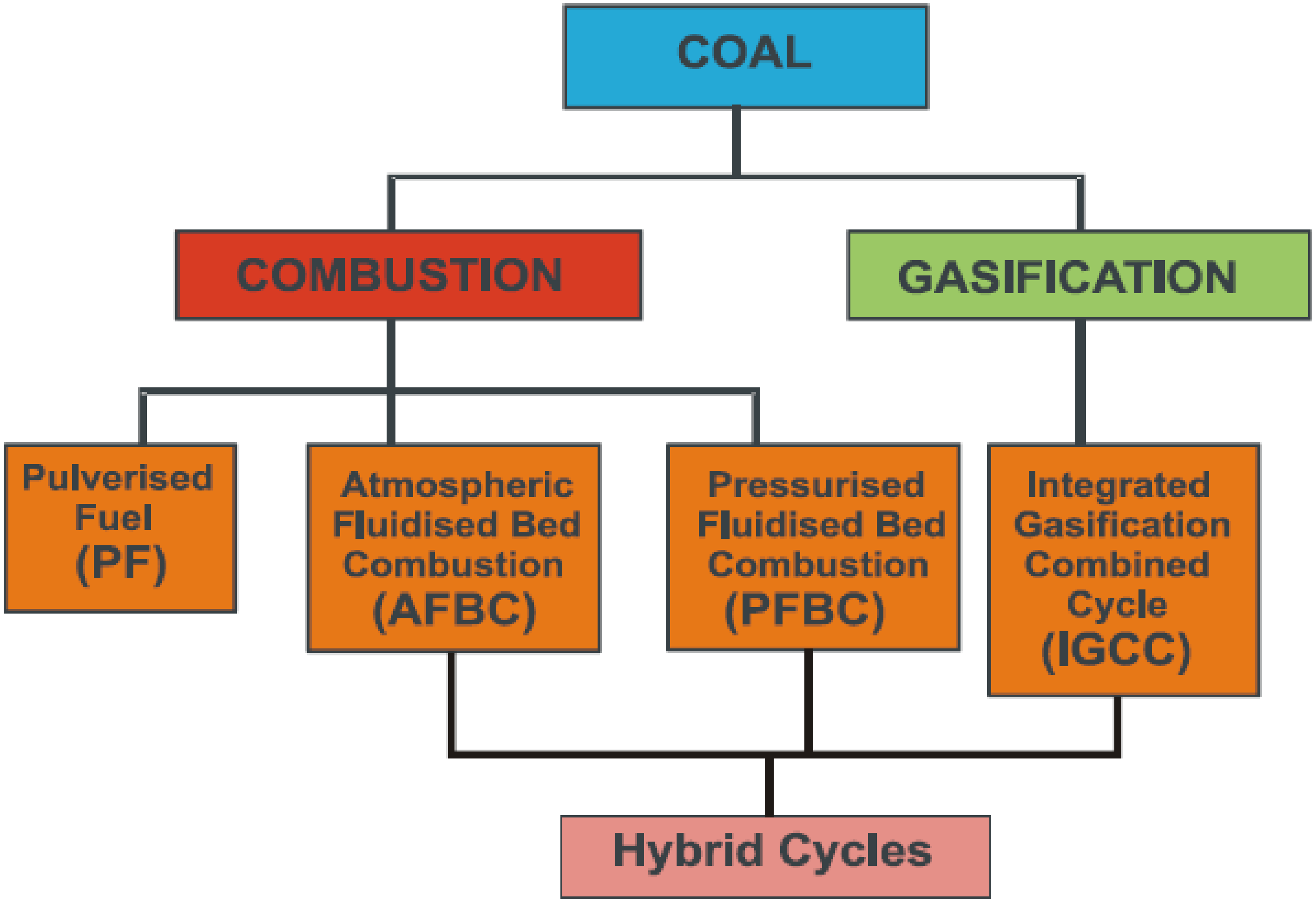
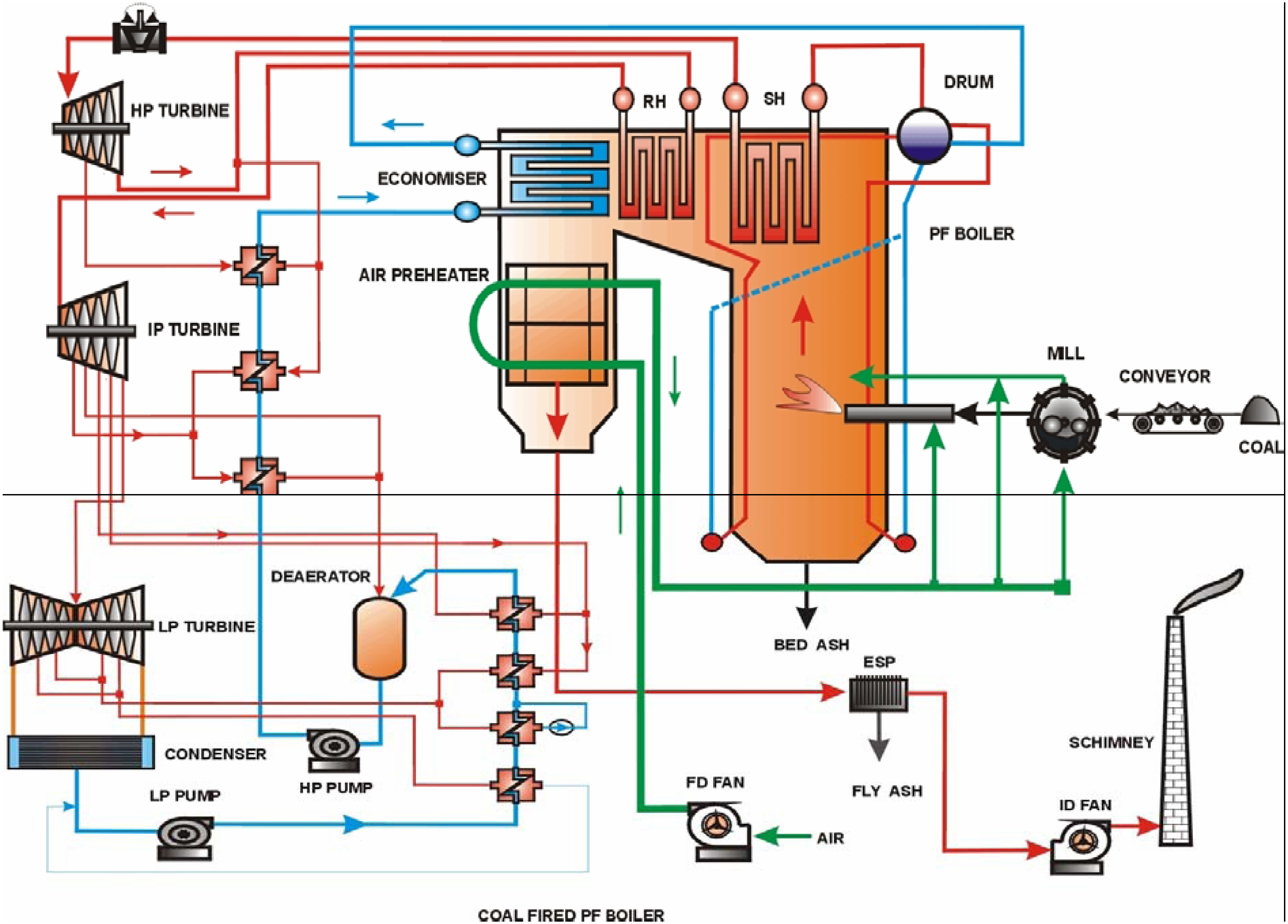
TECHNOLOGY CLASSIFICATION



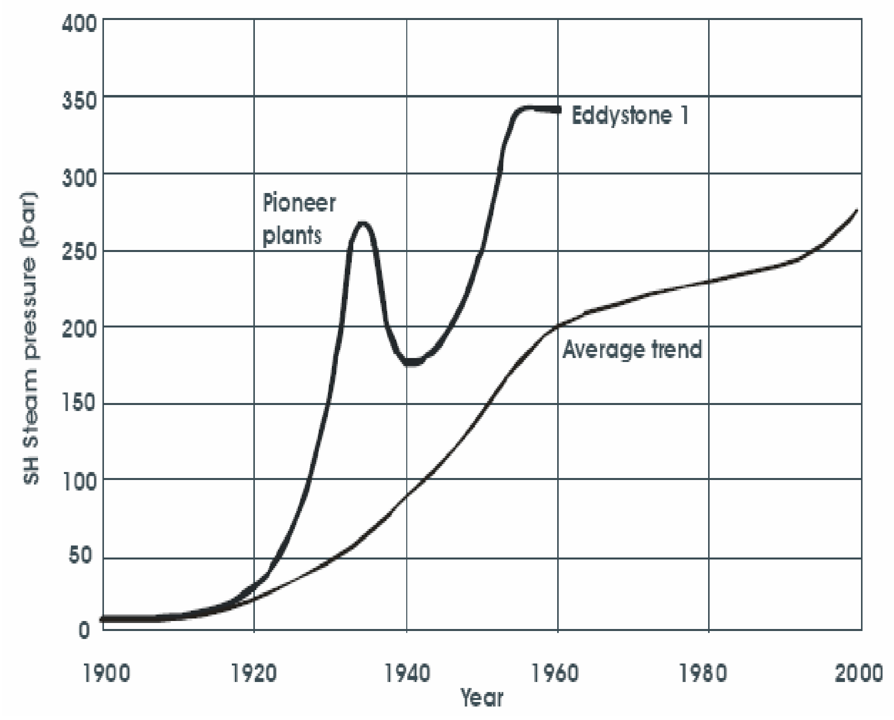
PULVERISED FUEL (PF) BOILER

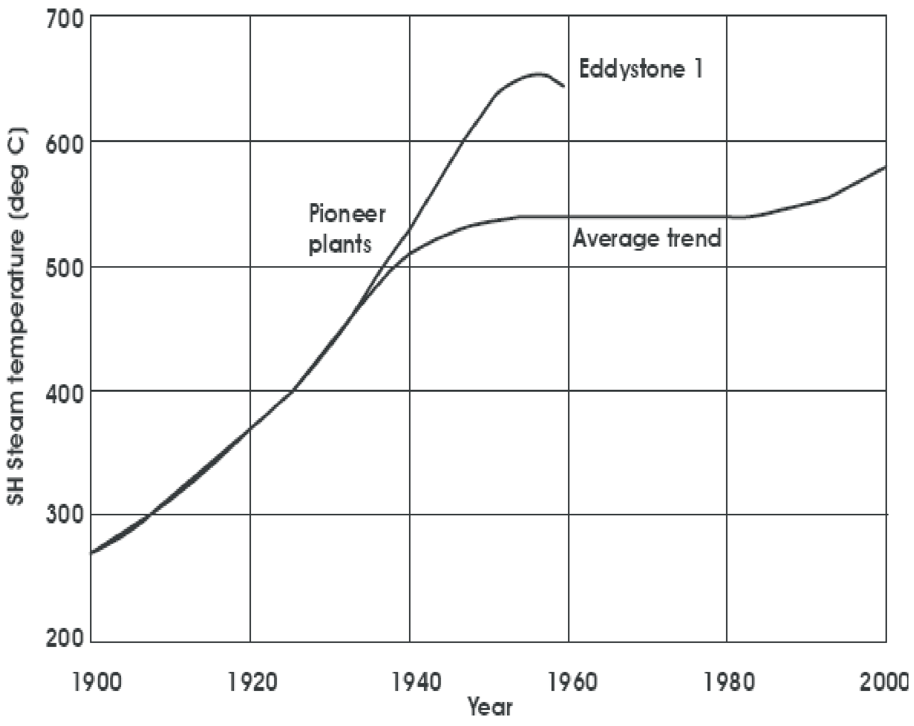
In pf boilers, coal is ground into fine particles and then injected with air through a number of burners into the lower part of a combustion chamber. The particles burn in suspension and release heat, which is transferred to water tubes in the combustion chamber walls. This generates high pressure, high temperature steam which is fed into turbine/generator sets to produce electricity. PF boilers are termed “subcritical” if the steam generated is below the critical pressure of 221.2 bar. Above this pressure, there is no distinct water-steam phase transition, and the boiler is said to be “supercritical”.



COAL FIRED PF BOILER

Historical Development of superheated steam **Pressure** and **Temperature**





Status of PF Technology

The transition to high steam conditions was accomplished in the late fifties and early sixties, with the introduction of numerous supercritical boilers operating at or above 565 °C and 24 MPa steam pressure. The earliest supercritical steam plant was Eddystone 1 (1959), designed to operate under steam conditions of 34.5 MPa and 650/565/565 °C. The plant has operated under de-rated conditions of 32.4 MPa and 605 °C for most of its service life because of mechanical and metallurgical problems. These problems and the low availability of supercritical plants temporarily dampened the interest of the utilities in supercritical (SC) or ultra-supercritical (USC) plants. As a consequence, most producers reverted to plants with sub-critical conditions of about 525 °C and 17 MPa. Economic considerations were also important because of the low energy prices of the period.

Status of PF Technology ….contd.

Today, supercritical technology has completely overcome the earlier problems and offers a more favourable cost of electricity with higher efficiency and lower emissions. The current state-of-the-art pf plants are represented by Avedöre 2 (Denmark), 400 MWe, 305 bar, 582 °C/600 °C and Tachibana-Wan 1 & 2 (Japan), 2x1050 MWe, 250 bar, 600/610 °C, both commissioned in 2001 and Niederaussem K (Germany), 260 bar/580 °C/600 °C, commissioned in late 2002.

IEA report indicates that, of the 22.4 GWe of new coal-fired capacity commissioned in OECD countries 1997-2000, 19.4 GWe (i.e. over 85%) is supercritical. In non-OECD countries, the figures for the same period are reversed only 5%

Boiler design

Two-pass and tower boiler designs are both in widespread use, with two-pass being the market leader. The most popular arrangement of tubing in the combustion zone is a spirally-wound membrane wall using smooth-bore tubing. This inclined tubing arrangement reduces the number of parallel paths compared to a vertical wall rrangement and therefore increases the mass flow of fluid (steam/water mixture) through each tube. This high mass flow improves heat transfer between the tube metal and the fluid inside, so the tube metal is adequately cooled despite the powerful radiant heat flux from the furnace fireball. The minimum load at which the furnace water flow is just sufficient to maintain adequate cooling of the furnace wall tubes (Benson load) for a once-through boiler with spiral wound furnace is between 35 and 40% of maximum cooling rate (MCR).

An alternative design concept is to use vertical tubing with internal fins to improve heat transfer,which allows low part-loads down to 20 to 25%, and reduces investment and operating costs . It also offers the ease of manufacture and installation of the tube walls that is typical of drum-type steam generators.

Boiler Design … contd.

The adoption of new high-strength ferritic steels has recently enabled steam conditions to be raised above 248 bar/566 °C. As superheater tubes must be designed to operate at temperatures ~35 °C above the live steam temperatures, for steam temperatures up to ~580 °C, the metal temperature will be ~615 °C and low-alloy steel tubes such as T22 may possess adequate creep strength. However, not only do the advanced steam parameters for supercritical plant impose higher stresses on the superheater tubes, they also increase the potential rates of both fireside and steam-side corrosion. Medium-chromium (Cr) steels such as X20 can be used at these temperatures or alternatively, for corrosive coals or higher temperatures, more expensive austenitic steels such as T316 and T347 can be used. The current maximum boiler reheat outlet steam temperature is 610 °C.

In summary, current state-of-the-art boiler outlet steam

Fuel Flexibility

The design characteristics of existing steam generators usually allow a wider range of fuels to be fired than was initially intended, though there are a few precautions to consider. This, together with the availability on the market of renewable combustion fuels (biomass) and high energy content residuals (sewage sludge, RDF, etc.) - in some cases at negative or near zero cost - has favoured their coutilisation in boilers in substitution for a small fraction of coal (5 - 15% in co-combustion).

Steam Turbine

Modern steam turbines for **supercritical** and **ultra supercritical** duty are of relatively high capacity, between 300 MWe and 1200 Mwe.

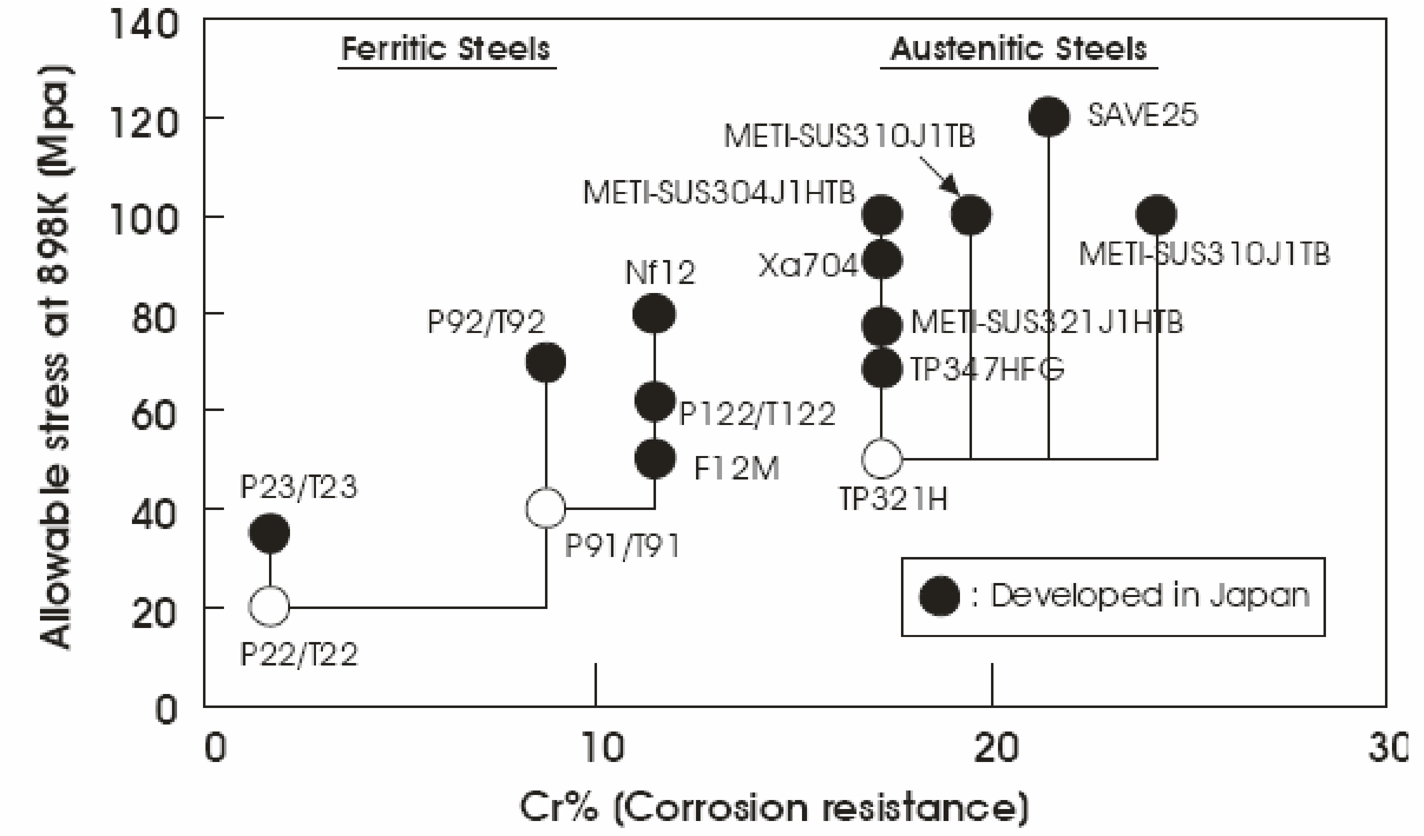
Siemens now claims to have developed a new type of 3DV blading (3D blading with variable stage reaction)

The highest efficiency (gross) of 49% has been claimed by Mitsubishi Heavy Industries (MHI) in their 1050 MWe steam turbine

Alloys have been developed that mitigate creep and creep-fatigue problems.

Currently, it is reasonable to view 593°C as a steam temperature for which ferritic steels for boilers and turbines are well established. It is likely that 620°C will be possible with ferritic steels in the near future, and perhaps even 650°C with

Candidate materials for turbine in Japan



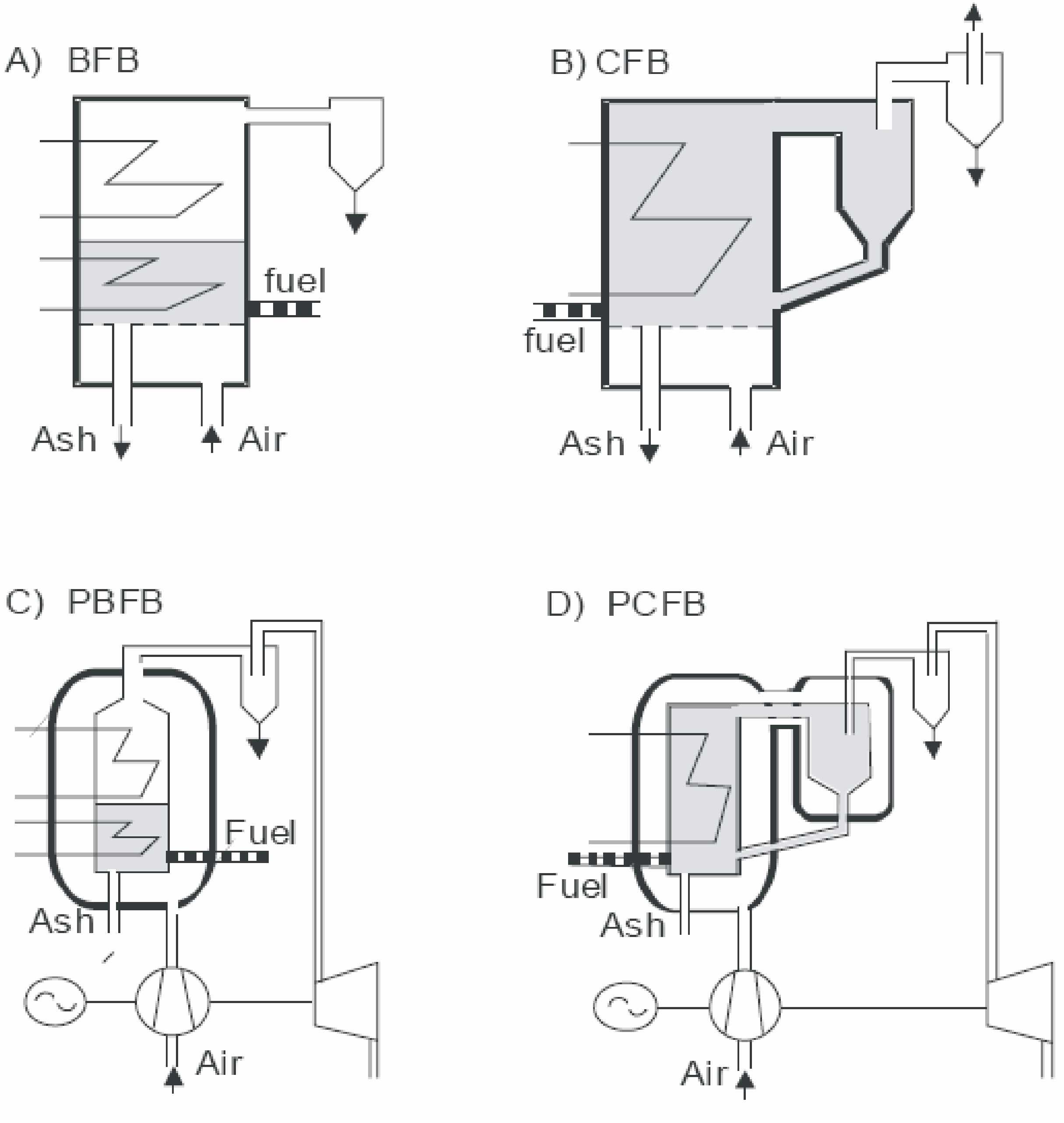
Fluidized Bed Combustion

Fluidised bed combustion (FBC) in its various forms offers a technology that can be designed to burn a variety of fuels, efficiently and in an environmentally acceptable manner, for a variety of applications.

Bubbling Fluidised Bed Combustors (BFBCs) operate in a regime in which the speed of the ascending air is sufficiently high to maintain the bed in a state of fluidisation, with a high degree of mixing, but is low enough that solid particles lifted out of the bed will mostly fall back into it again. This results in a dense bed with a uniform temperature, and with rather small over-temperatures for the burning char.

In Circulating Fluidised Bed Combustors (CFBCs), air is blown through the bed and entrains a percentage of the solid particles from the bed. If the fluidizing air velocity is increased above a defined level, the entrained particles are carried upwards away from the bed surface and the distinct surface layer that characterized the bubbling bed disappears. The burning particles are then recovered from the air flow and fed back into the lower part of the combustion chamber

Different Variants of Fluidized Bed Combustors



Advantage of Fluidized Bed Combustion Power Plants

- limited nitrogen oxide emissions thanks to combustion temperatures typically around 850°C.

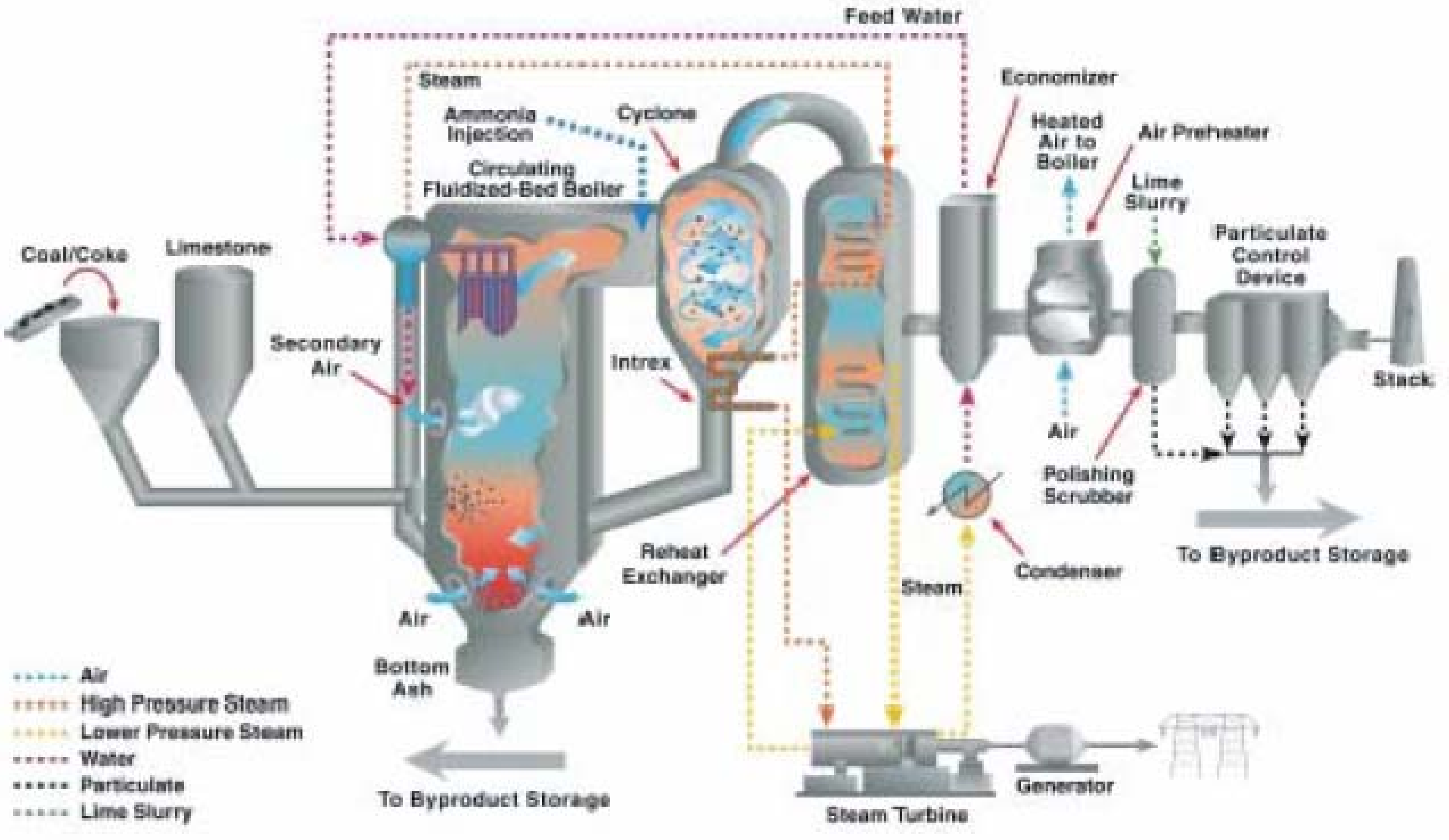
- high heat transfer to immersed boiler tubing, where steam is generated for expansion through a steam turbine, allowing for a compact boiler arrangement;

- high flexibility for use with different ranks of coal, including those with high sulphur and/or ash content;

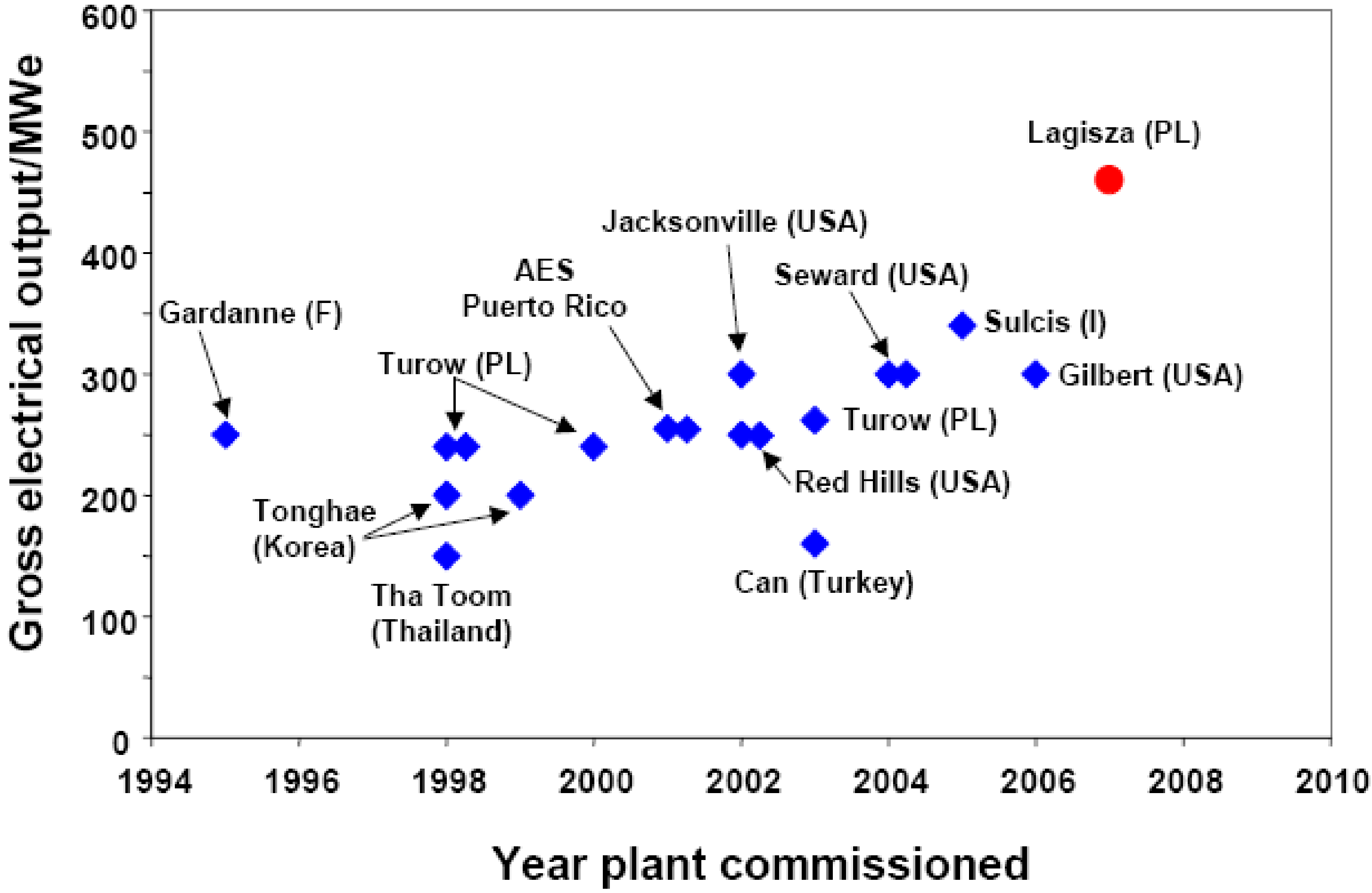
- possibility to burn low grade fuels, such as biomass, RDF and other waste substances and to perform “co-combustion” of different types of fuels;

- use of crushed fuel with relatively large particles, leading to reduced milling costs.

265 Mwe CFBC Power Plant



Larger CFBC Installations World-wide

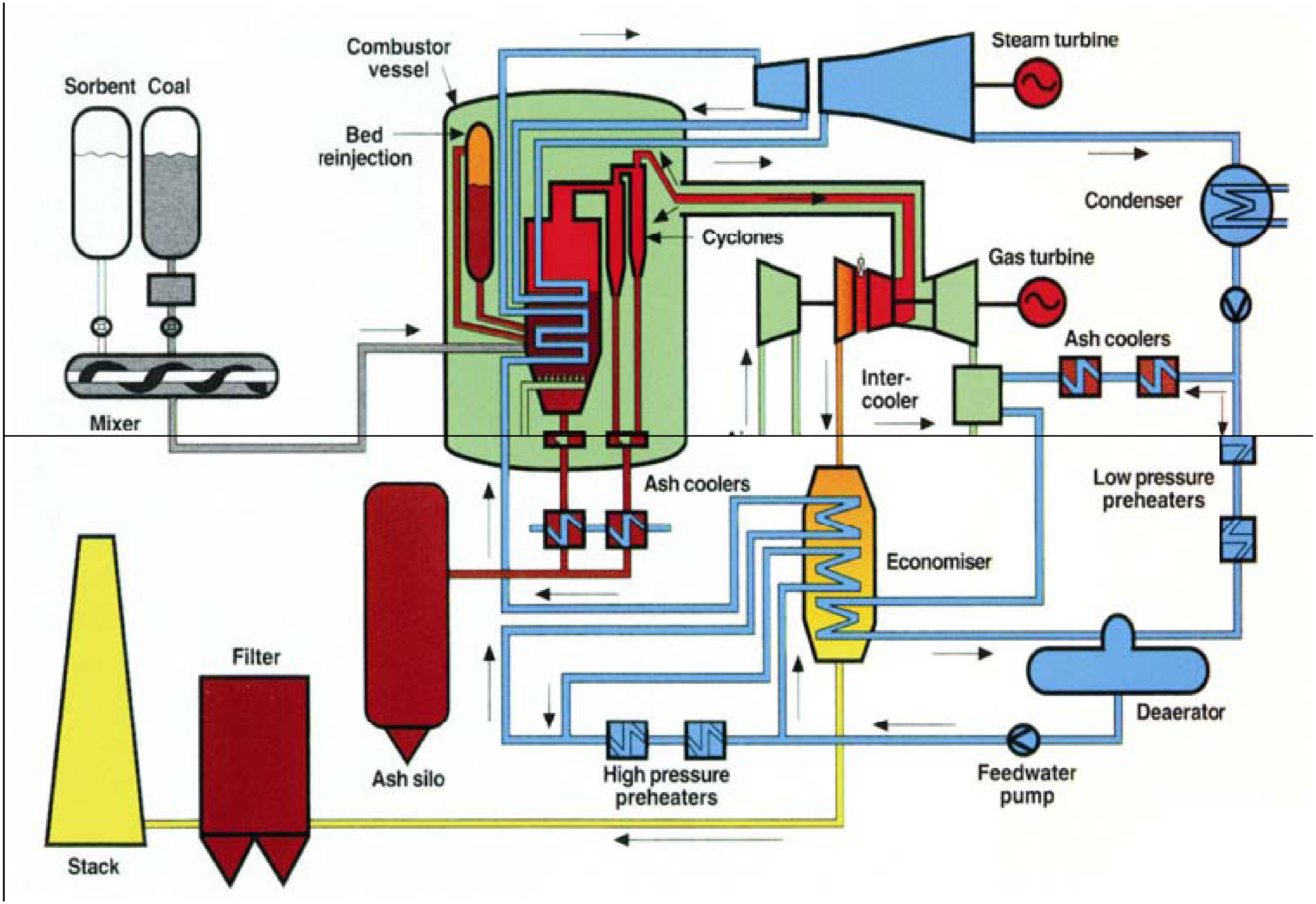


PBFBC & PCFBC

The pressurized fluidized bed concept for power generation from coal involves the combustion of the solid fuel in a fluidized bed at pressure, generation of steam in boiler tubes immersed in the fluidized bed and expanded in a steam turbine driving a generator, with expansion of the combustion gases in a gas turbine driving another generator. This results in a combined cycle arrangement, giving higher cycle efficiency. **Merits** in comparison with atmospheric are

- greater plant compactness for the same installed capacity;
- higher generation efficiency due to the combined cycle
- heat transfer coefficients over bed tubes are moderately higher;
- better utilization of the sulphur sorbent;
- higher combustion efficiency;

Pressurized PFBC



Why CFBC?

CFBC systems offer an alternative to PF plants, with the advantage of being able **to use low grade, variable quality coal, plus biomass and wastes, and still achieve high environmental performance at lower cost**. CFB boilers have been successfully demonstrated at the < 300 MWe scale, and there have been significant efforts by various manufacturers to develop the technology further, to achieve a breakthrough in utility solid fuel power generation by high efficiency CFB technology with supercritical (SC) steam parameters, as evidenced by the first commercial 460 MWe system with advanced steam conditions now being established in Europe. Such plants with supercritical steam parameters can now achieve overall net efficiencies in the 43-45% range depending on fuel and condenser conditions.

Inclusion of a 20% substitution of coal by renewables (biomass), which can reduce CO2 emissions by a further 20-25%. As a result, the advantages and new advanced characteristics of CFB technology could be fully utilised, enhanced further and transferred wider to the power generation industry. The technology will also benefit from any

INTEGRATED GASIFICATION COMBINED CYCLES (IGCC)

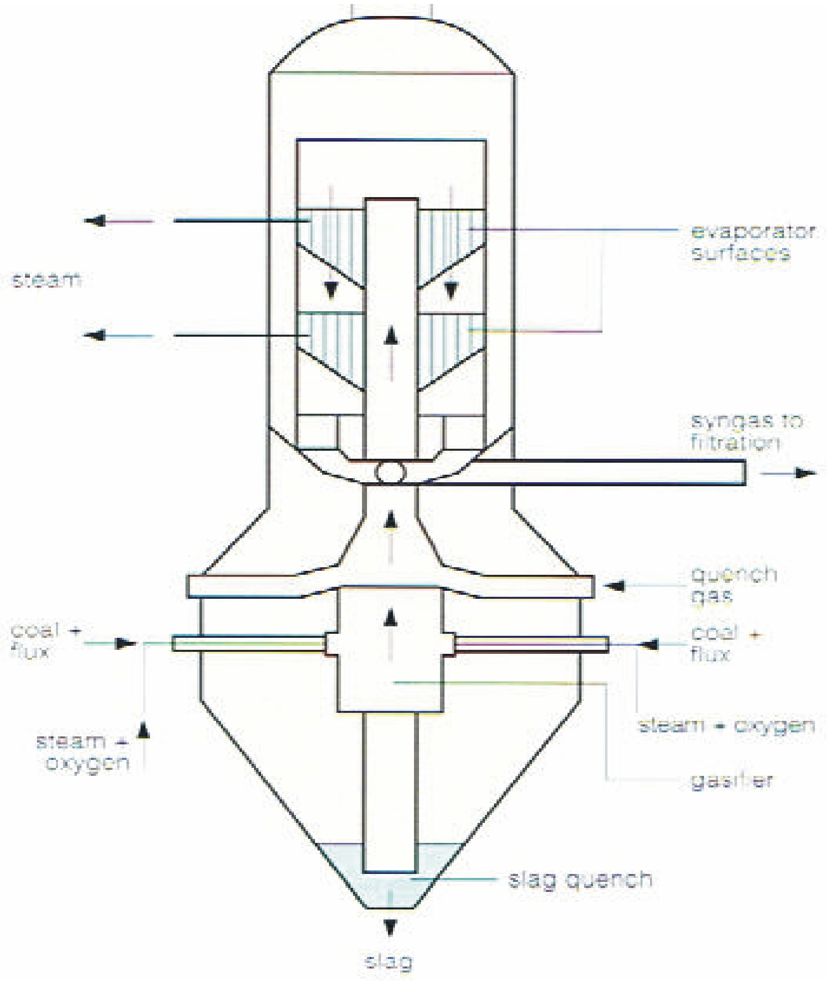
IGCC is based on Gasification technology.It is generally recognized that IGCC represents a primary option for efficient, environmentally compatible electricity production using coal and biomass resources. It is capable of providing the cleanest coal based power production process. However, the major problems for coal fuelled IGCC are the capital cost, and the present uncertainty concerning its operational track record.

Gasifiers:

There are three technology variants, classified by gasifier configurations according to their flow geometry:

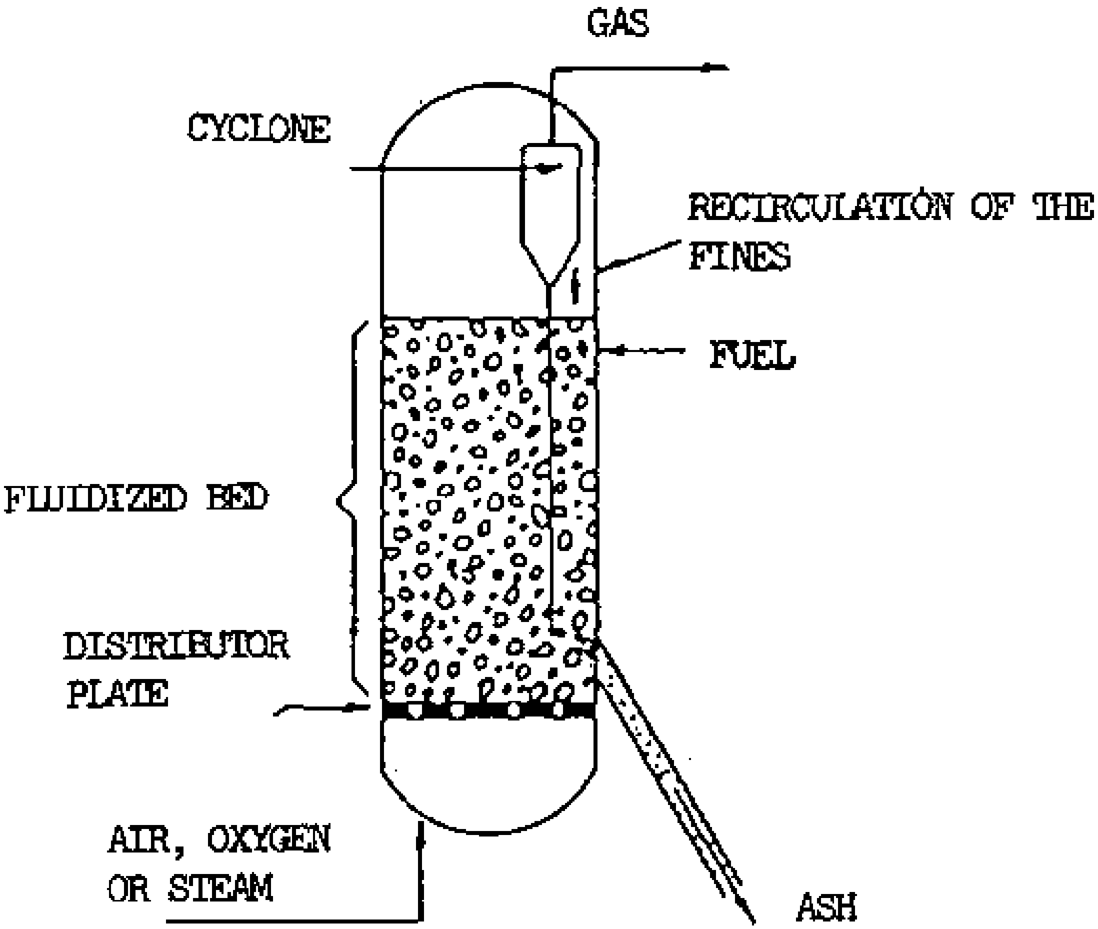
Entrained flow gasifier

Entrained flow gasifiers, in which pulverised coal particles and gases flow concurrently at high speed. The process accepts both solid and liquid fuels and operate at high temperature (above ash slagging temperatures) to ensure high carbon conversion and a syngas free of tars and phenols. However such high temperatures have an impact on burners and refractory life. Coals with a low ash content are preferred



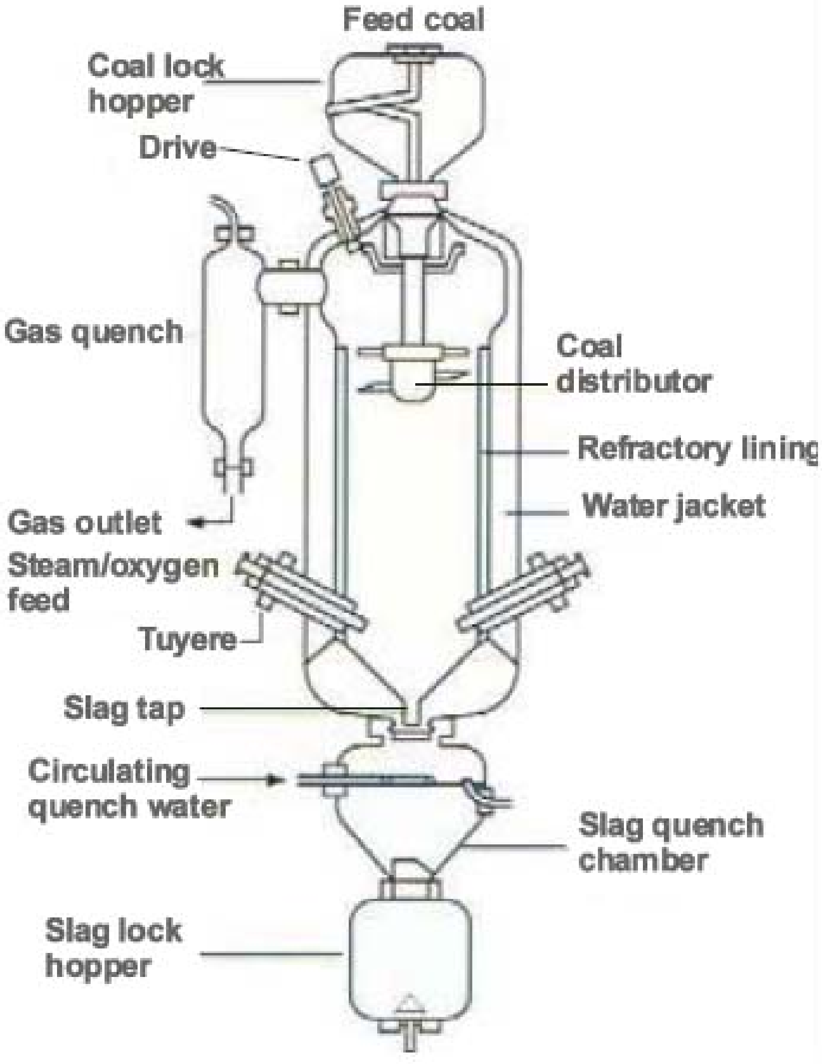
FLUIDIZED BED GASIFIER

Fluidised bed gasifiers, in which coal particles are suspended in the gas flow; coal feed particles are mixed with the particles undergoing gasification,

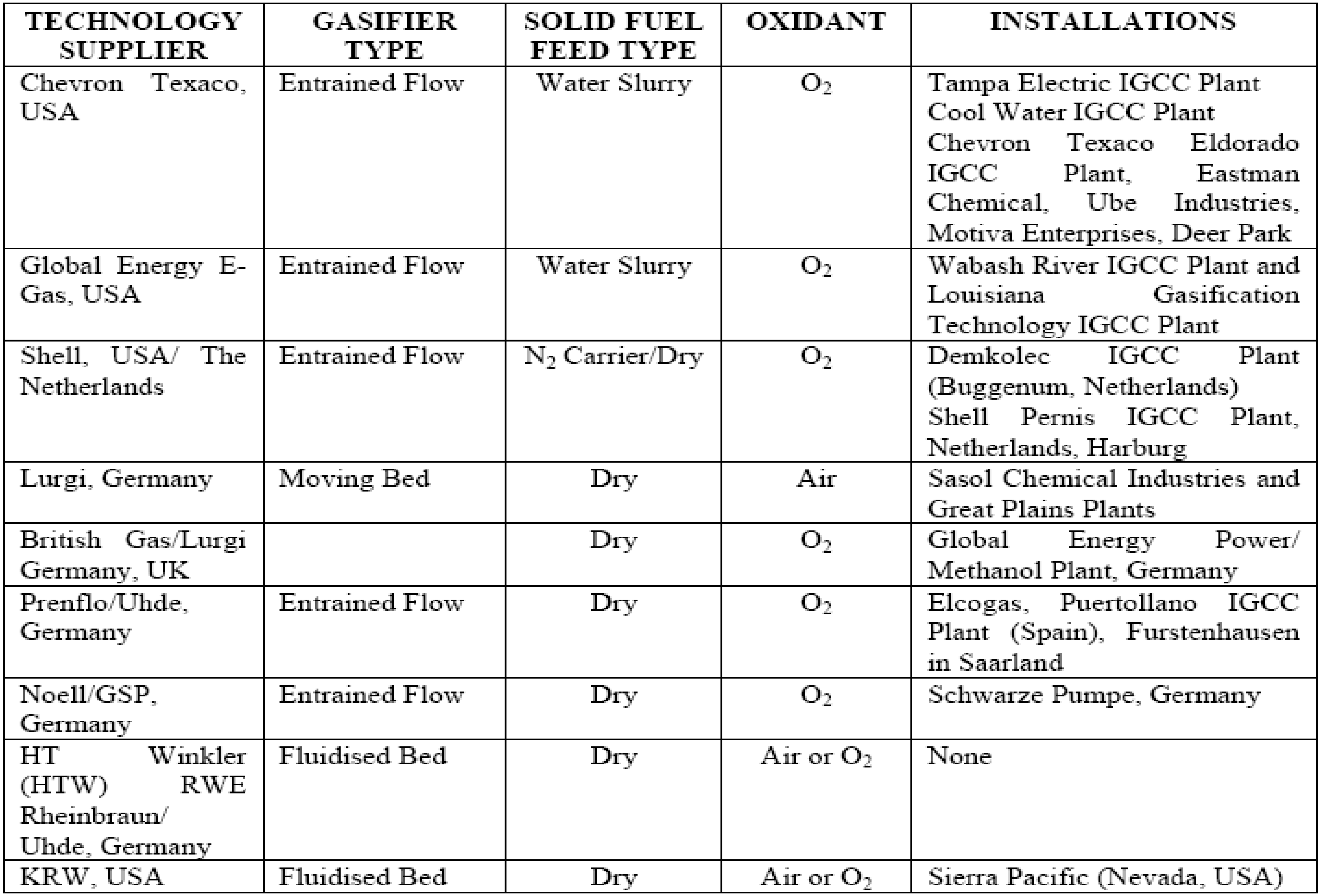


Moving Bed Gasifier

Moving bed (also called fixed bed) gasifiers, in which gases flow relatively slowly upward through the bed of coal feed. Both concurrent and countercurrent technologies are available but the former is more common.

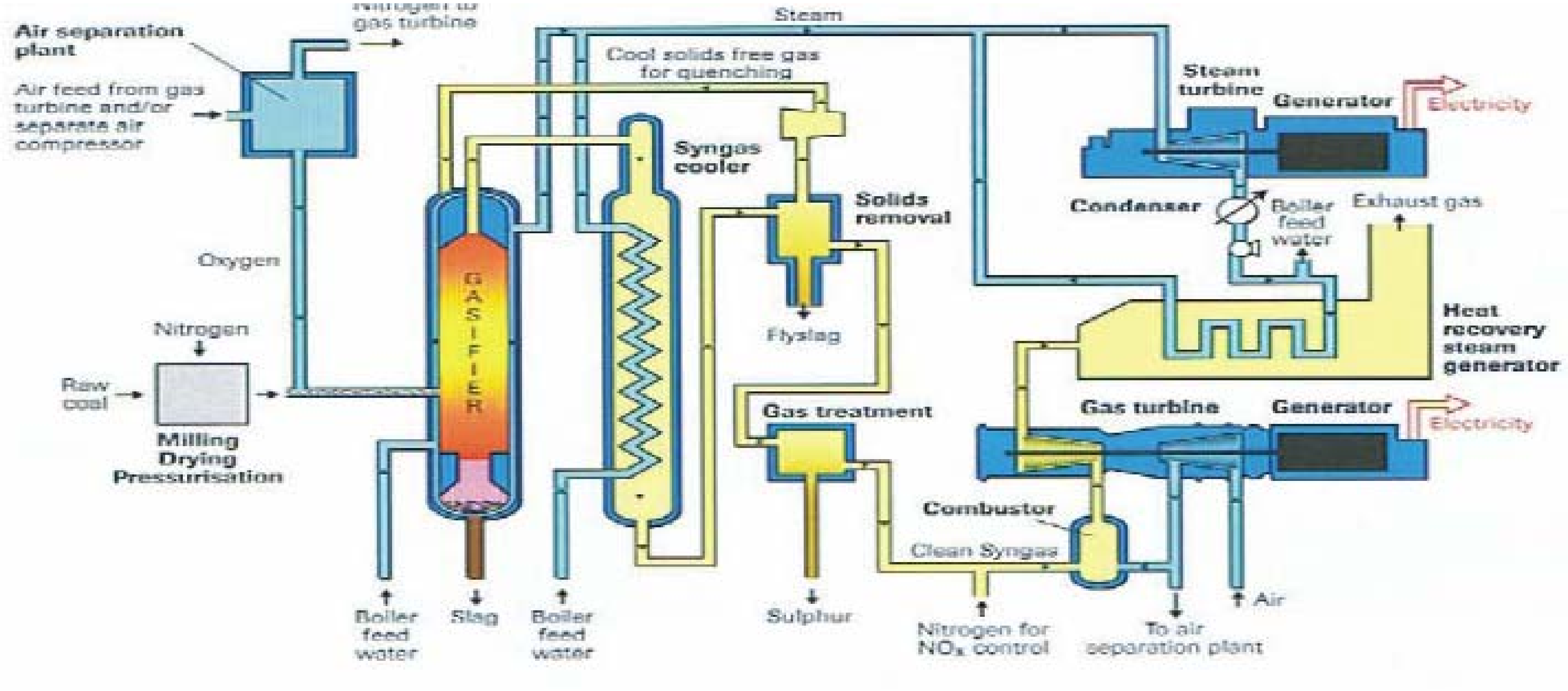


Technology suppliers for gasification projects worldwide

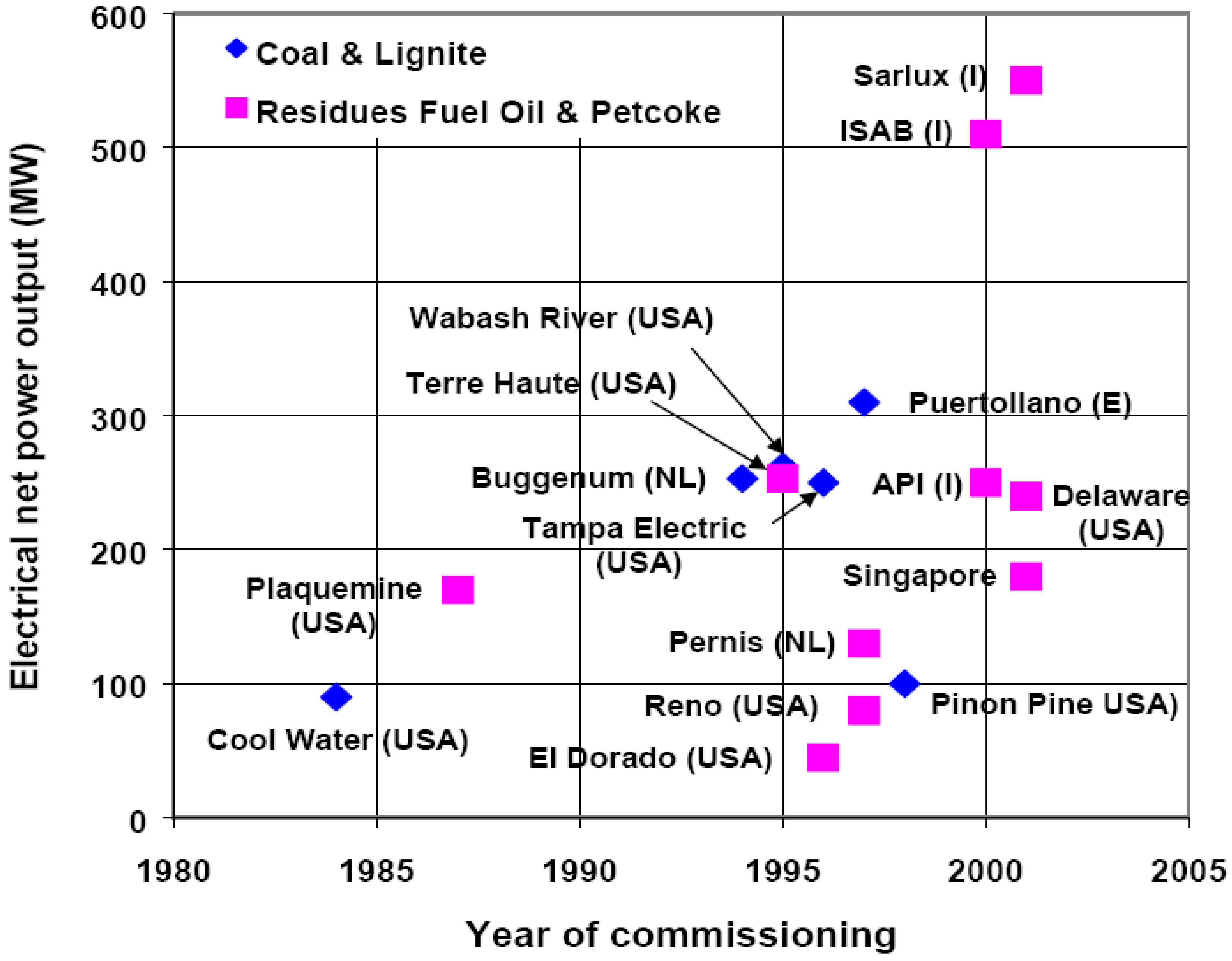


TECHNOLOGY SUPPLIER	GASIFIER TYPE	SOLID FUEL FEED TYPE	OXIDANT	INSTALLATIONS
Chevron Texaco, USA	Entrained Flow	Water Slurry	O_2	Tampa Electric IGCC Plant Cool Water IGCC Plant Chevron Texaco Eldorado IGCC Plant, Eastman Chemical, Ube Industries, Motiva Enterprises, Deer Park
Global Energy E-Gas, USA	Entrained Flow	Water Slurry	O_2	Wabash River IGCC Plant and Louisiana Gasification Technology IGCC Plant
Shell, USA/ The Netherlands	Entrained Flow	N_2 Carrier/Dry	O_2	Demkolec IGCC Plant (Buggenum, Netherlands) Shell Pernis IGCC Plant, Netherlands, Harburg
Lurgi, Germany	Moving Bed	Dry	Air	Sasol Chemical Industries and Great Plains Plants
British Gas/Lurgi Germany, UK		Dry	O_2	Global Energy Power/ Methanol Plant, Germany
Prenflo/Uhde, Germany	Entrained Flow	Dry	O_2	Elcogas, Puertollano IGCC Plant (Spain), Furstenhausen in Saarland
Noell/GSP, Germany	Entrained Flow	Dry	O_2	Schwarze Pumpe, Germany
HT Winkler (HTW) RWE Rheinbraun/ Uhde, Germany	Fluidised Bed	Dry	Air or O_2	None
KRW, USA	Fluidised Bed	Dry	Air or O_2	Sierra Pacific (Nevada, USA)

Schematic IGCC Plant



Deployment of IGCC Units



Power Plant Performance Factor

The performance of a power plant can be expressed through some common performance factors as

- heat rate (energy efficiency)
- thermal efficiency
- capacity factor
- load factor
- economic efficiency
- operational efficiency

Heat Rate (Energy Efficiency)

Overall thermal performance or energy efficiency for a power plant for a period can be defined as

$\varphi_{hr} = H / E$

where

φ_{hr} = *heat rate (Btu/kW, kJ/kW)*
H = *heat supplied to the power plant for a period (Btu, kJ)*
E = *energy output from the power plant in the period (kWh)*

Thermal Efficiency

Thermal efficiency of a power plant can be expressed as

$\mu_{te} = 100\ 3412.75 / \varphi$

where

μ_{te} = *thermal efficiency (%)*

Capacity Factor

The capacity factor for a power plant is the ratio between average load and rated load for a period of time and can be expressed as

$\mu_{cf} = 100\ P_{al} / P_{rl}$

where

μ_{cf} = *capacity factor (%)*
P_{al} = *average load for the power plant for a period (kW)*
P_{rl} = *rated capacity for the power plant (kW)*

Load Factor

Load factor for a power plant is the ratio between average load and peak load and can be expressed as

$\mu_{lf} = 100\ P_{al} / P_{pl}$

where

μ_{lf} = *load factor (%)*

P_{pl} = *peak load for the power plant in the period (kW)*

Economic Efficiency

Economic efficiency is the ratio between production costs, including fuel, labor, materials and services, and energy output from the power plant for a period of time. Economic efficiency can be expressed as

$\varphi_{ee} = C / E$

where

φ_{ee} = *economic efficiency (cents/kW, euro/kW, ...)*

C = *production costs for a period (cents, euro, ..)*

E = *energy output from the power plant in the period (kWh)*

Operational Efficiency

Operational efficiency is the ratio of the total electricity produced by the plant during a period of time compared to the total potential electricity that could have been produced if the plant operated at 100 percent in the period.

Operational efficiency can be expressed as

$\mu_{oe} = 100\ E / E_{100\%}$

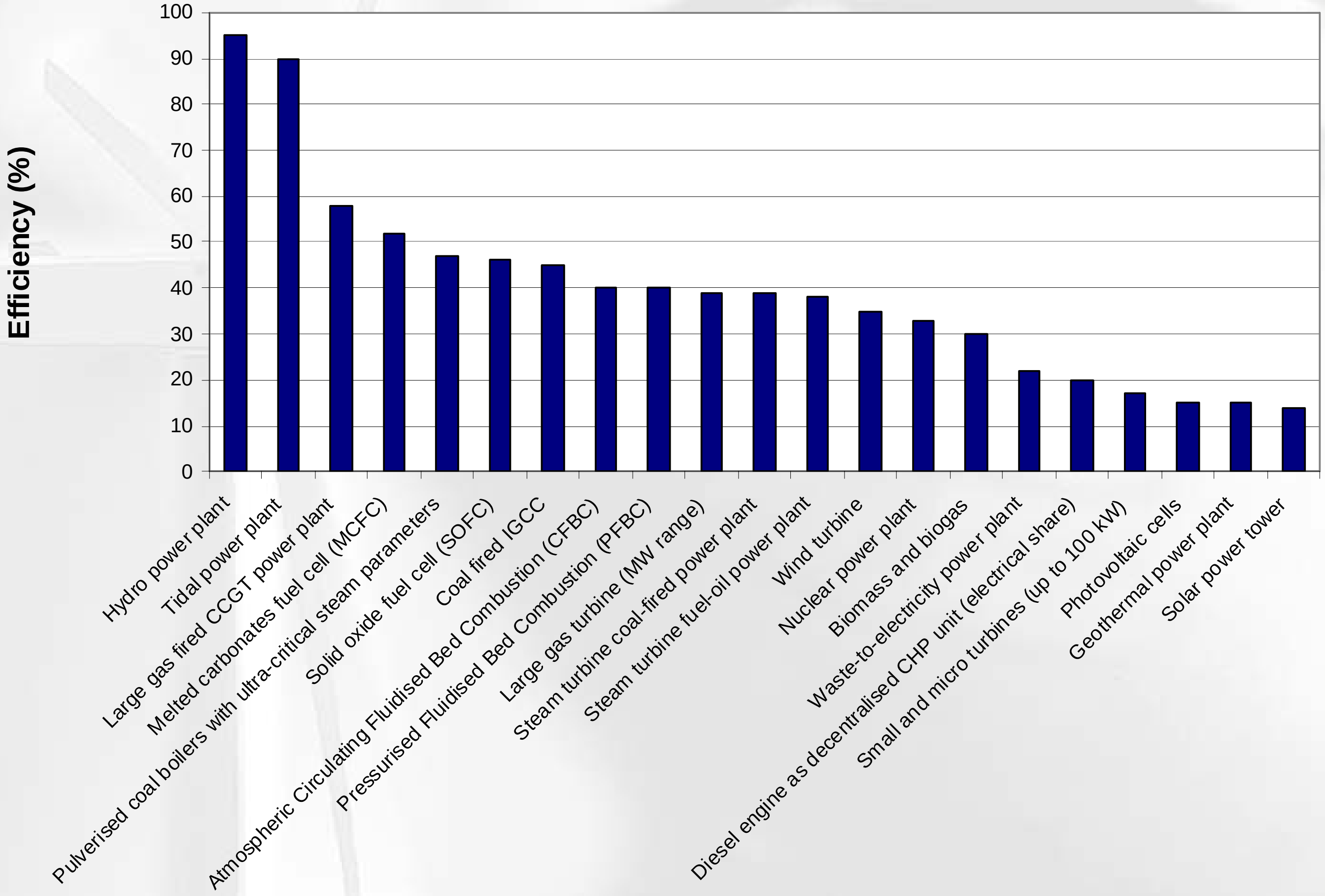
where

μ_{eo} = *operational efficiency (%)*

E = *energy output from the power plant in the period (kWh)*

$E_{100\%}$ = *potential energy output from the power plant operated at 100% in the period (kWh)*

KEMA Efficiency in Electricity Generation



KEMA POWER GENERATION & SUSTAINABLES