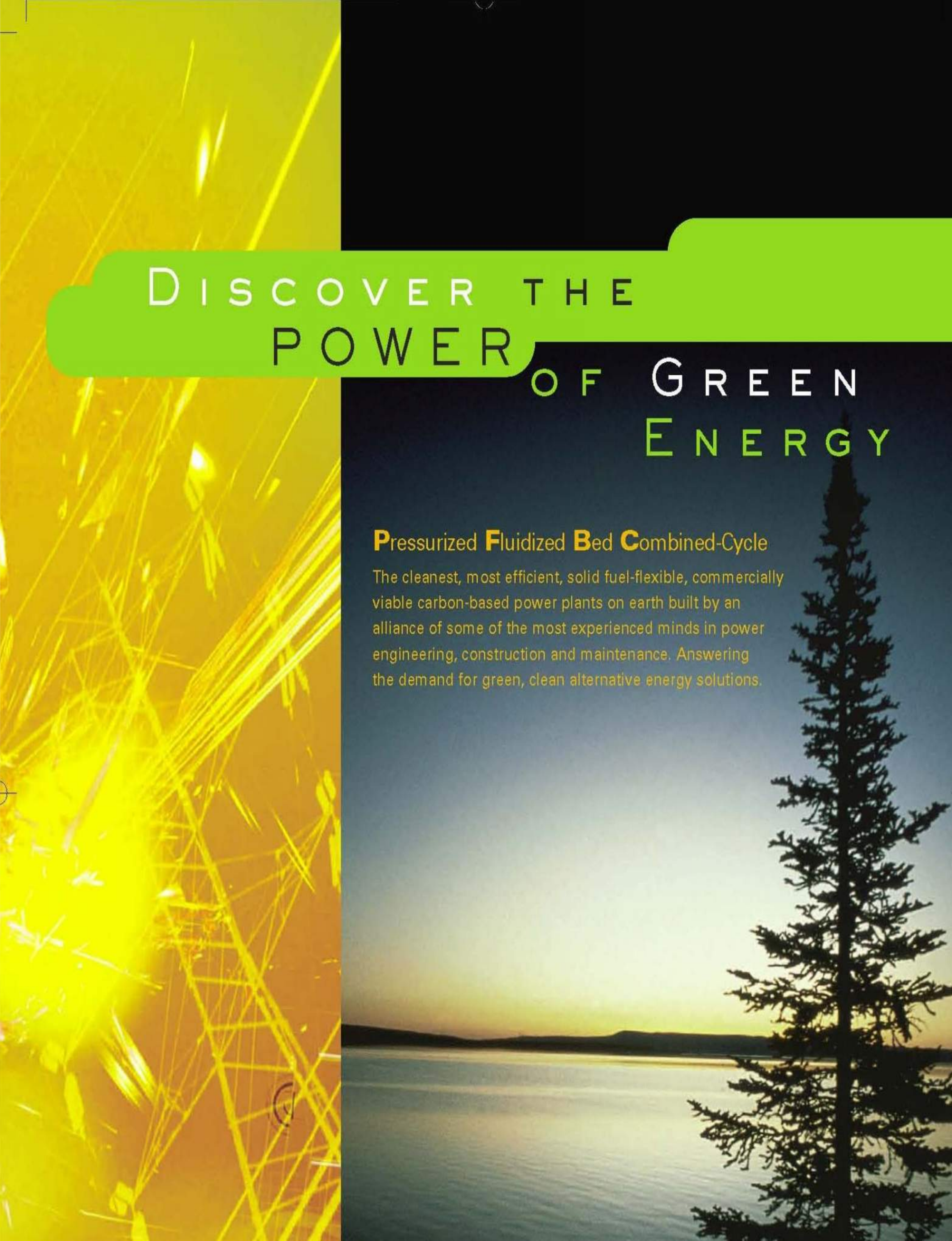
PFBC

Competitive Clean Coal Power Utilizing Pressurized Fluidized Bed Combined-Cycle Technology

PFBC clean-coal technology. A new generation of combined-cycle plants to meet the growing world need for clean and cost effective power.



PFBC: Clean Coal Technology

Sustained economic growth is a prerequisite for a stable society. Key to this is the generation and management of energy. Today, we realize that power must be generated with as close to zero environmental impact as possible. Three quarters of the world's population live in developing countries and aspire to the higher living standards of the industrial world. These aspirations depend on the availability of electricity. The only way to meet this increased demand is with more efficient technologies which make better use of natural resources and are ecologically sustainable.

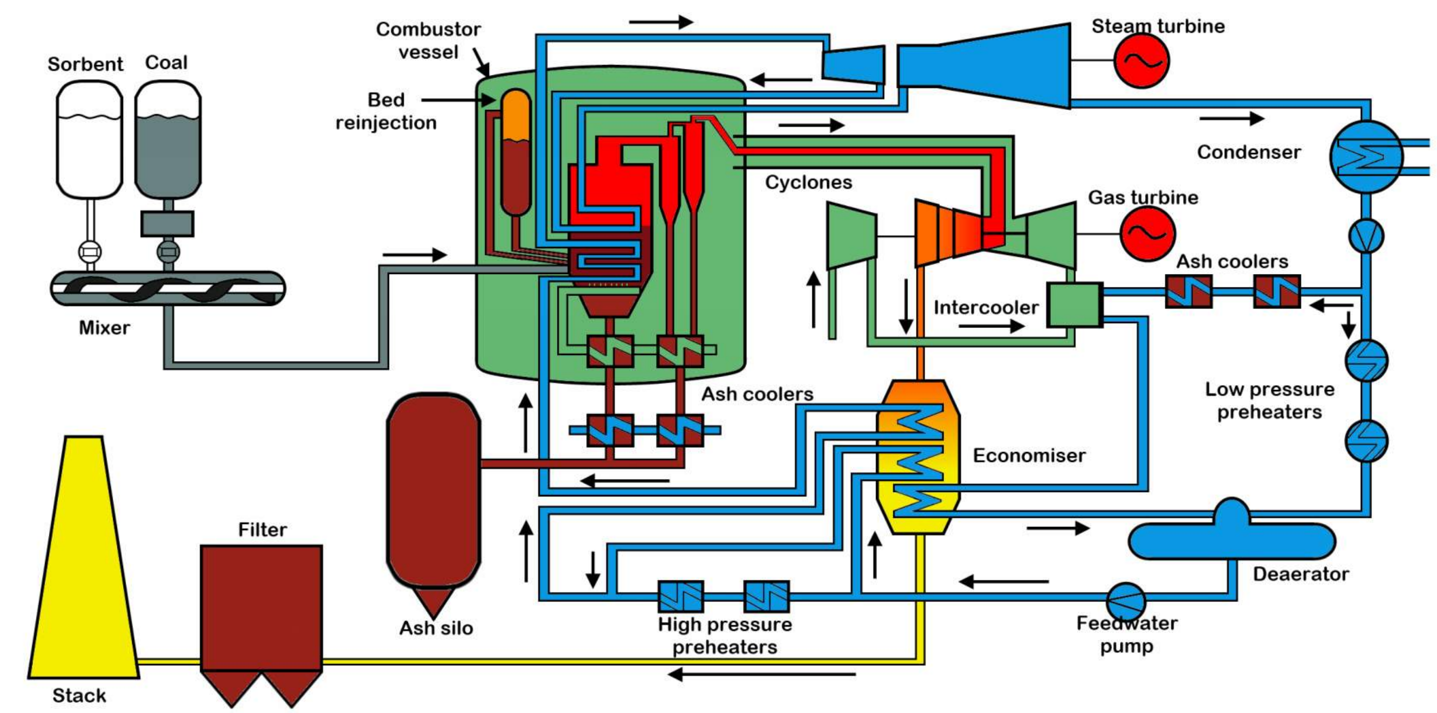
Foremost among these technologies is PFBC. PFBC is a proven technology for converting coal cleanly and efficiently into reliable power through a pressurized, fluidized bed, combined-cycle process. This process results in higher thermal efficiency than that achieved in conventional steam plants.

Coal is the most universal and readily available fuel known to man. Currently, it is used for almost 40% of the world's power generation, and its abundance ensures that it will be the major fossil fuel source for this next century. Pressurized fluidized bed combined-cycle (PFBC) technology has the potential of utilizing all coals, even the so-called "difficult" coals such as those with high-ash, high moisture, high-sulfur, low heating value or low reactivity – in an environmentally acceptable manner. It uses a combined-cycle for power generation; this provides the step-change in efficiency when compared to conventional coal combustion techniques.

Hence the significance of PFBC: Pressurized Fluidized Bed Combined-cycle – the result of 30 years intensive research and development and now proven in commercial operation to be the world's most advanced coal-fired generation system. It is clean, its emissions are low and its waste product is harmless.

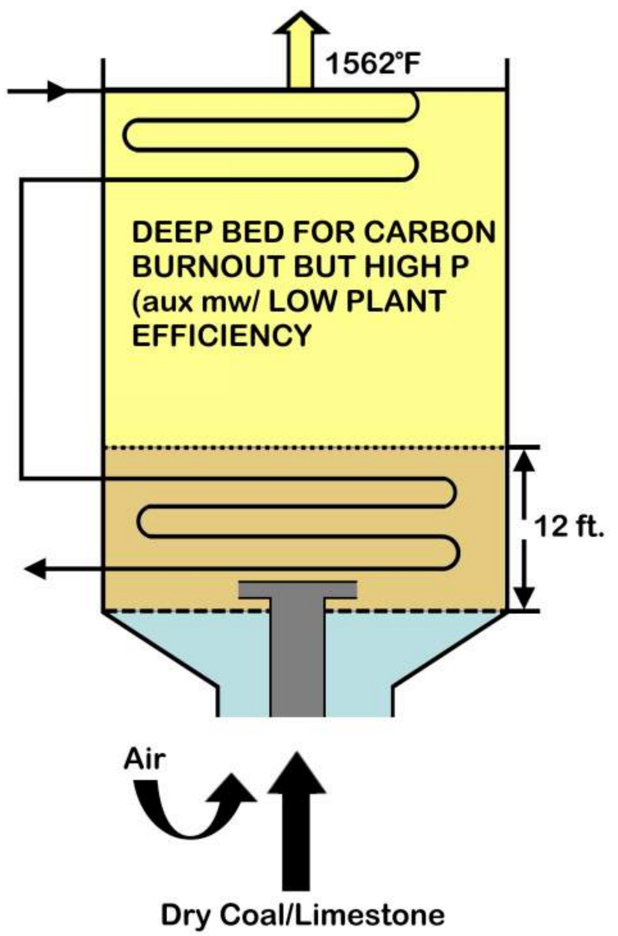
It is already highly efficient, with future thermal efficiencies forecast at over 50%. The combined-cycle process means lower operation costs.

The PFBC boiler's compact and modular design, only 1/5 of an atmospheric boiler's size, makes it equally suitable for re-powering as well as for new capacity applications.



Evolution of Fluidized Bed Combustion

FIRST GENERATION

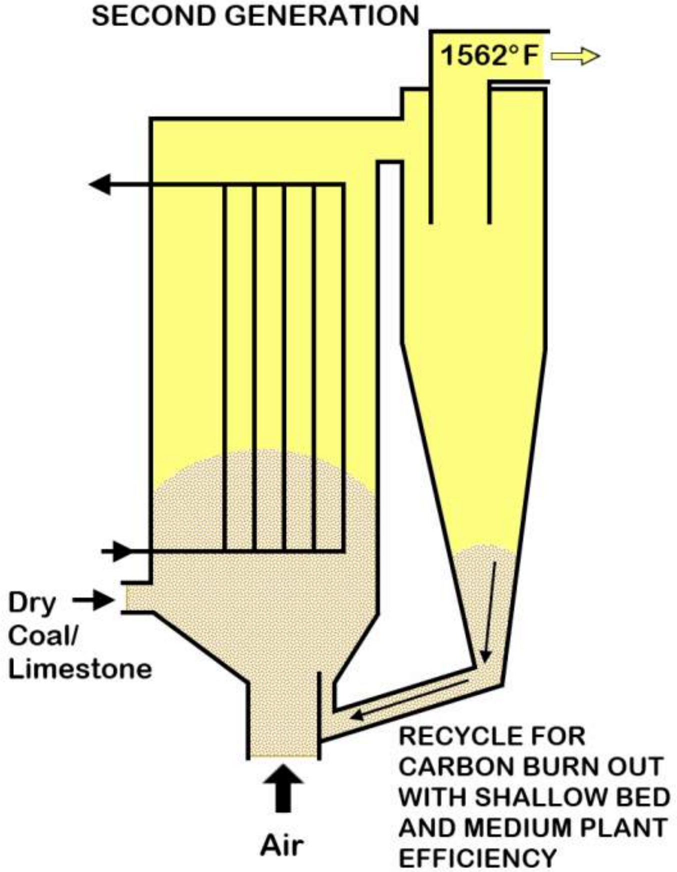


First Generation: Atmospheric Deep Bubbling Beds

- Burning at 1562° F eliminates formation of thermal NO_x and optimizes calcium to sulfur capture ratio
- Deep beds required for complete burnout (low CO)
- High pressure drop across the bed increases fan power, and lowers plant efficiency below 30%

Bed Velocity
V=6.5 to 9.8 ft/s
Erosion Potential Index
10 x Base

SECOND GENERATION

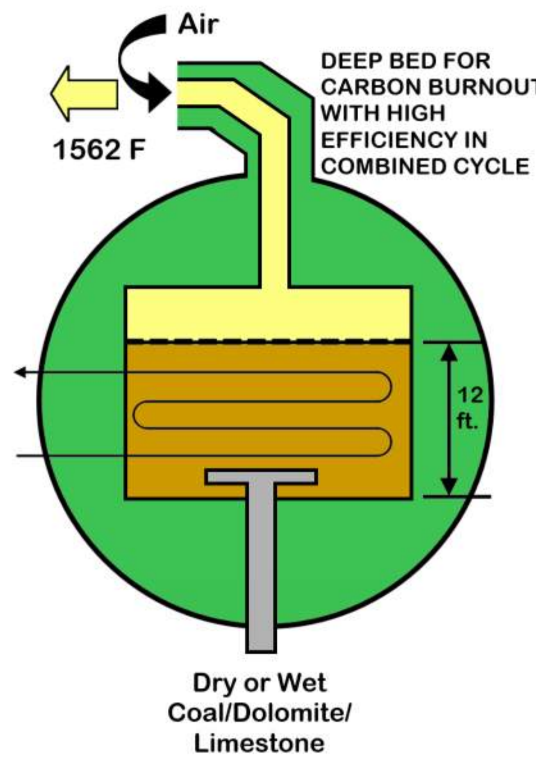


Second Generation: Atmospheric Circulating Shallow Beds

- Circulation accomplishes improved burnout
- Bed pressure drop lowered, but net plant efficiency is still lower than PC boiler plants

Bed Velocity
V=20 to 23 ft/s
Erosion Potential Index
100 x Base

THIRD GENERATION



Third Generation: PFBC - Pressurized Deep Bubbling Bed in Combined Cycle

- Allows deep beds for complete burnout and increases cycle efficiency to over 40%
- Integration of combined cycle with waste heat recovery increases plant efficiency (40.9% to 42.3%)
- Combustion at high pressure (176.4 psia to 235.2 psia):
  - Slows dissociation of nitrogen and oxygen, allowing fuel bound N to return to NO_2
  - Lower velocities allow In-Bed Boiler Tubes for:
    - Lower surface area (20% of PC Boiler at same rating) for reduced maintenance.
    - More uniform bed temperature distribution (Fewer hot pockets)
  - Reduces size of boiler island components
  - Changes chemistry of sorbent reaction, preventing formation of free lime
  - (CaO) in ash to $CaSO_4$

Bed Velocity
V= 3.3 ft/s
Erosion Potential Index
Base

There are many good reasons for using the Fluidized Bed technology for coal combustion in power generation applications:

- Good Fuel Flexibility
- Good Combustion Efficiency
- Low Emission Levels

When moving from atmospheric to pressurized conditions, additional benefits will follow:

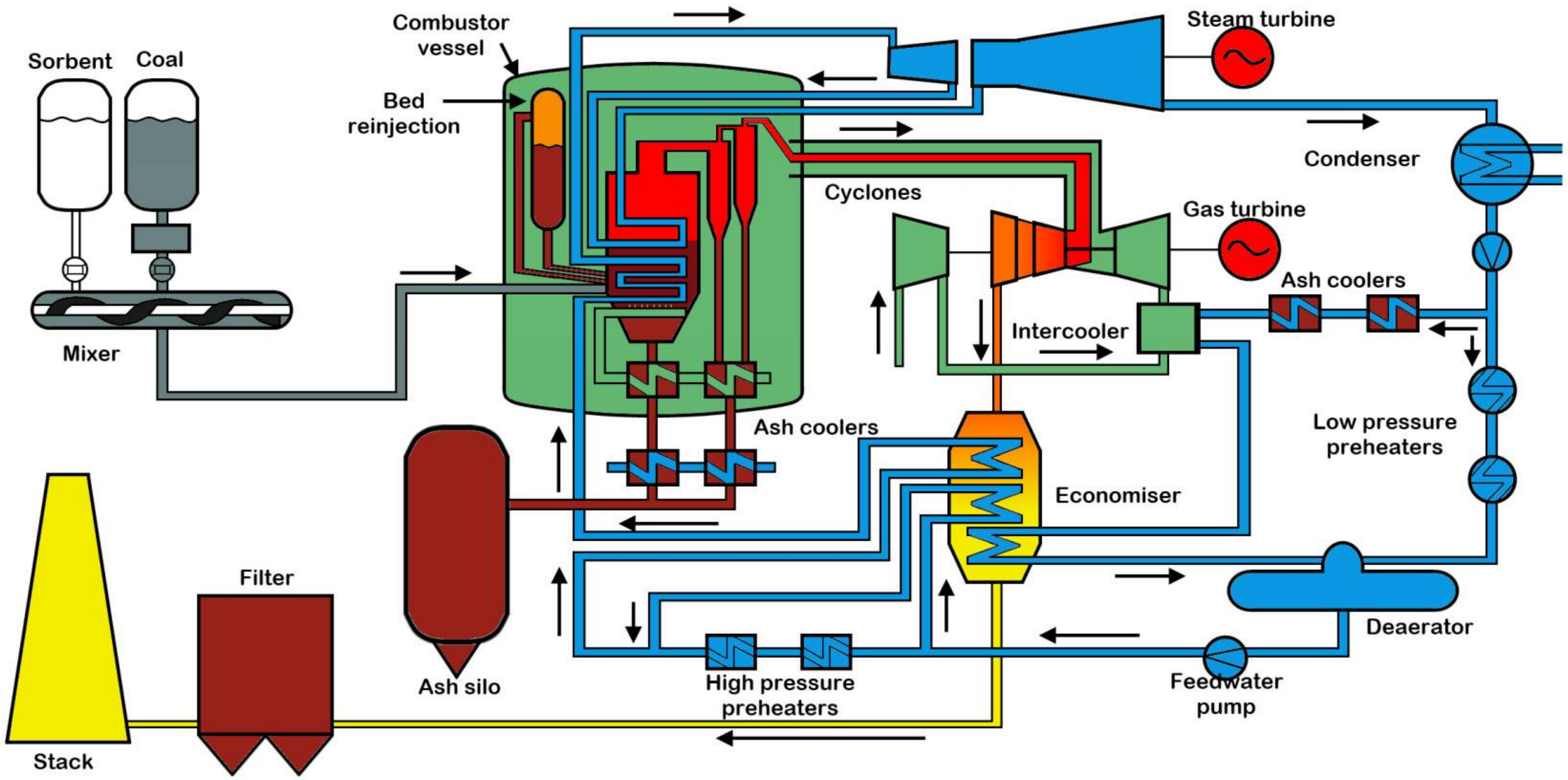
- Very good total plant efficiency
- Compact design
- Utilizes lower Btu value fuels
- Utilizes wet fuels
- Even higher combustion efficiency
- Even lower emission levels
- Produces useful ash products

PFBC: The System and Its Components

PFBC is the world's most advanced clean-coal system, yet much of it will be familiar. It is based on known, proven components: fluidized bed, gas turbine and steam turbine. It is a comparatively simple one-step process for converting coal directly into power, with a number of advantages over conventional coal-fired plants.

The pressurised fluidized bed offers a high combustion efficiency, irrespective of fuel quality. The combined cycle process further increases efficiency. Together these add up to fuel cost reductions of 10-15% (a considerable saving - fuel accounts for over half of the cost of generating electricity).

The fluidized bed inherently eliminates a high percentage of potential pollutants, making costly, energy-absorbing emission control "add-ons" unnecessary.



Fuel and sorbent feed
The coal, crushed to the required size of less than 1/4 inch, together with the sorbent, usually limestone or dolomite, is mixed with water and fed as a paste into the fluidized bed. Low grade coals are fed pneumatically.

Pressurized fluidized bed
As the combustion air is forced through the inert bed it behaves like a boiling liquid, hence the term "fluidized". The combustion takes place at 174-232 PSI pressure with the combustion air delivered by the gas turbine compressor. Burning the fuel under pressure allows a deep fluid bed that enhances the burning process, resulting in a very high combustion efficiency.

Steam Generator
Steam is generated in the tube bundles immersed in the deep fluidized bed. The heat transfer is 4 to 5 times more effective than in a conventional boiler. With heat emanating from the bed at 1562°F, any quality of main steam or reheat steam can be produced.

Cyclones
Before the high pressure flue gas leaves the pressure vessel, fine particulates or "fly-ash" are removed. Two stages of cyclones in series remove 98% of dust particles, sufficient to protect the gas turbine, since the remaining 2% are smaller than 10 microns and less than 500 ppm.

Gas Turbine
The coaxial pipe which supplies air from the compressors also delivers the cleaned flue gas to a specially developed twin-shaft gas turbine. The gas expands in the turbine, driving the compressors and the generator which provides about 20% of the electrical output.

Steam Turbine
The steam turbine produces about 80% of the electrical output. It receives the high pressure superheated steam, and if desired, reheated steam from the in-bed tubes. Steam of any quality can be raised for expansion in the conventional turbine.

Economizer
The economizer takes heat from the still hot gas turbine exhaust gases, (cooling them to appropriate stack temperatures) and pre-heats the feed water before it enters the tube bundles.

Filter
After the exhaust gases from the gas turbine have preheated the feed water in the economizer, they are driven through a back-end filter to meet environmental dust requirements, before passing into the stack.

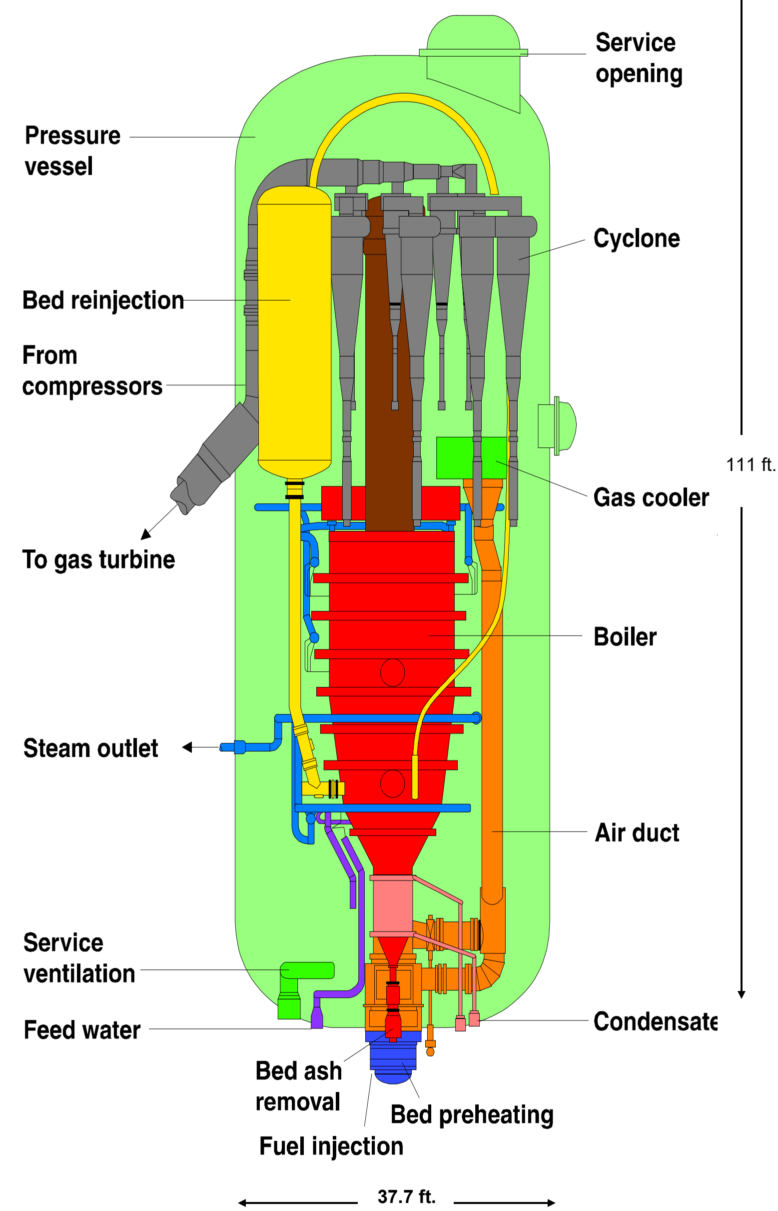
Combustor

The P200 combustor is a pressurized combustion/steam generating unit enclosed in a pressure vessel of approximately 37.73 ft. diameter and 111.55 ft. height. Operating pressure at full load is about 174 psi. The incoming air from the gas turbine compressors has a temperature of about 527°F. Combustion takes place in the bed vessel at about 1562°F. Bed material is ash and sorbent. Bed height is about 14.7 ft. at full load and the fluidizing velocity is less than 3.3 ft./s. Bed height is kept constant at full load by releasing bed ash from the bottom of the bed. Ash is cooled by condensate.

For start-up of the combustor, gas or oil-fired heaters are provided under the bed bottom for heating up the bed mass. When the bed temperature exceeds 1202°F coal injection is started and supplemental firing is successively shut off.

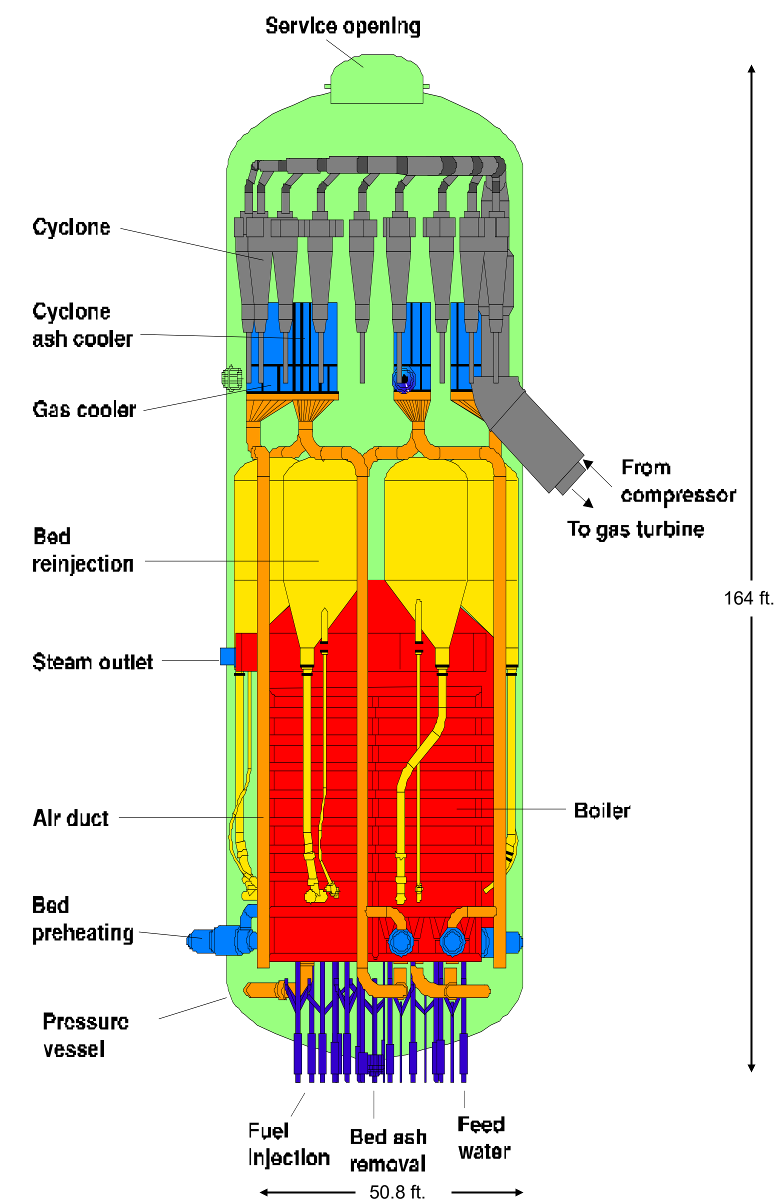
Inside the combustor pressure vessel, there are no moving elements except an air duct draught valve used at start up. Governing valves and control equipment are placed outside and available for inspection and service during operation.

P200 PFBC Combustor



Conditions: 0.29 psi condenser pressure
Steam data 2610.68psi / 1049°F / 1049°F
Ambient temperature 59°F
Steam pressure P200 2030.53 psi

P800 PFBC Combustor



Designation		P200	P800
P-machine		GT35P	GT140P
Nominal thermal input		~200	~800
Net Power Mwe		85-100	260-425
Net efficiency %,	LHV	42.5	45
	HHV	40.5	43

Electrical outputs

With the choices of P200 and P800 units, a wide variety of outputs and configurations can be planned.

The P200, which has an 85-100 MW$_e$ capacity, can operate singly or in a pair linked to a single steam turbine producing 170-200 MW$_e$. Multiple units of three or four can produce up to 400 MW$_e$.

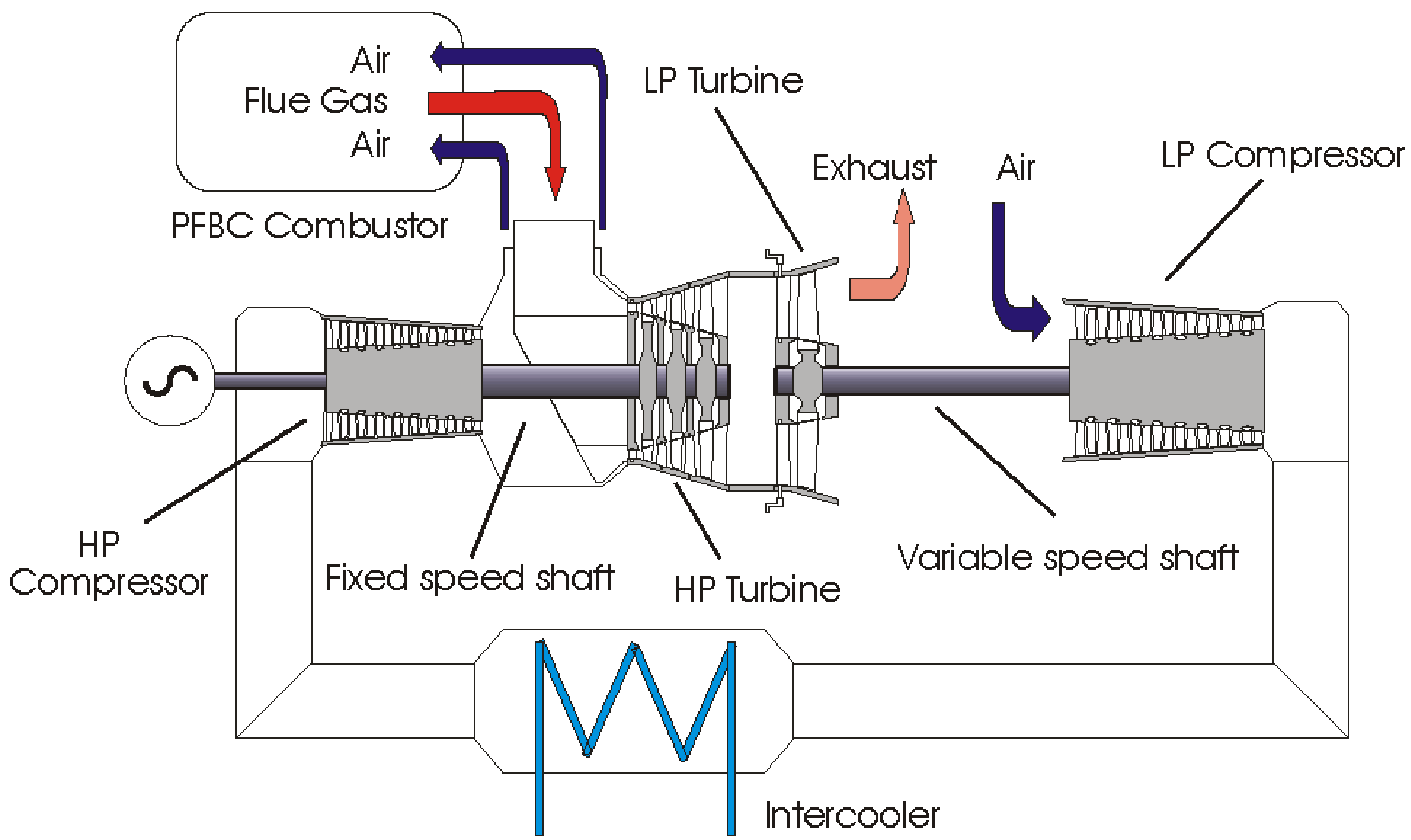
The larger P800 unit can also operate singly or be paired to provide up to 850 MW$_e$. The compact dimensions of the PFBC combustion vessel, as well as its modularity, make it easy to integrate with existing plant sites and plan additional capacity well into the future.

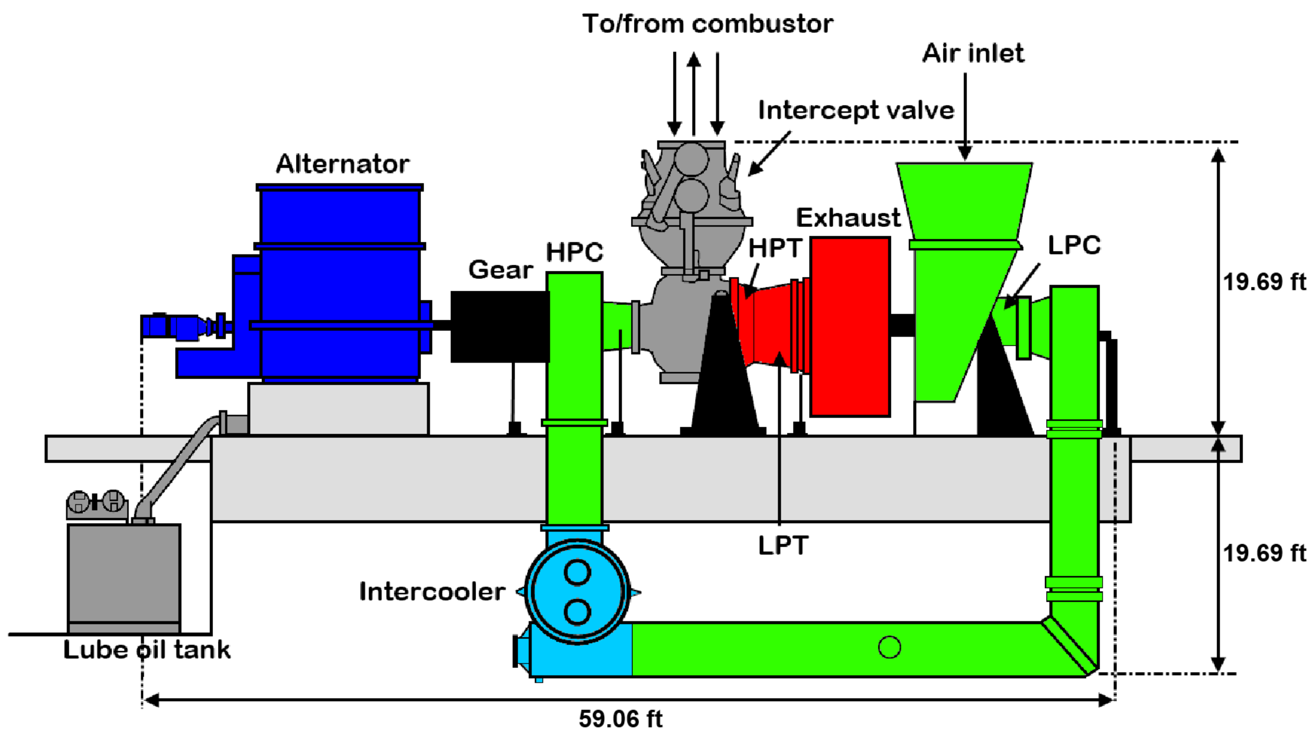
Key Data

	Single (P200)	Twin (P200)	Single (P800)	Twin (P800)
Total net plant output MW$_e$	85-100	170-200	350-425	700-850
Net efficiency (%, LHV)**	42-43	42-43	44-45	44-45
Coal consumption (lbs/s)	18	35	71	141
Ash production (lbs/s)	3.5	7	13	26.9
Firing rate MW$_{th}$	»200	»400	»800	»1600

Based on hard coal with about 1% sulphur.
** LHV, 59°F, 0.29 PSI condenser pressure

Configuration of the PFBC Machine





PFBC: A gas turbine that runs off coal

The PFBC system makes demands on a gas turbine that differ significantly from conventional applications.

The turbine must operate continuously and efficiently throughout the whole load range, with both air flow from the compressor and gas flow to the turbine varying between 40% and 100%.

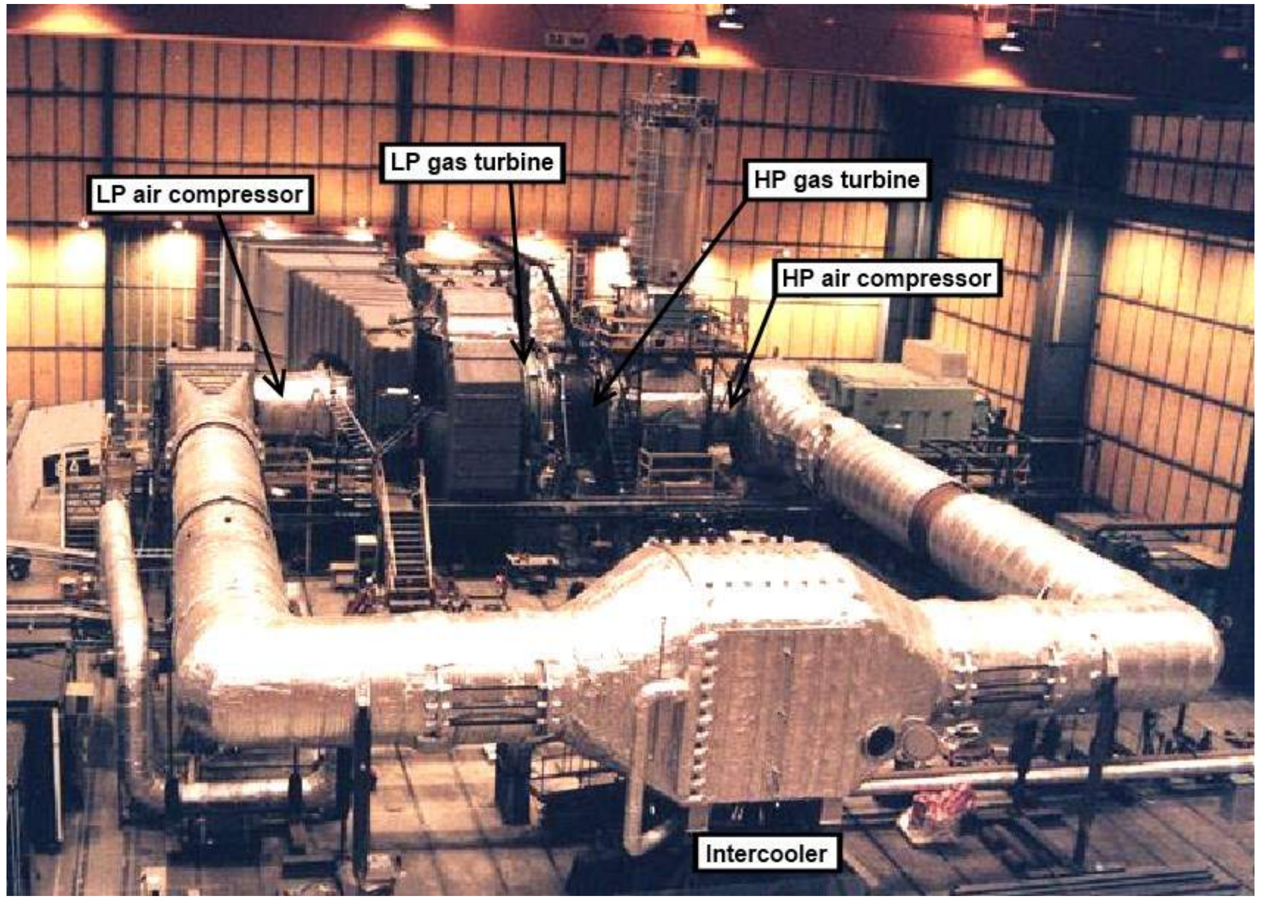
It must accept high-pressure flue gases, maintaining high reliability and availability over long periods, and resisting fouling and erosion from dust particles.

The GT35P turbine model has been specially adapted for incorporation with the P200 system, and the GT140P model for the P800.

Modified twin-shaft turbines with increased blade stages achieve the flexibility needed for variable load operations and for start-up and shutdown.

Measures have also been taken to ruggedize the turbine components. The bearings have been re-housed, and the blades themselves have been modified to lessen impact.

Over 250,000 hours of commercial operation have now proven the turbines´ flexibility and capability to operate in this demanding environment.



GT140P workshop testing for Karita, Japan P800 Project

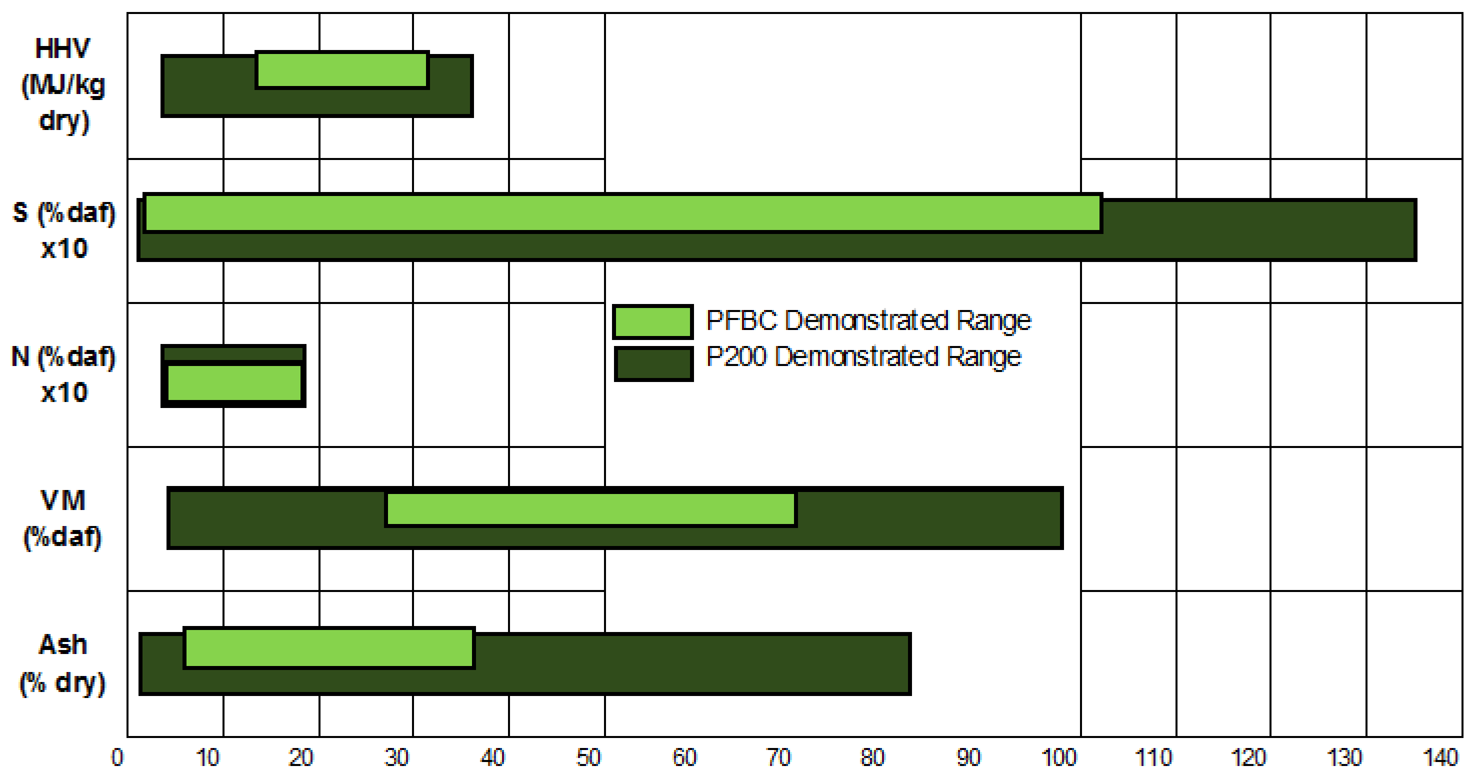
PFBC: Clean Coal Technology

The Fuel Flexibility of PFBC

A standard PFBC plant can burn a very wide range of fuels without the need to deviate from the standard design or sacrificing the high power output, efficiency, and excellent environmental performance which are the hallmarks of this clean coal technology. This means that plants can be designed, delivered, and put into operation more quickly and with a greater degree of confidence that no new "bugs" will be found. In addition, the plant can easily be adapted for operation with a range of different fuels during its lifetime, as long as provisions are made for this in the original design of ancillary systems, i.e. the fuel and ash handling systems are designed for the maximum flows.

Why is PFBC so fuel flexible?

Fuel flexibility requires a combustion process which is insensitive to variation in fuel type. The PFBC deep bubbling bed gives such a process. The combustion is carried out in a dense fluidized bed of mainly inert particles, where the concentration of burning particles is typically less than 0.5%. Fuels with ash contents as high as 80% have been shown to burn without problems in this kind of system. Another requirement for fuel flexibility is that the design and the size of the major components in the boiler and ancillary systems should not be affected by the properties of the fuel. A PFBC is designed around the air/gas flow provided by the compressor of the P-machine (the specially adapted gas turbine). The flow characteristic of the turbine ensures that the volume flow through the plant is constant: with varying mass flows of air, the pressure in the systems varies to maintain a constant volume flow. Since most of the major components in the PFBC island are designed for constant velocity, this results in the ability to use **exactly** the same design independent of the fuel to be burned. The volume flow of air/gas through the plant is constant, as defined by the characteristic of the P-machine. The turbine behaves like a flow nozzle giving a constant volume flow, but varying pressure upstream. The fluid bed is designed for a given fluidizing velocity whatever the fuel, so its cross-section is fixed. The cyclones are designed for a given inlet velocity so they don't change. The pressure vessel is sized to contain the bed vessel and the cyclones, so its fixed. The P-machine is constant velocity and doesn't change. *It's that simple!*



PFBC: Increased Efficiency

Efficiency is a major point in any utility's evaluation of power plant technologies. Before PFBC, coal generation was linked to a single steam cycle, which limited the opportunity to reach high efficiencies. PFBC technology has made a breakthrough. The unique characteristic of this system is that it already yields high heat efficiencies with low gas turbine inlet temperatures. At around 1562°F, it is already approaching 45% net efficiency.

PFBC attains these high levels through the use of a thermodynamic cycle, which very effectively combines the relatively low temperature but highly efficient gas turbine with a modern steam turbine.

The use of the gas turbine also reduces the demand for auxiliary power, allowing more of the electricity generated to be delivered to users.

In addition, by incorporating the tube bundles into the fluidized bed, the most advanced steam conditions can be generated, improving the performance of the steam turbine.

The combination of these developments and PFBC's simplicity already make it a commercially attractive proposition. The conservative inlet temperatures for the gas turbine and the ability to reach the most advanced steam data open the way for increased operating temperatures and even higher thermal efficiencies in the future.

Fuel Costs

PFBC is fuel efficient, irrespective of coal quality or sulfur content. Many aspects of the system's design contribute to this—above all, the combined-cycle process, which increases plant efficiency and reduces fuel costs by 10-15% compared to conventional coal technologies. In retrofit cases, the fuel savings could be over 20%.

Sample of Yearly Benefits of Increased Efficiency

PFBC gives 3-5% higher efficiency.

3% higher efficiency means:

- 52,000 tons of coal saved
- 3,500 tons less sorbent used
- 10,000 tons less ash production
- 1,000 tons less SO_2
- 240 tons less NO_x
- 122,000 tons less CO_2

Assumptions

- 350 MWe power plant
- 40—45% efficiency increase
- Coal: 1% sulfur, 15% ash, 10,000 BTUs
- 6,000 hours per year

Fuel Feed System

The fuel flexibility of the PFBC boiler requires auxiliary systems designed to efficiently and reliably handle and inject the fuel required to maintain the correct bed temperature in the pressurized combustor.

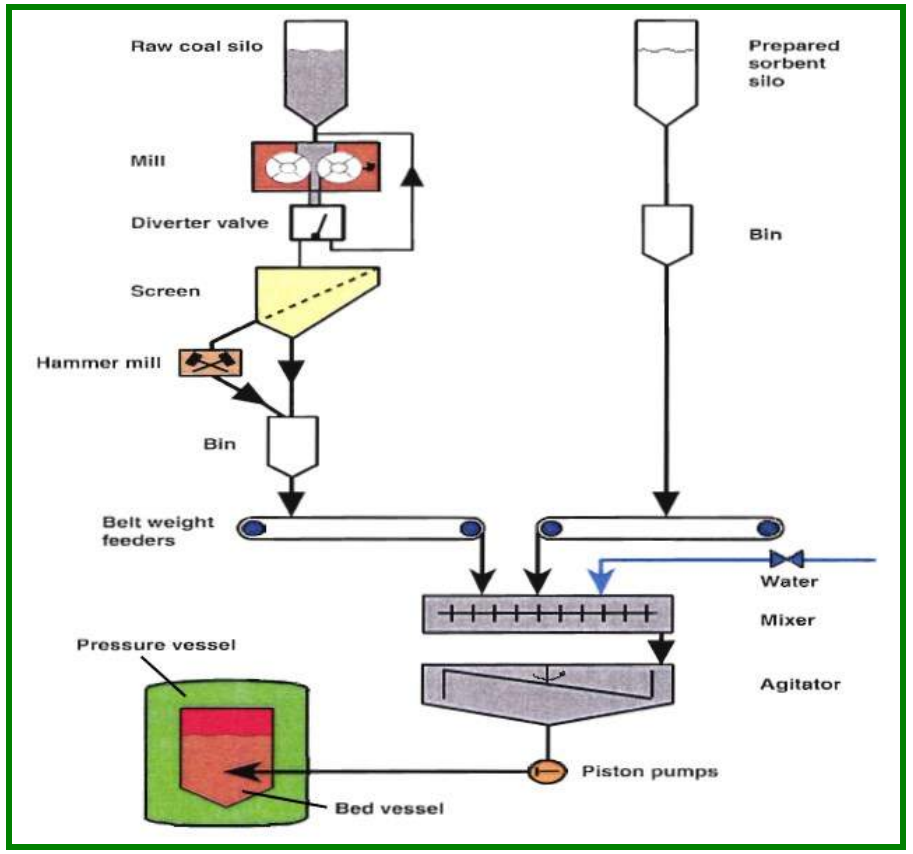
Two main concepts, with combinations, are used depending on the fuel type and composition. In general, with high sulfur and high ash fuels, a dry pneumatic fuel injection system is used. With high moisture, low ash, and low sulfur fuels, a hydraulic paste injection fuel system is used.

Dry Fuel Feeding Concept

The fuel systems include all the coal and sorbent handling to supply the pressurized fluidized bed inside the combustor with prepared, crushed and dried, well-mixed coal and sorbent in a controlled way according to the plant load.

Paste Fuel Feeding Concept

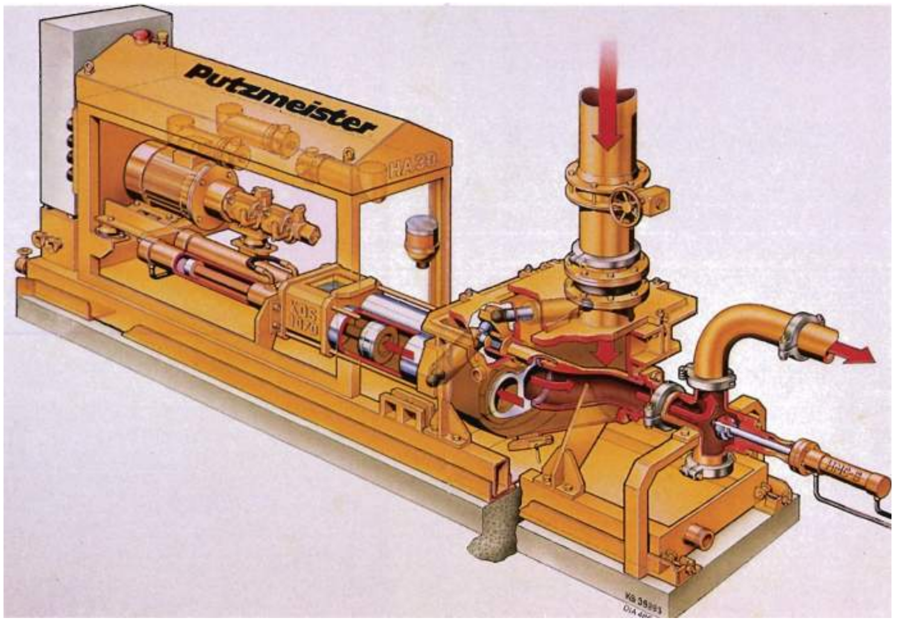
Unlike atmospheric boilers where there is an energy penalty for the evaporation of moisture in the fuel, PFBC utilizes the energy in the mass flow of the evaporated moisture, together with the flue gas, to drive the combustion air compressor gas turbine expander.

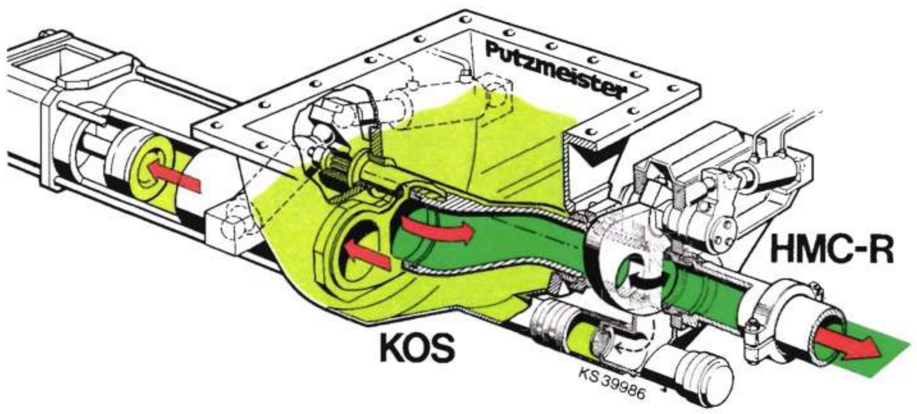


Considering the fuel injection pumps must have high accuracy and repeatability of the delivered flow and high turndown ratio, a hydraulically driven piston pump with positively actuated valves is used.

For the existing PFBC plants with paste feed fuel systems, the PUTZMEISTER KOS series oil-hydraulically driven S-transfer tube high density solid pumps have been used to transport fuel over long distances and elevations from the fuel preparation plant, and to inject the fuel into the PFBC boiler in the power station.

The PFBC experience with PUTZMEISTER pumps dates back to 1989, when PUTZMEISTER supplied the Värtan heating and power station in Stockholm with 17 high density solids pumps of the KOS series, as well as 1,050m stainless steel conveying line with PUTZMEISTER ZX flange systems. Among these pumps were 3 KOS 2180, which are the world's largest oil-hydraulically driven high density solids pumps for the transfer of coal from the coal prep plant to the power station. 14 KOS 1070 pumps were also needed for the charging of the coal into the pressurized combustors.





Coal Paste with Dolomite Added

PFBC Ash Utilization

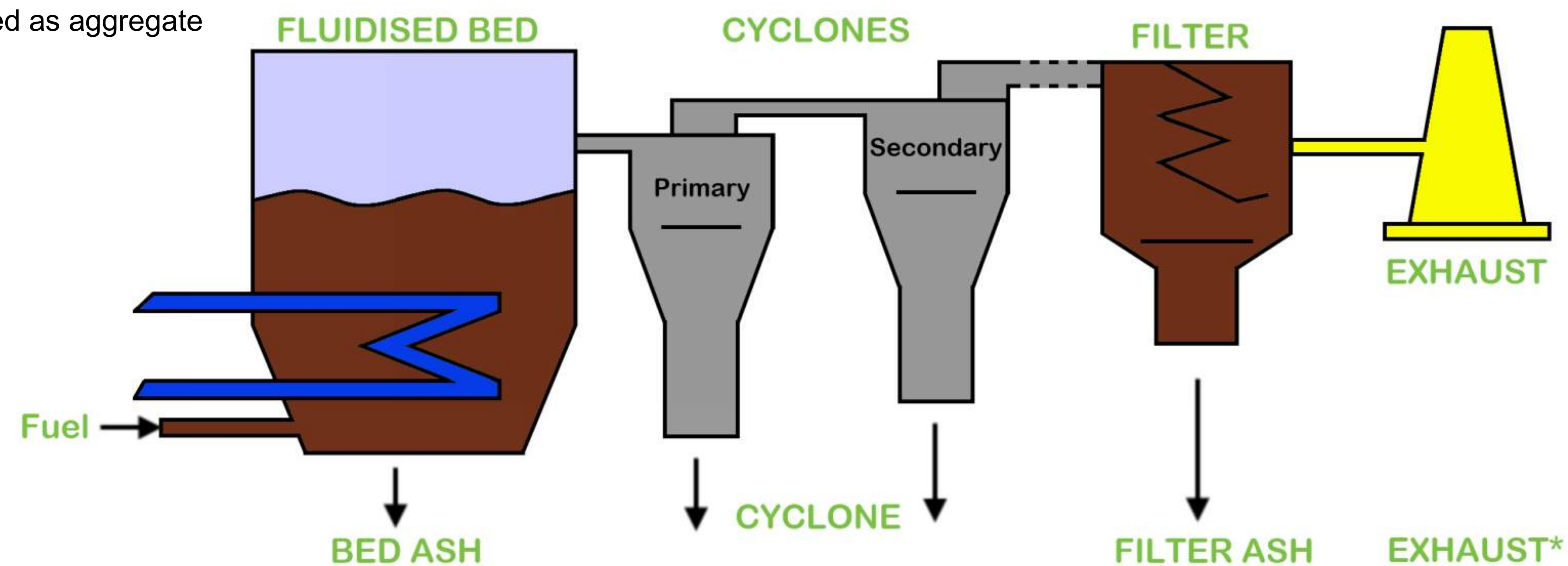
- Synthetic Gravel – The self-binding property of PFBC ash allows the formation of agglomerates. These can be crushed into gravel or formed into pellets. Such material has been used successfully as filler in a test road in Linköping, Sweden, since 1988.
- Landfill Preparation – The very low permeability and leaching characteristics allow the ash to be used for insulation, flooring, sectioning and cover of landfills. It can even be used as a sealing layer for hazardous waste.
- Land Reclamation – Agglomeration can be used in harbor areas and seaside locations. A land reclamation project using PFBC ash was performed at Wakamatsu, Japan.
- Building Material – The strength has proven to be similar to concrete. Bricks and slabs have been tested as driveways and walkways and have been proven to withstand weathering, salting, sanding, and snow clearance.
- 100% of the ash from the Karita, Japan PFBC Power Plant is utilized as aggregate for the manufacture of concrete.

Linköping uses synthetic gravel made from PFBC ashes

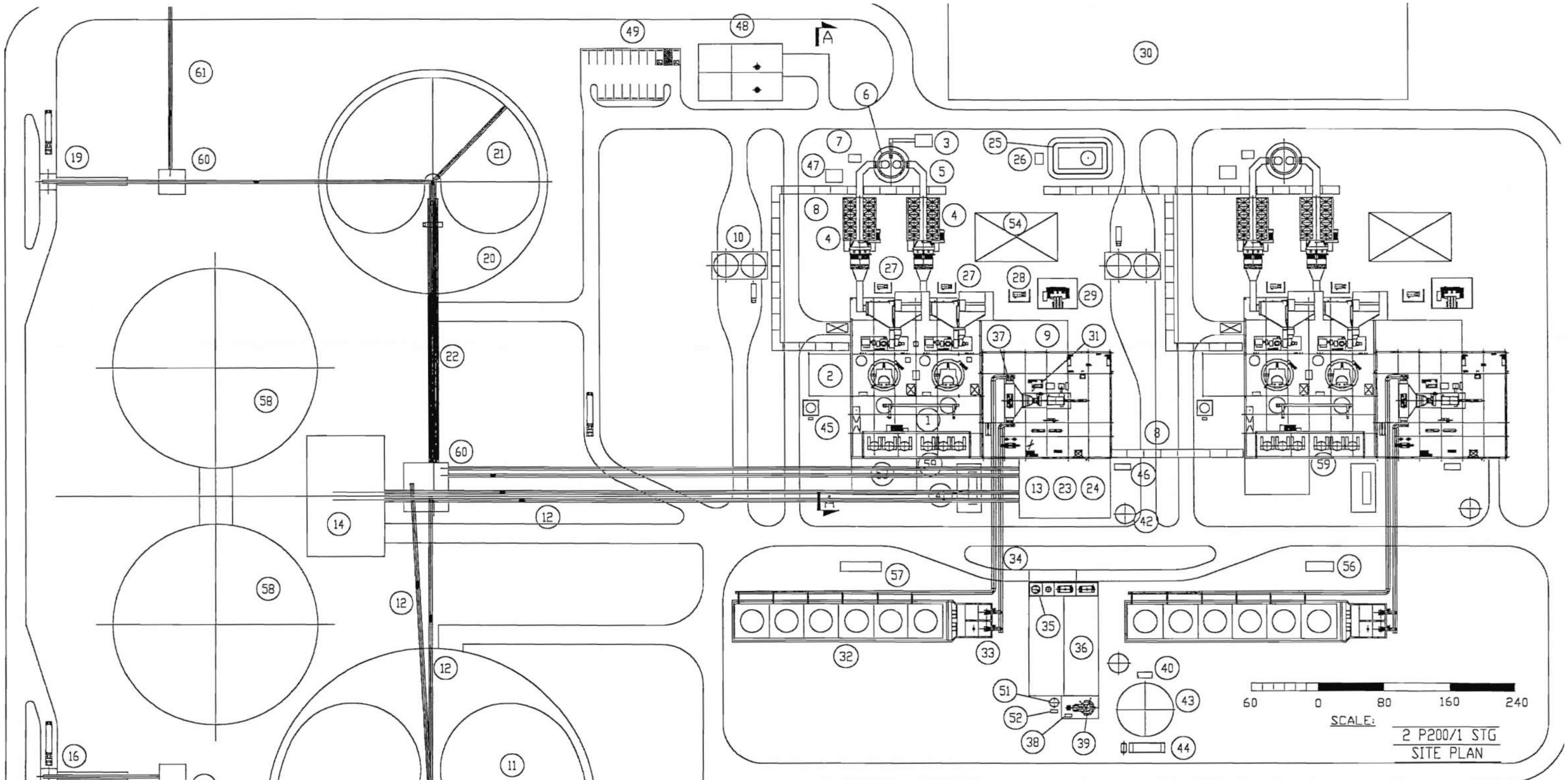
Properties of PFBC Ash

- Ash from PFBC, unlike ash from atmospheric fluid beds, contains virtually no free lime (CaO), making it easy and safe to handle.
- Ash from PFBC contains no sulfites ($CaSO_3$) or sulfides (CaS). It is a stable end product which can be easily and safely utilized or disposed of.
- The ash is self-binding with water, without any additive. If water is added, it will harden just like a concrete, after vibration.
- The hardened ash product has a very low permeability, comparable to the finest clays.
- The hardened ash product is water-resistant and therefore stable against rain and flooding.

ASHES FROM PFBC



Amount	**20 - 50%**	**45 - 75%**	**~3%**	**~2%**	**<10 ppm**
Size	**12 - 236 mil**	**0.04 - 12 mil**	**0.04 - 0.4 mil**	**0.04 - 0.4 mil**	**-0.2 mil**
Average Size	**~39 mil**	**0.8 - 2 mil**	**0.12 - 0.16 mil**	**0.08 - 0.12 mil**	**-0.08 mil**

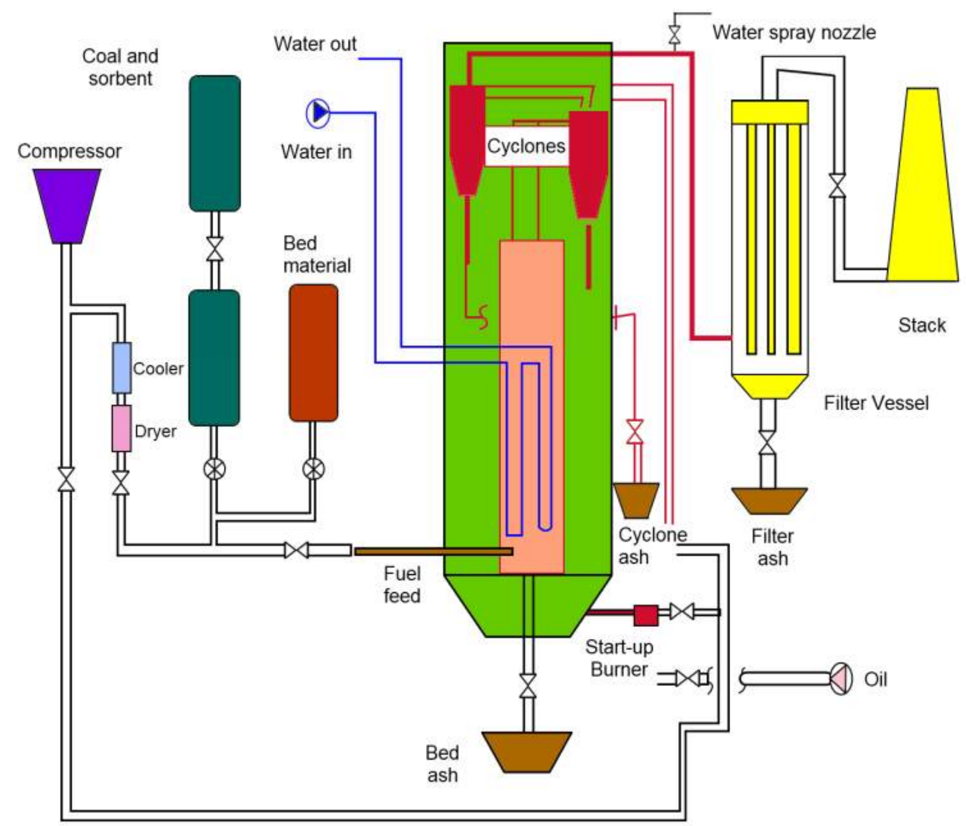


PFBC PLANT SITE DESCRIPTION

1 PFBC POWER BLOCK AREA
2 PFBC BOILER ERECTION AREA
3 AUXILIARY BOILER
4 BAGHOUSE
5 FLUE GAS DUCT
6 STACK
7 CEMS ENCLOSURE
8 UTILITY BRIDGE
9 CONTROL ROOM
10 ASH SILOS
11 FILTER CAKE DOME
12 FILTER CAKE CONVEYOR
13 RECEIVING SILO BUILDING
14 PLAYE & FRAME PRESS BUILDING
15 FILTER CAKE RECLAIM HOPPERS
16 OFF SITE WASTE FUEL TRUCK HOPPERS
17 OFF SITE WASTE FUEL CRUSHERS
18 OFF SITE WASTE FUEL STORAGE
19 LIMESTONE TRUCK UNLOADING
20 LIMESTONE DOME
21 LIMESTONE RECLAIM FEEDER
22 LIMESTONE RECLAIM CONVEYOR
23 LIMESTONE PREPARATION BUILDING
24 LIMESTONE STORAGE SILOS
25 FUEL OIL STORAGE TANK AND DIKE
26 FUEL OIL PUMP HOUSE
27 GT UNITY STEP-UP TRANSFORMER
28 UNIT AUX TRANSFORMER
29 STEAM TURBINE GENERATOR TRANSFORMER
30 SWITCHYARD
31 STEAM TURBINE GENERATOR
32 COOLING TOWER
33 CIRCULATING WATER PUMPS
34 CIRCULATING WATER PIPING
35 COOLING TOWER CHEMICAL FEED AREA
36 WATER TREATMENT BUILDING
37 CONDENSER
38 CLARIFIED WATER FORWARDING PUMPS
39 CLARIFIER
40 FILTERED WATER SUPPLY PUMPS
41 DIESEL DRIVEN BACK-UP FEED PUMP
42 CONDENSATE TANK (100,000 GAL)
43 CLARIFIED/FIRE WATER TANK (1,000,000 GAL)
44 SERVICE/FIRE WATER PUMP HOUSE
45 AMMONIA STORAGE TANK
46 OIL WATER SEPERATOR
47 BLOWER BUILDING
48 ADMIN/WAREHOUSE/MAINTENANCE
49 PARKING
50 WHEELED LOADER
51 RAW WATER STORAGE TANK
52 RAW WATER FORWARDING PUMPS
53 COMPRESSOR BUILDING
54 CRANE ACCESS AREA
55 DEMINERALIZED WATER TANK
56 COOLING TOWER 2 LOAD CENTER
57 COOLING TOWER 1 & WATER TREATING BLDG
58 250'-0' ø THICKENERS
59 BUFFER SILOS
60 TRANSFWE BUILDING
61 CONVEYOR FROM BARGE UNLOADING

The Process Test Facility

This pilot plant was designed for the testing of process parameters and was named the Process Test Facility, or PTF. Although the rig is small in size, the main process operating parameters - bed temperature and pressure, bed height and excess air - match those of a full scale plant. The plant is ideal for testing factors such as combustion efficiency, sintering and fouling propensity, emissions, etc. The results from the plant can be used to give a direct prediction of a full scale plant, as well as to compare with results obtained using fuels with known characteristics from commercial units.



How the facility works

The pressure vessel contains the bed vessel (boiler), which is water cooled by in-bed tubes. The height of the bed vessel is the same as that of a full size plant and the cross-section has been chosen to give the same fluidizing velocity as a full size plant. Load control is by variation of bed height, which, at full load, is approximately 11.5 ft. The freeboard is the same height as a full sized plant and is fitted with systems for SNCR and freeboard firing. The pressure vessel also contains the cyclones for fly ash separation and the gas-fired start-up burner.

Combustion air is supplied by a compressor to the pressure vessel and enters the bed vessel via air nozzles.

The PTF is equipped with a paste feed system in which the coal and sorbent can be crushed, if required, and mixed with biomass and water to a paste that is fed to the bed vessel with hydraulic piston pumps.

In case of dry fuels, the PTF will be equipped with a pneumatic lock hopper fuel system.

Bed ash is removed from the bottom of the bed vessel to a water-cooled bed ash cooler and then discharged via a lock hopper system. Fly ash is collected in a cyclone and air-cooled within the pressure vessel before being discharged pneumatically. A system for recirculation of fly ash can also be employed. A portion of the flue gas exiting the cyclone is withdrawn to the gas analysis equipment (FTIR). The remaining flue gas passes via a gas turbine blade test rig to a ceramic filter for final flue gas clean-up.

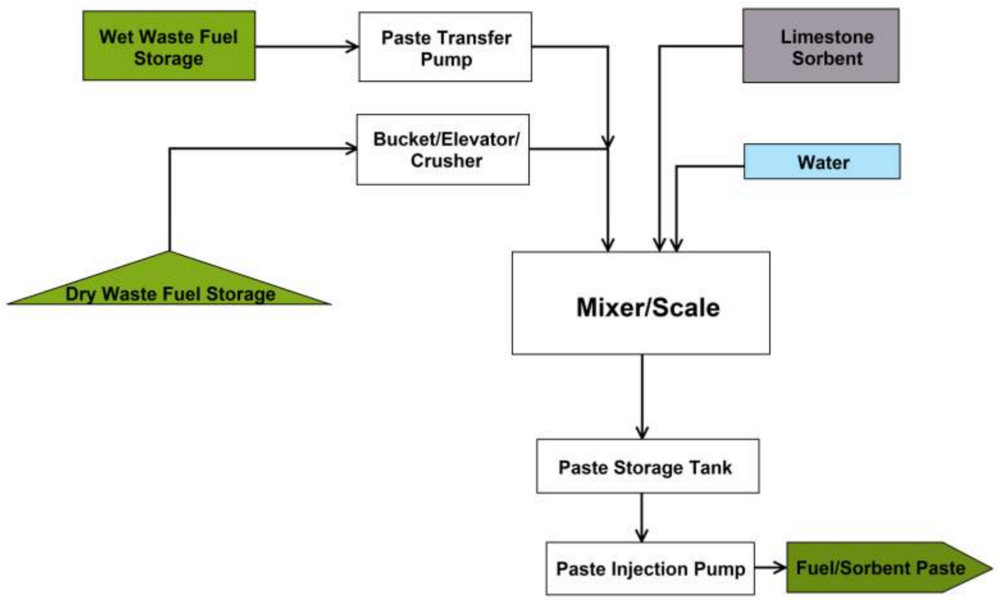
The unit is controlled via a master control system and is instrumented with approximately 120 measuring points, which are continually logged. In addition, there are some 380 local measuring points. Bed temperature and excess air level are controlled by fuel and air feed rate, respectively.

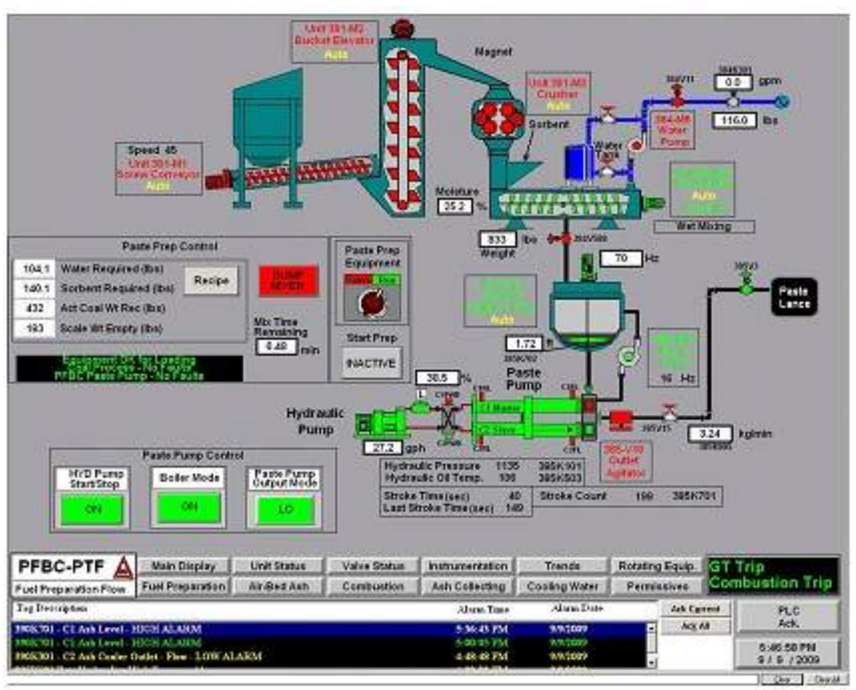
The Test Facility has accumulated nearly 5000 hours of experience during its operation. The table gives an indication of the scope and result of testing.

FUEL TYPE	SORBENT	HEAT VALUE (HHV) BTU/LB.	TEST HOURS	COMBUSTION EFFICIENCY (%)
SW Pennsylvania Waste Coal	Maple Grove Dolomite	13472	78	98.31
WV Waste Coal	Maple Grove Dolomite	9498	12	NA
SW Pennsylvania Waste Coal/Biomass	Maple Grove Dolomite	9467	33	NA
Polish Coal	Swedish Dolomite	12040	295	99.4
German Brown Coal	German Limestone	8170	53	>99.9
Israeli Oil Shale	None	1290	262	>99.5
Green Delayed Petcoke	Swedish Dolomite	14620	215	99.5
Polish Coal + Wood Chips	Swedish Dolomite	12040 + 8170	60	NA
Polish Coal + Olive Pips	Swedish Dolomite	12040 + 8170	75	NA
Polish Coal + Palm Nut Shells	Swedish Dolomite	12040 + 8170	64	NA
Anthracite	Swedish Dolomite	14620	168	NA
Spanish Lignite	Spanish Limestone	6450	303	
Israeli Oil Shale + Petcoke	None	2580	48	>99.5
Italian Lignite	Italian Limestone	9460	31	99.5
Italian Lignite + South African Coal	Italian Limestone	11180	98	99.5
Chinese Coal	Chinese Limestone	8600	176	>99.5
Australian Coal	Japanese Limestone		339	-
German Brown Coal + Dry Sewage Sludge	Polish Limestone	7310	61	-

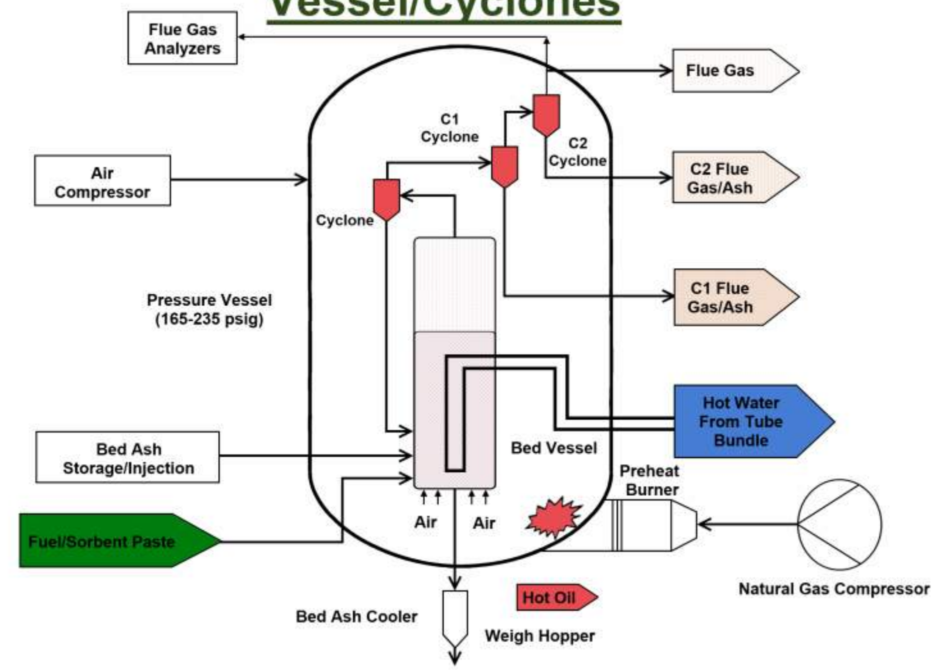
The Process Test Facility

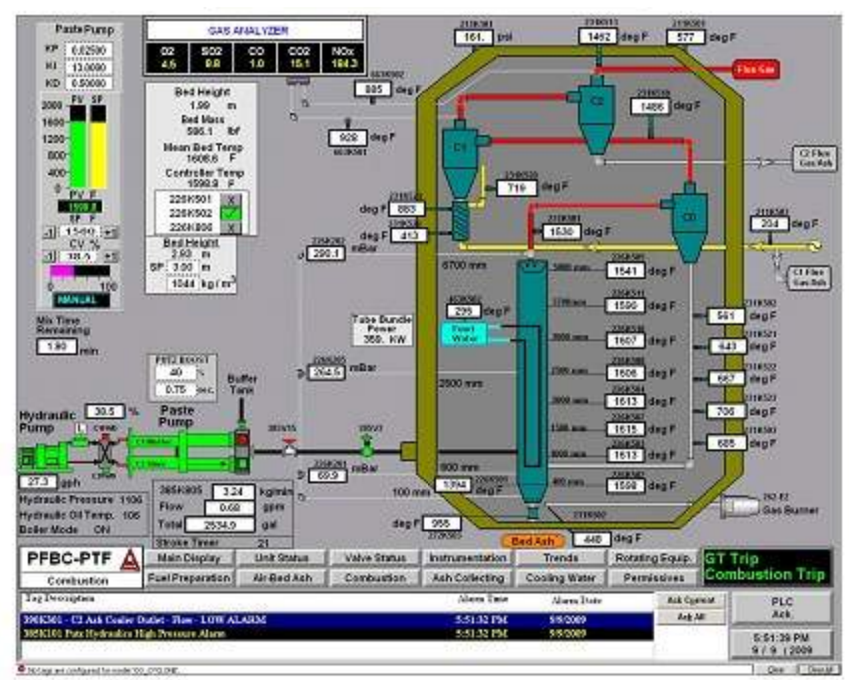
PTF Waste Fuel/Sorbent Preparation



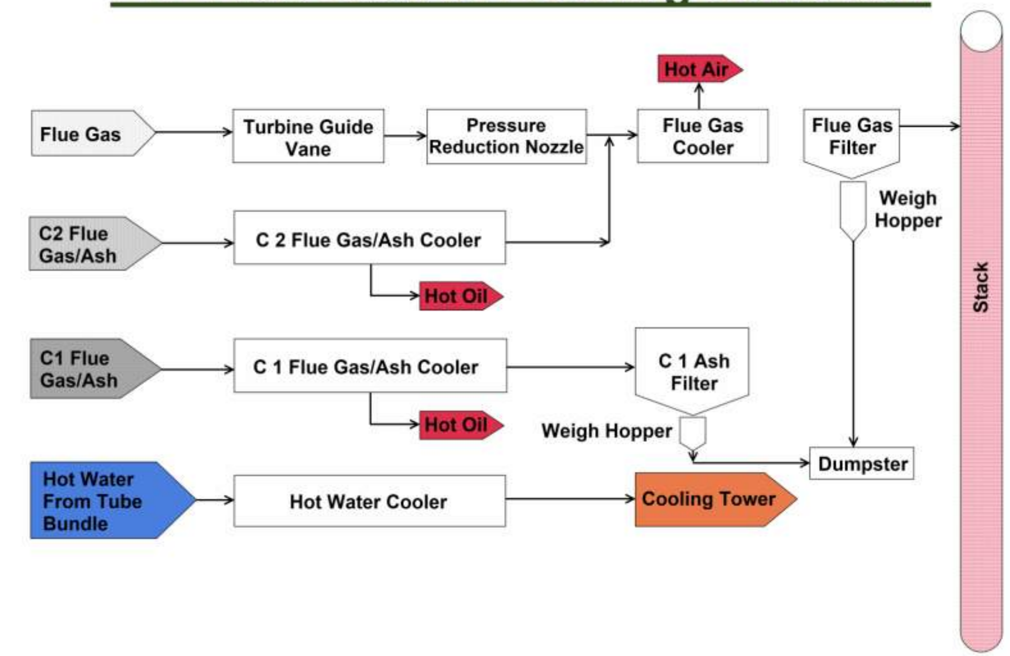


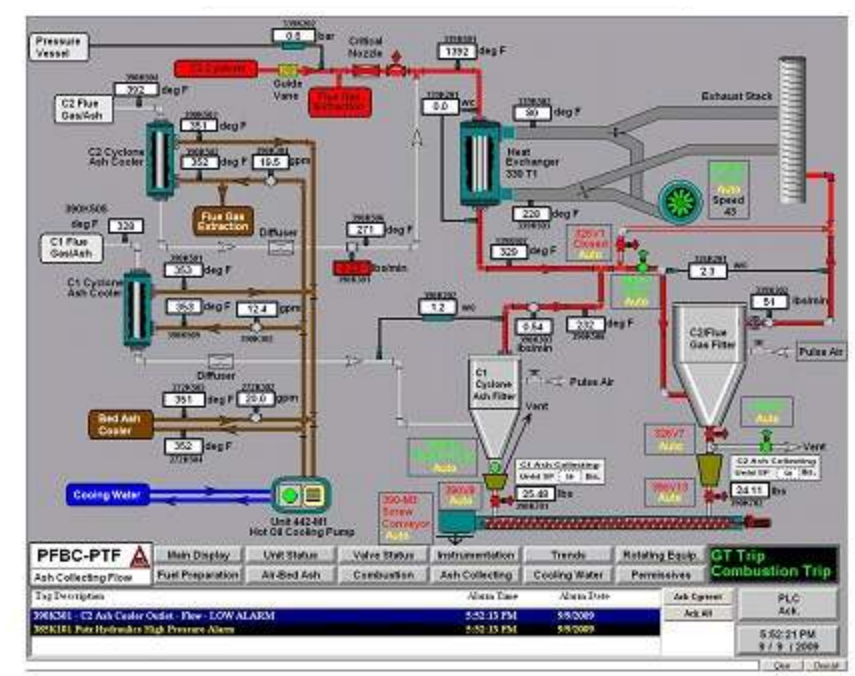
PTF Pressure Vessel/Bed Vessel/Cyclones





PTF Flue Gas/Ash Cooling-Collection

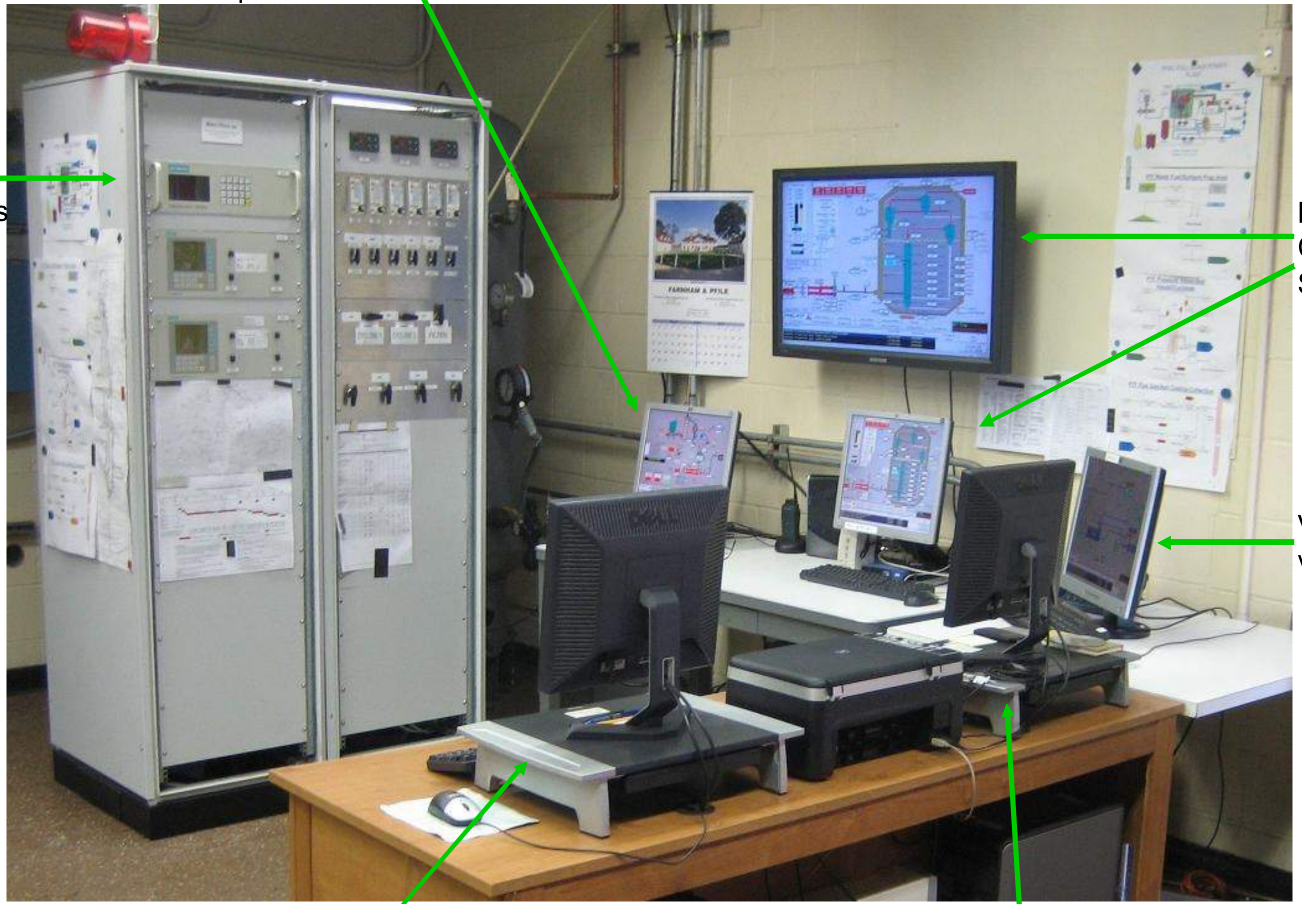




Process Test Facility Capabilities

- Fuel screening for project suitability
- Essential design data—bed heat transfer
- Emissions and emissions control data
- Ash handling and utilization
- O&M influence projections
- Fuel impact model
- Operator training
- Risk assessment and mitigation
- Define proposal scope for full scale plant cost

PTF Control Room



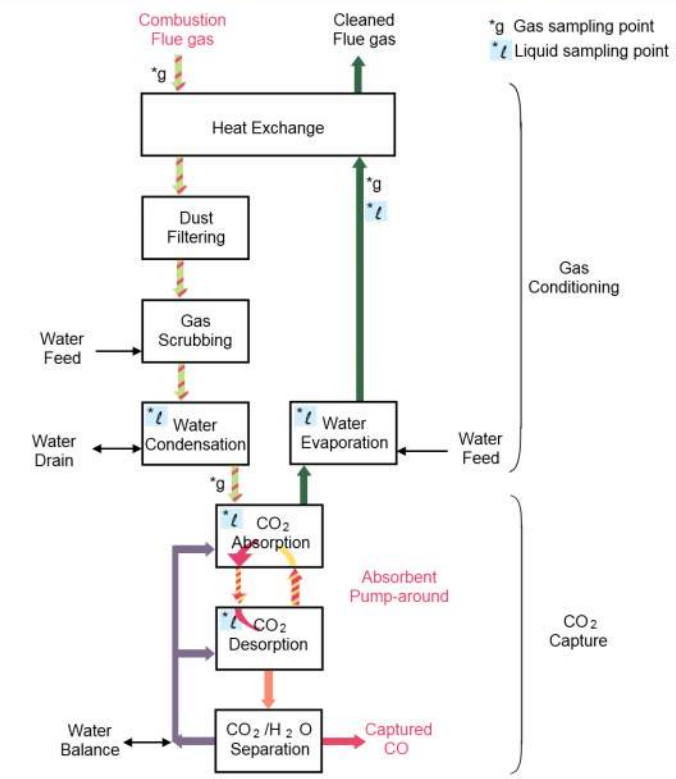
Relative to the flue gas from a conventional atmospheric combustion plant, the flue gas from the PFBC combustor has lower mass flow, lower volume flow, higher total pressure, higher CO_2 partial pressure, and very low flue gas oxygen content.

The PFBC flue gas is therefore well suited for CO_2 capture using existing technologies that can take advantage of these features, such as the Benfield process (http://www.uop.com/objects/99%20Benfield.pdf). Compared to many atmospheric processes, the combination of the pressurized PFBC and Benfield processes will lessen the cost and energy penalty associated with separating the CO_2 from the flue gas.

To demonstrate the PFBC readiness for the above CO_2 capture technology, PFBC-EET has equipped the PFBC Process Test Facility with a Sargas (http://www.sargas.no) manufactured test skid based on the Benfield technology.

Preliminary testing results have demonstrated CO_2 removal efficiency of greater than 98%, CO_2 quality greater than 94%, and less than 0.3% CO_2 in the cleaned flue gas.

Functional Diagram of Sargas Technology



Cottbus PFBC Plant, Germany

The municipality of Cottbus, in eastern Germany, decided in April 1996 to install a P200 PFBC plant at an existing site near the center of the town. The PFBC plant was designed to replace an old, heavily polluting, coal-fired plant that was due for closure. The PFBC plant provides the town with district heating, as well as electricity, its maximum production being 71 MWe and 40 MWth in district heating mode. The plant uses locally mined Lausitzer brown coal. The plant consists of one P200 module operating with separate high pressure and low pressure/intermediate pressure steam turbines. The PFBC module consists of a PFBC machine (specially ruggedized gas turbine) connected to a pressurized fluidized bed boiler, where the steam is generated. The steam generator delivers steam to the steam turbines for power generation and to the district heating system. In addition to the P200 module, the plant has two gas-fired boilers for use during periods of high heat demand, bringing the maximum heat output up to 220 MWth. Site work began in autumn 1996 and equipment erection at the beginning of 1997. After the start of commissioning in the summer of 1998, the plant came on line in the autumn of 1999.

PFBC Plants Around the World

Värtan, Sweden 2 x P200

Karita, Japan P800

Escatron, Spain P200

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