IN THE AUSTRALIAN COMPETITION TRIBUNAL

AGL ENERGY LIMITED

of 2014

RE: PROPOSED ACQUISITION OF MACQUARIE GENERATION (A CORPORATION ESTABLISHED UNDER THE ENERGY SERVICES CORPORATIONS ACT 1995 (NSW))

ANNEXURE CERTIFICATE

This is the annexure marked "**GS8**" annexed to the statement of **GLENN SCHUMACHER** dated 23 March 2014

Annexure GS8

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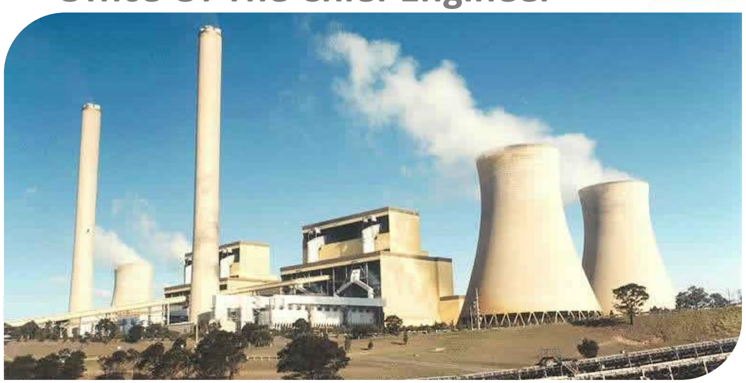
[Form approved 01/08/2011]

Project Hunter

Thermal Power Station Background (Black Coal Fired)

Version 3 March 2014

Office Of The Chief Engineer



Overview

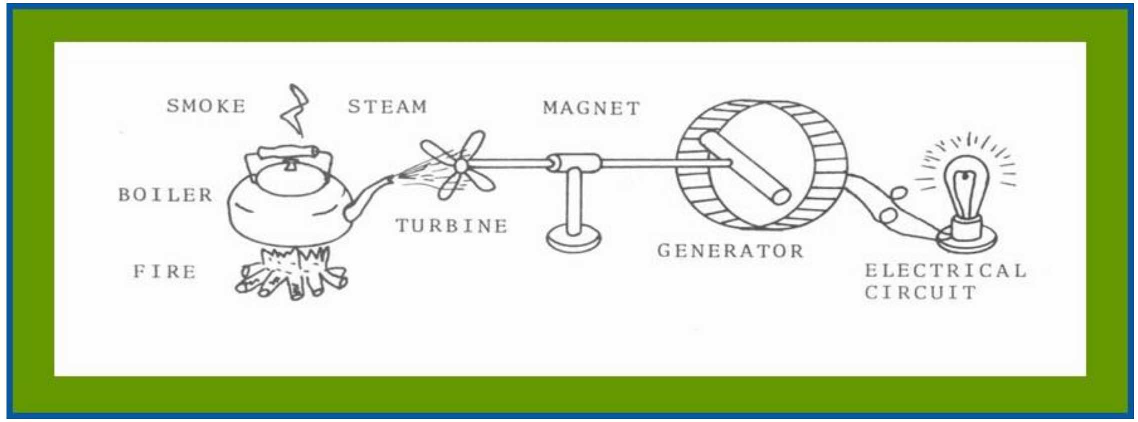
This monograph deals with the typical design operation of coal fired (Thermal) central generating plant (power stations). The fuel type (black coal) and that fuel's particular properties are critical to the consideration of the plant design and operation.

The basic concept of Thermal power stations is the conversion of chemical energy present in the fuel (in this case Black Coal) into electrical energy.

Even within broad fuel types such as 'black coal' there are a number of sub classifications such as Anthracite, Bituminous and Sub-Bituminous.

However, what is critical are the particular properties of each individual coal. Such properties include:

- Ash content (%);
- Moisture (%);
- Specific Energy (MJ/kg);
- Grindability (Hardgrove Grindability Index HGI);
- Abrasion Index;
- Ash Fusion Temperature and Slagging Index(s);
- Chemical composition of coal and ash.



Energy in Fuel → Electrical Power

Coal Performance

The performance of a particular coal is critical in both the design of new coal-fired boilers as well as existing steam raising plant. Coal is a naturally occurring material that is not homogeneous and changes within a single deposit is common. Thus, quality specifications are written by power stations to ensure that coal properties are within those that the plant can handle.

However, often issues of coal performance can be influenced by coal properties which are not generally specified by power stations. Thus, a knowledge of these more obscure coal facets are important in understanding problems that may arise in burning a particular coal. In addition, better understanding of coal properties and their effect on coal performance in a particular plant may allow improved coal utilisation as well as open coal purchasing to a wider array of coals.

Coal specifications typically include the following analysis:

- Total Moisture – the total amount of water in the coal. The total moisture (water) has two components; 1. inherent moisture; and 2. free or surface water. The inherent moisture is the water that is bound in the pores of the coal structure or chemically bonded to the coal.
- Proximate Analysis – includes moisture (air dried), ash, volatile matter and fixed carbon.
- Ultimate Analysis – gives the main organic constituents of the coal. These include carbon, hydrogen, nitrogen, sulphur and oxygen.
- Specific Energy – (sometimes referred to as Heating Value), is the amount of heat that will be released per unit mass of coal when the coal is burnt.
- Ash Analysis – aimed at finding the chemical composition of the ash constituents within the coal.
- Ash Fusion Temperature (AFT) – are the temperatures at which various stages of melting of an ash pellet occur. This measure has been traditionally a key indicator of the tendency for the coal to slag or foul a boiler furnace and gas pass. However, it can be a poor indicator if used in isolation.
- Hardgrove Grindability Index (HGI) – is an empirical measure of the grindability (the ease with which the coal is reduced in size) of a coal.

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Coal Specification

Coal specifications typically include the following analysis (Cont'd):

- Forms of Sulphur – can indicate the existence of minerals such as pyrite (FeS_2) which has significance on the coal behaviour in the boiler.

- Abrasive Index (AI) – may indicate the tendency of the coal and its ash to wear components of the coal and ash handling plant as well as the boiler and gas handling plant. A key element to be considered when examining a specific coal for its tendency to wear is the Quartz (SiO_2) content.

- Petrographic Analysis – is a microscopic examination of a coal to determine components of the coal that related to the original organic material from which the coal was formed. This has traditionally been a key tool for determining the "Rank" of the coal but, offers many other possible applications in determining coal behaviour.

- Trace Elements – chemical elements that are present in coal in very small proportions. However, their presence can have issues on both coal performance and issues such as environmental effects.

- Mineralogy of Coal & Ash – is the determination of what mineral "form" the chemical component of the coal and subsequent ash take. This is an area which is now shedding a lot of light on a number of coal behaviours.

When considering coal analysis (specification) data, <u>care should be taken</u> to understand on what basis the data is presented. For example Specific Energy (SE) or Heating Value can be reported on two basis: Gross SE (Higher HV) or Net SE (Lower HV) basis.

Coal properties can be quoted in four possible conditions:

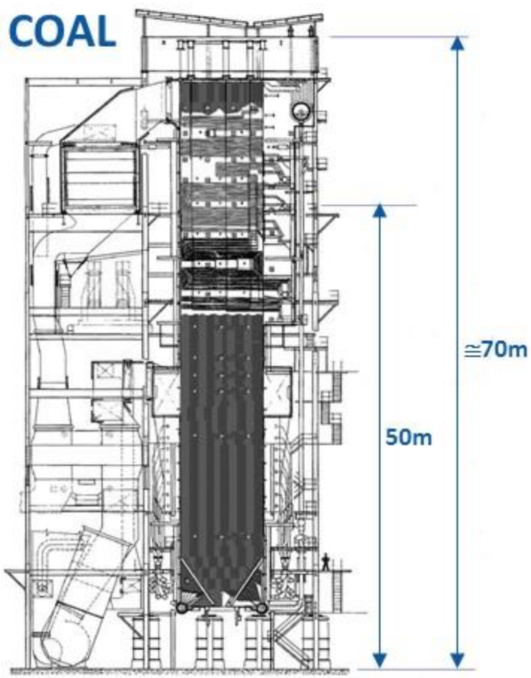
- Dry Ash Free (daf) – includes the fixed carbon and volatile matter;
- Dry Basis (db) – includes fixed carbon, volatile matter and ash;
- Air Dried Basis (adb) – includes fixed carbon, volatile matter, ash and air dried moisture;
- As Received (ar) - includes fixed carbon, volatile matter, ash and air dried moisture and surface moisture.

Fuel Type is Critical to Boiler Design and Size

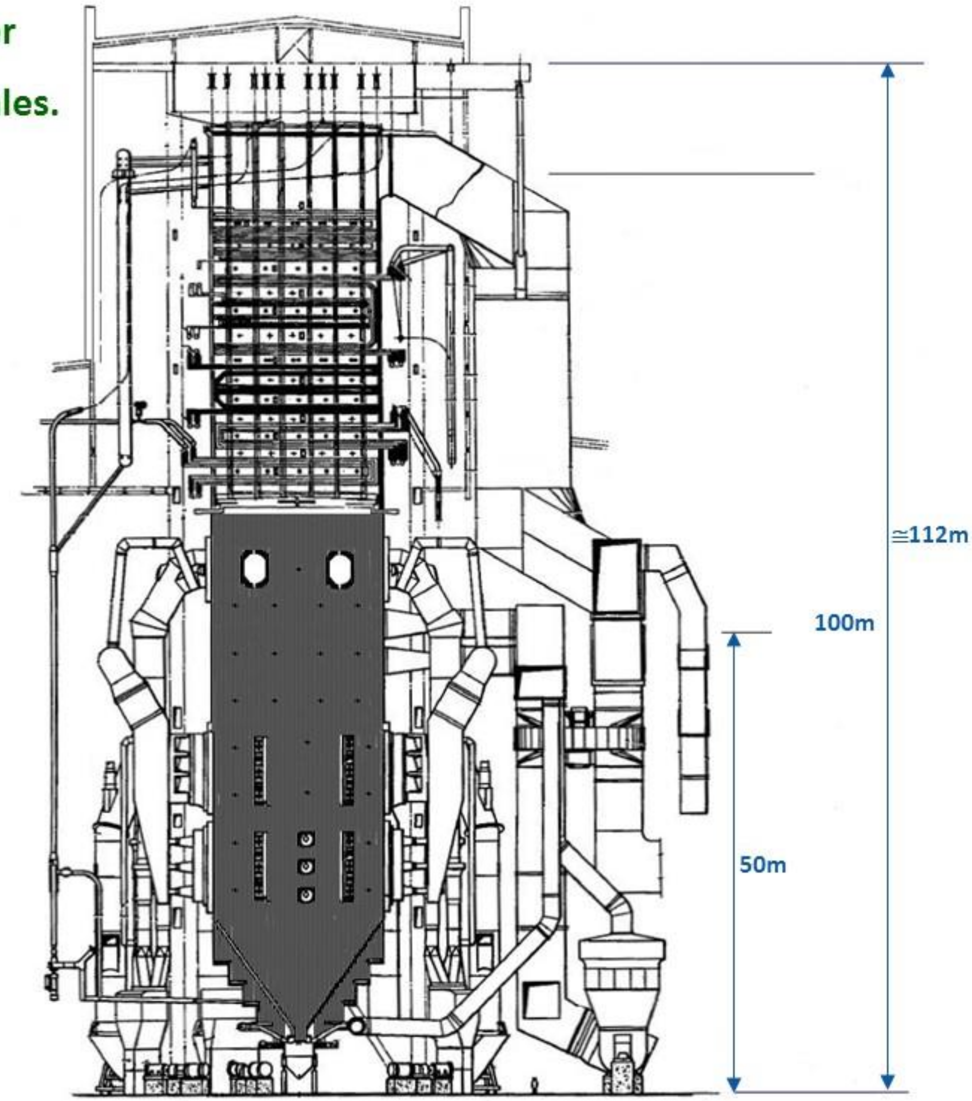
Black Coal – 500 MW Boiler at Liddell Power Station in the Hunter Valley, New South Wales.

Brown Coal (Lignite) – 500 MW Boiler at Loy Yang 'A' Power Station in the La Trobe Valley, Victoria.

BLACK COAL



BROWN COAL



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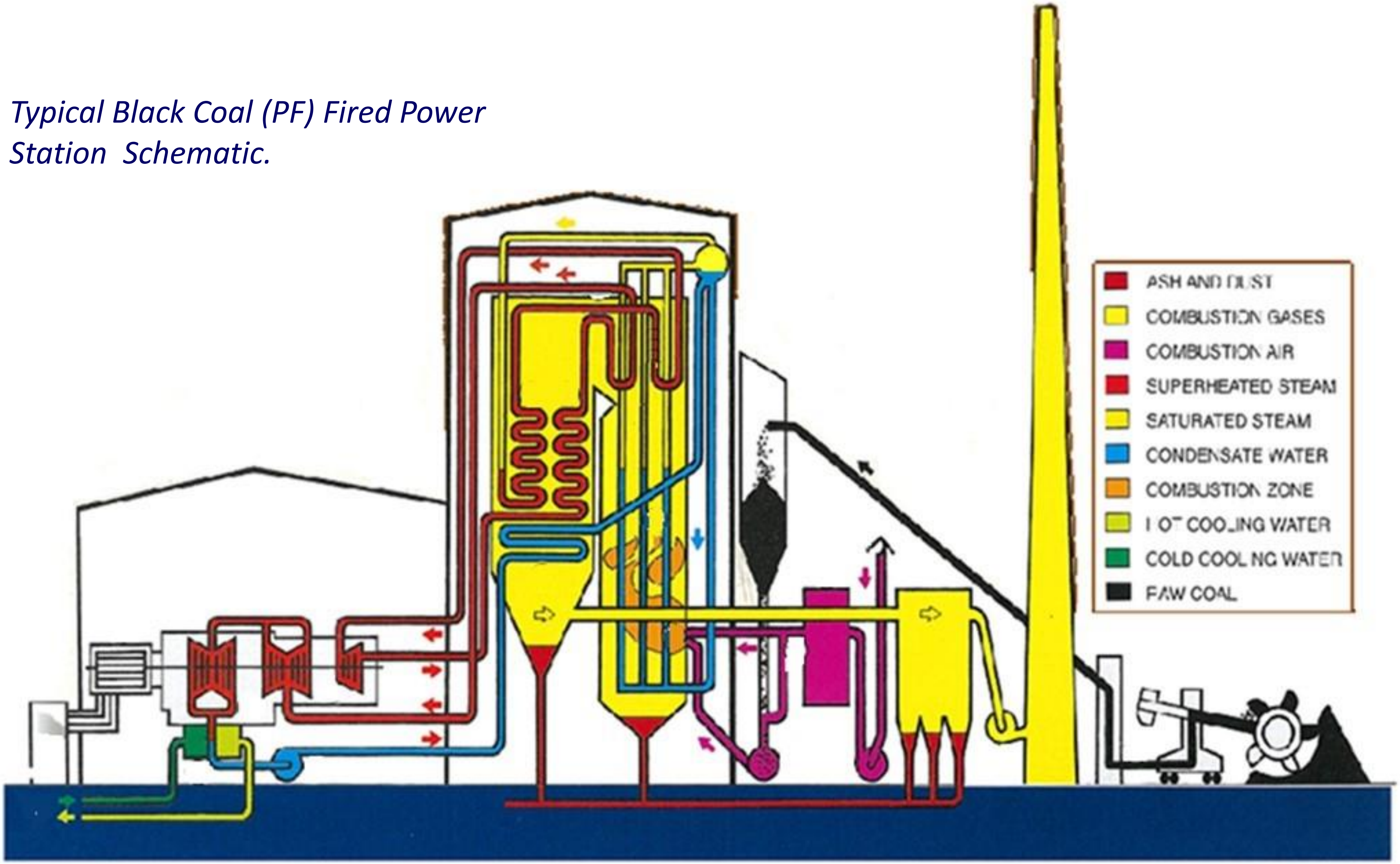
Energy Conversion Process – Coal to Electricity

Typical Black Coal (PF) Fired Power Station Schematic.



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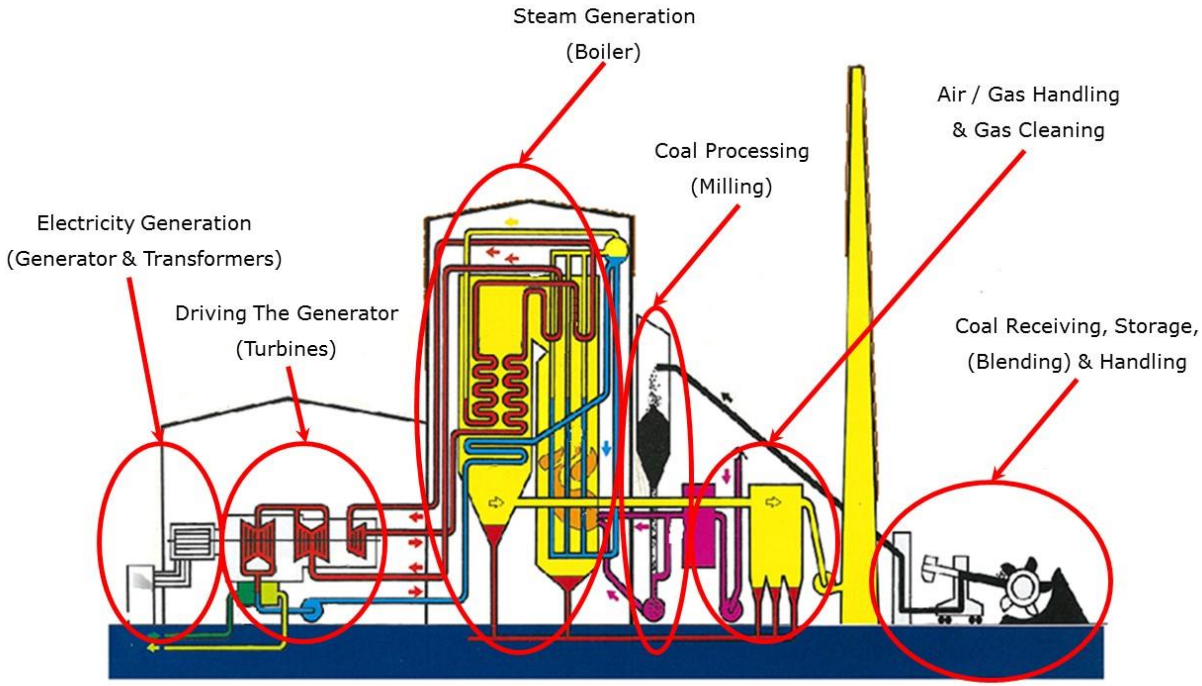
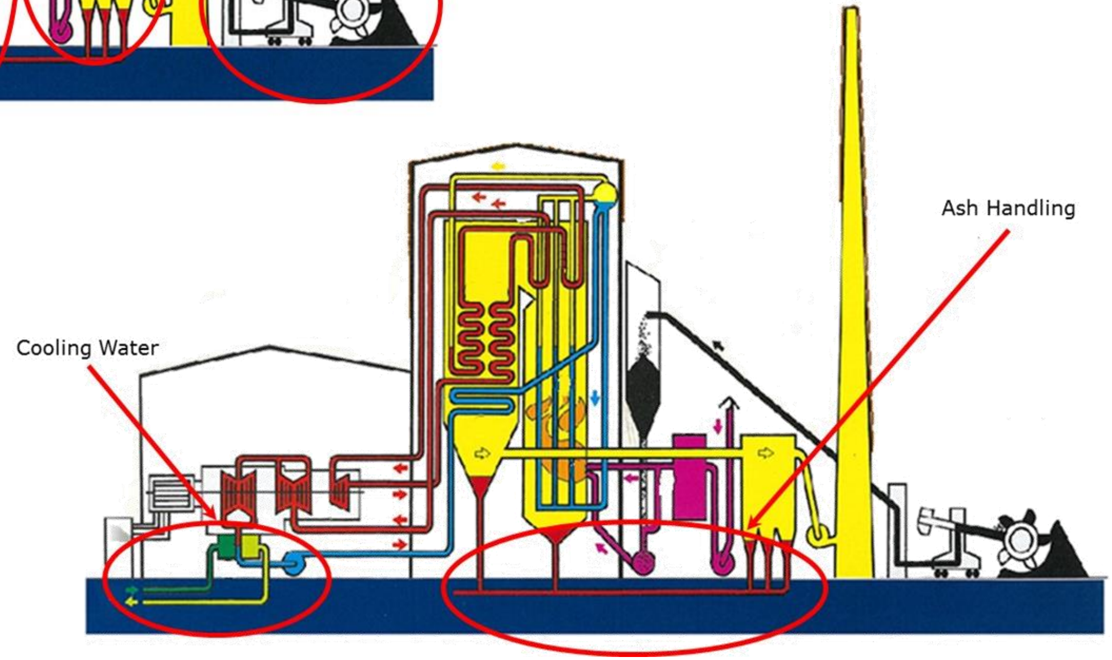
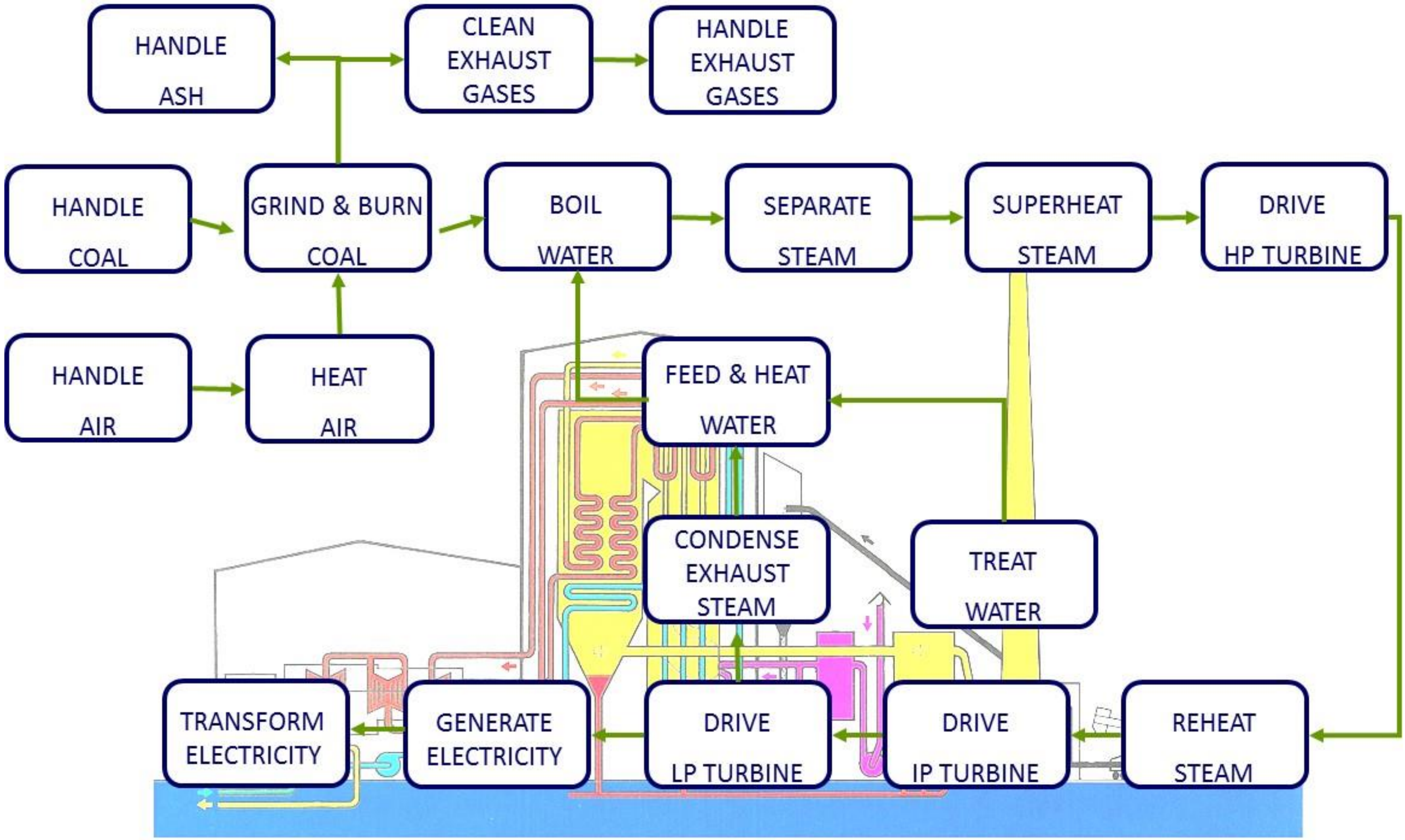
Key Energy Conversion Process Elements





Energy Conversion Process – Coal to Electricity



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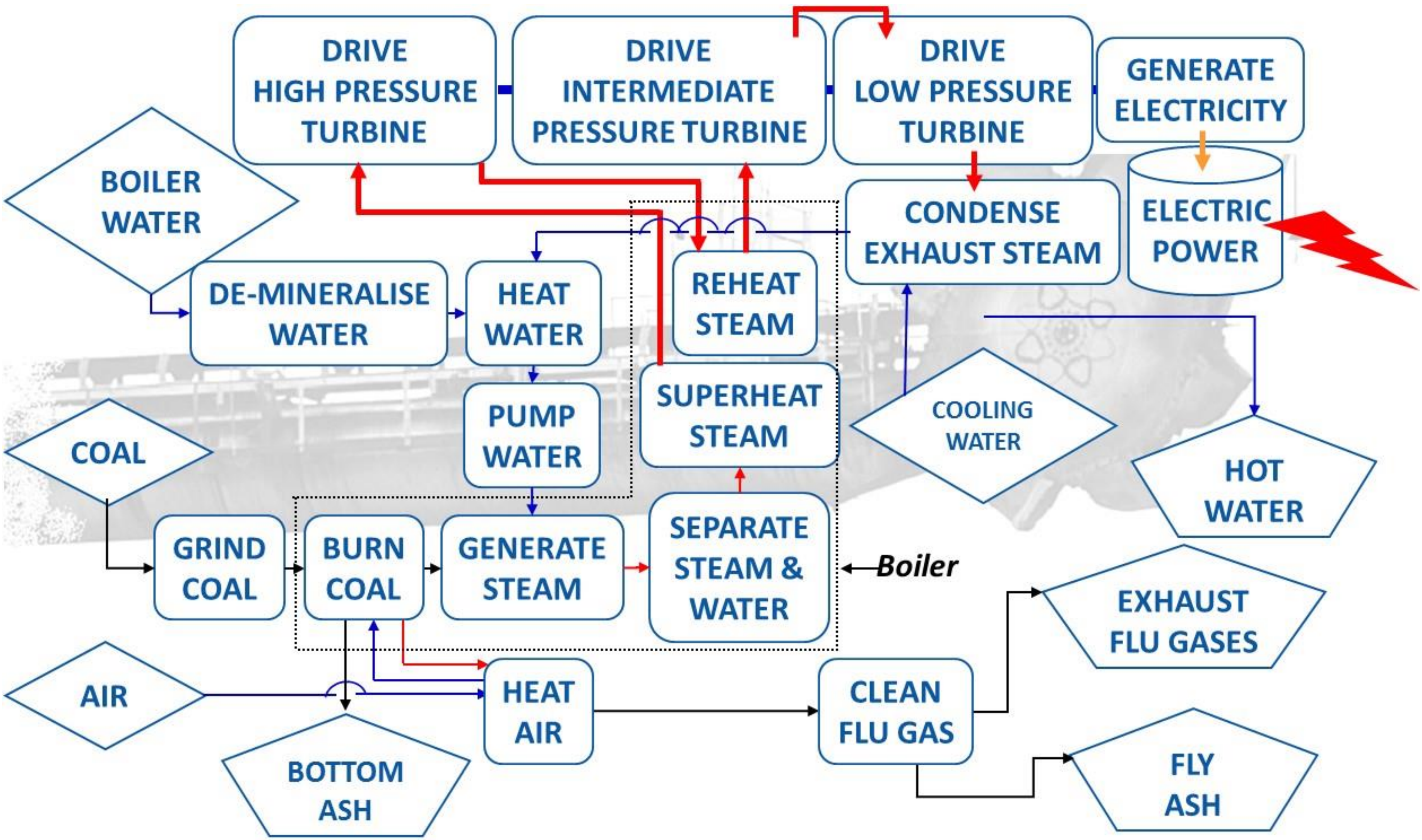
Energy Conversion Process – Coal to Electricity



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Energy Conversion Process – Coal Processing

Modern coal fired central generating plant (power stations) make use of a system called Pulverised Fuel [PF] (coal) firing system. The pulverised (comminution) process is carried out on an on-demand basis by devices called pulverisers (or mills).

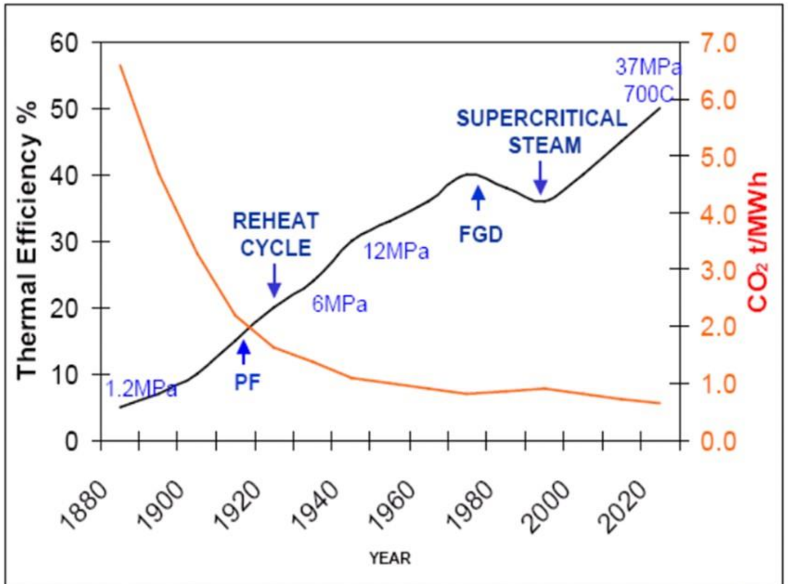
Despite current environmental concerns, coal remains an abundant and low cost fuel for power generation. Coal is burned to release the chemical energy that is stored within it. The heat energy released by the combustion of coal is released to water (and steam) in a boiler. The steam is then used to drive some arrangement of turbine(s) which in turn drive a generator. The combustion of coal can be undertaken in a number of ways depending upon the characteristics of the coal and the particular boiler application. However, pulverised coal (PF) firing – burning coal as a fine powder suspension in an open furnace – is the dominant method in use today for the generation of electricity in grid based power stations.

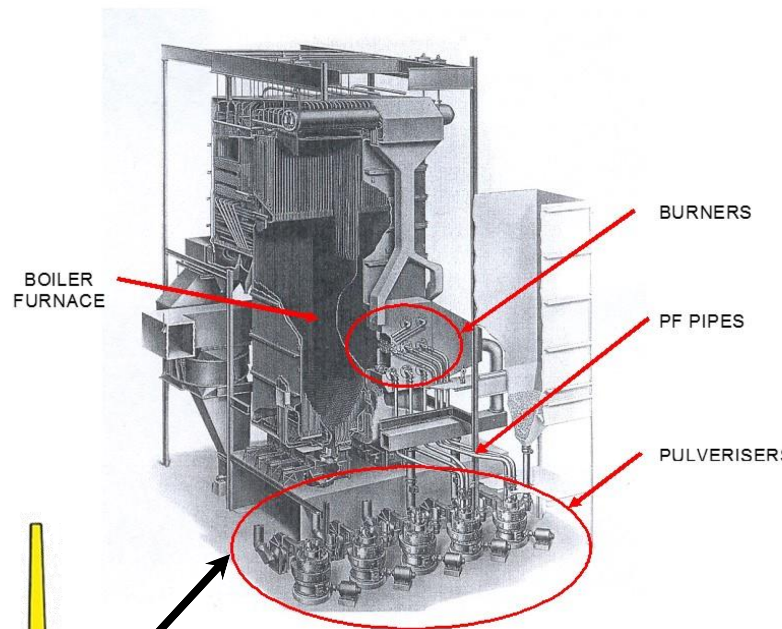
Pulverised coal was developed as early as the 1800s as a cost effective fuel for firing cement kilns replacing oil and gas. The early pulverising systems were not considered reliable mainly due to the nature of the pulverising equipment then available. A number of means of overcoming these problems were tried but their complexity on the whole the PF approach unattractive to steam generating plant. The PF systems ability to produce dry coal with very good particle size control and uniform coal feed were recognised.

With a need for larger steam generating plant for electric power generation, the PF system offered the potential for scale up whilst still improving the combustion process. However, the existing boiler design and technology was a limiting factor. For PF firing application boilers, there was a need to modify the boiler furnace geometry. In the early 20th Century, changes in boiler design saw the expansion of boiler fireboxes and crowded tube banks to allow the application of PF firing. Two key elements in the change to boiler design were the application of water-cooled furnaces and burner design advances to improve flame stability, provide better mixing, increase flame temperatures and improve combustion efficiency. These changes made advanced pulverised coal-fired systems possible in steam generation. Hand in hand with boiler design and construction went improvements in pulveriser design and reliability. This allowed direct firing PF systems that were both reliable and efficient.

PF: Pulverised Fuel.
Note: In this paper, the terms; *Pulverising, Milling* and *Grinding* are considered as interchangeable. So too are the terms *Pulveriser* and *Mill*.

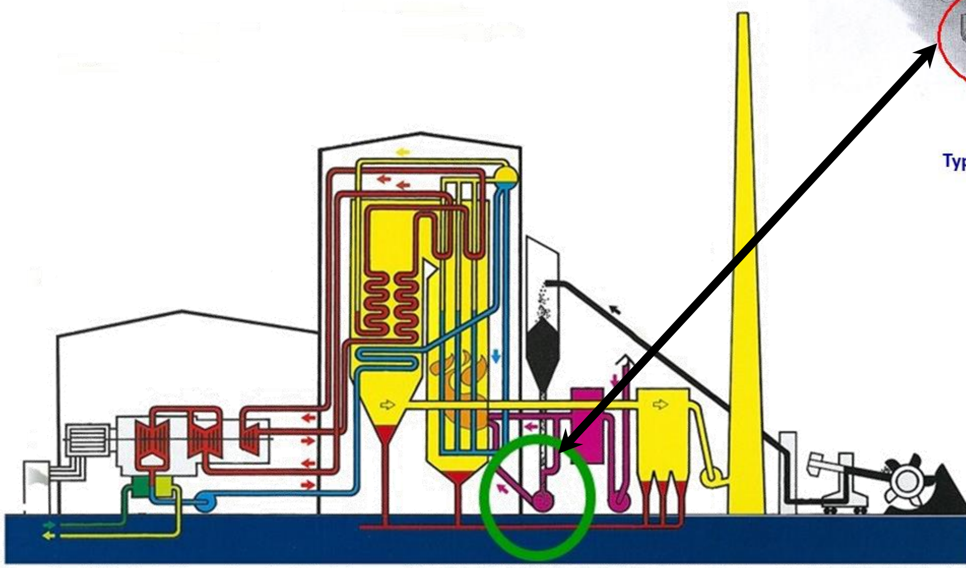
Energy Conversion Process – Coal to Electricity





Typical coal fired pulverised fuel boiler

In the Pulverised Fuel [PF] (coal) firing system the coal is milled (ground or pulverised) in dry air blown mills (pulverisers). The air not only helps dry the coal in the mill but transports the ground coal through the mill and on into the boiler furnace via the Burners. The air is then available for the combustion process.



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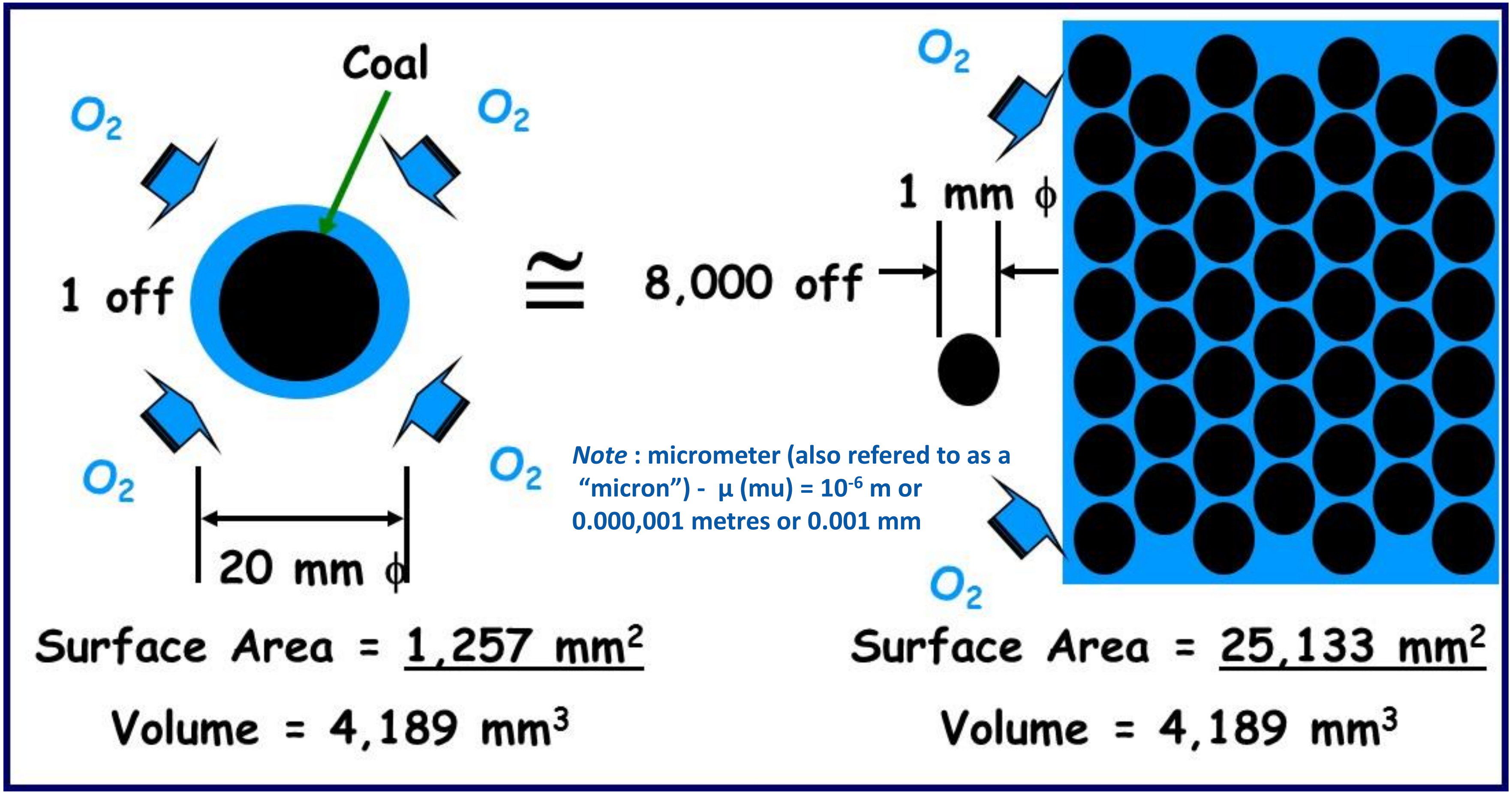
Energy Conversion Process – Coal to Electricity

Pulverised Fuel (PF) Firing



Pulverising – Milling - Grinding

Reducing the size of coal particles allows a greater oxygen/coal interface area

Typically: 75% Passing 200 Mesh (74 mm {microns} or 0.074 mm)

Human Hair Diameter : 17–50 µm (flaxen hair), to 56–181 µm (black hair)

Energy Conversion Process – Coal to Electricity

The key element of the pulverised fuel system is the coal pulveriser (mill). The purpose of the pulverisers is the comminution (size reduction) of incoming coal from a top size of between typically 50 and 75 mm down to 75 microns (µm). The resulting coal is blown by hot primary air into the boiler furnace via a set of delivery pipes (or ducts) and suitably designed burners.

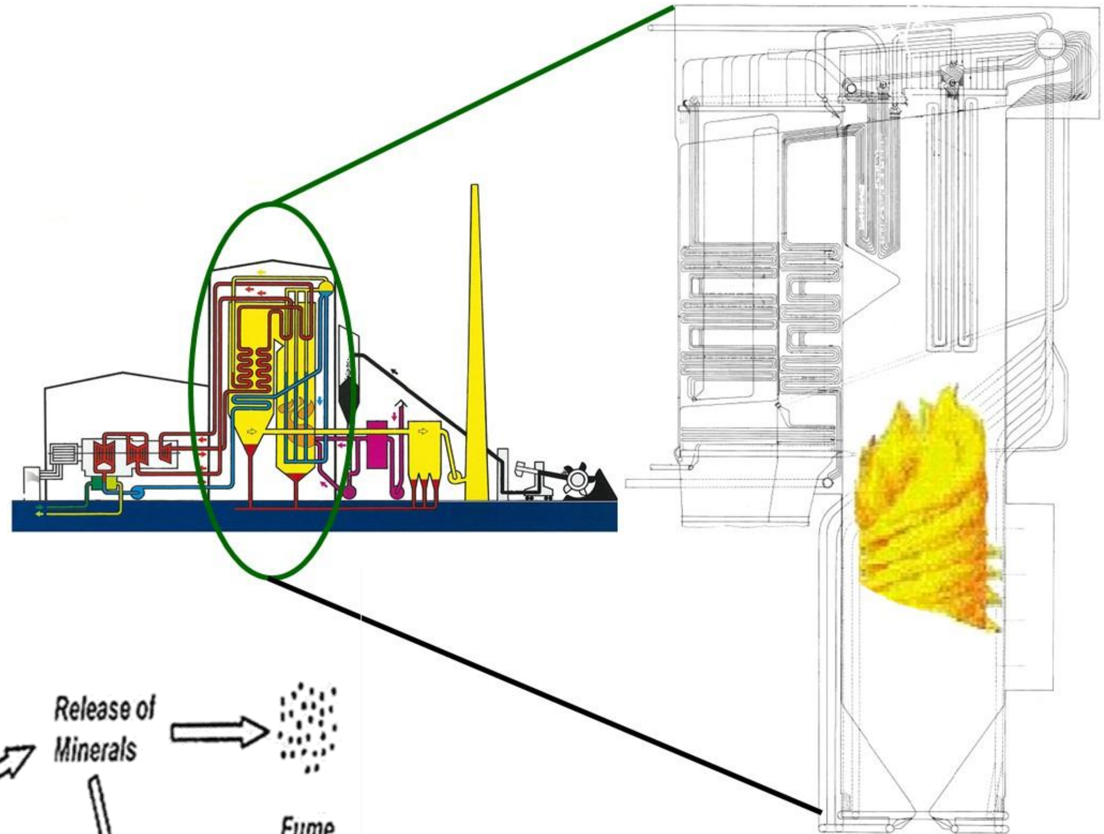
PF firing has made possible the large, efficient utility boilers used as the base load capacity in many utilities worldwide. Modern PF burners provide high combustion efficiency and low emissions through full integration with the entire boiler design.

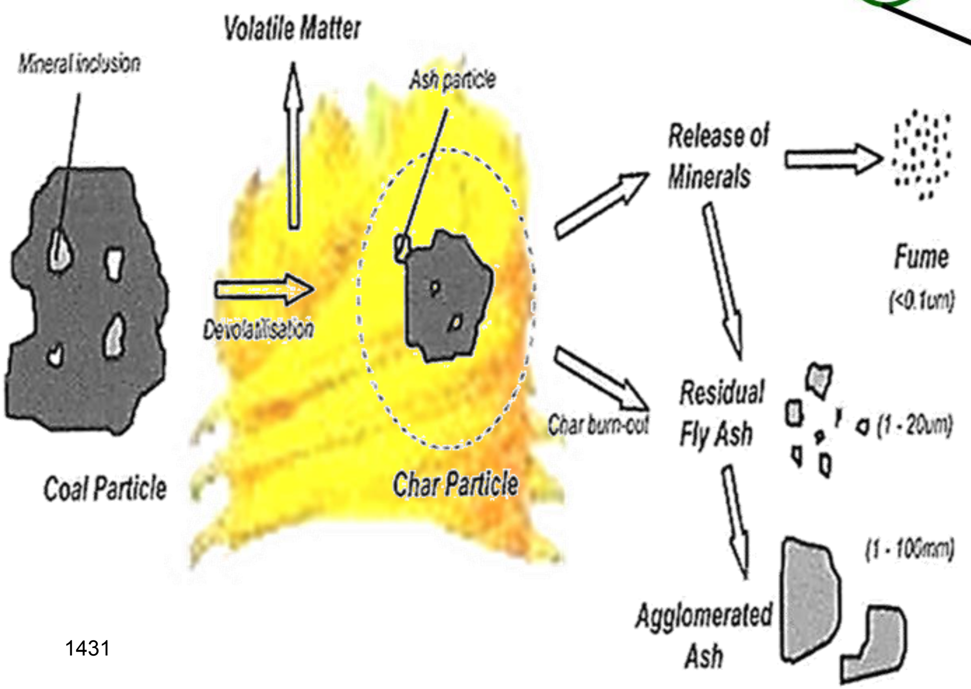
PF coal firing differs from the other coal combustion technologies primarily through the much smaller particle size used and the resulting high combustion rates. The combustion rate of coal as a solid fuel is, to a large extent, controlled by the total particle surface area. By pulverising coal to a nominal 75 microns (µm) diameter, the coal can be completely burned in approximately one to two seconds. This approaches the rate for oil and gas. In contrast, other firing technologies use crushed coal (lumps) of various sizes and provide substantially longer combustion zone residence times (up to 60 seconds or longer).

The application of the PF system has allowed the increase in boiler size which has supported the increase in thermal power generation units from a maximum of around 100 MW up to as large as 1,300 MW today. Today, nearly all types of coal from anthracite to lignite can be burned through pulverised firing. The added advantage in the PF system has been an increase in overall efficiency to the point that with direct firing technologies used with boilers, coal PF can approach that achievable with oil and gas (this refers to boiler direct firing not gas turbine technology).

Coal Pulveriser

Energy Conversion Process – Raising Steam





Energy Conversion Process – Raising Steam

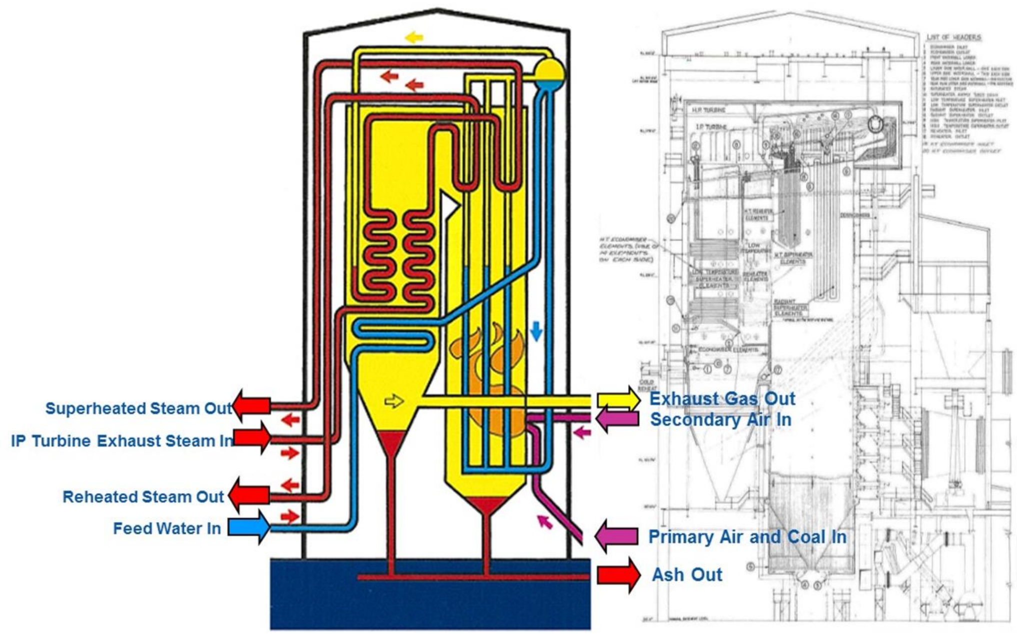
Modern coal fired power station boilers are known as water tube type boilers. That is water and/or steam passes through the tubes of the boiler as opposed to fire passing through the tubes in a traditional “locomotive” type boiler or fire tube boilers. The process set out below refers to subcritical type boilers.

The boiler consists of a furnace and convective gas pass. As the name suggests, coal combustion takes place in the furnace. The furnace consists of a box type structure who’s walls are made from steel tubes and are referred to as water walls. Water passes through these tubes. Heat from the coal combustion process passes through the tube walls and heats the water within. As the water is heated, the less dense hot water rises up through the tubes. On taking on enough heat from the furnace, the water starts to “boil” in the tube thus producing a mixture of steam and water.

Separation of the steam from the hot water takes place in a separator vessel at the top of the boiler called the steam drum. The hot water is returned to the bottom of the boiler to re-enter the water walls for further heating.

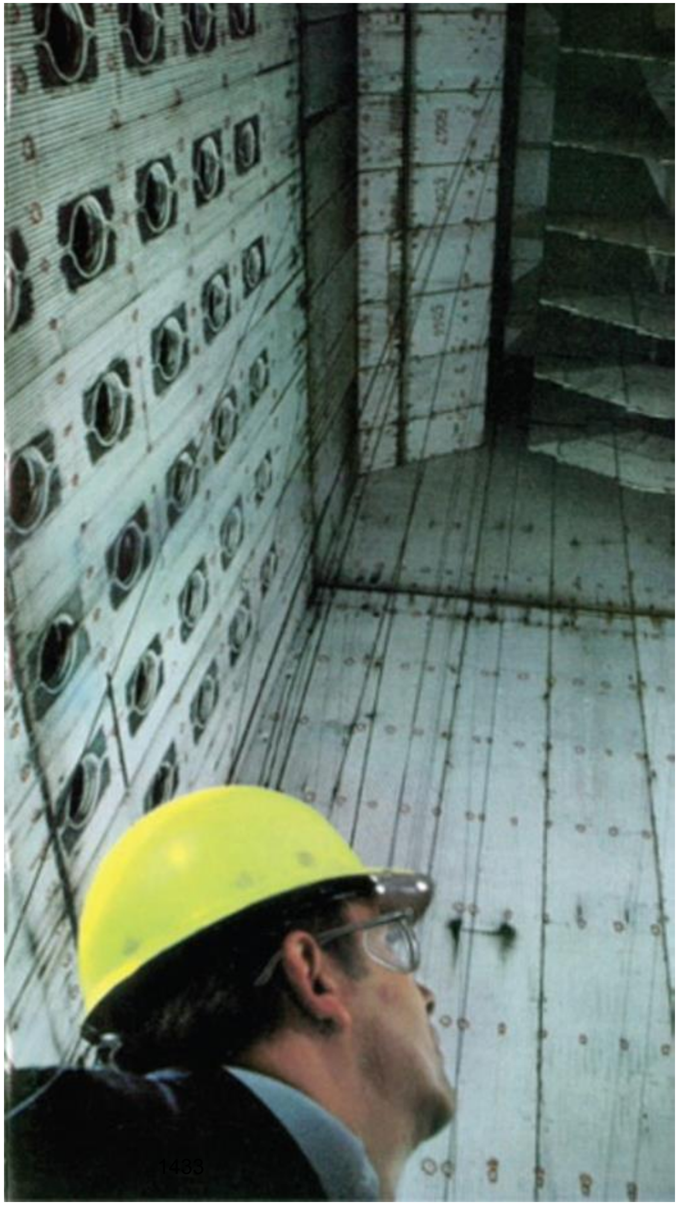
The separated steam passes to the superheater which consists of more tubes located in and around the hot gas pass of the boiler. The majority of these tubes are arranged in platens or bundles (sometimes known as elements) which hang in the path of the hot gases passing out of the boiler furnace. The superheater platens transfer heat energy from the hot gases to the steam within the tubes thus increasing the amount of energy in the steam. The steam then passes to the turbines to do work.

A second steam circuit can exist and that is the reheat circuit. This circuit involves steam which has typically passed through the high pressure turbine and is returned to the boiler to add more energy. The reheat circuit is typically tube platens also in the hot gas path of the boiler.

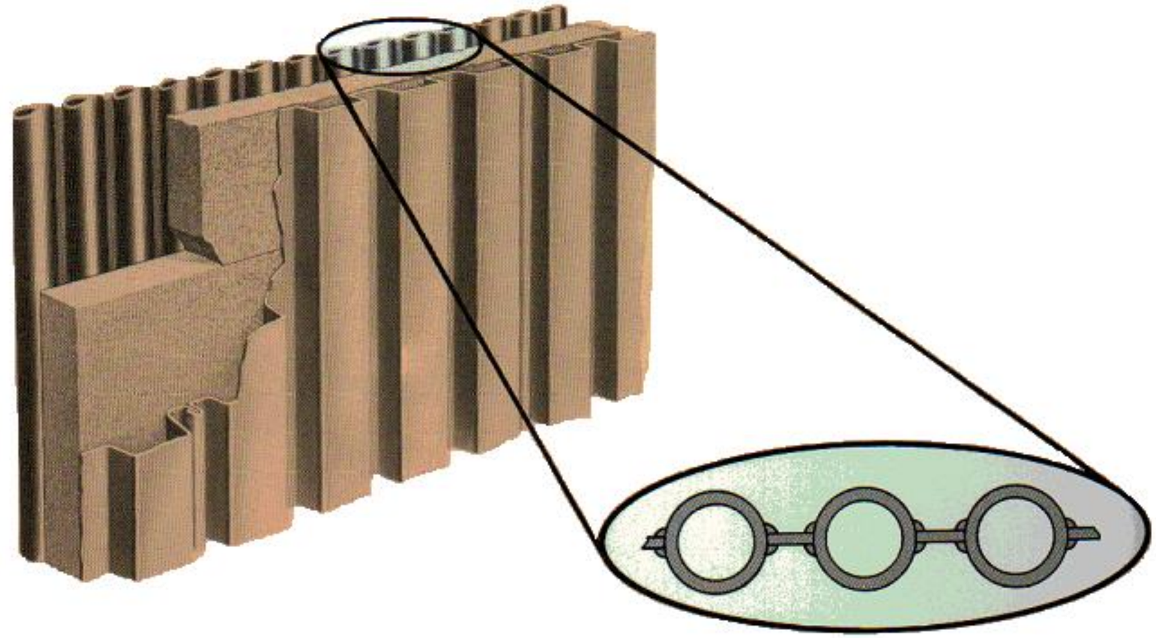


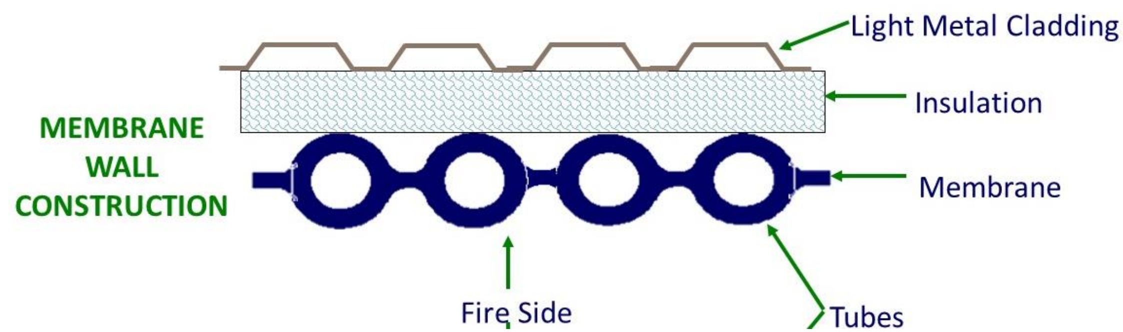
Energy Conversion Process – Raising Steam

The Walls of Boiler are made from steel Tubes in which the water / steam are contained



BOILER WALLS – MEMBRANE CONSTRUCTION





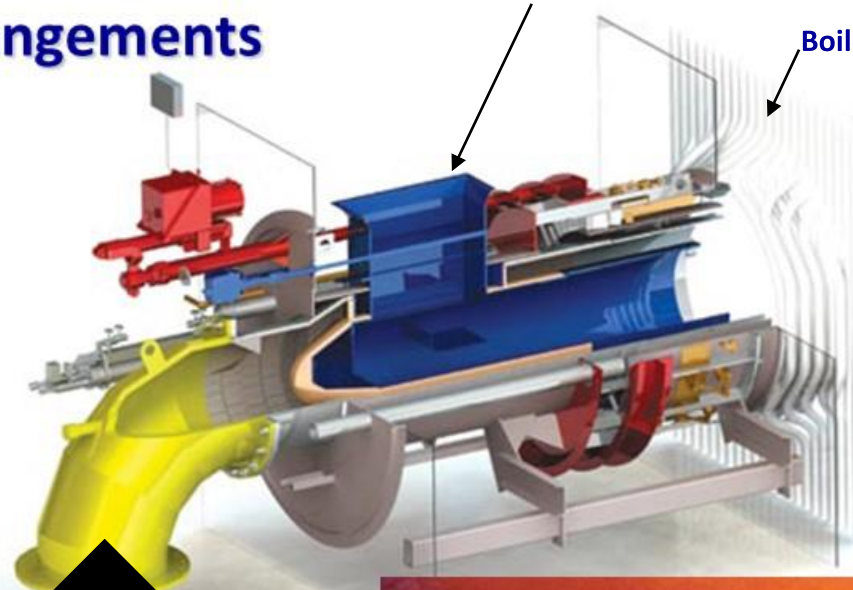
BOILER FURNACE

Energy Conversion Process – Raising Steam

Typical Coal-Fired Burner Arrangements

Burner

Boiler Furnance Wall



Boiler Furnance Wall

Pulverised Fuel & Primary Air

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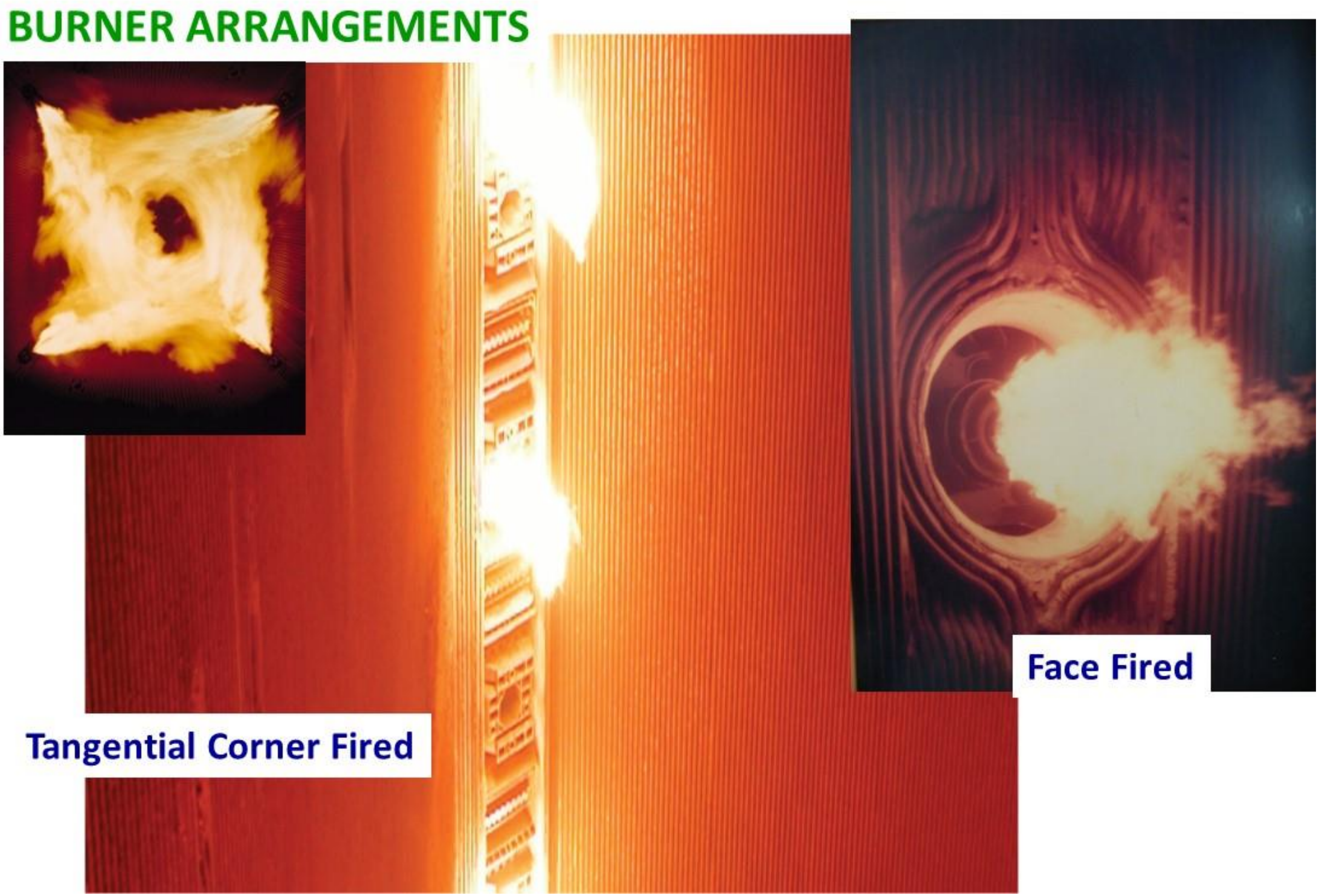
Burner

Energy Conversion Process – Raising Steam



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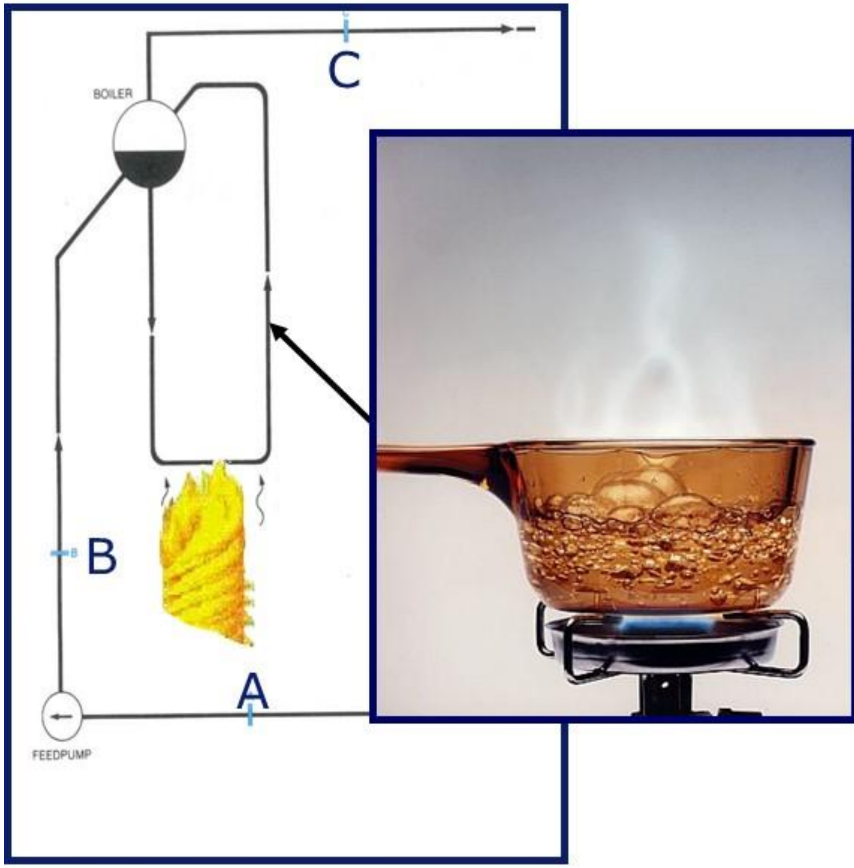
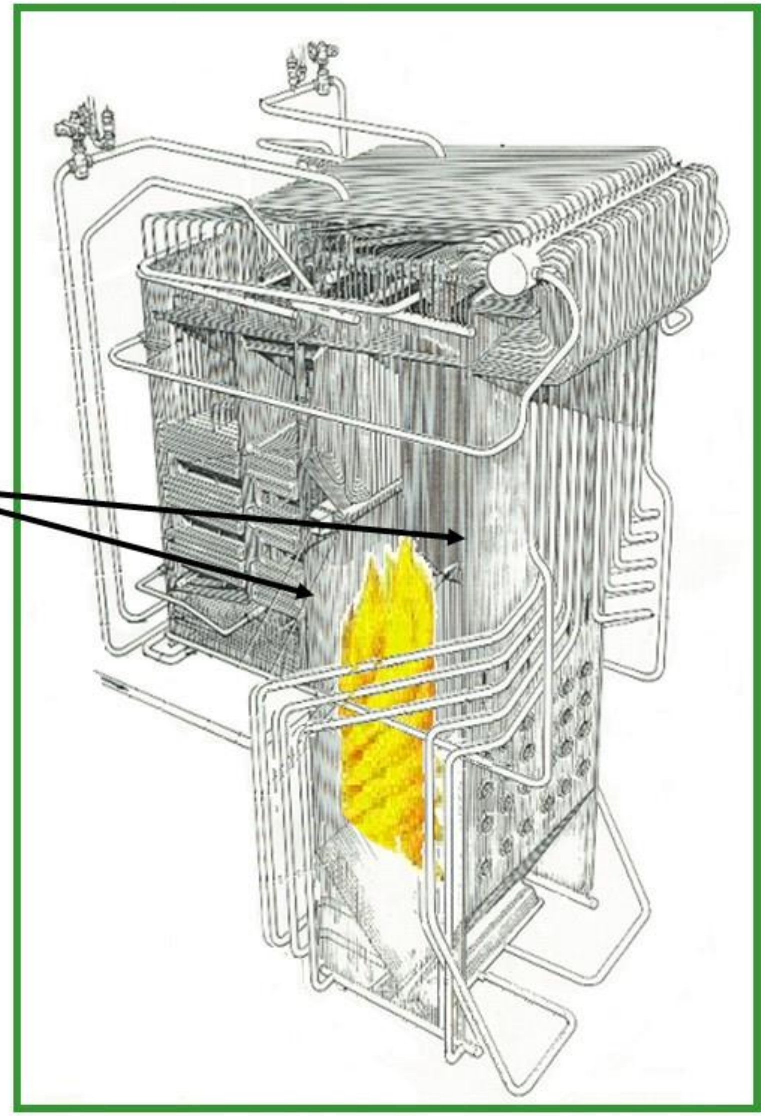
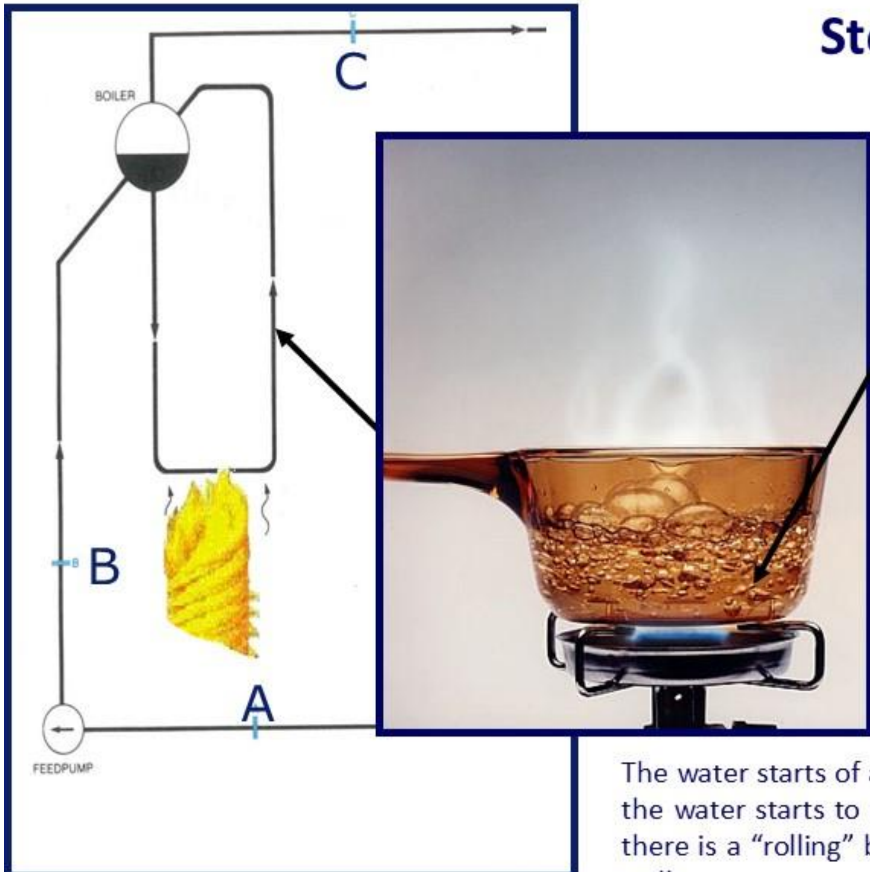
Energy Conversion Process – Raising Steam



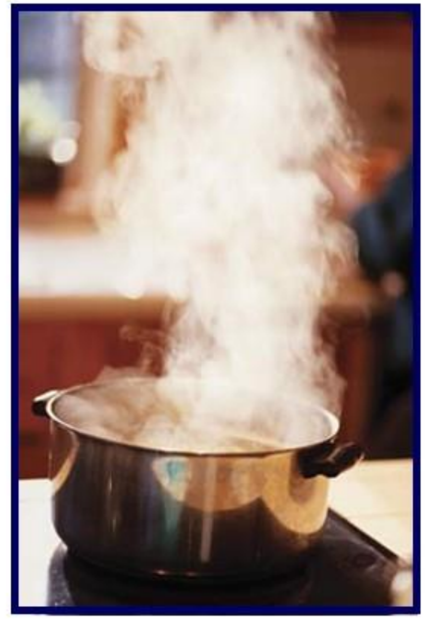


Boiling takes place in the water wall tubes of the boiler. These tubes form the boiler furnace.

Energy Conversion Process – Raising Steam



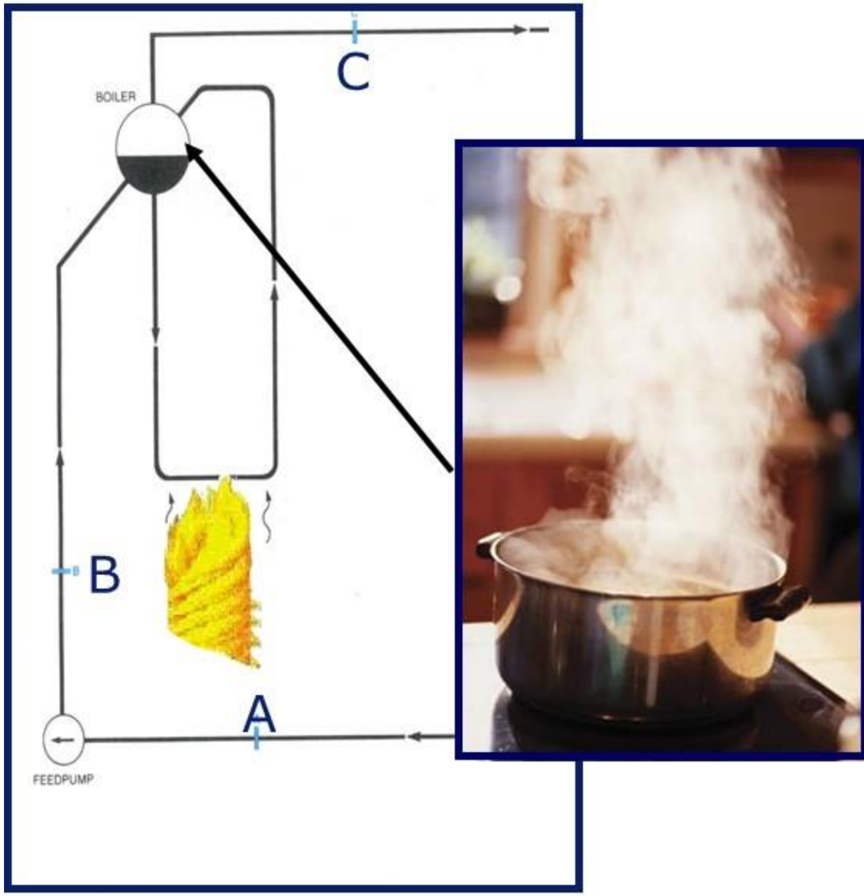
Steam Nucleation

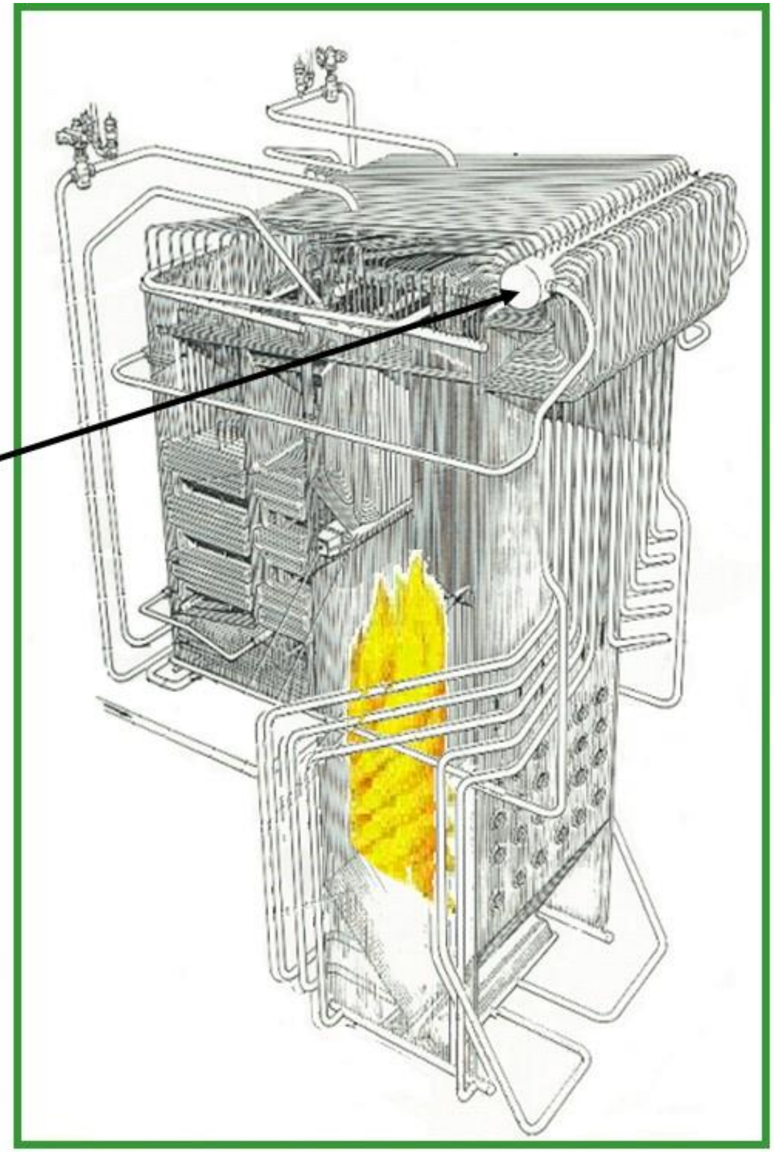


The water starts of at the bottom of the boiler as warm water[#1]. As more heat is applied the water starts to nucleate, that is gas (steam) bubbles form on the tube surfaces until there is a "rolling" boil. As the water heats up it becomes lighter and rises up the water walls.

#1. Water has been heated in the Feed Heating Section and the Boiler Economiser before reaching the Water Walls.

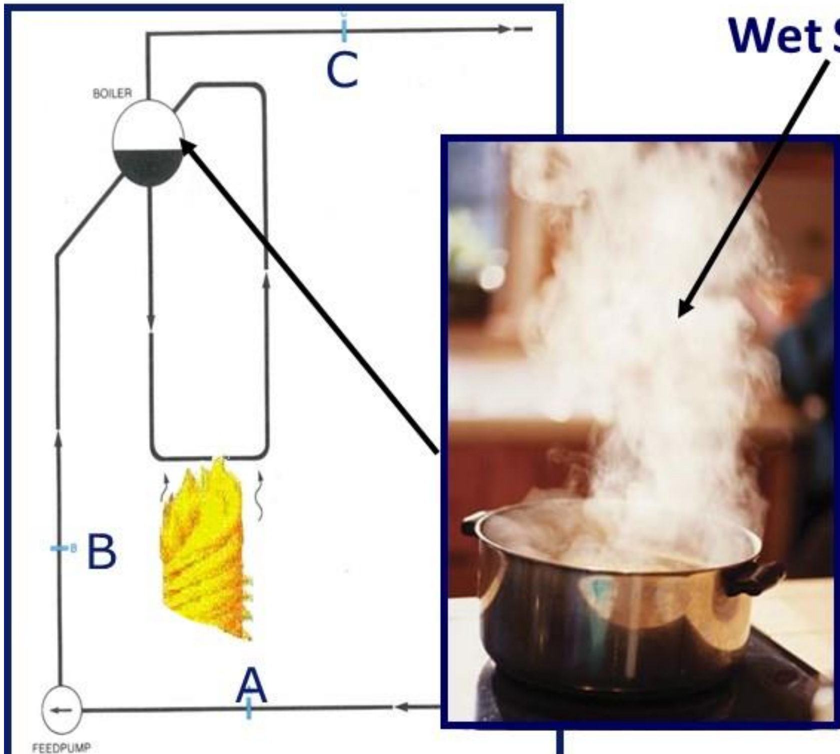
Energy Conversion Process – Raising Steam





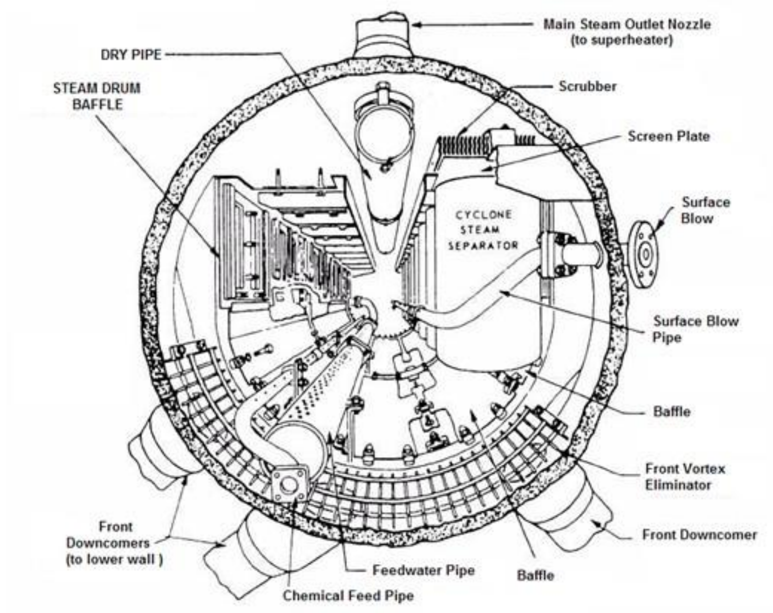
The mixture of water (liquid) and steam (gas) rises up the water walls and is collected in a device called a steam drum at the top of the boiler.

Energy Conversion Process – Raising Steam



Wet Steam

Steam Drum

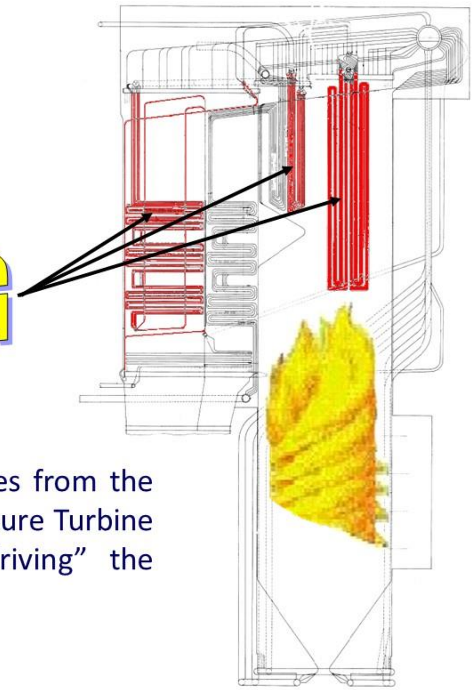


In the steam drum the water (liquid) and the steam (gas) are separated. The water returns to the water walls to be re-heated. The steam (gas) which reaches the steam drum is said to be “wet”. That is it is carrying water droplets. The steam leaves the Drum and is sent to the Superheater.

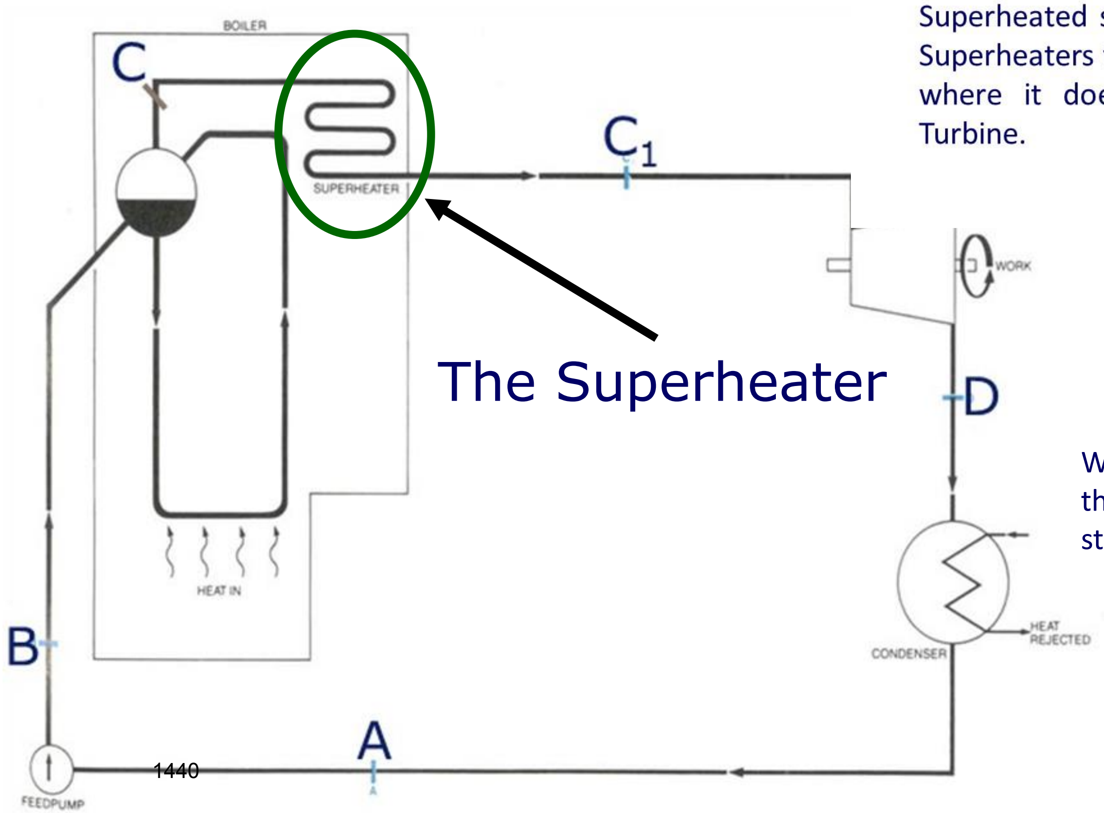
Energy Conversion Process – Raising Steam

The Superheater consists of arrangements of tubes called elements. Which is arranged in the Boiler to take up heat through either radiation in the Furnace or by convection in the Gas Pass.

Typical Black Coal Boiler Cross - Section



Superheated steam (gas) passes from the Superheaters to the High Pressure Turbine where it does work in "driving" the Turbine.

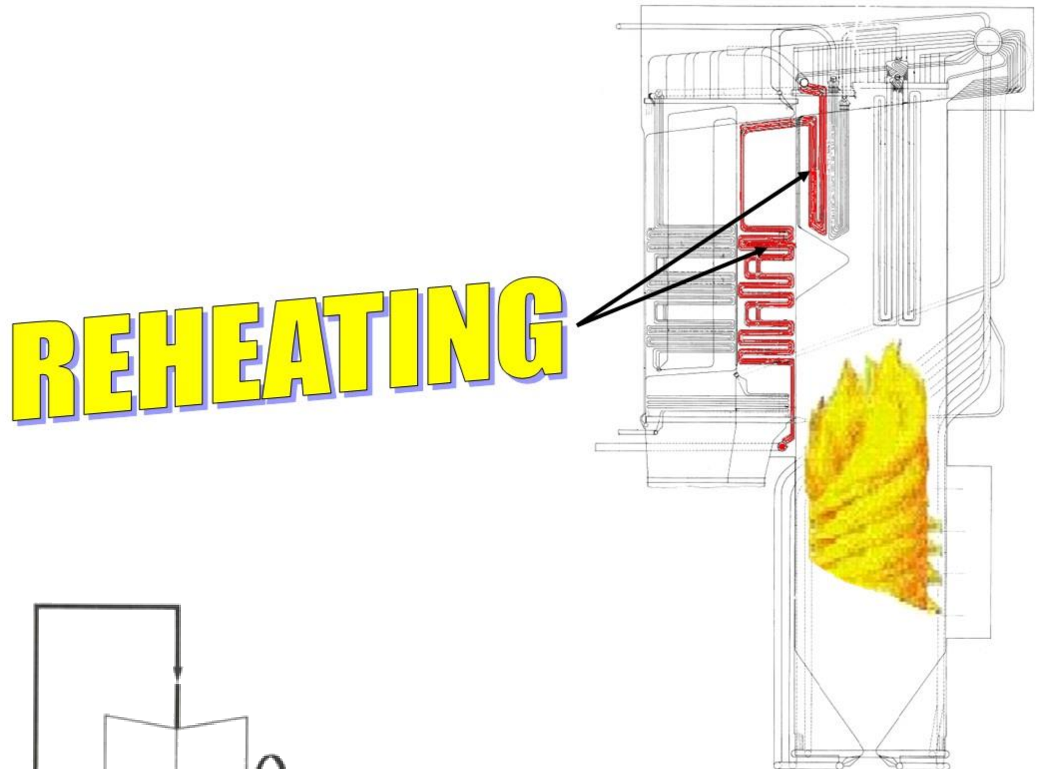


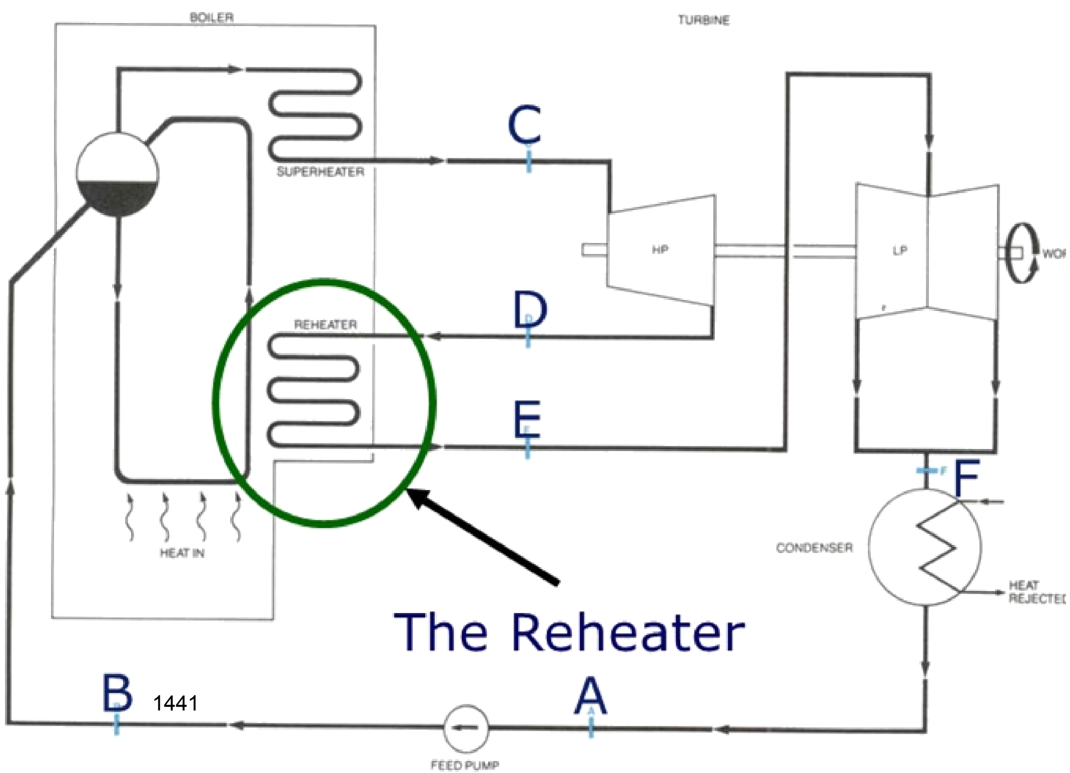
Wet Steam (gas) passes from the Steam Drum and passes through the Superheater where the steam is heated further drying the steam.

Energy Conversion Process – Raising Steam

Typical Black Coal Boiler Cross - Section

The Reheater consists of arrangements of tubes called elem
is arranged in the Boiler to take up heat through convectio
Pass.





After gaining additional energy in the Reheater, the steam returns to "drive" the Intermediate Turbine and then onto the Low Pressure Turbine.

Note: Some Boilers do not have a Reheater stage.

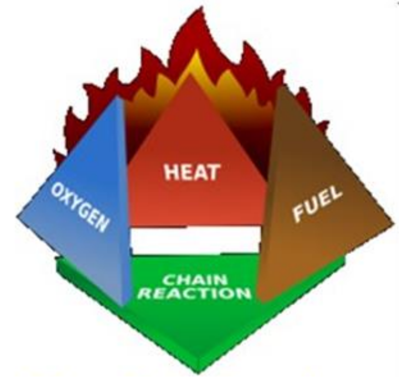
After doing some work in "driving" the High Pressure Turbine, the Steam has lost some of its energy. It is then returned to the Reheater in the Boiler to regain energy.

Energy Conversion Process – Air / Gas Handling

Combustion requires the presence of oxygen. Oxygen is made available to the combustion process in a coal fired boiler through the introduction of air in very large volumes. The point of introduction of the air is important to the completeness of the combustion process. Too little air results in incomplete combustion and too much air is an inefficiency.

The fire triangle illustrates the rule that in order to ignite and burn, a fire requires three elements: heat, fuel, and an oxidizing agent, usually oxygen. The combustion is prevented or extinguished by removing any one of them. A fire naturally occurs when the elements are combined in the right mixture. Without sufficient *heat*, combustion cannot begin, and it cannot continue. Without *fuel*, combustion will stop. Without sufficient *Oxygen*, a combustion cannot begin, and it cannot continue. The chemical reactions associated with a fire has led to development of the fire tetrahedron: a triangular pyramid having four sides including the bottom representing the sustaining of chemical reactions. That chemical reaction is called combustion and feeds a fire more heat and allows it to continue.

Fire Triangle

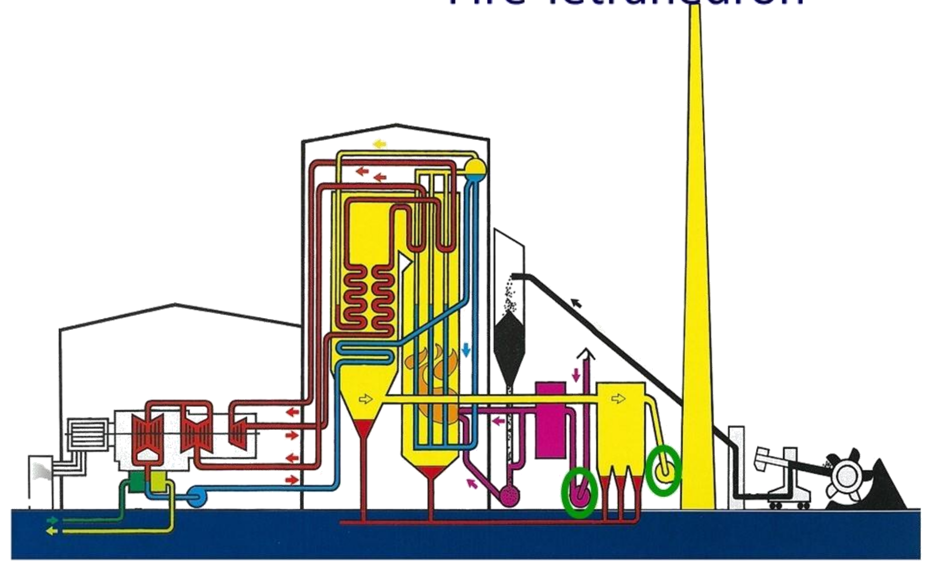


Fire Tetrahedron

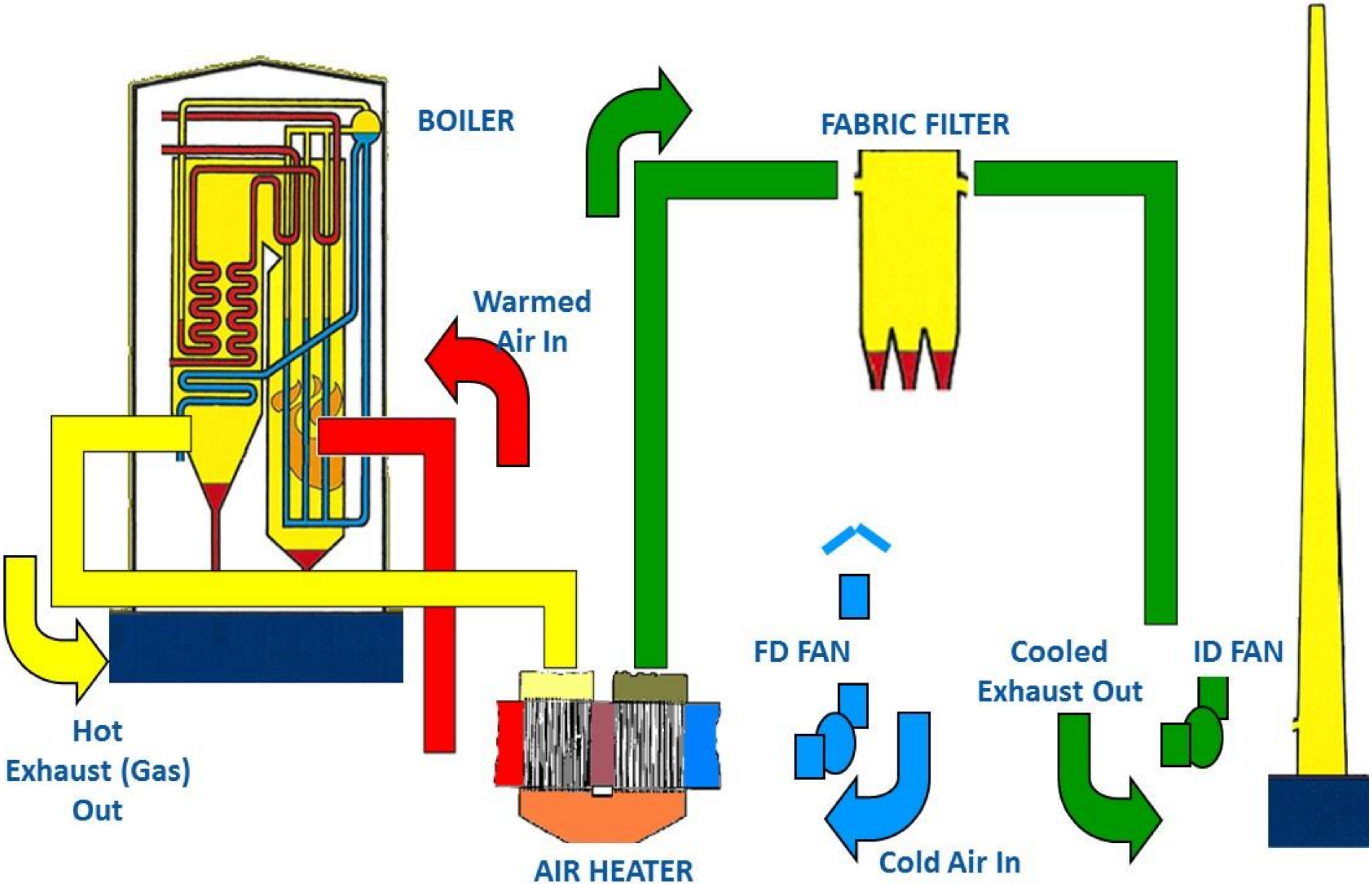
To aid efficiency, the air is heated prior to entering the boiler by passing it through a heat exchanger device known as an air-heater. The air-heater makes use of waste heat present in the boiler exhaust gases as they leave the boiler. There are basically two types of air heaters, tubular and regenerative.

The air is also used as a transport medium for the transport of the pulverised fuel through the mill and on into the boiler through the burners.

Many modern pulverised fuel boilers are called balanced draft as there are fans both pushing air into the boiler and other fans drawing exhaust gases out. The fans forcing air in are called forced draft fans and those drawing air out are called induced draft fans.



Energy Conversion Process – Air / Gas Handling



Energy Conversion Process – Air / Gas Handling

Regenerative Air Heaters – Rotating Element: consist of a central rotating arrangement (rotor) of heat transfer plates arranged in segments. This rotor is located within a casing that is divided into two (bi-sector type), three (tri-sector type) or four (quad-sector type) sectors containing seals around the element. The seals allow the element to rotate through all the sectors, but keep gas leakage between sectors to a minimum while providing separate gas air and flue gas paths through each sector.

Tri-sector types are the most common in modern power generation facilities. In the tri-sector design, the largest sector (usually spanning about half the cross-section of the casing) is connected to the boiler hot gas outlet. The hot exhaust gas flows over the central element, transferring some of its heat to the element, and is then ducted away for further treatment in dust collectors and other equipment before being expelled from the flue gas stack.

The second, smaller sector, is fed with ambient air by a fan, which passes over the heated element as it rotates into the sector, and is heated before being carried to the boiler furnace for combustion. The third sector is the smallest one and it heats air which is routed into the pulverises and used to carry the coal-air mixture to the boiler burners. Thus, the total air heated in the Air Heater provides: heating air to remove the moisture from the pulverised coal dust, carrier air for transporting the pulverised coal to the boiler burners and the primary air for combustion.

The rotor itself is the medium of heat transfer in this system, and is usually composed of some form of steel and/or ceramic structure. It rotates quite slowly (around 3-5 RPM) to allow optimum heat transfer first from the hot exhaust gases to the element, then as it rotates, from the element to the cooler air in the other sectors.

In this design the whole air heater casing is supported on the boiler supporting structure itself with necessary expansion joints in the ducting.

The vertical rotor is supported on thrust bearings at the lower end and has an oil bath lubrication, cooled by water circulating in coils inside the oil bath. This arrangement is for cooling the lower end of the shaft, as this end of the vertical rotor is on the hot end of the ducting. The top end of the rotor has a simple roller bearing to hold the shaft in a vertical position.

The rotor is built up on the vertical shaft with radial supports and cages for holding the baskets in position. Radial and circumferential seal plates are also provided to avoid leakages of gases or air between the sectors or between the duct and the casing while in rotation.

Energy Conversion Process – Air / Gas Handling

Regenerative Air Heaters – Rotating Element cont'd: For on line cleaning of the deposits from the baskets steam jets are provided such that the blown out dust and ash are collected at the bottom ash hopper of the air heater. This dust hopper is connected for emptying along with the main dust hoppers of the dust collectors.

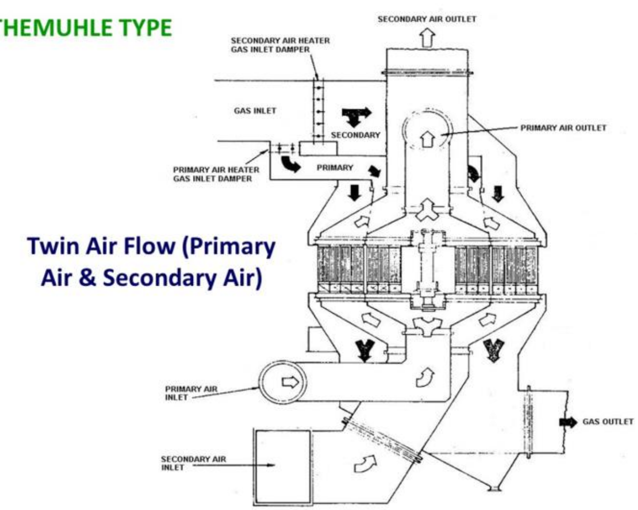
The rotor is turned by an electric motor and gearing, and is required to be started before starting the boiler and also to be kept in rotation for some time after the boiler is stopped, to avoid uneven expansion and contraction resulting in warping or cracking of the rotor.

The baskets are in the sector housings provided on the rotor and are renewable. The life of the baskets depend on the ash abrasiveness and corrosiveness of the boiler outlet gases.

Regenerative Air Heaters – Stationary Element: are a type of regenerative air heater and are also installed in a casing, but the heating plate elements are stationary rather than rotating. Instead the air ducts in the air heater are rotated so as to alternatively expose sections of the heating plate elements to the up flowing cool air. There are rotating inlet air ducts at the bottom of the stationary plates similar to the rotating outlet air ducts at the top of the stationary plates.

Stationary element regenerative air heaters are also known as Rothemuhle air heaters, manufactured for over 25 years by Balke-Dürr GmbH of Ratingen, Germany as well as a number of licenses around the world.

ROTHEMUHLE TYPE



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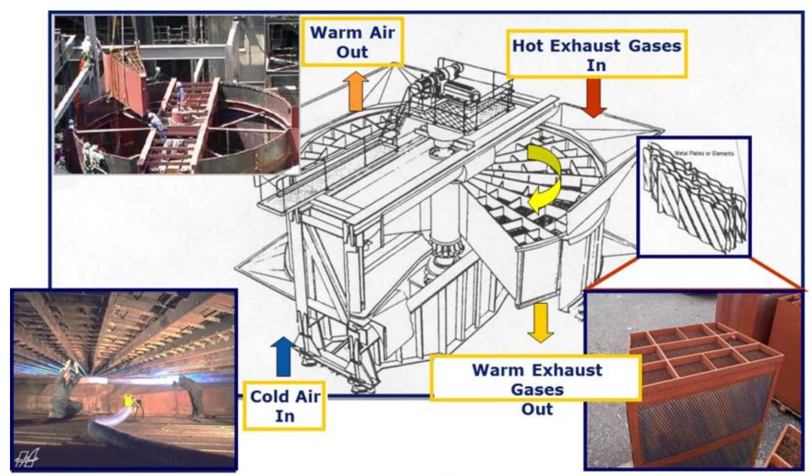
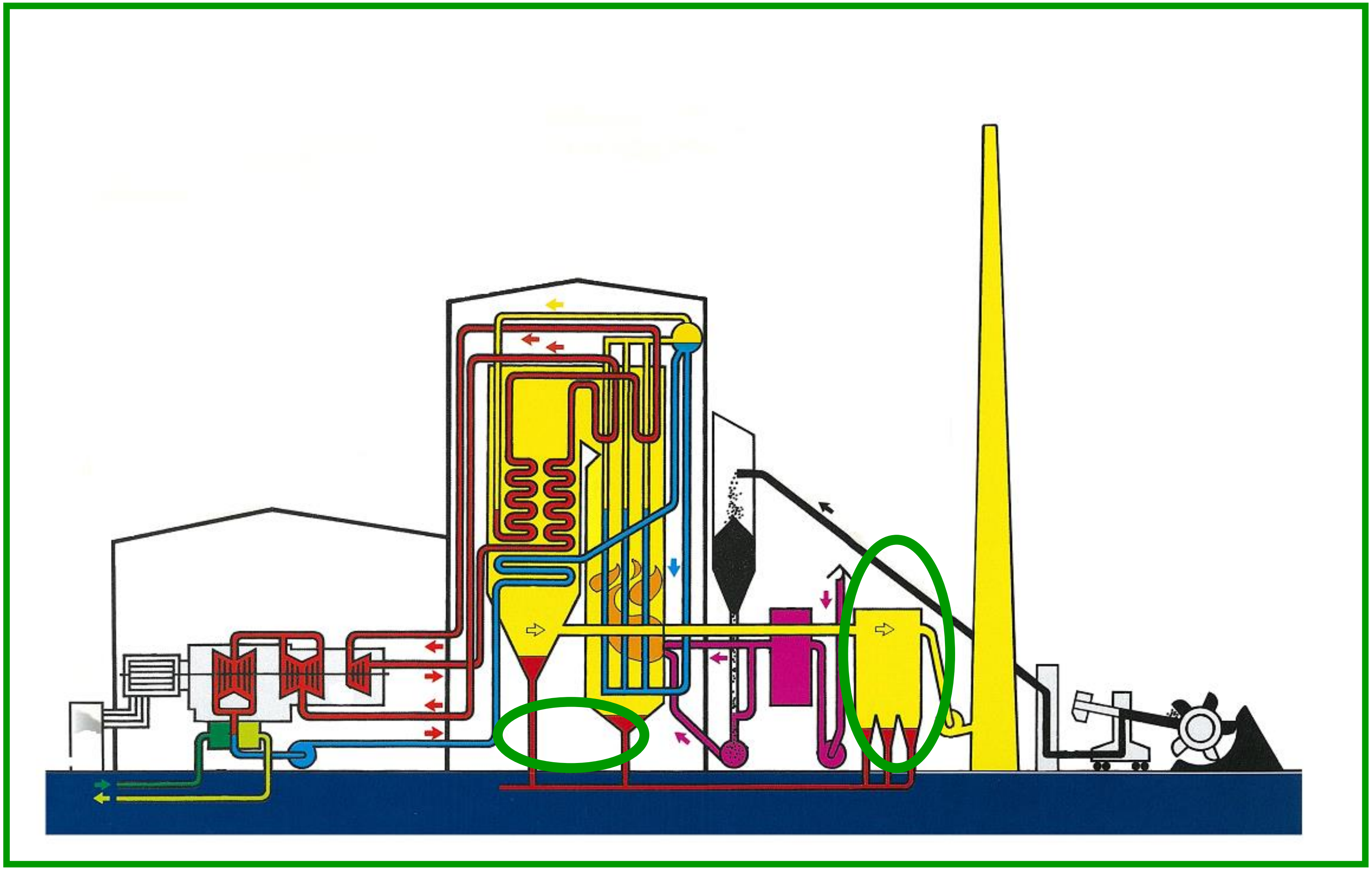


Lungstrom Type

Energy Conversion Process – Gas Cleaning / Ash Handling



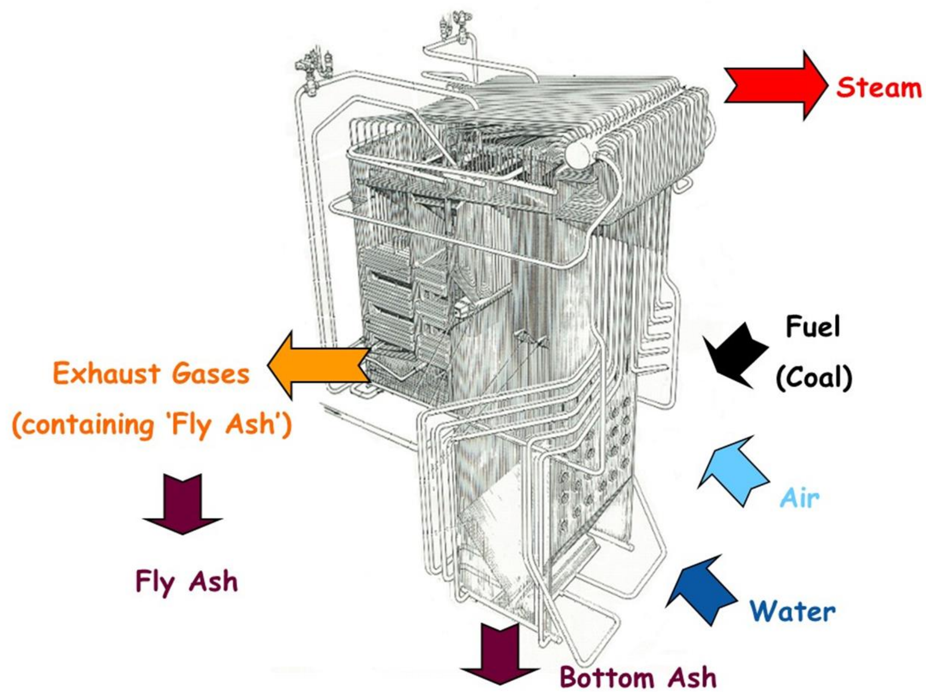
1446

Energy Conversion Process – Gas Cleaning / Ash Handling

The solid by-products of coal combustion in ash. Modern pulverised fuel fired boilers produce ash in two forms, bottom ash and fly ash. As the name suggests bottom ash represents the heavier ash particles which fall to the bottom of the boiler furnace and are removed. The fly ash is the majority of the ash produced and consists of small and lighter particles which are carried out of the boiler in the exhaust gas stream.

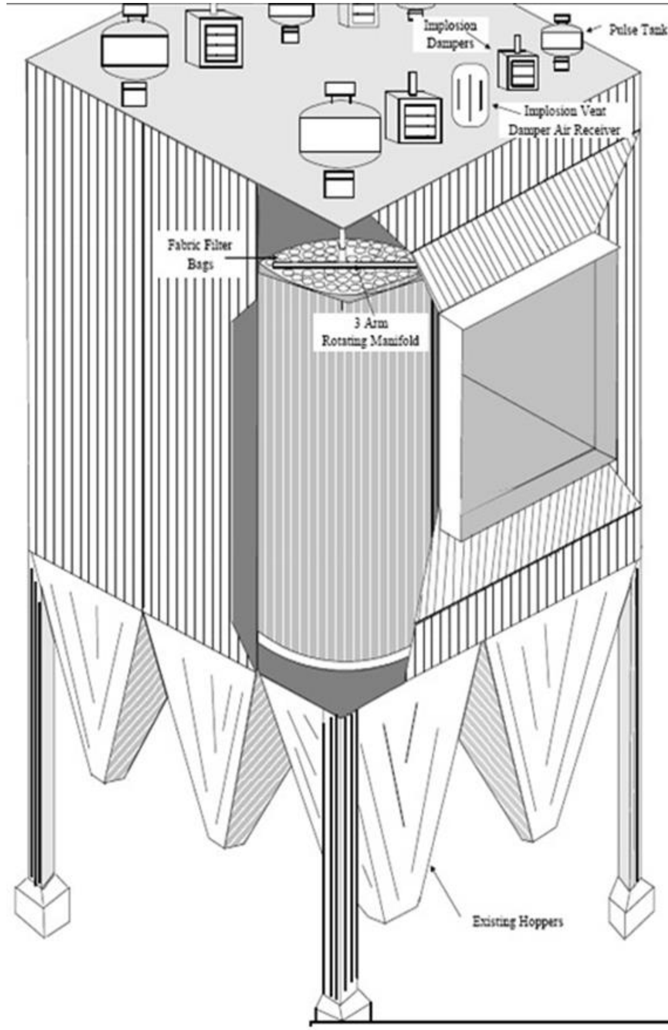
The exhaust gases are destined for final release to the atmosphere and thus the vast majority of ash particles must be cleaned from the exhaust gases. There are two basic methods for the cleaning of exhaust gas streams. The first is the use of fabric filters or bag houses. In this case the exhaust gas is passed through a porous fabric filter material which traps the ash particles and forms a cake of dust on the up stream surface of the fabric. The particles are routinely removed from the fabric filter by applying a pulse air blast in the opposite direction to the exhaust gas flow. The ash cake falls into a hopper below for removal.

The second method of removing fly ash from the exhaust gas streams is by the use of electrostatic precipitation. Electrostatic precipitators use electrostatic forces to separate dust particles from exhaust gases. A number of high-voltage, direct-current discharge electrodes are placed between grounded collecting electrodes. The contaminated gases flow through the passage formed by the discharge and collecting electrodes. The airborne particles receive a negative charge as they pass through the ionized field between the electrodes. These charged particles are then attracted to a grounded or positively charged electrode and adhere to it. The collected material on the electrodes is removed by rapping or vibrating the collecting electrodes either continuously or at a predetermined interval.



Ash from coal fired power stations also has a number of applications such as an additive to concrete and as road stabilising material.

Energy Conversion Process – Gas Cleaning



Typical Fabric (Bag) Filters

AGL

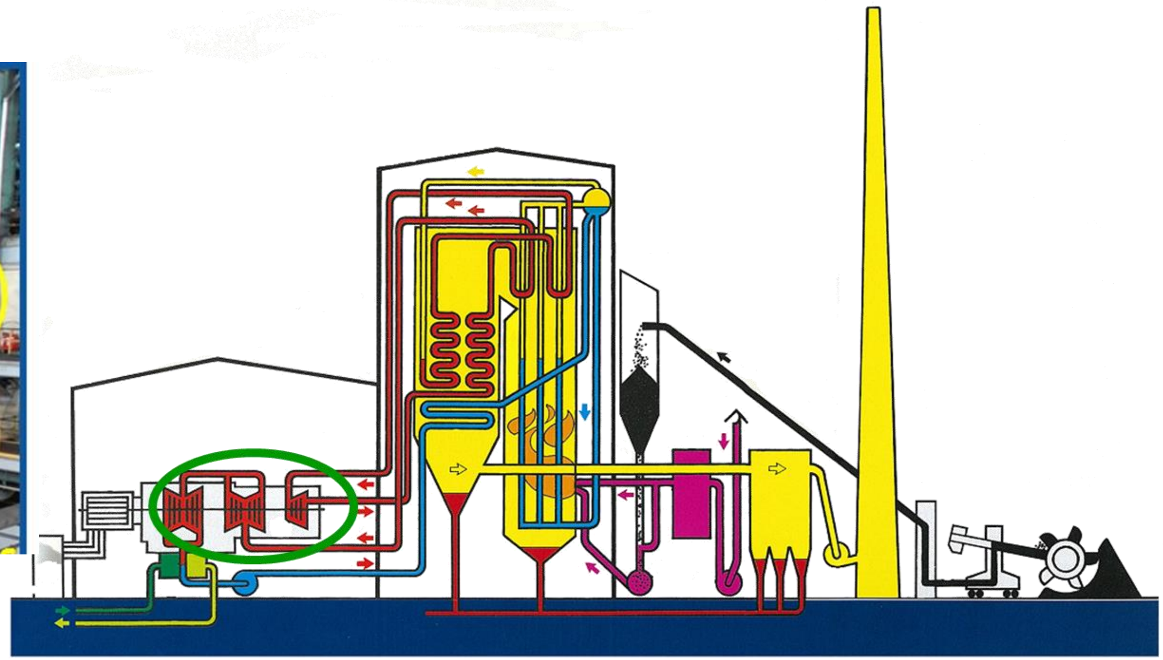
Energy Conversion Process – Steam Turbine

Steam from the boiler is used to drive steam turbines which are themselves joined via a shaft to the generator. The turbines convert the energy in the steam into mechanical energy to drive the generator.

Typically there are a series of turbines consisting of high pressure, intermediate pressure and low pressure. There are a number of combinations of turbines which have found applications. It is not uncommon on large units to find more than one low pressure turbine.

Steam turbines consists of a set of stationary blades held in the casing and a set of rotating blades mounted on the turbine shaft. Steam is directed by the fixed blading onto the rotating blading causing the rotating blading to drive the turbine shaft. There are a number of stages of blading in any turbine. Each successive stage of blading sees steam with slightly less energy as some energy has been given up as work in the previous stage.

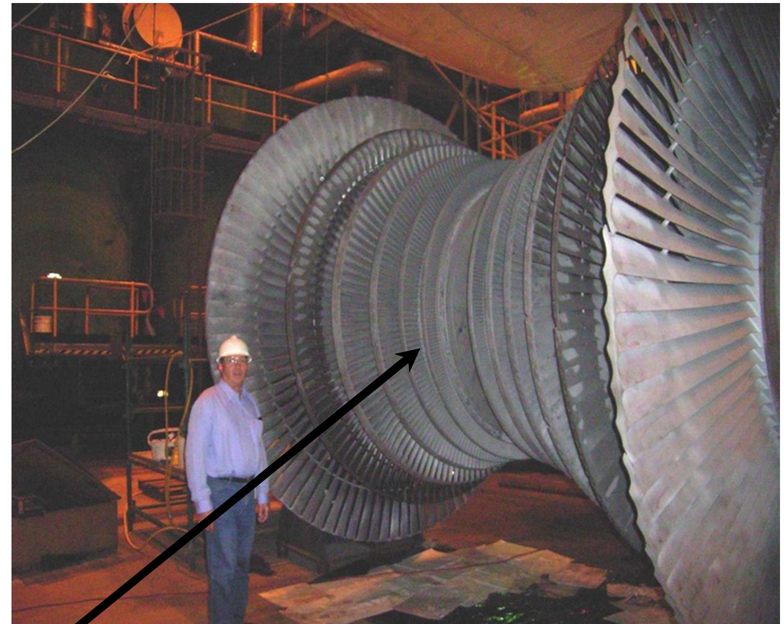
Typical
Power Station
Turbines



Energy Conversion Process – Steam Turbine

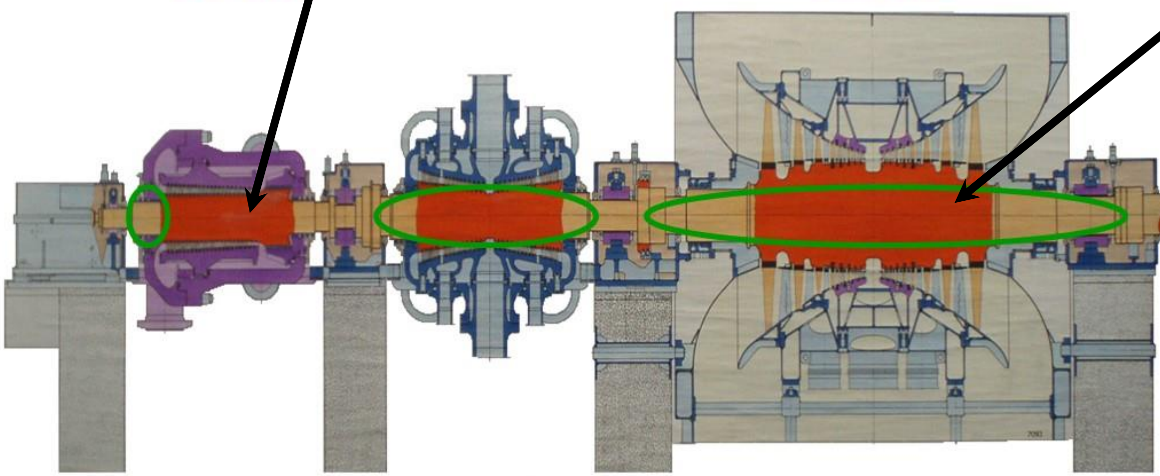
High Pressure Turbine Rotar

Low Pressure Turbine Rotar



High Pressure (HP) Turbine

Low Pressure (LP) Turbine



Typical Power Station Turbines Arrangement

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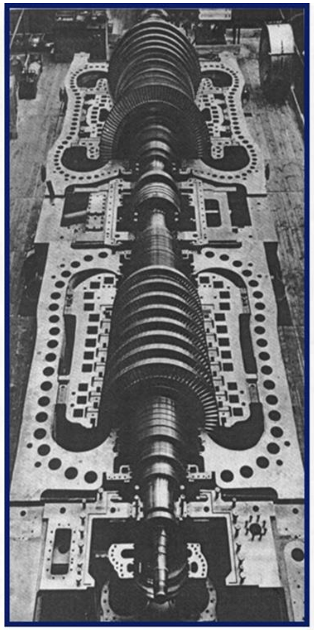
Intermediate Pressure (IP) Turbine

Energy Conversion Process – Steam Turbine

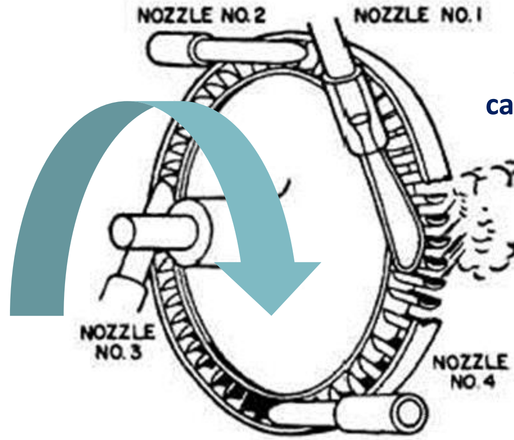


HP AND LP ASSEMBLY
(Horizontal Split Casing Design)

HIGH PRESSURE (HP) STEAM TURBINE BLADE

1451

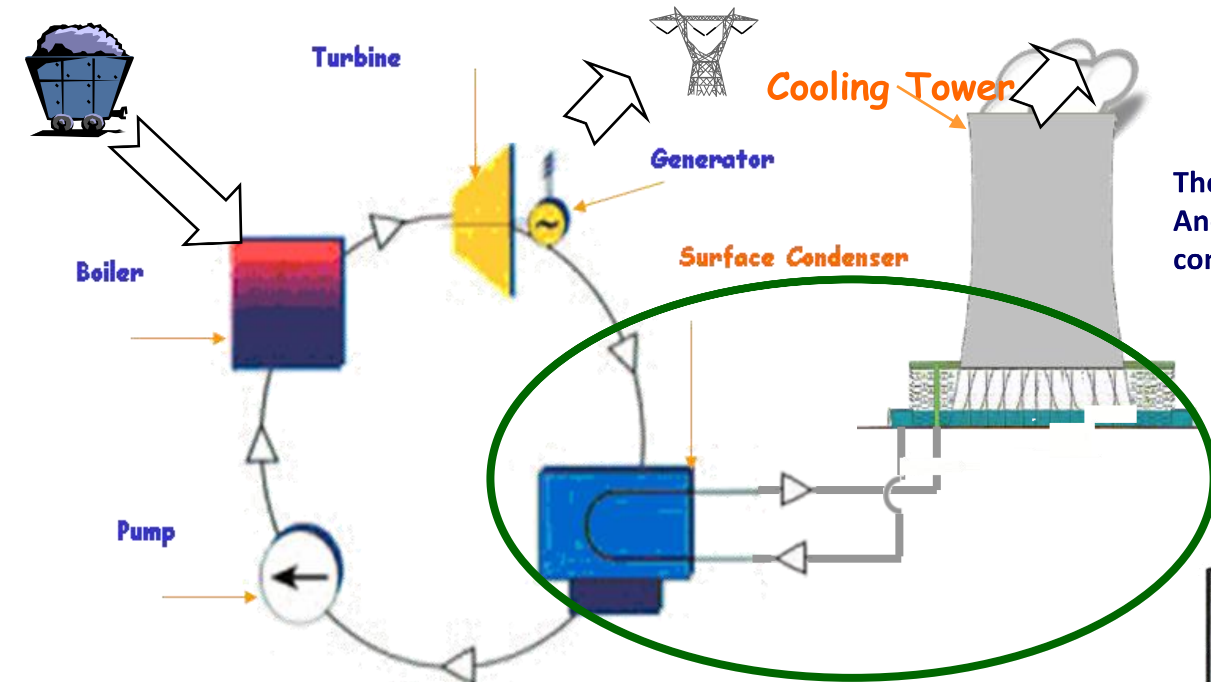
LOW PRESSURE (LP) STEAM TURBINE BLADE



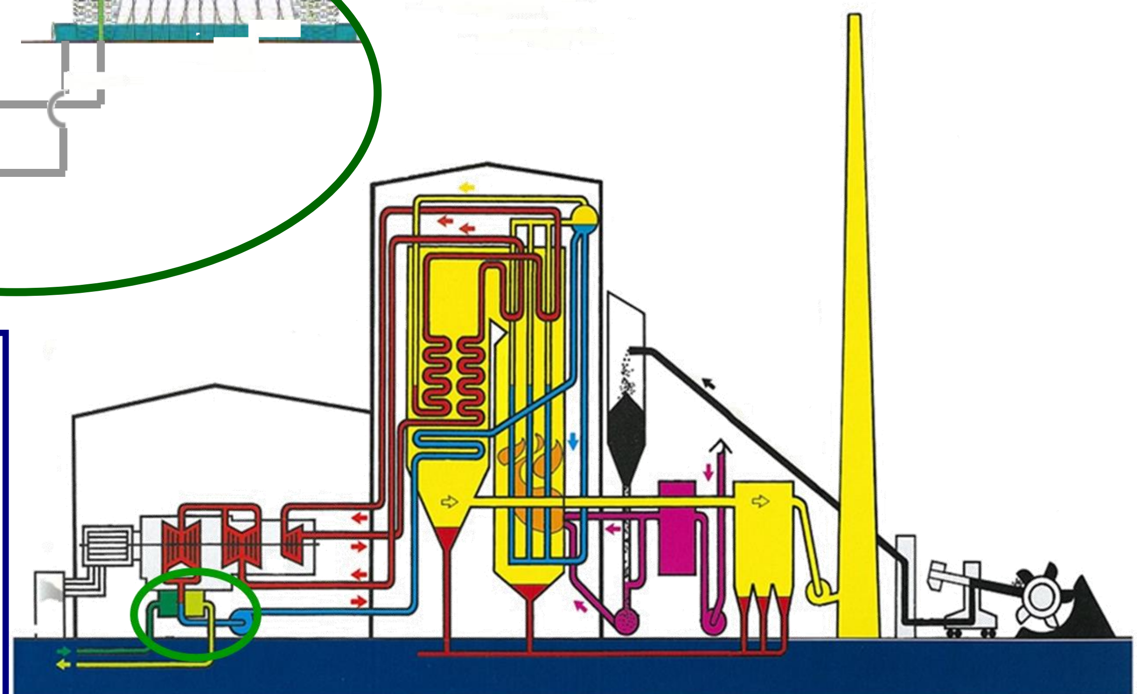
Steam “pushes’ on the Turbine Blades causeing them to rotate the Turbine Rotor

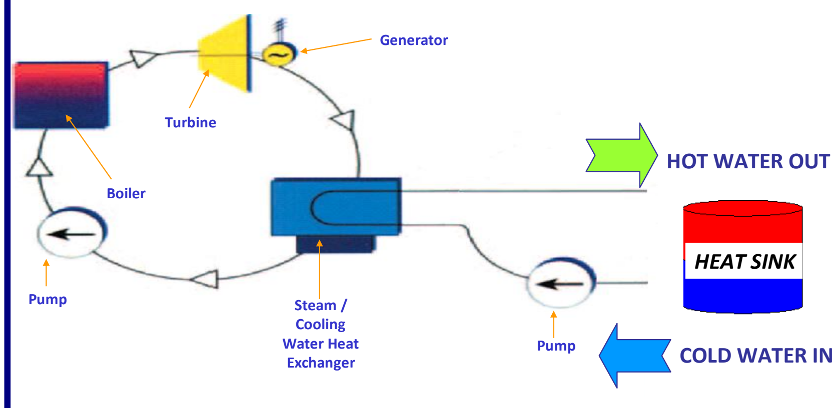
280 MW HP TURBINE BLADE

Energy Conversion Process – Cooling Water System



The Laws of Physics: For energy to be useful, it must flow And it wants to flow from high concentrations to lower concentrations.



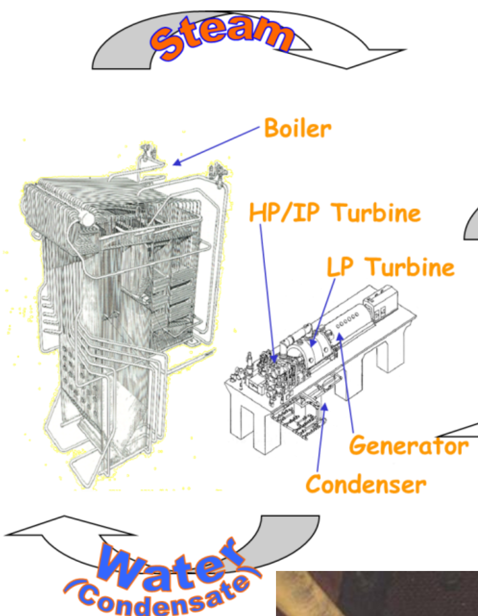


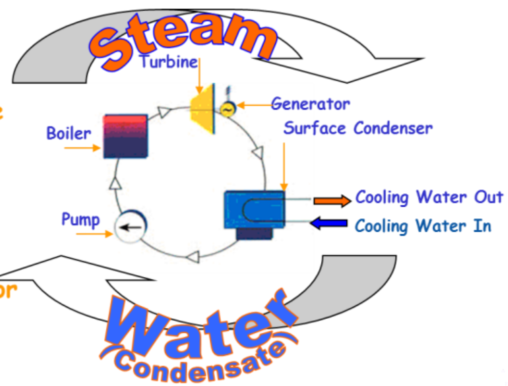
Cooling Water System

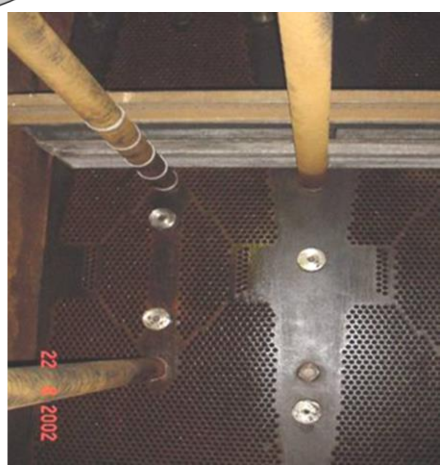
Energy Conversion Process – Cooling Water System

The primary function of a cooling water system within a thermal power station is the cooling of the steam turbine exhausts so that in accordance with the Second Law of Thermodynamics: work can be done by the steam passing through the turbine due to the flow of heat from a hot to cold body (the steam).

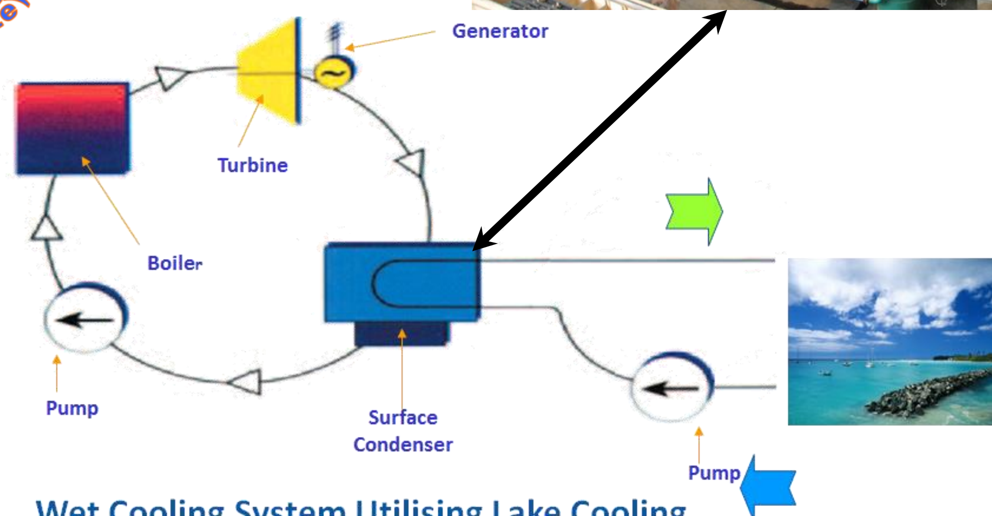
Cooling systems usually have a secondary function, cooling auxiliary systems such as Generator Hydrogen Coolers.







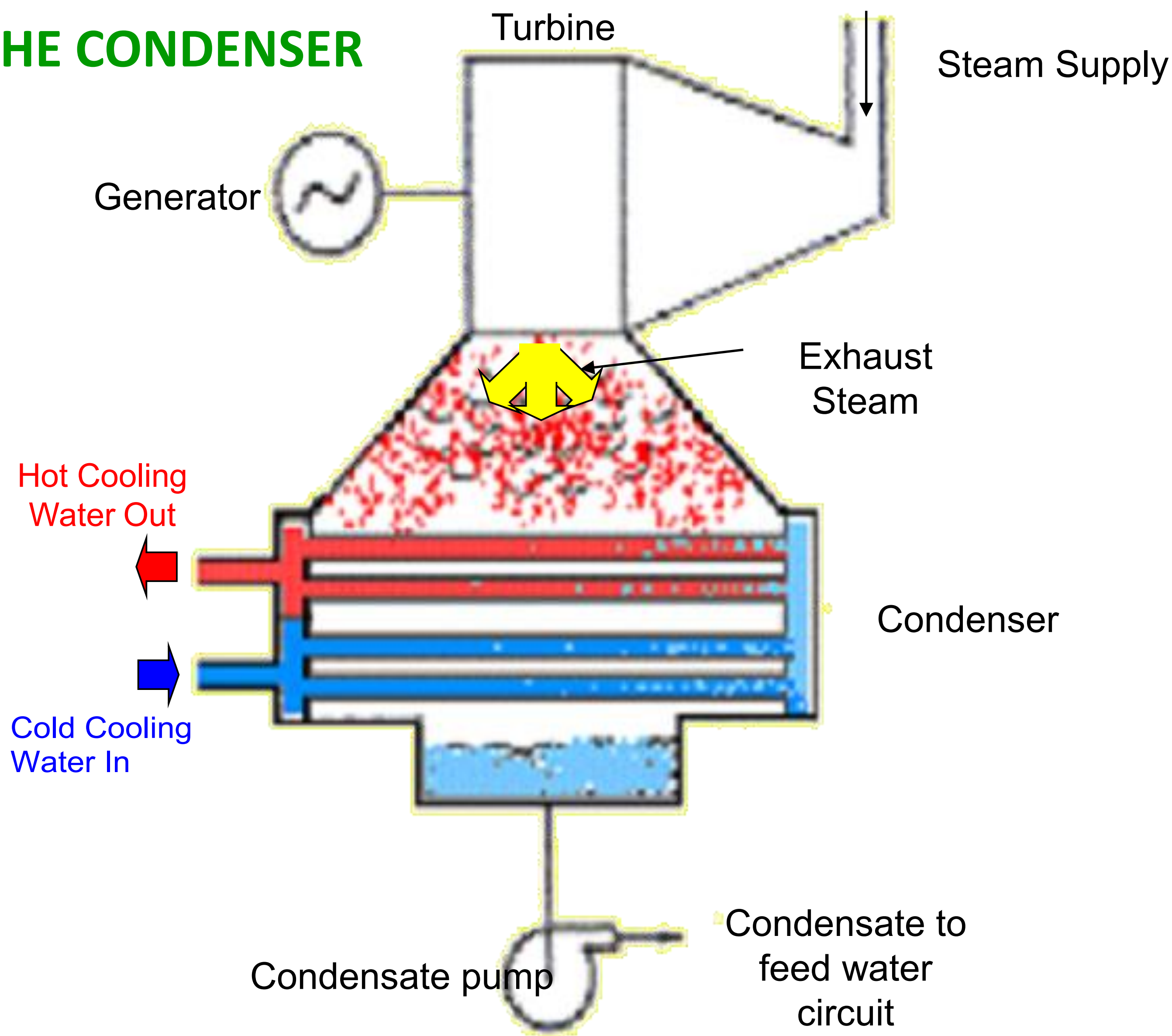
Internal View of Condensor



Wet Cooling System Utilising Lake Cooling

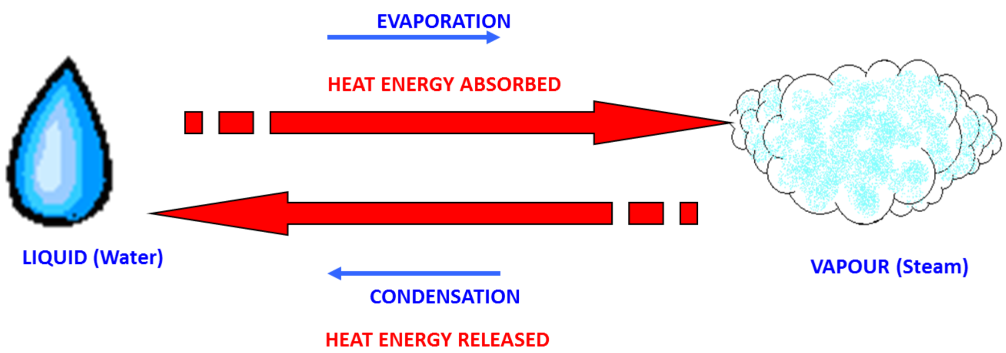
Energy Conversion Process – Cooling Water System

THE CONDENSER



Energy Conversion Process – Cooling Water System

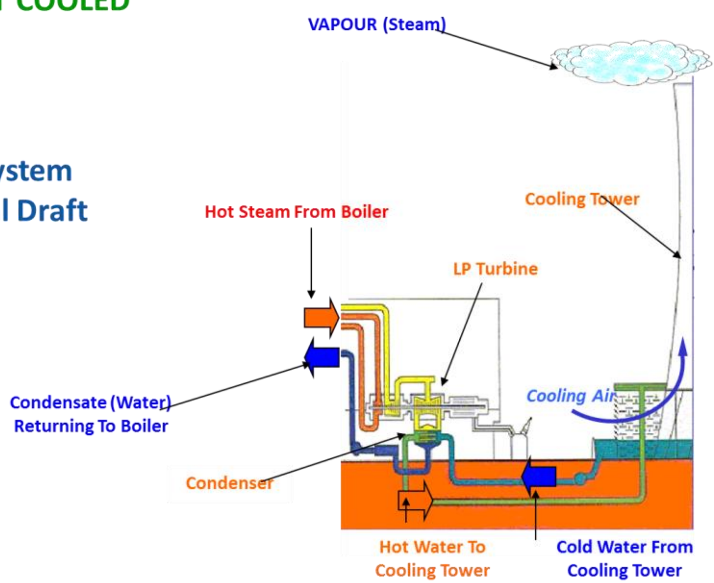
WET COOLED



Wet Cooling - Latent Heat of Vaporisation Principle

WET COOLED

Wet Cooling System Utilising Natural Draft Cooling



1455

Liddell Power Station in NSW is cooled by water circulated through a man-made Lake

LAKE COOLED

AGL

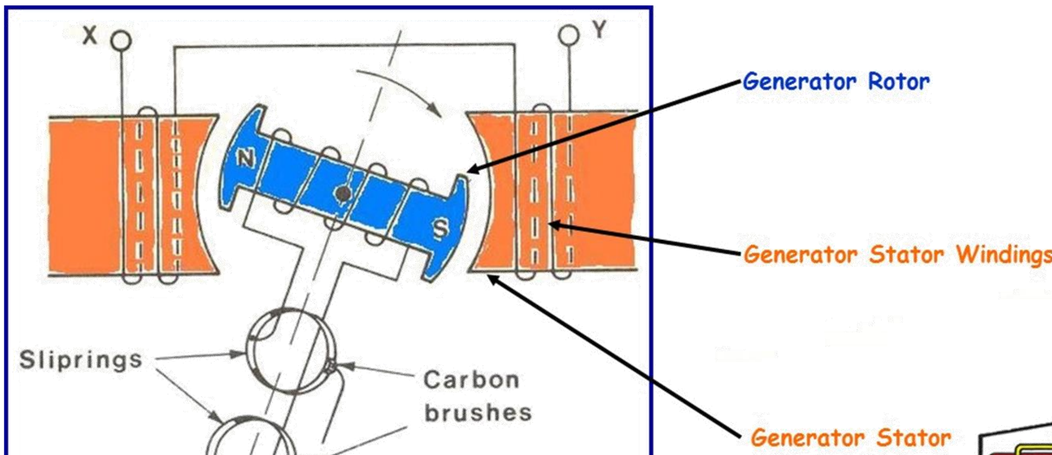
Energy Conversion Process – Generators

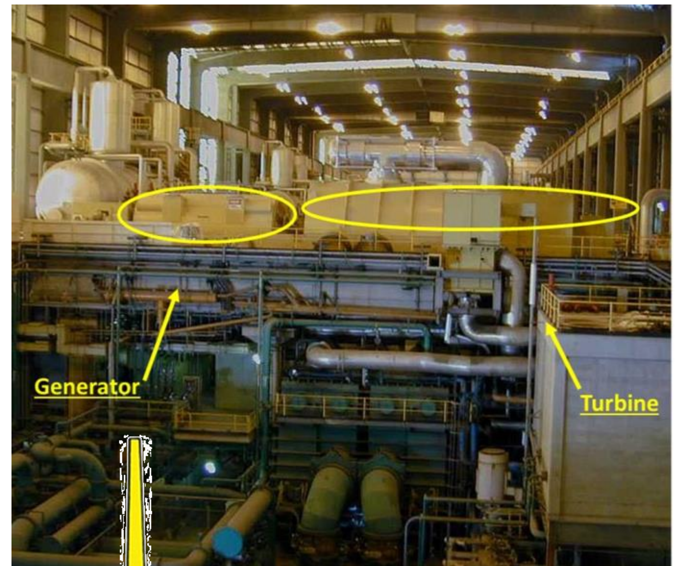
The generator is driven by a common shaft from the turbines. The generator consists of a rotor (rotating element) and a stator (stationary element). The rotor is driven by the turbines. The rotor forms a rotating electro magnet. The stator consists of the windings in which a current is induced.

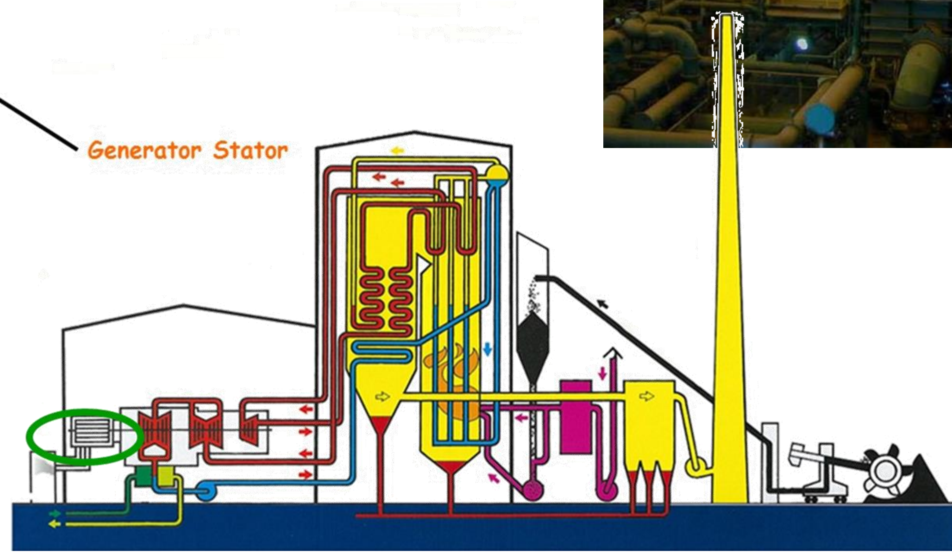
A large amount of heat can be generated in large power station generators and thus various cooling mechanism must be employed. A common method is to cool the rotor and stator with hydrogen gas. Hydrogen is used for its excellent heat transfer capacity. Stator windings can be either hydrogen cooled or additionally water cooled.

Alternating Current (AC)

Power Station Generator Construction



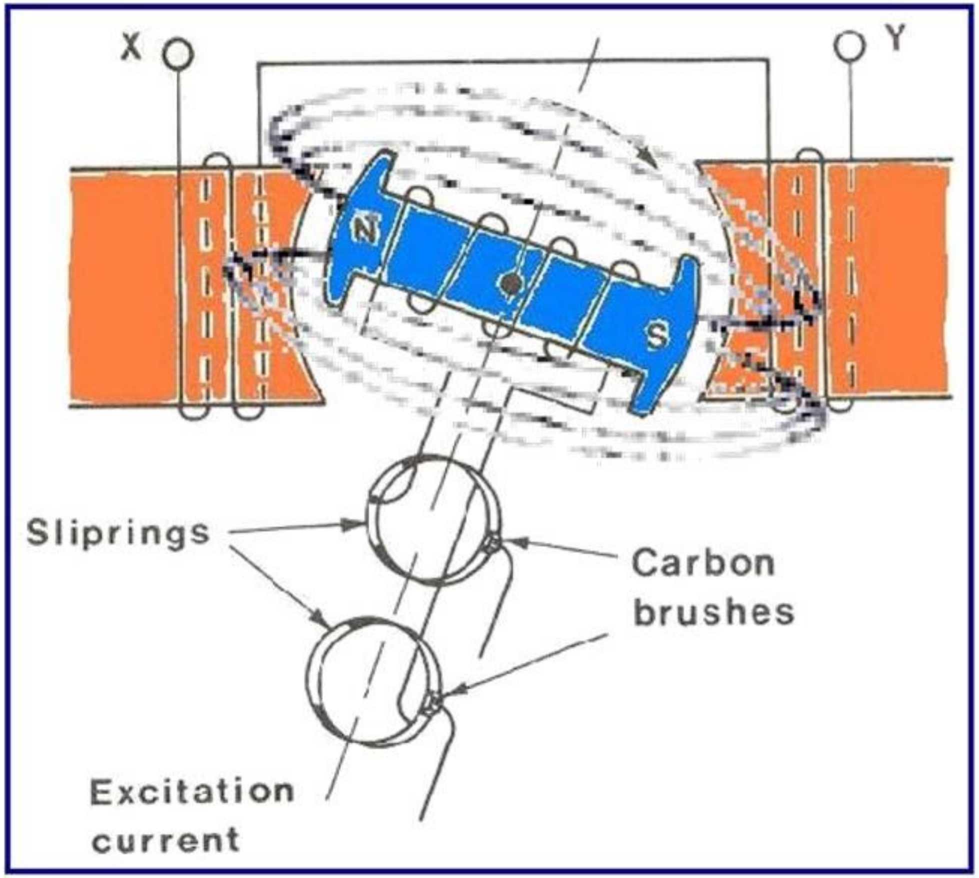




Energy Conversion Process – Generators

Alternating Current (AC)

Frequency = Number of Cycles per Period of Time (Cycles per Second)



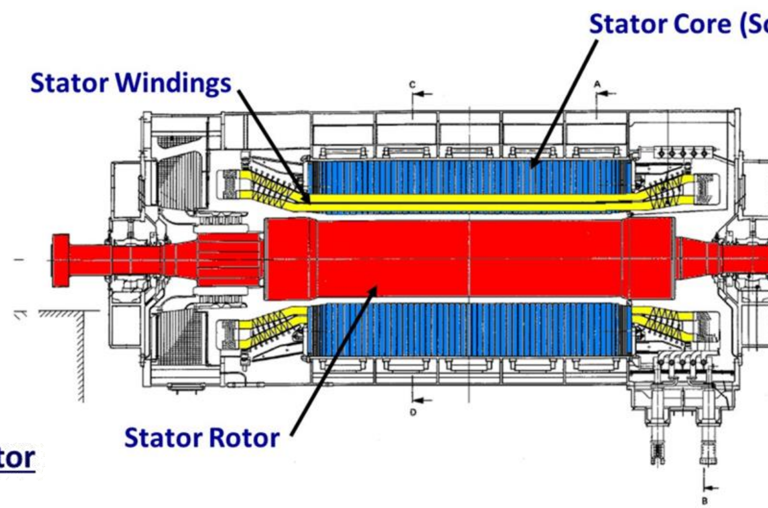
- The Generator Rotor creates a rotating magnetic field.
- The Magnetic Field 'cuts' through the windings of the Generator Stator causing a current (flow of electrons) to flow in the Stator Windings.
- In the course of one complete revolution of the Rotor, the current flows first in one direction and then in the opposite direction. That is the current ALTERNATES in direction.
- In 1 full revolution of the Rotor, 1 complete cycle is made. Thus the speed at which the Rotor rotates determines the number of cycles per any given period of time.

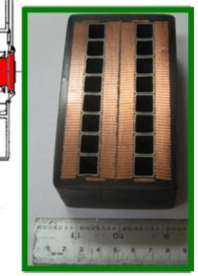
1457

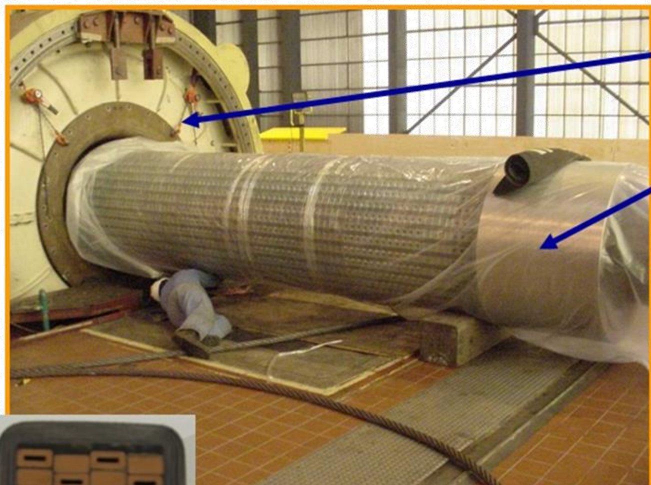
3,000 r.p.m. = 50 Cycles per Second {50 Hertz (Hz.)}

Energy Conversion Process – Generators

The speed of the generator rotor is kept <u>constant</u> to maintain the frequency. The power produced by the generated (Mega Watts) is effectively changed by the strength of the rotating magnetic circuit. With increasing field strength, the torque required to drive the rotor increases and thus the power required from the turbines and boiler increases.







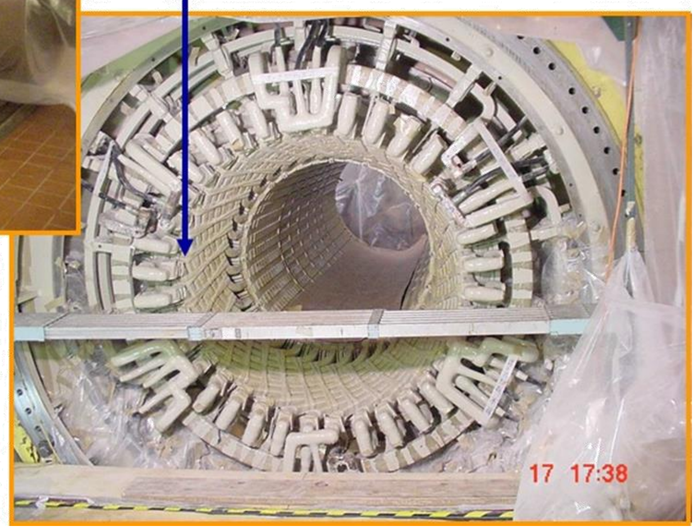
Generator Stator

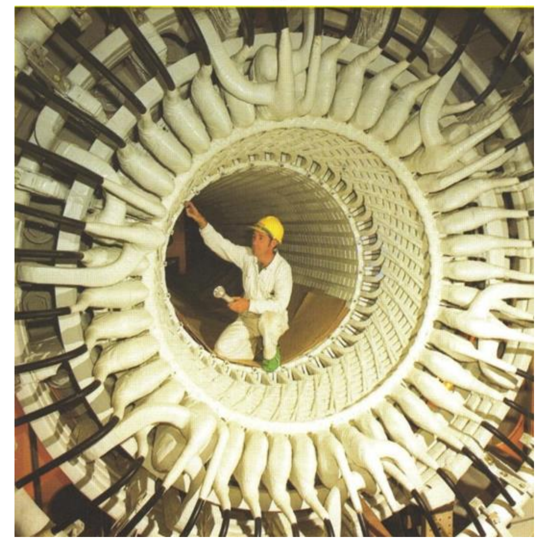
Generator Rotor

Generator Stator Windings

1458

Water Cooled Stator Winding

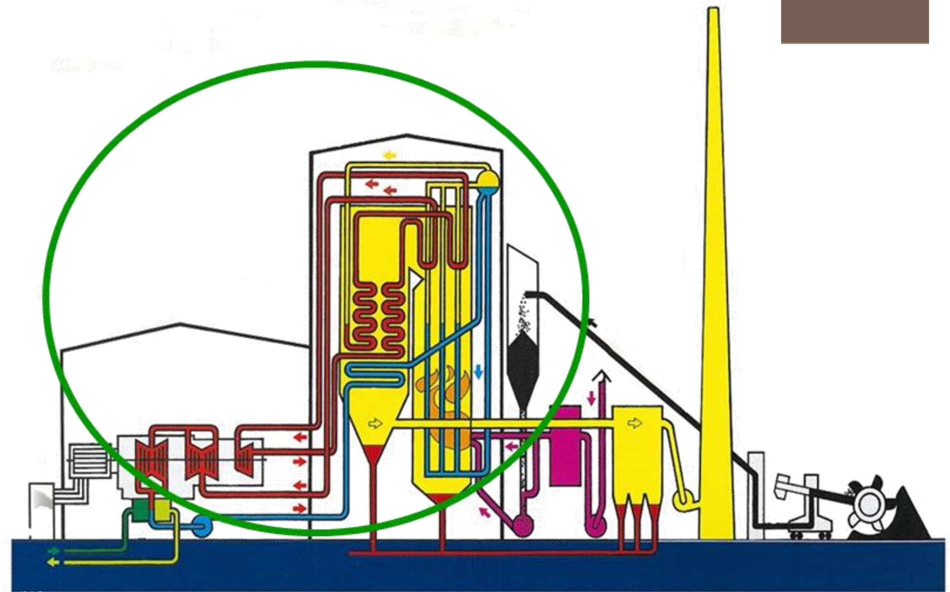


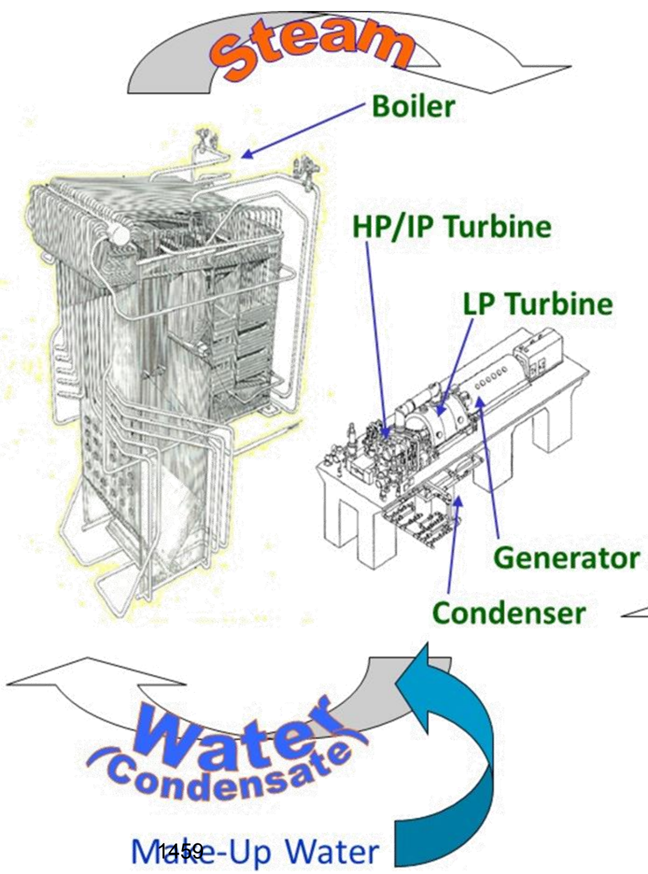


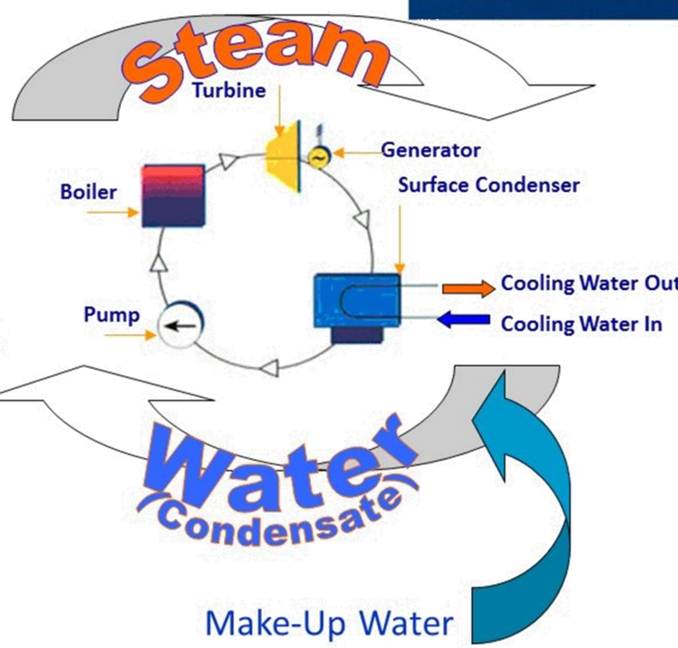
660MW Toshiba/GE Generator Stator

AGL

Energy Conversion Process – Water Systems







Energy Conversion Process – Water Systems

Water chemistry is critical to steam generating plants.

In the steam-generating plant, water treatment is particularly critical to both operating efficiency and equipment life. The feedwater makeup must be pure, and the recirculating boiler water and condensate must be kept scrupulously free of contaminants and dissolved oxygen (usually). The pH must be precisely controlled; and the exposed metal surfaces in the boiler, the feedwater heaters, and the boiler feed pumps must be protected.

Boiler feedwater consists of makeup water plus condensed steam. For makeup, many plants utilise raw water that requires pretreatment with some combination of clarifiers, sand filters and mixed media filters. The resulting water then undergoes additional treatment through reverse osmosis (RO) membranes, demineralisers, electrodeionisers, ultrafiltration or other systems. The final low conductivity ultra pure water provides the levels needed for optimal boiler performance.

So, boiler water treatment can fall into broad areas:

1) Makeup water preparation; and

2) Internal boiler water (including condensate) treatment.

All natural waters contain varying amounts of suspended and dissolved matter as well as dissolved gases. Feedwater must be pretreated to remove impurities to control deposition, carryover, and corrosion in the boiler system. Poor quality water gives poor quality steam. The first step in any treatment is filtration of suspended solids.

<u>Dissolved minerals:</u>
Dissolved minerals picked up by the water consist mainly of calcium carbonate (limestone), calcium sulphate (gypsum), magnesium carbonate (dolomite), magnesium sulphate (epsom salts), silica (sand), sodium chloride (common salt), hydrated sodium sulphate (glauber salt), and smaller quantities of iron, manganese, fluorides, aluminium, and other substances. The nitrates and phosphates found in water are usually due to sewage contamination.

Energy Conversion Process – Water Systems

Dissolved gases in water:

Water contains varying amounts of dissolved air (21% oxygen, 78% nitrogen, 1% other gases including carbon dioxide). Water can contain up to 9ppm oxygen at room temperature and atmospheric pressure. As the temperature increases, the solubility of oxygen decreases, but water under pressure can hold higher amounts of dissolved oxygen. Nitrogen, being inert, has little effect on water used in boilers. Water can contain 10ppm of carbon dioxide, sometimes much more than that due to decaying vegetation and organics in soil. Hydrogen sulphide and methane may be dissolved in water but this is rare. These gases can be troublesome when they are present in the feed water.

Other impurities in water:

Natural waters contain varying levels of soil, sand, turbidity, colour, precipitated minerals, oil, industrial wastes and other suspended solid particles. Turbidity is due to very fine organic materials and micro-organisms, as well as suspended clay and silt. Colour is due to the decaying vegetable matter.

Corrosion:

Corrosion is basically the reversion of a metal to its ore form. Iron, for example, reverts to iron oxide as a result of corrosion. The process of corrosion is actually not so simple, it is a complex electro-mechanical reaction. Corrosion may generally be over a large metal surface but sometimes it results in pinpoint penetration of metal. Though basic corrosion is usually due to reaction of the metal with oxygen, other factors including stresses produce different forms of attack. Corrosion may occur in the feedwater system as a result of low pH water and the presence of dissolved oxygen and carbon dioxide. Corrosion in the boiler itself normally occurs when boiler water alkalinity is too low or too high or when the metal is exposed to oxygen-bearing water during either operation or idle periods. High temperatures and stresses tend to accelerate the corrosion. In the steam and condensate system pipeline corrosion is generally the result of contamination with carbon dioxide and oxygen.

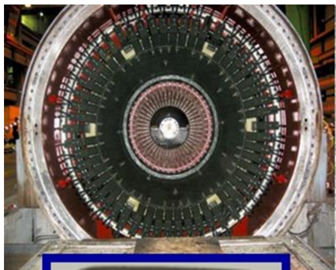
Deposits:

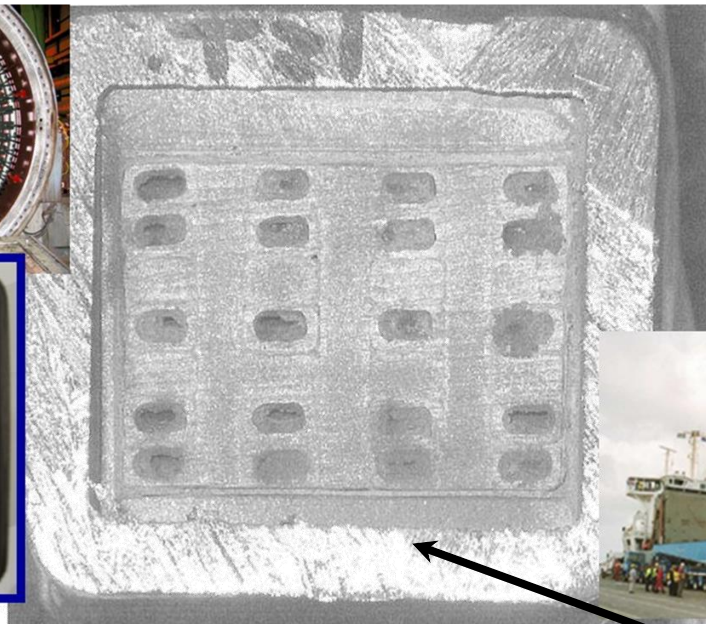
Deposits in the steam/water circuit of the boiler, turbine and feeding/ heating systems can vary from silicates to copper. In many cases sludges can accumulate in the boiler and are addressed through blowing down. However, a number of contaminants can deposit on “wetted” surfaces causing problems with heat transfer and flow restrictions. Heat transfer problems are often a cause of pressure part failures.

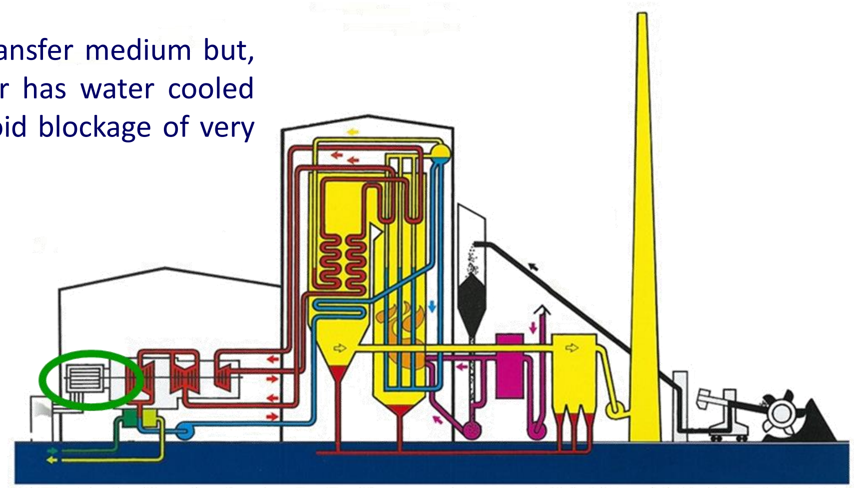
Energy Conversion Process – Water Systems (Generators)

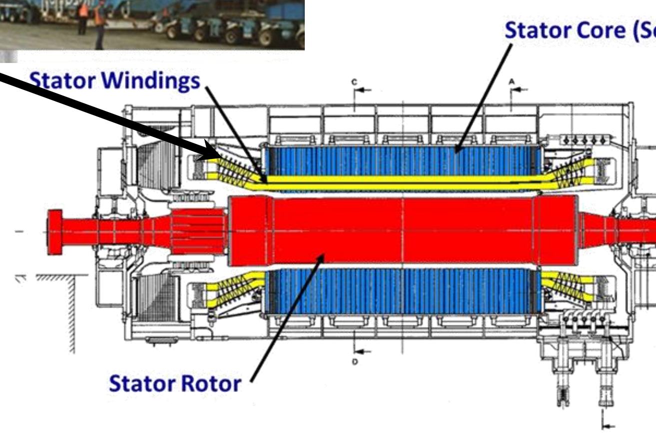
Due to the energy concentrations and the materials involved, large Generators require significant amounts of cooling.

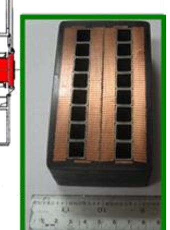
A key element in the cooling process is Hydrogen gas which is a very good heat transfer medium but, then must itself be cooled. It is also common to find the Stator of the Generator has water cooled components (Bars). The water used in these applications MUST be very pure to avoid blockage of very small and long cooling channels.







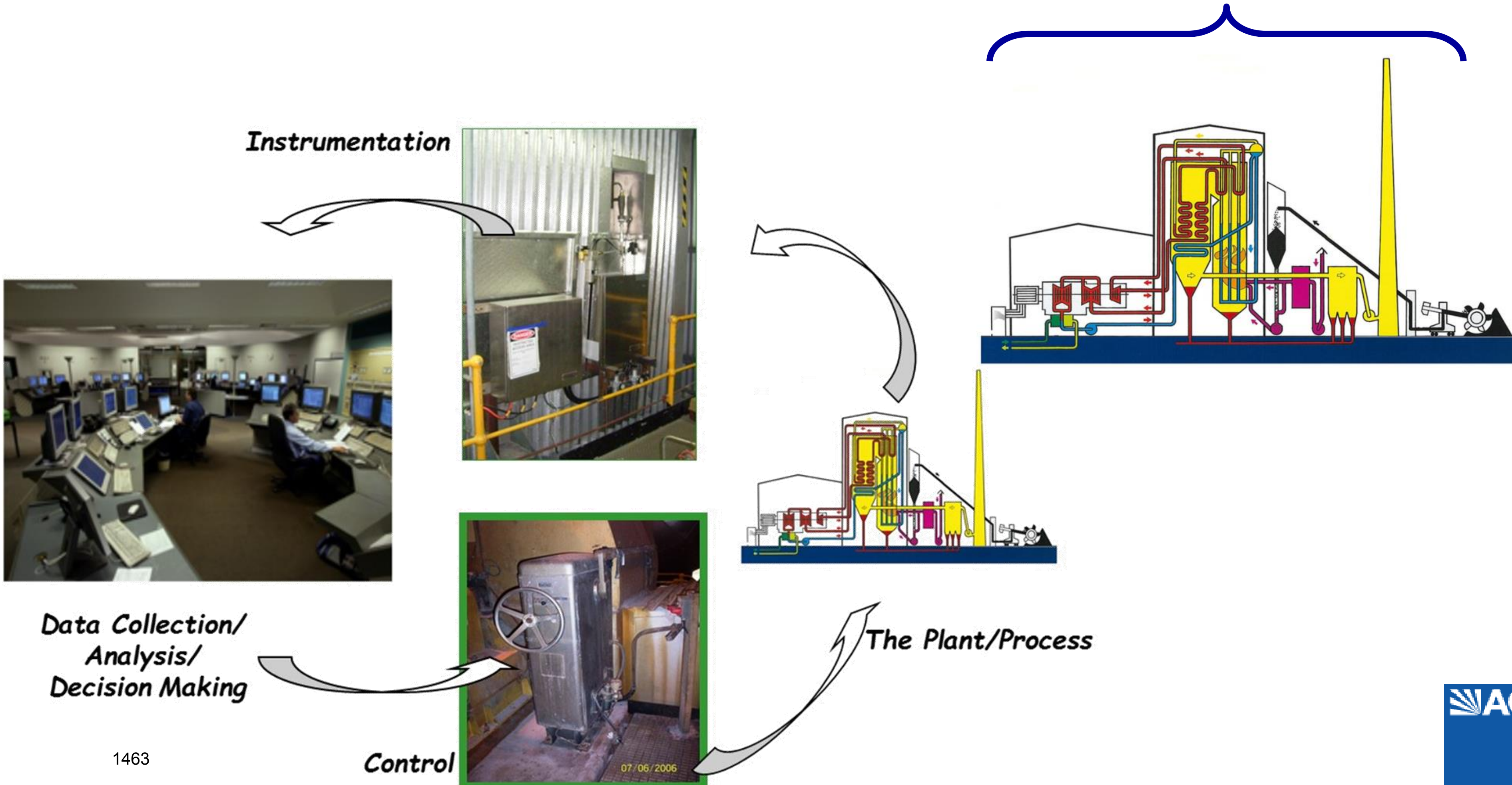




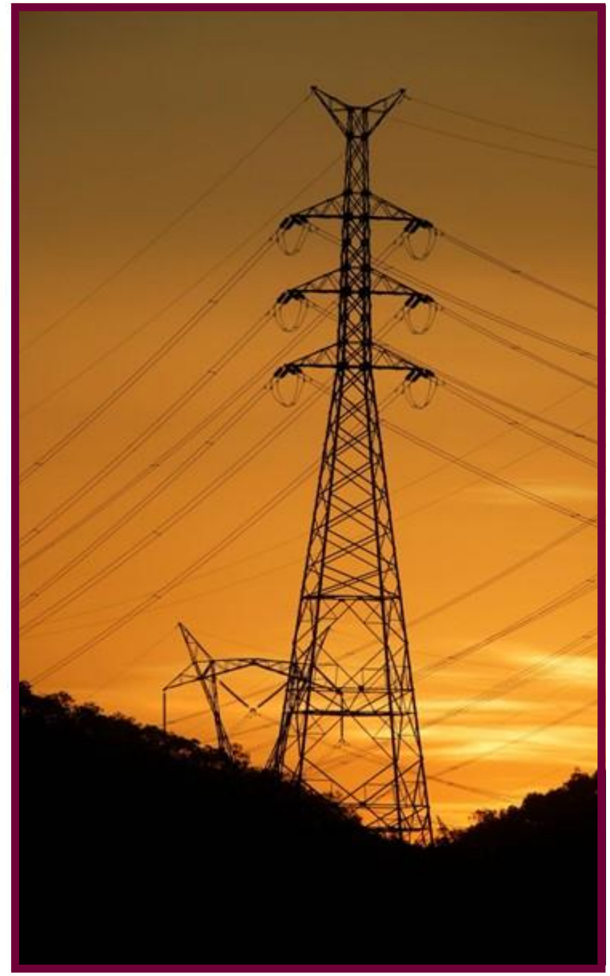
Copper corrosion in the strands of a Generator Stator bar due to poor water chemistry

Energy Conversion Process – Instrumentation & Control

All of the physical plant elements of a large modern thermal power station are tied together via a control system. The control system consists of instruments distributed through the plant that report back to a central data processing unit information related to the operating conditions of the plant and processes. The central processing elements then analyse this information and check against parameters that are either automatically set or set by the operator. Then any changes or adjustments to the plant are made through the control elements of the control system which consists of signals being sent to various devices throughout the plant that can act to change plant or process conditions.



Energy Conversion Process – Sending Electricity Out



Typical Power Station Generator Transformer

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