Treatment Plant.

The flue gas flow at the inlet of the DCC is about 866 t/h. At the outlet of the DCC, after the water condensation, the flue gas flow is about 742 t/h.

Part of the flue gas is recirculated to the boiler via the primary air fan while the rest is sent to the GPU. This stream named “CO_2 rich flue gas” has a flow of about 354 t/h.

2.4.7.1 Selective Catalytic Reduction System

The NOx emissions are controlled by the low NOx firing system and the Selective Catalytic Reduction System (SCR), using anhydrous ammonia.

The purpose of the SCR is to reduce the NOx in the flue gas by mixing vapour ammonia with flue gas at the boiler outlet. The SCR System is composed of three layers of catalyst within a catalyst chamber.

The reduction reaction takes place as the gases pass through the catalyst chamber with the NOx being reduced to nitrogen and water vapour.

Anhydrous ammonia is unloaded from a tanker truck to the two anhydrous ammonia storage tanks located in the ammonia storage area. Ammonia from the storage tanks is sent by forwarding pumps to the ammonia vaporisers, with excess ammonia recirculated back to the storage tank.

The SCR system is started up and shutdown in a sequence integrated with the operation of the steam generating unit. When the proper thermal operating environment is achieved, vaporised anhydrous ammonia is supplied to the ammonia injection grid located upstream of the SCR reactor. The ammonia flow control unit consisting of dilution blowers, electric heaters, static mixer and ammonia flow control valve regulates the flow of anhydrous ammonia to the system.

2.4.7.2 *SO_3 Mitigation System*

The SO_3 mitigation system is installed upstream of the Ljungstrom GGH preheater to suppress the acid dew point and minimise the acid corrosion in all downstream equipment. The system injects a sodium carbonate solution upstream of the SCR to limit the SO_3 concentration entering the GGH.

The sodium carbonate reacts with the SO_3 and the resulting sodium sulphate particles are collected in the downstream ESP.

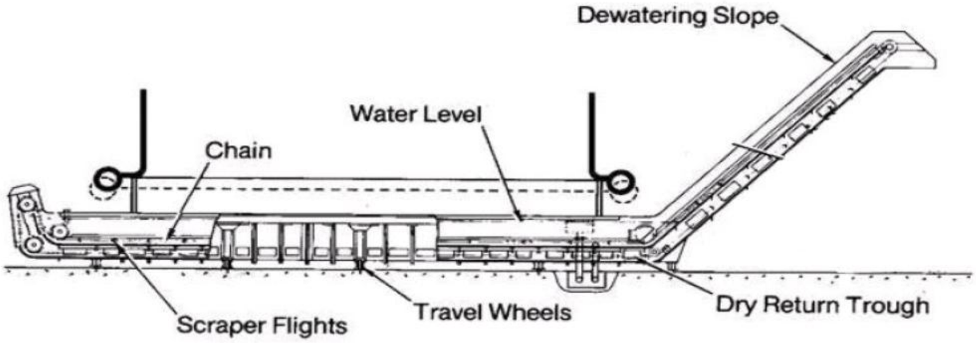
2.4.8 De-ashing System

The purpose of the de-ashing system is to remove and collect the ash produced by the coal combustion in the boiler furnace (Figure 2.16).

There are two types of ash:

- bottom ash; and
- fly ash.

Figure 2.16: De-ashing System



Source: Alstom

2.4.8.1 *Bottom Ash*

The heaviest and largest ash is collected at several locations: bottom ash from the furnace, ash collected under the economizer and ash collected under the inlet duct to the SCR.

A submerged scraper conveyor is provided under the furnace bottom hopper section for the removal of the furnace bottom ash. This uses a drag chain and flight conveyor of heavy construction submerged in a water trough below the furnace. The ash is evacuated mechanically on a continuous basis so there is no long-time storage in the water impoundment beneath the furnace. After discharge from the submerged scraper conveyor in a dewatered condition, ash is dumped into the diverter grizzly screen for further particle size reduction.

Finally, the bottom ash is transported by conveyors to an elevator. From the top of the elevator a conveyor delivers the ash into the Bottom Ash Silo with a storage capacity of three.

The maximum bottom ash production rate is about 7 t/h dry ash (about 11 t/h wet ash).

The silo is emptied by truck.

2.4.8.2 *Fly Ash*

Fly ash is driven within the flue gas through the GGH. Some of it falls in the bottom of the heater and is collected in the GGH hoppers. The rest of the ash is removed in the ESP and collected in the ESP hoppers. From the hoppers, the fly ash is transported by the fly ash handling system using compressed air for the ESP hoppers and blower air for GGH hoppers. Fly ash is delivered in the fly ash silo with a storage capacity of three days.

Fly ash production rate is around 20 t/h.

The silo is emptied to the Drax Fly Ash Conveyor using flushing blowers or by truck.

2.5 Turbine- Generator

The steam turbine (ST) will be a single-shaft, tandem compound, 3000 RPM, single-reheat condensing turbine.

Figure 2.17: Steam Turbine

Source: Alstom

The ST train consists of one single flow high pressure (HP) turbine, one double flow intermediate pressure (IP) turbine, and two double flow low pressure (LP) turbines exhausting downward into the surface condenser.

The steam cycle parameters are ultra-supercritical. The cycle conditions, including final feedwater temperature, the number of feedwater heaters, terminal temperature differences, heater drain arrangement, condenser and last stage blade selection are optimised with regard to economics and efficiency.

The general design of the turbine supports the reduction of thermal stresses due to start-up, load changing and other operation modes in order to extend the lifetime and sustain high levels of efficiency.

During normal operation the turbine will be operated in sliding pressure mode. As required, the turbine will support the fulfilment grid code requirements (e.g. by throttling, condensate stop, etc.).

2.5.1 Turbine Auxiliary Systems

The lube and control oil system provides lube oil for the turbine and generator bearings and control oil for the turbine safety and control systems. The main items of equipment are a common oil tank with attached coolers, dedicated pumps and filters for the lube oil and the control oil system.

The main lube oil pump is shaft driven. An electrical driven 100% auxiliary lube oil pump for normal start-up and shutdown is mounted directly on the tank. Additionally, a 40% capacity emergency direct current (DC) oil pump will be provided to safely run down the turbine in abnormal operating conditions.

2.5.2 Generator

The turbo-generator is a two pole three phase synchronous unit with hydrogen gas cooling of all internal components.

Figure 2.18: Turbo-generator

Source: Alstom

The generator has a closed gas cooling circuit for direct hydrogen cooling of stator core, winding and rotor winding. The hydrogen is circulated through the main components by two single stage radial flow fans. A hydrogen control and conditioning unit dries the gas as well as monitoring the pressure, purity and hydrogen gas consumption of the generator.

2.6 Boiler Steam and Water System

The steam generator will be designed to produce a continuous steam flow to the turbine generator.

The nominal boiler maximum continuous rating (BMCR) outlet conditions, for both air and oxy mode of operation, are around:

- 300 kg/s, 600ºC and 260 bar at the super-heater outlet; and
- 260 kg/s, 620ºC and 50 bar at the re-heater outlet.

The boiler proper consists of all the feed water, super-heater and re-heater heat transfer surfaces along with their connecting piping, headers, de-super-heater systems, support attachments, enclosures and casings, start-up system vessels, valves, and piping.

During boiler start-up and below the minimum once-through load, the flow in the water walls is kept above a minimum value. At low loads, a mixture of water and steam leaves the waterwalls and the water separator operates in a “wet” condition. Below minimum once-through load, the separator performs its steam/water separation function. The steam goes to the superheaters and the water is recirculated to the boiler using the start-up system boiler water circulating pumps (BWCP). Above the minimum once-through load, the mass flow rate in the waterwalls is large enough to cool the water wall tubes sufficiently, so that the BWCP is no longer needed in operation.

The BWCP eliminates the loss of treated feed water and reduces thermal losses during start-up conditions. The BWCP takes its suction from a mixing tee located downstream of the separator. The tee combines the flow of the feed water system with the drain water flow from the separator storage tank.

During the initial start-up, when no steam is being produced, the feed water pump is on recirculating mode and the BWCP supplies the entire flow through the economiser and waterwalls. As steam production begins, the level in the separator storage begins to decrease. The feed pump must replenish the separator storage water inventory. As this occurs, the flow through the evaporator begins to vary from entirely water recirculation to a mix of feed water and water recirculation. This trend continues until the minimum once-through load is reached, at which point the BWCP is taken out of service. Above the minimum once-through load, the steam generator has entered into the once-through mode where all of the water is being evaporated into steam and the entire flow through the evaporator is supplied by the feed water pump.

2.7 Water and Steam Cycle

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.

In the condenser, the condensed water is collected in the condenser’s hotwell and is transferred to the feed water tank by two stages of condensate extraction pumps with a flow of about 200 kg/s.

Between the two stages of condensate extraction pumps, the condensate is purified through a polishing plant, which uses ion exchange technology to remove trace dissolved minerals and filter any suspended corrosion products.

In order to increase the plant efficiency, the condensate stream is heated-up through six low pressure heaters by steam from the low pressure turbine section.

2.7.1 Feedwater and HP Heating Plant

The pre-heated water is sent to the feed water tank which is a buffer water reserve ensuring stable operation of the cycle. The water in the feedwater tank is heated by steam extracted from the intermediate pressure turbine section. The feed water tank system include the deareator, the, purpose of which s to remove the non-condensable gases to prevent boiler tubes corrosion.

From the feedwater tank, the boiler feed water pumps transfer the feedwater at high pressure to the boiler economiser inlet. The feedwater is heated-up through three high pressure heaters using steam extraction from the high pressure turbine section.

In the boiler the feedwater temperature is first increased in the economiser. After the economiser, it enters into the evaporator where the water is transformed into steam. The steam is then superheated to meet the steam turbine’s inlet characteristics.

At the outlet of the superheater the “live steam” (about 260 bar, 600°C), from the outlet of the superheater, is sent to the high pressure turbine via the high pressure admission valves.

From the high pressure turbine exhaust, the “cold reheat steam” returns to the boiler re-heater to reheat the steam.

The “hot reheat steam” (about 50 bar, 620°C), exiting the re-heater, is sent to the intermediate pressure turbine via the intermediate admission valves.

The steam from the intermediate pressure turbine exhaust is sent directly to the low pressure turbine section.

In the turbine, the steam expansion provides mechanical energy to the ST shaft, which is coupled (on the same shaft) with the turbo-generator.

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.

The turbo-generator transforms the mechanical energy into electrical energy. The turbo-generator is synchronised to the Grid in order to allow for power export. The rotation speed is 3000 rpm and the nominal gross power output is up to 448 MW_e.

During plant start-up or in case of ST trip, the produced steam is bypassed directly to the cold re-heat using the high pressure bypass system. The hot re-heat steam is also bypassed directly to the condenser using the intermediate / low pressure bypass system.

2.7.2 Main Cooling Water Systems

Figure 2.19: Sketch of Main Cooling Water System

Source: Arup Associates

The purpose of the main cooling water system is to remove the thermal heat load from the following main equipment items:

- ST Condenser;
- Closed Cooling Circuit;
- GPU; and
- ASU.

The main cooling water operates as a loop. First, the equipment heat load is absorbed by the main cooling water and secondly released into the atmosphere through evaporative cooling in the forced draft mechanical cooling tower.

From the cooling tower water basin, three cooling water pumps, with a total flow of about 57,000 m^3/h, distribute the cold water in parallel to the ST condenser, the closed cooling circuit, the GPU and the ASU.

The thermal heat load absorbed from each component is up to:

- 448 MW from the condenser;
- 14 MW from the closed cooling circuit;
- 175 MW from the GPU; and
- 27 MW from the ASU.

The “hot” cooling water is transferred to the cooling tower.

The cooling tower is a counter-flow wet-dry type, mechanical induced draft split into 28 cells. The “hot” water is first used to indirectly warm some air in the dry section of the tower and then distributed in the top of the wet section of each cell by spray nozzles. The air is circulated in counter current with the “hot” water by the fan. As the water falls the thermal heat load is transferred to the atmosphere by evaporation of some of the water. The cold water is collected in a basin beneath the cells and transferred to the pumping station. Mixing of the air streams from the dry section and the wet section of the cooling tower takes place to obtain discharge air conditions which will avoid the development of plumes.

During the thermal transfer to the atmosphere a part of the hot water is vaporised and lost in the atmosphere. Raw water make-up is provided to maintain the water level constant in the cooling tower's pumping station.

As the circuit operates on a continuous loop, a part of the water flow is discharged to the Waste water system as purge to prevent the water concentration of dissolved solids becoming too high.

The main cooling water is distributed as following:

- Three pumps (3 x 33.3%) ensure the cooling of the ST condenser, the GPU systems, the ASU systems, the power block closed cooling water circuit and the condenser vacuum pump.

The main cooling water system pumps also provide water for the submerged scraper conveyor and bottom ash cooling.

The make-up water to the cooling tower basin is raw water.

The condenser is equipped with tube cleaning systems on each path.

2.7.3 Raw and Demineralised Water Systems

The Raw and Demineralised Water Systems supply service water and demineralised water to the OPP.

The raw water transferred from the existing Drax facility arrives at the raw water pre-treatment plant in a mixing header tank before entering in the coagulation/flocculation and sedimentation trains. The maximum capacity is about 1,600 m^3/h. The sludge from the raw water treatment plant is mixed with blow-down from the cooling tower before being discharged (see Waste Water System section).

The raw water at the outlet of pre-treatment is stored in a tank of 6,400 m^3 capacity. A portion of the stored capacity is reserved for the firefighting system with the remainder providing a reserve in the event of a raw water pre-treatment plant outage and is also use as a buffer to avoid an over design of the water system. With this buffer, the water system can be designed for the average water need and not maximum cases (especially the cooling tower make-up during extreme summer condition).

The raw water is also used as service water.

The main portion of pre-treated raw water flow is used for the cooling tower make-up. This water is also used for boiler washing and to provide inlet water for the demineralised water plant production.

The trains of demineralised water production provide water at the quality required for the water steam cycle loops make-up (main steam and auxiliary steam). Each train is equipped with a set of safety cartridge filters, an ultra-filtration train, a booster pump, a reverse osmosis train, a degassing system and a continuous electro-de-Ionisation system.

The demineralised water is stored in a tank of 1,800 m^3 capacity. The stored capacity can be used in case of demineralised water production outage.

2.7.4 Waste Water Systems

The purpose of the waste water system is to collect the plant effluents and drains. Depending on the type of effluent, they have either to be treated before delivery at the interface points or can be directly delivered.

The main types of effluents are:
- Industrial effluents;
- Chemical effluents;
- Cooling water effluents;
- Oily effluent;
- Waste water;
- Fuel oil effluent;
- Rain water drains; and
- Sanitary domestic waste water.

The industrial effluents are mainly coming from:
- the water steam cycle loop;
- the boiler drains; and
- the flue gas condensate (FGD and GPU).

OPP industrial effluents mainly arise from the water steam cycle loop, the boiler drains and the flue gas condensate (GPU and FGD). These effluents are sent to the Waste Water Treatment Plant (WWTP).

Chemical effluents that mainly arise from the demineralized water production plant and the polishing plant are neutralized before being discharged to the WWTP.

In the WWTP the chemical and industrial effluents are combined and their pH raised through the addition of hydroxide.

The effluents are then sent to the precipitation tank where sulphide addition along with the raised pH leads to the conversion of soluble heavy metal salts to insoluble salts which precipitate.

The precipitation process generates very fine particles which are hard to remove, so the stream is sent to the flocculation tank where the addition of chemical coagulants in conjunction with low-sheer mixing promotes contact between the particles, and allows them to clump together into larger heavier particles which can settle at a faster rate. The mixture is sent to a sedimentation tank where the heavy metal containing floc settles to the bottom and can be removed as a sludge. The sludge is sent to a filter press to recover the solids which are sent for off-site treatment.

The liquid from the sedimentation tank passes to a buffer tank before the biological treatment section where the ammonia in the effluent is treated in a two-step process.

Liquid from the buffer tank passes through a heat exchanger and undergoes pH adjustment with acid addition before entering the Nitrification basin. Here the ammonia is converted to nitrite and then to nitrate - the nitrification process. This process is mediated by bacteria which require oxygen for growth and the metabolism of nitrogen, and so must proceed under aerobic conditions.

Following nitrification the effluent’s pH is adjusted by caustic addition prior to the second step of the process - denitrification, the conversion of nitrate to nitrogen gas. This process is also mediated by bacteria, but must proceed under anaerobic conditions, with the dissolved oxygen level at or near zero. Methanol is added to provide the bacteria with a carbon food source which they metabolise to carbon dioxide.

Following the denitrification process a Flotation basin separates the organic solids generated in the process from the effluent as a sludge which is sent to a filter press for solid separation. Clear effluent is released to the water discharge point.

Treated water is mixed with cooling water effluents (mainly the cooling tower blowdown) before being discharged to the Drax water discharge system.

The sludge are removed by truck estimate quantity is 18m^3 per day with an expected dryness of 30 to 40%.

Potential oily effluents (mixed with rain water) may come from the oil transformer areas, parking and weighbridge areas, or from the work shop (floor cleaning). They are collected for treatment.

Potential fuel oil effluents may come from the fuel oil storage and fuel oil unloading areas (mixed with rain water).

The oil / fuel oil content is separated in a water/oil separator, the water is discharged to the North storm basin, and the oil is recovered for external treatment.

In order to control the water flow discharge according to the regulation:

- the clean rain water at the north of the Care Dyke is collected and stored in the north storm basin, before being discharged to existing Drax water discharge system; and
- the clean rain water at the south of the Care Dyke is collected and stored in the south storm basin, before being discharged to the Carr Dyke.

The sanitary domestic water is collected and discharged to the Drax treatment system.

Effluent is discharged to the interface point with Drax in compliance with Drax's existing environmental permit. Key limits for the discharged effluents are:

▪ pH	within the range 6 – 9;
▪ temperature	maximum 30ºC;
▪ copper	maximum 0.1 mg/l;
▪ mercury	maximum 0.005 mg/l; and
▪ cadmium	maximum 0.01 mg/l.

Flow measurement is included in order to demonstrate the OPP's contribution to the total flow at the Drax outfall.

Table 2.2: Effluents

Effluent	Means of Discharging
Industrial effluents	▪ treated in the WWTP ▪ water is sent to Drax's existing water discharge system ▪ sludge is removed by truck - estimated quantity is 18 m3 per day with an expected dryness of 30 to 40 %.
Chemical effluents	▪ mainly from demineralised production plant and polishing plant ▪ neutralised and discharged to the WWTP before sent to Drax's existing water discharge system
Cooling water effluents	▪ mainly from cooling tower blow-down which is mixed with raw water treatment plant sludge ▪ sent to Drax's existing water discharge system
Potential oily effluents (mixed with rain water)	▪ may come from oil transformer areas, parking, weight bridge areas, workshop (floor cleaning) ▪ collected in dedicated treatment plant ▪ oil is separated by the water/oil separator, while water is discharged to the

Effluent	Means of Discharging
	storm basin. - oil is recovered for external treatment.
Waste water	- waste water discharged effluents are monitored (pH, flow, temperature)
Fuel oil effluents	- may come from the fuel oil storage and fuel oil unloading areas (mixed with rain water). - fuel oil is separated by the water/fuel oil separator, while water is discharged to the storm basin - oil is recovered for external treatment
Clean rain water at North of Care Dyke	- collected and stored in a storm basin before sent to Drax's existing water discharge system
Clean rain water at South of Care Dyke	- collected and stored in a storm basin before discharged to the Carr Dyke
Sanitary domestic water	- collected and discharged to the Drax

Source: Alstom

2.7.5 Auxiliary Steam

The purpose of the auxiliary steam is to provide steam flow both during unit start-up and during continuous operation.

The steam is mainly used and distributed for:
- ASU process regeneration;
- LOX vaporisation (in the event of an ASU outage);
- Turbine gland steam system;
- Heating the combustion air (in air mode only);
- Cleaning the air pre-heater's shoot blower systems; and
- Warming up the feed-water tank before boiler start-up or in case of turbine trip.

During unit start-up, the steam is produced by an auxiliary boiler. The auxiliary steam boiler uses fuel oil. The total production is about 50 MW thermal.

During normal operation, the auxiliary boiler is not in operation, and the auxiliary steam is provided by turbine bleeding or by the main boiler when the turbine is by-passed.

A CEMS is installed on the auxiliary boiler stack to monitor the emission level.

2.8 Air Quality Control Systems

The oxy boiler is equipped with an ESP to comply with the emission limit values for particulates.

The FGD will reduce the emissions of SOx to comply with the large combustion plant directive (LCPD) emissions limit values and the SOx limits described in the industrial emission directive (IED). The particulate levels in the flue gas are also further reduced by the FGD plant.

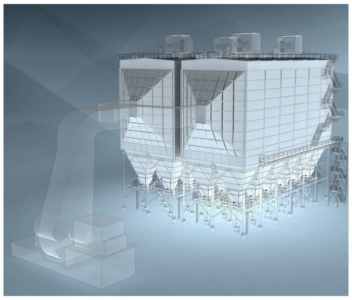
Flue gases from the oxy boiler will be directed through the ESP and FGD before being directed to the GPU.

2.8.1 Electrostatic Precipitator

ESP is located between the GGH and the induced draft (ID) Fan and cleans the flue gas from the dust/fly ash released during the combustion process in the boiler. The flue gas is routed to the ESP through ductwork and an inlet nozzle. At the inlet of the ESP, gas distribution screens are provided to ensure uniform distribution of the flue gas over the entire cross section of the ESP.

While the dust loaded flue gas passes through the ESP, the dust is precipitated by charging the dust particles under the influence of high voltage electric field created by the transformer rectifier sets. The collected dust is then rapped off from the electrodes through the rapping mechanism.

Figure 2.20: ESP



Source: Alstom

The collecting plates are rapped periodically to dislodge the deposited dust to the hoppers below the ESP casing. The rapping system employs ‘tumbling hammers’, which are mounted on a horizontal shaft in a staggered fashion, with one hammer for each shock bar. As the shaft rotates slowly each of the hammers in turn tumbles, hitting its associates shock bar. A uniform rapping effect is thereby provided over all collecting plates in one row, which causes the collected dust to fall down in large agglomerates.

The clean gas leaves the ESP to the FGD through the ID Fan.

2.8.2 Wet Flue Gas Desulphurisation

Flue gas desulphurisation is achieved by the limestone-gypsum wet method. This process technology uses limestone slurry as sorbent and at the end product gives gypsum.

The process is composed of the following main parts:

- the flue gas desulphurisation system;
- the reagent storage and preparation system; and
- the gypsum dewatering and storage system.

2.8.2.1 *Flue Gas Desulphurisation System*

Figure 2.21: Wet FGD

Source: Alstom

The flue gas enters the FGD absorber spray tower from the bottom and flows upward.

Inside of the FGD absorber, the flue gas travels upward in counter current to a continuous spray of recycled slurry that cools down the flue gas and absorbs SO_2 and other acid gases such as HCl and HF.

The flue gas exits the FGD absorber through a mist eliminator section that removes entrained droplets of slurry. The sprayed slurry is collected at the bottom of the FGD absorber and transferred to a tank where ambient air is injected to complete the chemical reactions. Fresh reagent is added to the tank where it reaches equilibrium with the bulk of the recycle slurry prior to being sprayed again in the FGD absorber.

The tank is equipped with agitators to keep the solid suspended.

2 *Reagent Storage and Preparation*

Limestone is used as reagent in the process.

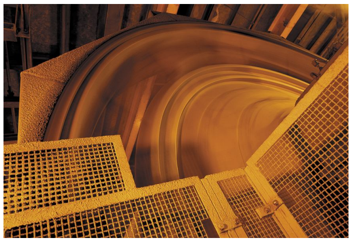
Limestone gravel is stored into two silos. Each silo is sized for a capacity of 314 m^3. Each silo is sized to provide 24 hours of limestone for the FGD running at 100% load with the performance coal.

Two milling systems are provided to wet grind the limestone gravel to the required size. The prepared reagent slurry (suspension of powdered limestone in water) is stored in a tank and from this tank is fed to the FGD absorber to replenish the reagent consumed in the absorption phase. Feeding rate is controlled based on a pH signal from the FGD absorber.

The raw limestone can be received from the existing Drax's limestone storage via two dedicated conveyors or by truck. The conveyors nominal flow is 13 t/h with a maximum flow of 60 t/h.

2.8.2.3 *Gypsum Dewatering and Storage System*

Figure 2.22: Gypsum Drum



Source: Alstom

The chemical reaction between SO_2 and limestone results in the formation of gypsum. A stream of the FGD absorber slurry is bled from the system and sent to the gypsum dewatering and storage system.

The gypsum dewatering system is divided in to two stages as described below:

- Hydrocyclones are used for the first stage of dewatering producing a stream of highly concentrated slurry rich in gypsum crystals; and
- This stream is sent to the second stage where vacuum belt filters are used to remove the residual water and produce a dry cake of gypsum that can be then stored in a silo.

The silo is sized for a capacity of 2,660 m^3 to provide four days of storage for the FGD running at 100% load with the performance coal.

From the silo the produced gypsum can be reclaimed and sent to either Drax's existing gypsum storage by conveyor or loaded onto trucks.

2.9 CO_2 Processing and Compression

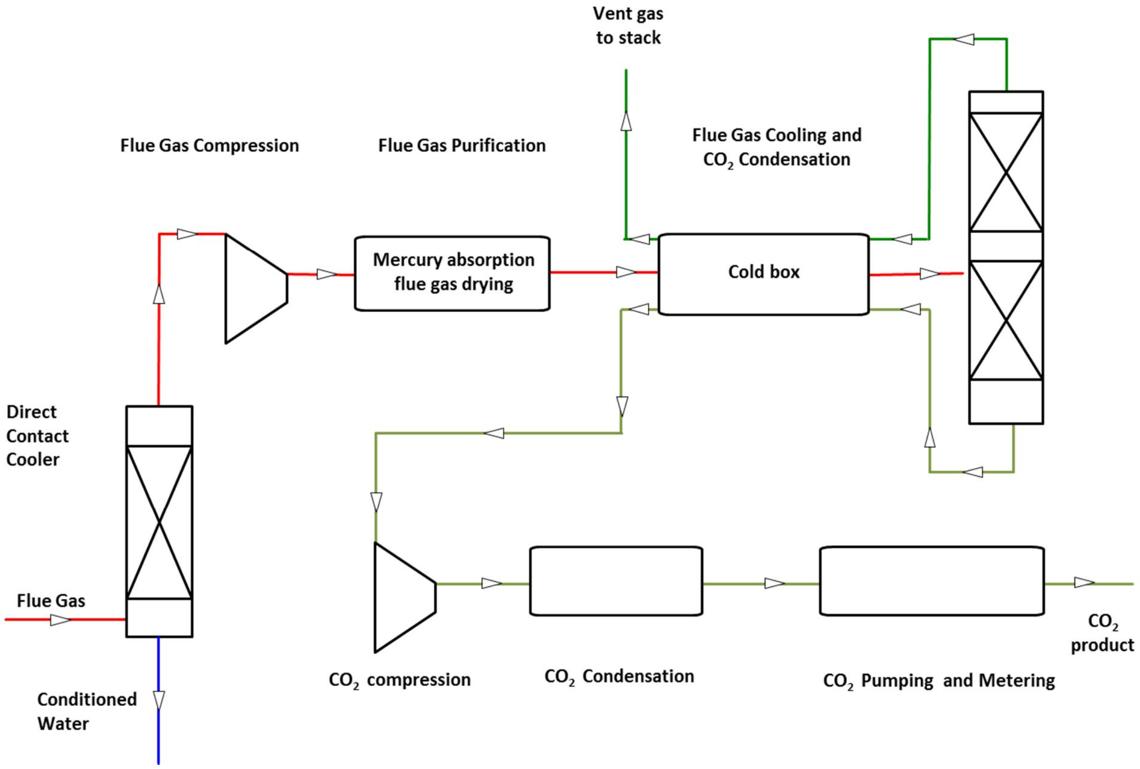
The CO_2 processing and compression will be undertaken in the GPU. The purpose of the GPU is to purify and compress the CO_2 rich flue gas and to provide a CO_2 product stream that meets the specification for onward transport and storage.

The GPU can be divided into the following main sub-systems:

- Flue Gas Compression;
- Conditioning and Drying;
- Regeneration Gas System;
- CO_2 Chilling and Separation;
- Off-gas Handling; and
- CO_2 Recompression.

The GPU process is based on the condensation of CO_2 at low temperature and elevated pressure. The GPU is designed for a CO_2 recovery rate of about 90%.

Figure 2.23: GPU Process Flow Diagram



Source: Alstom

The flue gas at the inlet of the GPU has the following approximate composition: 56% CO_2, 29.5% H_2O, 14.5% inert gas and oxygen.

The GPU is designed to process around 355 t/h of flue gas. The main purpose is to remove the inert gas and the oxygen from the flue gas in order to produce a high purity CO_2 product at a flow rate of 269 t/h.

The residual vent gas of about 80 t/h is sent to the main stack. A CEMS is installed to monitor the emission level.

2.9.1 Direct Contact Cooling System

The treatment of the flue gas starts in DCC system where the flue gas is cooled and the water is condensed by means of circulating water pumped back into the DCC. Condensed water is conditioned for pH adjustment. Surplus condensate leaves the system and is sent to the WWTP. The cooled flue gas leaves the DCC overhead and is sent to the flue gas compression.

2.9.2 Flue Gas Compression

In the flue gas compression system, the flue gas is compressed in a four stage flue gas compressor. Interstage cooling is done by means of water intercoolers. Condensed water is separated after each intercooler and sent to the WWTP. The flue gas is then further processed in the mercury adsorption and flue gas drying system.

2.9.3 Drying and Regeneration

Mercury must be removed from the flue gas to avoid harm to the used material for the cold box installed downstream.

Also, the residual water must be removed by means of a drying system to avoid blockage to the downstream unit because the CO_2 is separated at temperatures below the water freezing point. If mercury and water are removed the CO_2 can be condensed out of the flue gas by the cold box system.

2.9.4 Cold Box

The purified and dried gas is sent to the cold box where the flue gas is cooled against the vent gas from the CO_2 separation system. In the cold box the CO_2 condensation begins. To reach the envisaged CO_2 purity further processing of the CO_2 condensate is necessary in the CO_2 separation system.

2.9.4.1 CO_2 Separation System

The separation of the CO_2 from the inert gas and the oxygen is completed in the CO_2 separation system where the CO_2 achieves a purity of greater than 99.9%. The purified CO_2 is taken from the bottom of the separation system and sent to the cold box whereas the inert gas and oxygen (vent gas) is taken from the overhead. The condensed CO_2 is expanded and vaporised (to produce cold for the process). Also, the vent gas is expanded to recover the energy and is sent to the stack after it has passed the cold box.

2.9.5 CO_2 Compression

Due to the vaporisation of the purified CO_2 a multi sage compressor is used to recompress the CO_2. Interstage cooling is done by means of water intercoolers. Compression of the CO_2 is necessary to condense the purified CO_2 against an available utility at the downstream system.

2.9.6 CO_2 Condensation

Due to the increased pressure, CO_2 condensation can be achieved by cooling against cooling water or by using a chiller system.

2.9.7 CO_2 Pumping and Metering

The condensed CO_2 stream is finally pumped to the pipeline for transport to the storage site. This is more energy efficient than using a compressor to achieve the specified battery limit pressure.

The CO_2 export process parameters are:
- temperature 20°C;
- pressure up to 135 barg; and
- flow 269 tonnes/hour.

2.10 Heat Integration

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.

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.

3 Interconnections with Existing Drax Facilities Process Description

3.1 Introduction

This section outlines the extent and nature of modifications required to be undertaken to the existing Drax infrastructure in order to construct and operate the interconnections over the design life of 30 years. The existing assets at Drax that are used to support the operation of the OPP are critical infrastructure for Drax's current operations. Their condition was reviewed and no modifications, beyond those described for the individual interconnections are required. Drax currently operates a rolling 5 year asset maintenance programme during which any major repairs or refurbishments are identified and planned. This approach will ensure asset availability over the design life of the OPP.

Table 3.1: Interconnection Process Details

Terminal Point (TP)	Description	From	To	Pressure / Temp (design)	Flow
1	Coal Supply	Drax	OPP	N/A	2x 650 t/h
2	Biomass Supply	Drax	OPP	N/A	1x 80 t/h
4a	Limestone	Drax	OPP	N/A	1x 60 t/h
5	CW Make-up	Drax	OPP	4 bar / 30°C	1600 m^3/h
6	Potable Water	Yorkshire Water	OPP	6 bar / 20°C	10 m^3/h
8a	CW Purge	OPP	Drax	4 bar / 30°C	1,650 m^3/h
9	Sewage	OPP	Drax	4 bar / 30°C	10 m^3/h
10a	Fly Ash Disposal	OPP	Drax	N/A	100 t/h
12c	11 kV Connection	Drax	OPP	N/A	9 MVA
12d	11 kV Connection	Drax	OPP	N/A	9 MVA
14a	Gypsum Disposal	OPP	Drax	N/A	60 t/h

Source: Drax

3.2 Process Description

3.2.1 Coal Supply

Coal for the OPP will be delivered to site by rail and will be unloaded at the existing Drax coal rail unloading facility. This facility has a series of existing coal conveyors that are currently used to convey the coal to the existing Drax coal yard.

A new 350m^3 ground level hopper provided for exclusive use by the OPP will receive coal from either the existing emergency stock-out conveyors connected to the Drax coal rail unloading facility, or as a back-up. The new hopper can be loaded from the coal yard by vehicles to and including the size of the coal yard scraper. The existing conveyors will be fitted with pneumatically operated diverter chutes to allow coal to be diverted to the new ground hopper, but will maintain the ability to provide emergency stock-out the Drax the coal yard when required.

From the ground hopper, coal is discharged by three vibratory feeders and then, by means of pneumatically operated diverter chutes, will feed one of two new 1000mm width trough belt conveyors (duty and stand-by). Each conveyor line is capable of carrying 650 t/h of coal to the OPP coal silos.

Both conveyor lines will include a belt weighing system immediately before the ferrous separation system. Ferrous separators, over-band magnets at the head end of the conveyors, remove any ferrous material which is then transferred via chutes to ground level skips. In addition, trash screens remove oversize material. Fuel sampling is undertaken at the first transfer tower

The conveyors will follow a route paralleling the existing rail spur, with transfer towers along the route to accommodate changes in the conveyor direction.

At each main transfer tower, both coal conveyors will include appropriate chutes and pneumatically operated diverter chutes to enable the coal flow to be diverted to the standby conveyor, to ensure the target availability of 99.5% is achieved.

At the final transfer tower, the coal is transferred to one of two tripper conveyors which run to the tippers. These will be mounted on rails above the coal silos and both tripper carriages will be capable of independent movement to allow positioning over the respective discharge chute.

To provide further availability of coal supply, a road unloading facility has been provided adjacent to the OPP facility. This facility consists of a covered ground hopper with a capacity of 90m^3 which be filled from both tipper trucks and coal yard scraper vehicles.

The ground hopper will include two vibratory feeders to discharge the coal to a single conveyor. Similar auxiliary systems to the main coal supply system will be provided including a belt weigher and an over band magnetic separator. These systems are provided at the conveyor head in tower transfer tower.

In the transfer tower the coal will be transferred to a conveyor which transfers the coal to the two tripper conveyors which feed the OPP's coal silos.

Coal is supplied on a batch basis to the OPP when its coal silos require filling. When the silo filling is nearing completion, coal feed to the conveyors is stopped but the belts continue to run until empty.

3.2.1.1 *Modifications to Existing Infrastructure for Coal Supply*

As detailed above, two new divert gates will be required to be retro-fitted to the discharge end of existing conveyors. These will divert coal flow to either the new ground hopper, or to the existing coal yard for emergency stock-out.

All other equipment for coal supply to the OPP interconnection is ‘stand-alone’ from the existing site infrastructure.

3.2.2 Biomass Supply

Drax has two independent biomass storage and distribution systems on site; the selected interface for the OPP is with the road delivery and storage system only. This system has a total of 6 biomass storage silos (see Figure 3.1), 4 of which are available for supplying to the OPP.

Figure 3.1: Biomass Silos

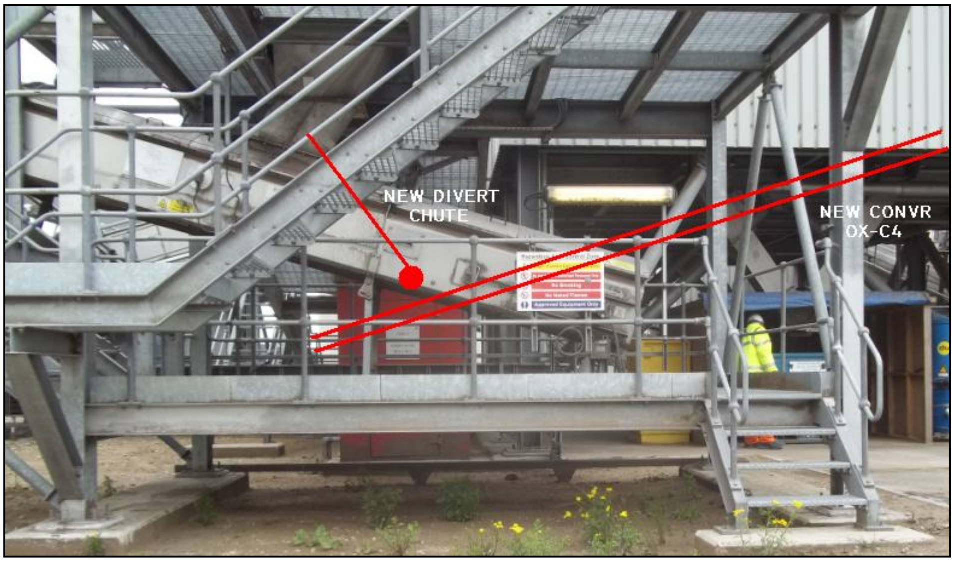
Source: Drax

Biomass is delivered to site by road and then screened for oversized objects and the presence of ferrous materials before being stored in the silos. When required, the biomass pellets are reclaimed from the silos using the existing screw conveyor reclaim system and then conveyed by the existing conveyors to the new conveyor system to supply the OPP.

The head end of the existing conveyor will be modified (see Figure 3.2) to include a purpose designed pneumatically operated diverter chute which will intercept the flow of pellets and transfer them to the new conveyor, which in turn transfers the pellets directly to a new transfer tower.

Belt weighing rollers are located immediately before the sampler at the transfer tower and a cross belt sampler collects fuel samples.

Figure 3.2: Location of Tie-in to Existing Biomass System



Source: Drax

The biomass pellets will then be conveyed along the same route as the coal conveyors, arriving at the boiler house's storage silo top. At this point, the biomass fuel is discharged via a chute to dedicated biomass silo.

The biomass conveyors are 600mm wide air glide systems, sized for a flow rate of 80t/hr. This conveyor selection reflects the flammable and dusty nature of the biomass fuel. Air glide conveyors provide a fully enclosed and efficient system for its movement, complete with dust extraction at several points along the route.

Biomass is supplied on a batch basis to the OPP when the biomass silo requires filling. When the silo filling is nearing completion, biomass feed to the conveyor is stopped but the system continues to run until empty.

3.2.2.1 *Modifications to Existing Infrastructure for Biomass Supply*

As discussed, the existing conveyor is modified to include a new pneumatic divert gate. This gate will divert biomass fuel onto the new conveyor ready for conveying to the OPP.

All other equipment for the biomass fuel interconnection is ‘stand-alone’ from the existing site infrastructure.

3.2.3 Limestone

Limestone is delivered to the Drax site by either rail or by road and is stored in the existing limestone store. From here, an ‘A-frame’ portal reclaimer reclaims the limestone and conveys the material to the Drax FGD plant for processing.

The new limestone conveyor system intercepts the existing feed of limestone to the Drax FGD plant, and diverts it to OPP instead. The new limestone conveyor system is fed via two new pneumatically operated diverter chutes, fitted in the discharge chutes of the existing limestone conveyors in the Limestone junction house, either of which can deposit the limestone onto the first new conveyor of the system.

From here, through a series of new conveyors and transfer towers, the limestone conveying system joins the main conveyor gantry and then runs parallel to the coal and biomass conveyor lines.

Finally the limestone is conveyed to the tops of the limestone storage silos. A pneumatically operated diverter chute located above the limestone silos diverts material to either of the silos as required.

The new limestone conveyor is a 600mm wide trough belt conveyors, sized for a flow rate of 60 t/h and includes belt weighing rollers.

Limestone is supplied on a batch basis to the OPP when the limestone silos requires filling. When the silo filling is nearing completion, limestone feed to the conveyor system is stopped but the system continues to run until empty.

3.2.3.1 *Modifications to Existing Infrastructure for supply of Limestone*

There will also be some modifications to the existing junction house to allow the construction of the new chutes and conveyor to carry material to the new transfer tower.

All other equipment for this interconnection is ‘stand-alone’ from the existing site infrastructure.

3.2.4 Gypsum

A single gypsum conveyor line has been designed to receive gypsum from beneath the OPP gypsum storage silos.

The gypsum conveyor is a 600mm wide trough belt design, sized for a flow rate of 60 t/h, and includes belt weighing rollers.

The new conveyor system will transfer gypsum from the OPP gypsum silos via a series of new conveyors and transfer towers and in part along the main gantry line to the existing gypsum junction house. At this point new chutes and pneumatically operated divert chutes allow the gypsum to be deposited onto either of the existing shuttle conveyors. These conveyors then transfer the gypsum onto the main Drax stockpile from which the gypsum is exported from site by either rail or road.

Gypsum is exported on a batch basis from the OPP when the gypsum silos require to be emptied. Once the silos are discharged, the conveyor system continues to run until empty.

3.2.4.1 Modifications to Existing Infrastructure for supply of gypsum

As described, the gypsum will enter the existing storage system via existing conveyors, and modifications to the chute work in the gypsum junction house are required to accommodate this. The junction house itself will also be modified to accommodate the addition of new conveyor.

All other equipment for this interconnection is ‘stand-alone’ from the existing site infrastructure.

3.2.5 Pulverised Fuel Ash

Pulverised fuel ash (PFA) is conveyed pneumatically from the OPP to Drax’s existing 2000 tonne PFA storage silo.

The system uses dense phase pneumatic conveying. This has the advantages of lower overall air consumption and the lower conveying velocities minimise wear on the conveying pipe.

The system begins from the outlet of the OPP PFA silo. PFA enters one of two pressure vessels where compressed air is injected to fluidise the PFA. Motive air then empties the pressure vessels and conveys the PFA through the conveyor pipework to the Drax silo.

The top of Drax's silo will be modified to include a new termination box which allows the conveyor pipe to deposit the conveyed PFA into the silo. Once in the silo, the motive air is filtered and discharged to atmosphere via a new silo top filter unit.

Two screw compressors (duty and stand-by) provide air for the pneumatic transport and fluidising of the PFA. The conveying pipeline bends are of hard wearing materials to ensure minimal erosion from the abrasiveness of the ash.

The single conveying line has a transfer rate of 80 t/h.

PFA is exported on a batch basis from the OPP when the PFA silo requires to be emptied. Once the silo is discharged, the motive air will continue to push any remaining PFA through the system until empty.

3.2.5.1 Modifications to Existing Infrastructure for PFA

To accommodate the new pneumatic conveyor line, a new termination box and filter unit are located on top of the existing 2000 tonne PFA silo.

All other equipment for this interconnection is 'stand-alone' from the existing site infrastructure.

3.2.6 Raw Water Make-up

Raw water for the OPP will be taken from Drax's cooling water (CW) make-up distribution tower located on the east side of the Drax site.

The raw water make-up required by the existing Drax generating station is abstracted from the River Ouse. The water is fed to four make-up water pumps via two intake screens and supplied to four sedimentation tanks via two pipelines. The treated water from the sedimentation tanks is taken to the distribution tower via two pipelines.

To supply water to the OPP, a connection is to be made on the outlet pipeline which supplies make-up water to the North generation units. The make-up water is pumped via two new 100% centrifugal pumps (duty / standby) to the OPP tie-in point via a single buried glass fibre reinforced plastic (GRP) pipeline.

The cooling water distribution tower has two steel outflow pipes (1000mm diameter), one of which feeds the North cooling towers make-up system and the other feeds the South cooling towers make-up system. The tie-in, to feed OPP, is made onto the steel outflow pipe which supplies make-up water to the generation units located to the North.

A pump house containing two 100% duty centrifugal cooling water pumps provides 1,600m^3/h of make-up water at the required conditions at OPP's terminal point, located to the south of the OPP.

A buried 500 mm diameter GRP pipeline delivers a maximum flow of the make-up water from the pump house to the OPP.

3.2.6.1 *Modifications to Existing Infrastructure for Raw Make-up*

As described, the raw water make-up line will interface at the Drax end with the North cooling towers connection to the CW make-up distribution tower. This is achieved by a hot-tap process.

All other equipment for this interconnection is 'stand-alone' from the existing site infrastructure.

3.2.6.2 *Water Return to Drax*

A combination of cooling water purge, treated industrial waste water and collected rainwater run-off form the OPP is monitored and returned to the Drax facility.

The combined water stream from the OPP is fed into a new connection to an existing access chamber located on the 1050mm diameter North cooling towers purge water pipeline in the Drax cooling water purge network. This existing northern purge pipeline feeds purge water to the north-west chamber in the purge pump station. Two existing purge pumps are then used to discharge the purge water from the chamber back to the River Ouse via the purge outfall chamber.

A direct buried 600mm diameter GRP pipe will be used to interconnect the two systems.

Flowrate from the OPP is limited to a maximum of 1,500 m^3/h

3.2.6.3 *Modifications to Existing CW purge Infrastructure*

The existing access chamber is modified to accept the new connection by removal of an existing air valve, the installation of a new 'tee' and then the re-fitting of the air valve on top of the 'tee' to provide a flanged connection for the water from the OPP.

All other equipment for this interconnection is 'stand-alone' from the existing site infrastructure.

3.2.7 Sewage

A sanitary sewage connection is required to dispose of sewage from the OPP.

Sewage from the OPP is gravity fed to an underground chamber in an existing sewage pump station where it is pumped by two submerged pumps into the existing sewage network. This then arrives at the Drax's main sewage treatment plant.

A direct buried 100 mm diameter uPVC pipe will be used to interconnect the two terminal points.

3.2.7.1 *Modifications to Existing Infrastructure for Sewage*

Some minor modifications to the foul pump station (FPS) will be required to accept the new sewage line from the OPP. This will be limited to civil engineering activities to modify the chamber itself to receive the new pipe.

No other modifications to the existing Drax infrastructure will be required.

4 Control and Performance Monitoring Systems

Control systems on the OPP including safety instrumentation will be implemented to ensure the highest levels of process and operational safety.

4.1 Control Systems

The OPP is operated from the single central control room (CCR). The CCR is equipped with an overall plant process control system based on distributed control system (DCS) technology. This system enables safe and reliable operation, control and supervision of the process with a high degree of automation.

One ST controller is provided for the ST governing and protection. The controller is based on a similar technology as the DCS.

The ASU will operate as a standalone system based on Siemens controller and will interface with to the OPP DCS via hardwired and serial link. The ASU servers will be located in the OPP server CCR. The ASU will have a local control room and remote control from the BOC remote operations centre in Sheffield via the BOC technical network.

The OPP control system interfaces with NGC T&S control system to exchange relevant operational parameters.

The OPP control system interfaces with National Grid Electricity Transmission (NGET) for grid operator control operation and to exchange relevant operational parameters.

The OPP control system interfaces with Drax’s control system for the conveyors (coal, biomass, limestone, gypsum, fly ash) and for the raw water supply.

The DCS system provides functions such as:
- Signal conditioning, annunciation, recording;
- Operation, monitoring and supervision;
- Open and closed loop control, sequence logic, protection; and
- Data communication, plant management applications.

Autonomous systems are equipped with their own local control systems. These systems are provided with local control panels allowing for full local operation, control and monitoring. The necessary information for remote monitoring and/or control is transferred to the overall plant control system.

Several CEMS are installed to monitor the emission level.

4.1.1 ASU Control System

Under normal operating conditions, the ASU will respond to load following signals related to the gaseous oxygen flow demand from the OPP control system and will ramp up and down within the designated flow range. This principle will also apply to the production of liquid oxygen depending on the selected mode of operation.

If a deviation from normal operating conditions is identified, the supervisory system will send a corresponding signal to the machinery controllers to adjust the mass flow of air into the machine and onwards into the plant.

At the same time, or within a determined time envelope set at commissioning, the various control surfaces will adjust to provide the required flow of product through the plant whilst analysis feedback will bias towards maintaining the product purity within specification.

Alarm management is established to provide warning when a process parameter is exceeded so that the operator can then respond.

The control system forms part of the overall safety management system concept for the installation and together with the required gas and electrical flow metering equipment forms the performance monitoring system for the installation.

4.1.2 Coal Supply Control System

Drax will supply coal on a batch basis when requested to do so by CPL.

CPL will send a ‘request coal delivery’ signal to Drax when the bunkers are required to be filled. CPL will start one of the two dedicated coal conveyors and position the tipper(s) accordingly. Drax will control the remainder of the coal conveying system and will start their delivery system once a ‘conveyors running’ permissive signal is received from CPL. The permissive signal will be required to be exchanged between the two plants to initiate this transfer and to stop the system in the case of plant failures or safety issues.

It is envisaged that one operator will be dedicated to the OPP and one dedicated to the materials handling tasks, including communications with Drax.

CPL will send a ‘Stop’ signal to Drax which shall be interpreted as ‘stop feeding the conveyor belt’. The vibratory feeders will then stop, but the belts will continue to run until empty; this will be achieved by implementation of a run-on timer, built into the control software. The run-on timer value will be calculated during detailed design.

The road unloading facility will be operated locally by Drax. A ‘local / remote’ switch will be provided to enable remote control from the Drax materials handling control room if required. Local operation of the conveyors from this location will be subject to the same permissive signals and run on timers as the other coal conveyors.

4.1.3 Biomass Supply Control System

In a similar manner to the supply of coal, Drax will supply biomass on a batch basis when requested to do so by CPL.

CPL will send a ‘request biomass delivery’ signal to Drax when the bunkers are required to be filled. When a subsequent permissive signal is received by Drax, indicating the OPP system is properly configured to receive biomass, Drax will start their biomass materials handling systems accordingly. The permissive signals are required to be exchanged between the two plants to stop the system in the case of plant failures or safety issues.

At an appropriate time during the transfer, the OPP will send a ‘stop’ signal to Drax, which shall be interpreted as ‘stop feeding the conveyor’. The conveyor will continue to run until empty using the same run-on logic as the coal conveyors.

4.1.4 Limestone Control System

In a similar manner to the supply of coal, Drax will supply biomass on a batch basis when requested to do so by CPL.

CPL will send a ‘request limestone delivery’ signal to Drax when the bunkers are required to be filled. When a subsequent permissive signal is received by Drax, indicating the OPP system is properly configured to receive limestone, Drax will start their limestone materials handling systems accordingly. The permissive signals are required to be exchanged between the two plants to stop the system in the case of plant failures or safety issues.

At an appropriate time during the transfer, CPL will send a ‘stop’ signal to Drax, which shall be interpreted as ‘stop feeding the conveyor’. The conveyor will continue to run until empty using the same run-on logic as the coal conveyors.

4.1.5 Gypsum Control System

CPL will send a ‘request to empty gypsum’ signal to Drax when the gypsum silo is required to be emptied. Drax will then start their materials handling systems and once configured correctly, will send a ‘ready to receive gypsum’ permissive signal to CPL. The OPP will then be able to deposit gypsum onto the conveyors.

The permissive signals are required to be exchanged between the two plants to stop the system in the case of plant failures or safety issues.

At an appropriate time during the transfer, Drax will send a ‘stop’ signal to CPL, which shall be interpreted as ‘stop feeding the conveyor’. The conveyor will continue to run until empty.

4.1.6 PFA Control System

CPL will send a ‘request to empty PFA’ signal to Drax when the OPP PFA silo is required to be emptied. Drax will then configure the PFA handling system to receive the material and will then send a ‘ready to receive PFA’ permissive signal to CPL. CPL will then be able to start the PFA bunker emptying. Permissive signals will be required to be exchanged between the two plants to stop the system in the case of plant failures or safety issues.

The permissive signals are required to be exchanged between the two plants to stop the system in the case of plant failures or safety issues.

At an appropriate time during the transfer, Drax will send a ‘stop’ signal to CPL, which shall be interpreted as ‘stop feeding the conveyor pipework’. The motive air will continue push any remaining PFA through the system until empty.

4.1.7 Raw Water Make-up Control System

The OPP raw water tank needs to be maintained at a constant level. There are two 100% (duty/standby) raw water makeup pumps on the Drax site. One pump runs constantly whilst the OPP is operational and a control valve will control the water level in the dock.

The water level in the Drax CW makeup distribution tower is maintained by monitoring the water level in the tower, and adjusting the CW makeup pumps to keep an appropriate level. The flow rates out of the tower are measured and used to trim the control loop. The addition of the raw water makeup flow to the OPP to the existing trim function will be the only modification required to maintain level in the tower.

4.1.8 Water Return Control System

Flow, pressure, temperature, pH and chlorides will be monitored before the OPP water return enters the Drax purge network. The existing Drax purge CEMS will remain the main environmental monitoring system, but the additional instrumentation allows differentiation of any purge water quality issues between the Drax Site and the OPP.

A permissive signal will be required from Drax, the status of which will be determined by the measurements in the OPP waste water monitoring pit and on the purge line. A status signal from OPP 'water return running' will be required.

4.1.9 Sewage Control

The sewage will be pumped from the OPP to Drax. A permissive signal 'sewage flow permitted' from Drax to CPL will be required to enable pump operation. This signal may be manually initiated by Drax operators or may be derived from the Drax sewage chamber high level instrumentation.

4.2 Safety Instrumentation

The OPP has a number of safety instrumentation systems installed that are designed to protect personnel, the environment, and the plant.

In addition to process safety instrumentation within the OPP process control systems, there are a number of specific safety systems, independent from those relating to process control. These key safety instrumentation systems for the OPP comprise:

- Emergency Shut Down (ESD) system;
- Fire and gas detection system; and
- High Integrity Pressure Protection System (HIPPS).

4.2.1 ESD System

Stand-alone ESD systems are provided for each of the main OPP control systems. The ESD systems are based on fail safe technology systems and ensure that the plant remains in a safe state. The systems are responsible for tripping associated plant in the event of dangerous conditions occurring or if critical process variables are outside their normal safe operating range.

4.2.2 Fire and Gas System

A dedicated fire and gas detection system is provided for the OPP. This independent system will reliably detect, alarm and if necessary initiate an orderly system shutdown via the ESD systems. It includes gas detection in the areas of the OPP where there is a risk to safety of the personnel from CO_2 exposure, or from oxygen enrichment or depletion.

4.2.3 HIPPS System

A HIPPS is provided to protect the CO_2 pipeline against overpressure from the OPP. The HIPPS is a packaged control system comprising of a fast acting shut-off isolation valve, pressure sensing transmitters and a logic controller that will isolate the pipeline before an unacceptable pressure level occurs.

4.3 Metering Systems

The section below describes the metering systems.

4.3.1 Coal Supply

Both conveyor lines will include a belt weighing system immediately before the ferrous separation system. The belt weighing system will comply with the required ±0.25% accuracy (class 0.5).

The sampling system has been specified to meet OFGEMs specifications for fuel sampling and will be designed and operated in accordance with BS ISO 13909. Once in operation, collected samples will then be sent to an ISO 17025 accredited laboratory for analysis.

4.3.2 Biomass Supply

Belt weighing rollers are included in the system. The weighing system will comply with the required ±0.25% accuracy (class 0.5).

A primary cross belt sampler with a secondary and tertiary sampling system has been included in the design and has been carefully specified in consultation with manufacturers and Drax to ensure compliance with OFGEM’s biomass fuel sampling requirements. The sampled material will be collected via suitable chute to a ground mounted drum carousel.

4.3.3 Limestone

Belt weighing rollers are included in the system. The weighing system will comply with the required commercial accuracy.

4.3.4 Gypsum

Belt weighing rollers are included in the system. The weighing system will comply with the required commercial accuracy.

4.3.5 Raw Water Make-up

The raw water supply for the OPP is metered by means of a magnetic flow meter provided after the tie-in point. The 600 mm diameter pipeline from the tie-in feeds the centrifugal pumps housed in the pump house.

4.3.6 11kV Electrical

Both supplies 10MVA and 11kV will be metered to the required commercial standard.

4.3.7 CO_2 metering

Differential pressure flow meters are the most common flow meter in use. There are references available for the usage of differential pressure flow meters in CO_2 service (e.g. Vattenfall CCS Project in Schwarze Pumpe Germany, In Salah CCS Project in Algeria).

The CO_2 metering system for the White Rose project will:

- Use a Venturi tube as primary element according to ISO EN 5167 delivered together with the required disturbance free up- and downstream piping ;
- Redundant installation consisting of redundant transmitter (differential pressure, pressure, temperature and density) and redundant calibratable flow calculator;
- Use hydraulic zero adjustment for the differential pressure transmitter for highest accuracy;
- Calibrate whole installation on a test bench under similar flow conditions (with water at similar Reynolds numbers); and
- The measured volumetric flow will be compensated to the design conditions regarding pressure, temperature and density, and finally multiplied with the density.

5 Power Plant Operating Modes

5.1 Introduction

The OPP has two operating mode; an air-firing mode which is the conventional mode for a fossil fuel power plant and an oxy-firing mode where the air is replaced by the oxygen produced by the ASU.

The air-firing mode will be used during start-up and shut down and in case the systems required to support oxy mode, the ASU, GPU or T&S network, are not available.

The CO_2 capture is only possible during oxy-firing mode. The operational intention is to run the plant continuously in oxy-firing mode and to minimise the number of starts. Operation will be primarily base load.

5.2 Air Mode Operation

Air-firing mode will be used for boiler start-up ahead of transition to oxy-firing mode, but the unit is capable of continuous operation in air mode if required.

In air mode the plant can operate in a range from 100% to 35%, the minimum boiler load without fuel oil support.

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).

However for turndown, the boiler operates in the sliding pressure mode, where pressure is reduced with load. This allows relatively constant first-stage turbine temperature in order to reduce thermal stress on components as the unit is cycled. As the load and pressure reduce, the boiler first moves from supercritical to sub-critical once through operation, and then as the load is reduced towards minimum load it transitions from once-through to recirculation mode, in which water/steam separation occurs, and water is recycled back to the waterwalls.

CO_2 capture is not possible in air mode operation and the flue gas is sufficiently cleaned in the AQCS, before being emitted via the main stack, to comply with the IED limits.

5.3 Oxy-Firing Mode Operation Regimes

In oxy-firing mode the plant has the capability to operate in two main operating regimes:

- Normal operation; and
- Flexible operation.

The plant operators will be assisted by a “unit master load controller”. This will predict and monitor the electrical power demands, margins and reserves. The operators will use this to initiate the appropriate type of operating mode required.

5.4 Oxy-Firing Mode - Normal Operation

In normal operation, base load is expected to be the main operating point. The plant can ramp up and down with a normal loading and unloading ramp rate of 2% per minute.

In normal operation, the most efficient operation of the plant is expected to be between 80% and 100% load. This is due to the ASU and GPU compressors operating ranges, below ~75% to 80% load they are in recycling mode. The also ASU has the option of producing LOX, assuming there is unused capacity in the LOX storage vessels, to reduce its GOX production.

In base load operation the boiler uses the full ASU GOX production and there is no LOX production or use of stored LOX.

5.5 Oxy-Firing Mode - Flexible Operation

In oxy-firing mode the OPP has a flexible operation mode that mimics the traditional “two shifting” of conventional power plants. In this mode the plant moves to a position that results in nearly no net power exchange with the grid while still generating the clean power needed to operate the ASU and GPU and providing CO_2, at a reduced rate, to the T&S network.

5.5.1 Min Load

Min load is achieved by ramping the plant to its minimum stable load (~ 25% in oxy mode without fuel oil support) while at the same time maximising LOX production from the ASUs, which has the effect of increasing their power consumption. As a result there is nearly no net power exchange with the grid but the OPP operation is maintained, including CO_2 capture and supply to the T&S system. A significant portion of the energy “stored” in the LOX production can be recovered in the associated “high load” mode. The OPP can operate in “min load” mode for up to 8 hours, until the LOX storage vessel for flexible operation is full. The plant is then ramped back to full load and the ASUs returned to GOX only production.

5.5.2 High Load

During periods of high power demand, LOX produced in “min load” can be re-injected into the ASU process where its stored energy is recovered, reducing the net ASU power consumption while maintaining full GOX output to the boiler. This results in an increase in the net export from the OPP of around 10 MW above its normal full load value. During this time the boiler operates at 100% load. “High load” can be maintained for a period of up to ~ 13 hours from the LOX produced and stored during 8 hours of “min load” operation.

The economics of the flexible operation mode are driven by the savings realised from the reduction in the number of start-ups and shut-downs (lower fuel oil consumption, lower stress to the mechanical equipment), maintaining CO_2 capture as well as by “electrical energy storage” in the form of LOX.

5.6 Air to Oxy Mode Operation Transition

The start-up of the plant is in air mode. The normal transition from air to oxy mode takes place between 40% to 50% load. The normal transition load range from oxy mode to air mode will take place in the same range.

In the transition from air mode to oxy mode, the oxidant streams supplied to the furnace through the PA and FD fans are progressively transitioned from air drawn from the atmosphere to a mixture of GOX from the ASUs and recirculated flue gases. Switching from air mode to oxy mode takes about one hour. Once oxy-firing is established, the resultant CO_2 rich flue is introduced to the GPU, and once the CO_2 specification is achieved OPP full CCS operation can commence.

6 CCS Deployment Specifics

Oxyfuel technology is considered a near-term technology for CO_2 capture from pulverised coal power plants. Using oxygen rather than air as the oxidant in the combustion process, a flue gas consisting essentially of CO_2 and water vapour is produced due to the exclusion of N_2 from the combustion process.

The main benefits of oxyfuel technology are:

- The cryogenic ASU required for the process is widely used commercially and is considered a mature technology;
- Robust technology – main subsystems commercially proven and / or developed from existing processes;
- Can be use d for a large range of fuels (coal, lignite, biomass, waste, natural gas);
- Can be readily scaled-up for large commercial plants;
- Can be used with high efficiency cycles;
- CO_2 purity can be optimised for the requirements of each project (typical 95% or up to 99.9% when required);
- Offers options for improved operational flexibility; and
- Adaptable to new installation and retrofit for existing power fleet.

This technology still faces some challenges such as:

- The ASU and GPU represent a substantial element of capital and operating costs;
- A significant auxiliary load (~30%) is required due to the ASU and CO_2 compression;
- Air in-leaks must be controlled to minimise contaminants in the exhaust gas, which can lead to increased operating costs; and
- Commercial scale demonstration of operation and performance to validate development results and allow for further optimisation.

It is believed that as the technology matures, future oxy- fired generation plants could offer reduced investment costs and complexity.

6.1 Alstom's Experience

An overview of Alstom's experience with oxyfuel technology is presented in Table 6.1**Error! Reference source not found.**.

Table 6.1: Alstom Oxy-fuel Combustion Experience

Project	Activities
Oxy-Firing Demonstration at Alstom Boiler Simulation Facility	Since 2008, Alstom's research and development facility in Windsor, Connecticut, USA has been conducting comprehensive technology development and verification in conjunction with the U.S Department of Energy, two state coal development offices and ten electric utility customers. The process has featured Alstom's purpose-designed, tangentially fired 15 MW pilot plant which included the full oxy-combustion process from oxygen supply to boiler/firing system, as well as air quality control systems and gas processing to produce high

Project	Activities
	quality supercritical CO_2 product. The plant has been employed to study the effect of oxy-combustion on different types of coal as well as evaluating the optimal design of the boiler under different operating conditions while collecting data on combustion, heat transfer, emissions, deposition and corrosion. The pilot program, which ended in April 2014, has produced a wealth of detailed information on the potential design and performance of full-sized plants. The results demonstrate that there are no technical barriers restricting the continued development and commercialisation of oxy-combustion technology for CO_2 capture.
Schwarze Pumpe Pilot	Alstom has engineered and built the oxyfuel steam generator system for the Vattenfall pilot plant located at the Schwarze Pumpe power station in Brandenburg, Germany. Alstom supplied the oxy-boiler for this plant and is a partner in the two-year testing program. The pilot plant started to operate in oxy-firing mode and produced the first tonnes of CO_2 in September 2008. The oxy-fuel pilot plant consists of a steam generator with a single 30MW top-mounted pulverized coal burner and the subsequent flue gas cleaning equipment, wet flue gas desulphurization and the flue gas condenser. In addition to these typical power plants components, a CO_2 purification and compression plant is placed downstream of the flue gas condenser to produce CO_2. The gaseous oxygen with a purity of 99.5% needed for the combustion is supplied by a cryogenic air separation unit.
Lacq CCS Pilot	Alstom supplied the retrofit of a 30MW conventional boiler for oxy-firing combustion for TOTAL pilot plant, located at a natural gas refinery in Lacq, near Pau in southwest France. This is a fully integrated CCS pilot project, financed and operated by TOTAL. CO_2 is stored in depleted gas fields in the Lacq region. The pilot plant, which produces some 40 t/h of steam, will emit up to 150,000 tonnes of CO_2 over a 2 year period. Construction work was completed in January 2009, and commissioning of the plant in mid-2009. These stages are being followed by a 2 year test period. Since January 2010, the project has been testing the entire CCS chain.
Jänschwalde (cancelled)	Alstom participated in the feasibility study of Vattenfall for its carbon capture and storage programme launched at Jänschwalde Power Plant. The project was cancelled due to the political impasse with regard to a German CCS law. The EU-supported project would have been operational by 2015/16. It was planned to introduce two different capture technologies at Jänschwalde Power Plant, both provided by Alstom. One new 250 MW Oxy-fuel boiler was to be built to replace one of the existing boilers, capturing 1.4 million tonnes per annum of carbon dioxide. The other existing boiler in the block was to be retrofitted with a post-combustion capture technology based on chilled ammonia process, capturing an additional 0.3 million tonnes of CO_2

Source: Alstom

The experience with the CCS specific units is:

- Oxy Boiler: experience with oxy boilers and oxy-fired operation from Pilot plant in Windsor and Schwarze Pumpe, test runs over several years, conventional boiler technology in operation all over the world;
- ESP: conventional technology, additional sealing systems tested in pilot plant Schwarze Pumpe;
- Wet FGD: conventional technology, many wet FGDs are in operation all over the world;
- ASU: conventional technology, many ASUs are in operation all over the world; and
- GPU: experience from pilot plant, test runs over several years. Selected equipment (e.g. compressors, pumps, columns, plate fin heat exchangers) are widely used in petrochemical and chemical plants and have Alstom and industry references at scale.

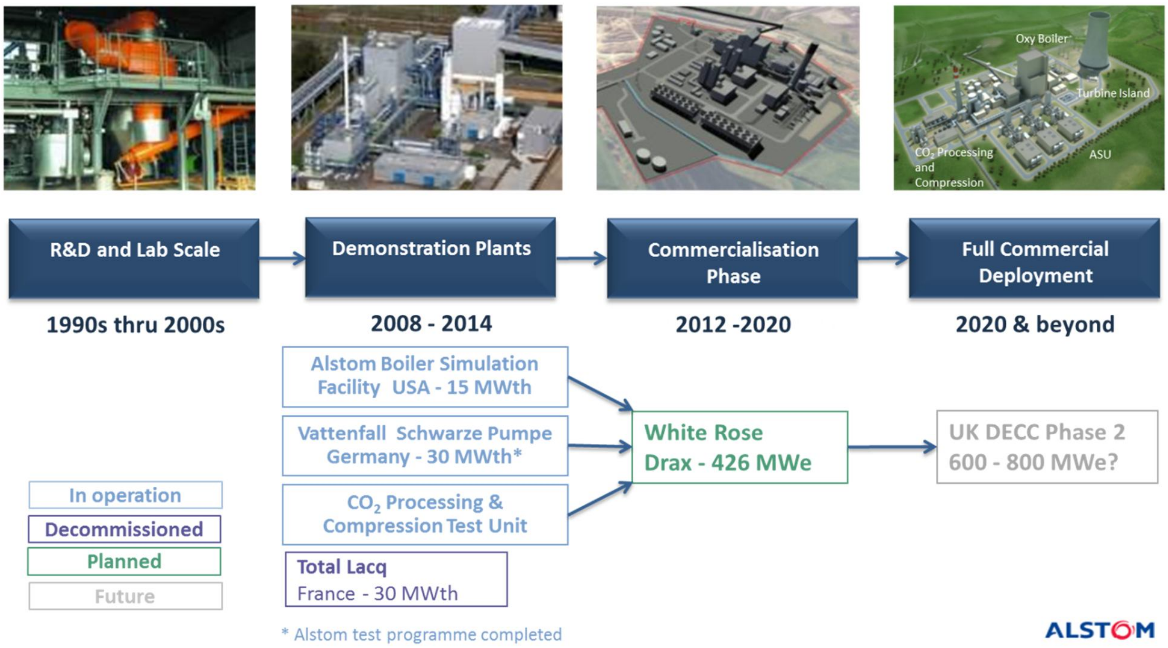
6.2 Retrofit/Repowering Potential

Existing air-fired power plants might be retrofitted with ASU, oxy-fired burners, flue gas recycle, and a GPU. The resulting plant would be de-rated by the auxiliary power these systems consume, less any improvement in steam cycle capacity that might be available. Alternatively, the existing plant, typically a sub-critical steam cycle, might be repowered by adding an ultra-supercritical topping steam cycle and a new, ultra-supercritical, oxy-fired boiler.

While such retrofit/repowering schemes have been proposed, it has yet to be shown that they can result in an oxy-fired plant that is lower in cost than an optimized, new-build plant. The large fleet of air-fired power plants in service, however, calls for more study of this option.

6.3 Alstom's Oxy Combustion Commercialisation Roadmap

Figure 6.1: Oxy Combustion Commercialisation Roadmap



Source: Alstom

7 Glossary

Term	Description
AQCS	Air Quality Control Systems
ASU	Air Separation Unit
AVR	Automatic Voltage Regulator
BAC	Boosted Air Compressor
BS	British Standard
BMCR	Boiler Maximum Continuous Rating
BMS	Burner Management System
BWCP	Boiler Water Circulating Pump
CCOFA	Close Coupled Over Fired Air
CCR	Central Control Room
CCS	Carbon Capture and Storage
CEMS	Control Emission Monitoring System
CO_2	Carbon Dioxide
CPL	Capture Power Ltd
CW	Cooling Water
DC	Direct Current
DCC	Direct Contact Cooler
DCS	Distributed Control System
DECC	Department of Energy and Climate Change
DPL	Drax Power Ltd
EN	European Standard
ESD	Emergency Shut Down
ESP	Electrostatic Precipitator
FD	Forced Draft
FEED	Front End Engineering Design
FGC	Flue Gas Condenser
FGD	Flue Gas Desulphurization
FGR	Flue Gas Recirculation
FPS	Foul Pump Station
GGH	Gas to Gas Heater
GOX	Gaseous Oxygen
GPU	Gas Processing Unit
GRP	Glass fibre reinforced plastic
HCl	Hydrogen Chloride
HF	Hydrogen Fluoride
HIPPS	High Integrity Pressure Protection System
HP	High Pressure
HV	High Voltage
IED	Industrial Emission Directive
ID	Induced Draft
IP	Intermediate Pressure
ISO	International Standard Office

Term	Description
kV	Kilovolt
LCPD	Large Combustion Plant Directive
LFO	Liquid Fuel Oil
LOX	Liquid Oxygen
LNTFS	Low NOx Tangential Firing System
LP	Low Pressure
MAC	Main Air Compressor
MP	Medium Pressure
MW	Megawatt
MW_e	Megawatt of electrical power
NGC	National Grid Carbon Ltd
NGET	National Grid Electricity Transmission
NOx	Nitrous Oxides
O&M	Operation and Maintenance
OFA	Over Fire Air
OFGEM	Office of Gas and Electricity Markets
OPP	Oxy Power Plant
PA	Primary Air
PFA	Pulverised Fuel Ash
PFD	Process Flow Diagram
SCR	Selective Catalytic Reactor
SOFA	Separated Over Fire Air
ST	Steam Turbine
T&S	Transport and Storage
uPVC	Unplasticised Poly Vinyl Chloride
WWTP	Waste Water Treatment Plant