

Internal Recirculation Circulating Fluidized-Bed Boilers

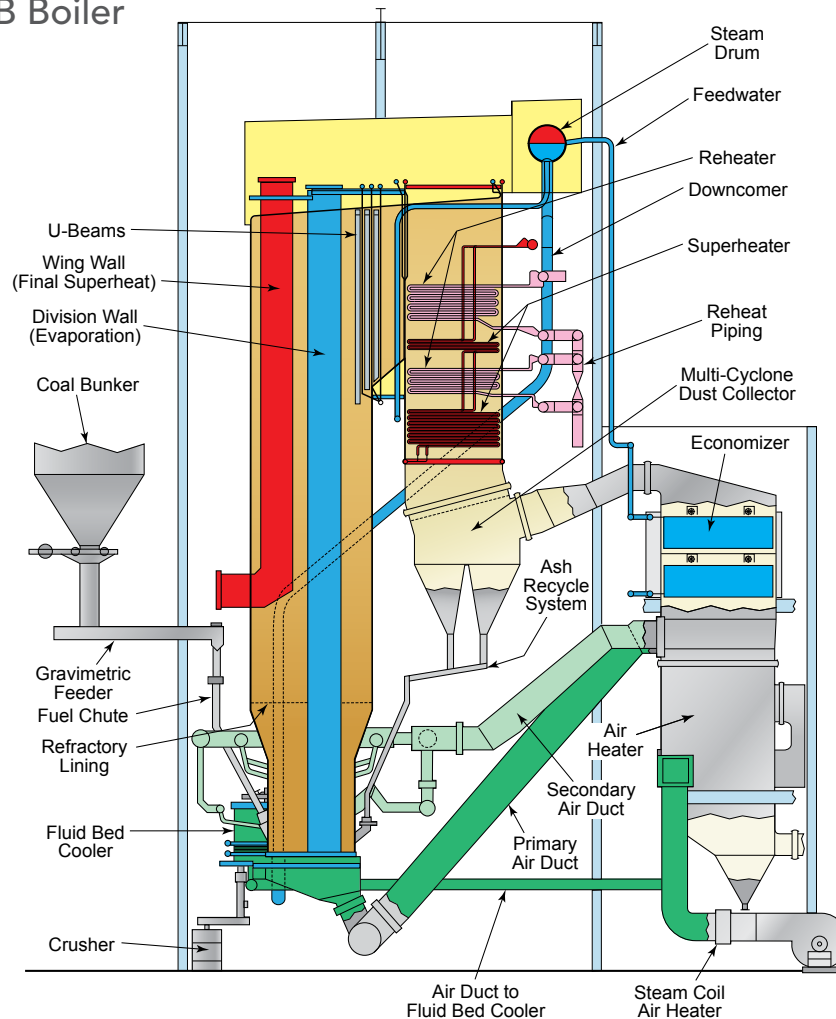
High Availability | Low Maintenance



Proven | Flexible | Reliable | Economical



B&W IR-CFB Boiler



The Technology of Choice for High Availability and Low Maintenance

Since 1867, Babcock & Wilcox (B&W) has been the leading worldwide producer of steam generation technology and equipment. B&W remains at the forefront of technological advancements related to efficient and environmentally sound combustion methods for waste fuels, corrosive fuels, biomass fuels, and hard-to-burn fuels.

Drawing upon our extensive technical expertise and operating experience, B&W developed the Internal Recirculation Circulating Fluidized-Bed (IR-CFB) boiler which is the technology of choice for power plant owners seeking economy, reliability and flexibility. In addition, load-following capabilities are attainable with B&W's in-bed heat exchanger technology.

B&W's IR-CFB technology offers:

- Higher reliability and availability
- Lower maintenance costs
- High combustion efficiency
- A compact, economical design
- Reduced erosion
- Fuel flexibility
- Low emissions

Capacity

- To 2,200,000 lb/h (277 kg/s) or greater as required

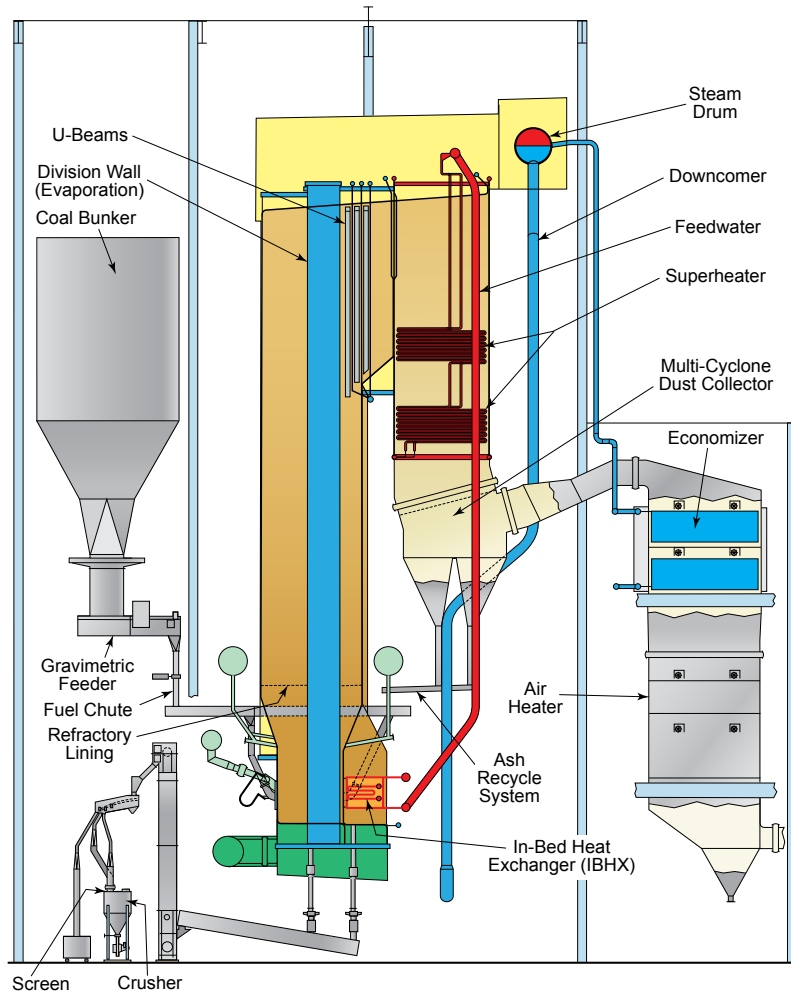
Steam pressure

- To 2600 psig (17.9 MPa)

Steam temperature

- As required, usually to 1050F (566C)

B&W IR-CFB Boiler with In-Bed Heat Exchanger (IBHX)



Load-Following Capability

For remote applications with load-following requirements typical of modern turbine power generation systems, an internal fluid bed heat exchanger (IBHX) is incorporated into the bottom of the furnace. The final superheat and/or reheat surfaces are placed in the IBHX which features a bubbling fluid bed (BFB) that offers critical benefits for steam generation. Heat transfer rates are higher in a BFB than in the furnace and convection areas. Sections of the BFB bed can be turned on and off independently to follow load. The IBHX operates at reduced gas velocities for increased reliability and low maintenance.

Overall, the IBHX allows for improved control of the temperature of the superheated steam, providing:

- Faster load-following capability
- Steam temperature control over a wide load range

The design of the IBHX is such that steam output can be adjusted quickly up or down over a wide load range while keeping other process parameters, such as steam temperature, within an acceptable tolerance band. The ramping rate for steam flow is up to 4% of MCR per minute using the IBHX compared to 1% of MCR per minute without the IBHX.



Improved Performance, Reduced Costs, Minimized Maintenance

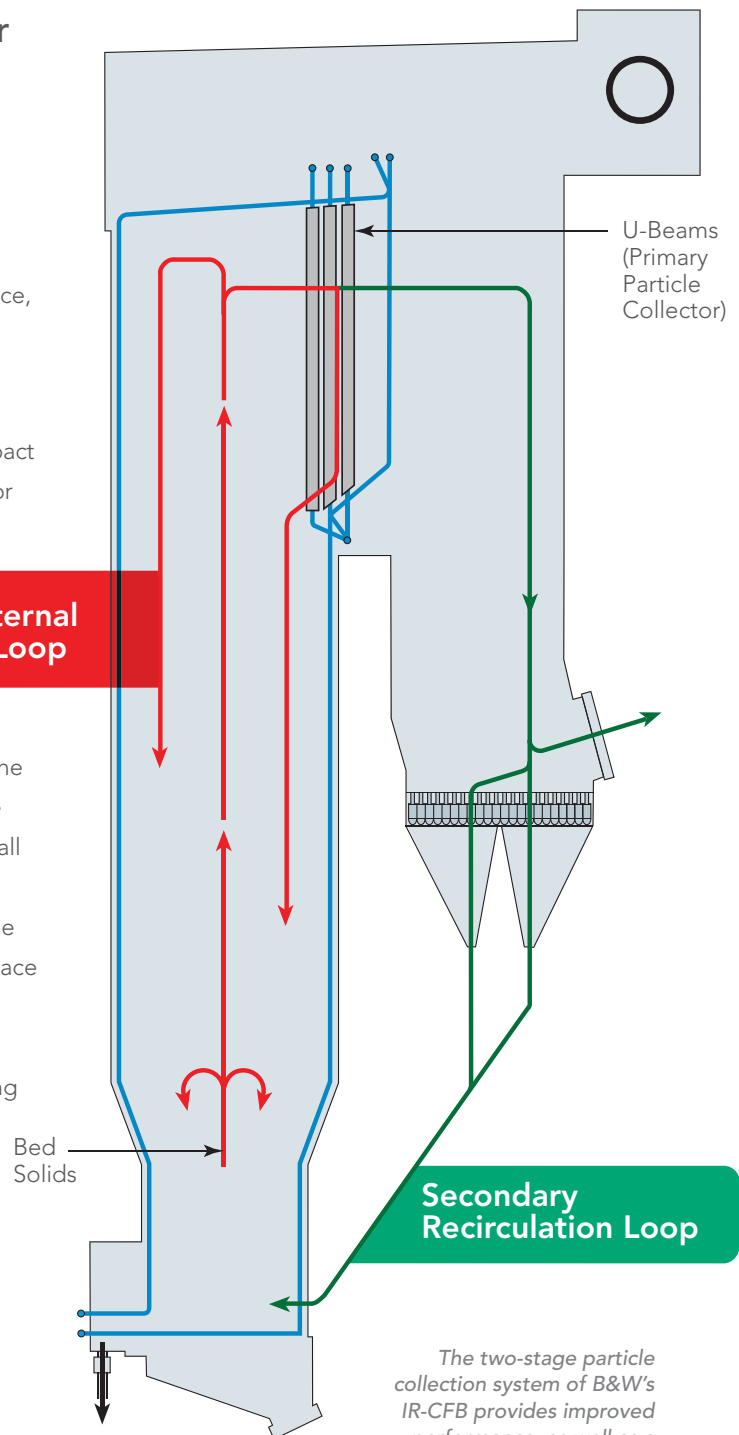
Two-Stage Particle Separation for Superior Combustion Efficiency

B&W's IR-CFB boiler design employs a two-stage particle separation system to provide high-solids loading and a uniform furnace temperature profile. The benefits of this technology include superior combustion efficiency, low emissions, low maintenance, low pressure drop, and high turndown, resulting in improved overall plant performance.

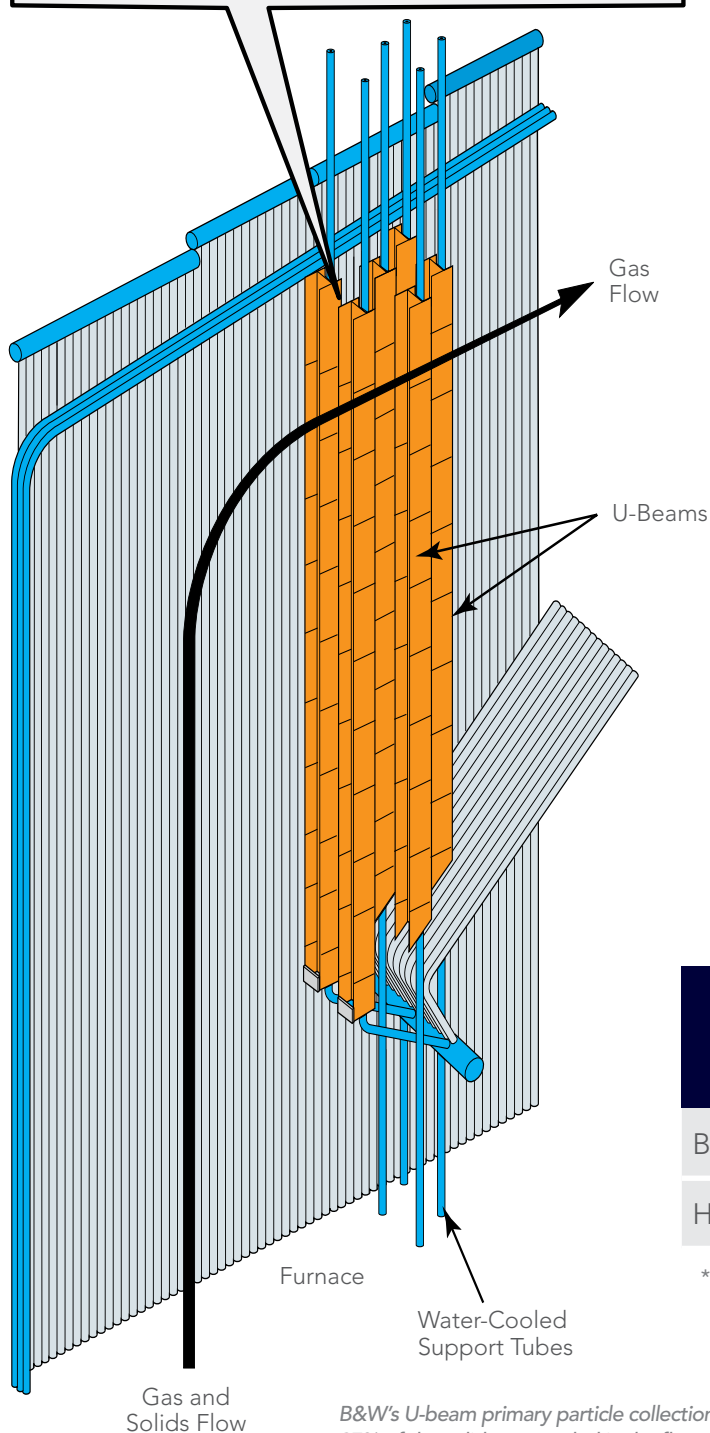
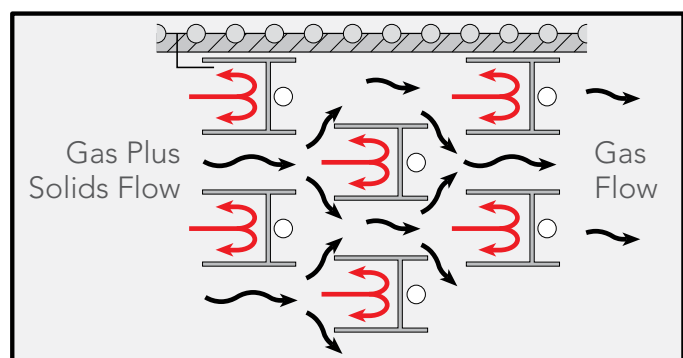
Our two-stage system includes a primary U-beam impact separator and a secondary multi-cyclone dust collector (MDC) which work together to provide a combined particle collection efficiency greater than 99.8%.

The U-beams, a staggered array of stainless steel channels at the furnace exit plane, capture nearly all of the solids suspended in the flue gas leaving the furnace and internally recirculate these solids to the lower furnace. The MDC, with small diameter (<10 in., 250 mm) cyclones, captures the finer material that passes beyond the U-beam particle separators and returns this material to the lower furnace in a controlled manner. The ability to regulate the secondary recycle system provides the operator with unprecedented furnace temperature control, resulting in improved boiler performance and load response.

Compared to hot-cyclone CFBs, maintenance of IR-CFB boilers is 33 to 50% lower with two-stage particle separation, reduced diameter zone, lower velocity convection section and the elimination of refractory-lined cyclones and loop seals.



The two-stage particle collection system of B&W's IR-CFB provides improved performance, as well as a simplified, cost-effective boiler design.



B&W's U-beam primary particle collection system recirculates more than 97% of the solids suspended in the flue gas back to the furnace.

Compact, Low Maintenance Design

B&W's two-stage particle separation system results in a compact, simplified boiler arrangement. The entire U-beam particle separator is located at the furnace exit. Compared with hot-cyclone CFB designs, the IR-CFB has significantly lower furnace exit gas velocity. By relying on internal recirculation, the IR-CFB design eliminates J-valves, loop seals, and high-pressure blowers which are required with other CFB designs. For the IR-CFB, compact and simple equals economical.



CFB Boiler Availability Comparison (8- to 10-year annual average), Bituminous Coal*

B&W IR-CFB	97.2%
Hot-Cyclone CFB	91.5%

* Reference: Industrial Fluidization of South Africa, October 2017.

Higher Availability, Lower Maintenance

The high reliability of B&W's IR-CFB boiler is due to its low maintenance design and avoidance of a thick refractory layer. Availability figures for IR-CFBs are 95 to 97% with bituminous coals, high ash and low ash content, respectively (averages for the past 10 years until 2017 for two units operating more than 20 years each). Based on a survey of CFB boiler operators, average maintenance downtime of an IR-CFB boiler is approximately 1 week per year compared to 1.5 to 2 weeks for hot-cyclone CFBs.

Reduced refractory

The IR-CFB's unique design results in significantly less maintenance compared to a cyclone-type CFB. The dual solids collection system, U-beams and MDC together achieve high solids collection efficiency and low pressure drop in a compact plan area. Metallic materials selected for U-beams and MDC have low erosion for this service and a long expected lifetime. The IR-CFB boiler eliminates high maintenance areas found in other designs:

- Large refractory linings which are the highest maintenance area in cyclone CFB boilers, and
- Hot refractory-lined gas inlet duct and expansion joints which are typical in some other CFBs.

The IR-CFB boiler heats and cools faster because refractory linings have been minimized. The IR-CFB boiler can remain in operation 14 hours longer each time the unit is shut down for maintenance.

Reduced tube erosion

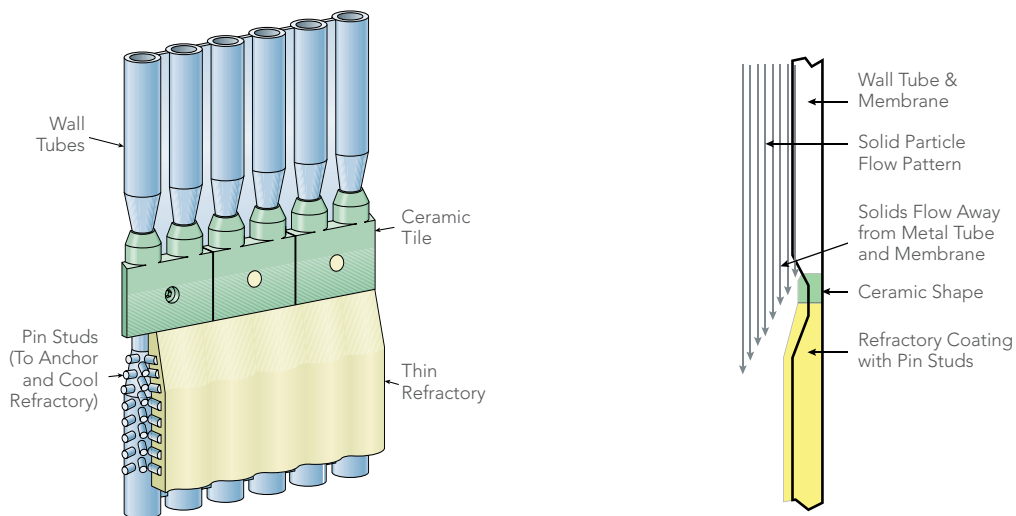
Erosion is a major cause of maintenance costs and problems in CFB boilers due to the high solids loading in the flue gas. The severity of this erosion is exponentially related to the velocity of the flue gas through the system. On hot-cyclone CFBs the particle separator depends upon an extremely high flue gas velocity to provide the energy needed to efficiently disengage the particles from the flue gas. B&W's U-beam particle separator is designed to operate efficiently with a much lower flue gas velocity. The particle capture efficiency actually increases as the flue gas velocity through the U-beam separator decreases. By operating at such a low gas velocity, the potential for erosion in the IR-CFB is significantly reduced.

B&W's reduced diameter zone (RDZ) tube section is another feature designed to reduce maintenance. The RDZ consists of a reduced diameter tube section mating to a specially shaped ceramic tile. This almost completely eliminates erosion of the membrane wall tubes above the lower furnace refractory.



B&W's IR-CFB Low Maintenance Design Features

- Two-stage particle collection requires less maintenance than hot cyclones:
 - » Eliminates thick refractory linings
 - » Subject to lower erosion and can be thermally cycled faster than thick refractory
 - » U-beams capture and recycle solids at lower gas velocities
 - » MDC with metallic cyclones operate at lower temperature
 - » Air slides eliminate loop seals and loop seal blowers
 - » No sootblowers are needed with lower gas velocity convection pass; fine solids clean the tubes
 - » MDC storage hoppers offer independent heat transfer control and more operating flexibility
- Thin cooled refractory with higher stud density in furnace is a robust wall protector
- IR-CFB uses 1/10 the mass of refractory of a hot cyclone CFB
- RDZ almost completely eliminates solids erosion of membrane wall at the transition section (solids flow obstructions from refractory and change in wall angle)
- Bubble caps minimize back sifting of bed solids and bubble cap erosion
- U-beams are contained in a water/steam-cooled enclosure eliminating hot expansion joints
- Open bottom design can handle tramp materials in feed (available)



The reduced diameter zone tube section has proven to reduce maintenance by eliminating localized membrane wall erosion above the refractory interface in the lower furnace.

Downtime Required for Cold Startup and Cool-Down Cycle

Procedure	IR-CFB	Hot-Cyclone CFB	Reduction
Cold startup 75 to 1600F (24 to 871C)	10 hours	16 hours	6 hours
Cool down 1600 to 75F (871 to 24C)	8 hours	16 hours	8 hours
Total downtime	18 hours	32 hours	14 hours

Fuel Flexibility, Lower Emissions

Fuel and Sorbent Flexibility

One of the main advantages of CFB technology is that it allows the owner to specify a wide variety of fuels to optimize profitability. B&W has the engineering expertise and operating experience needed to supply an IR-CFB boiler that is capable of burning a wide range of fuels, including:

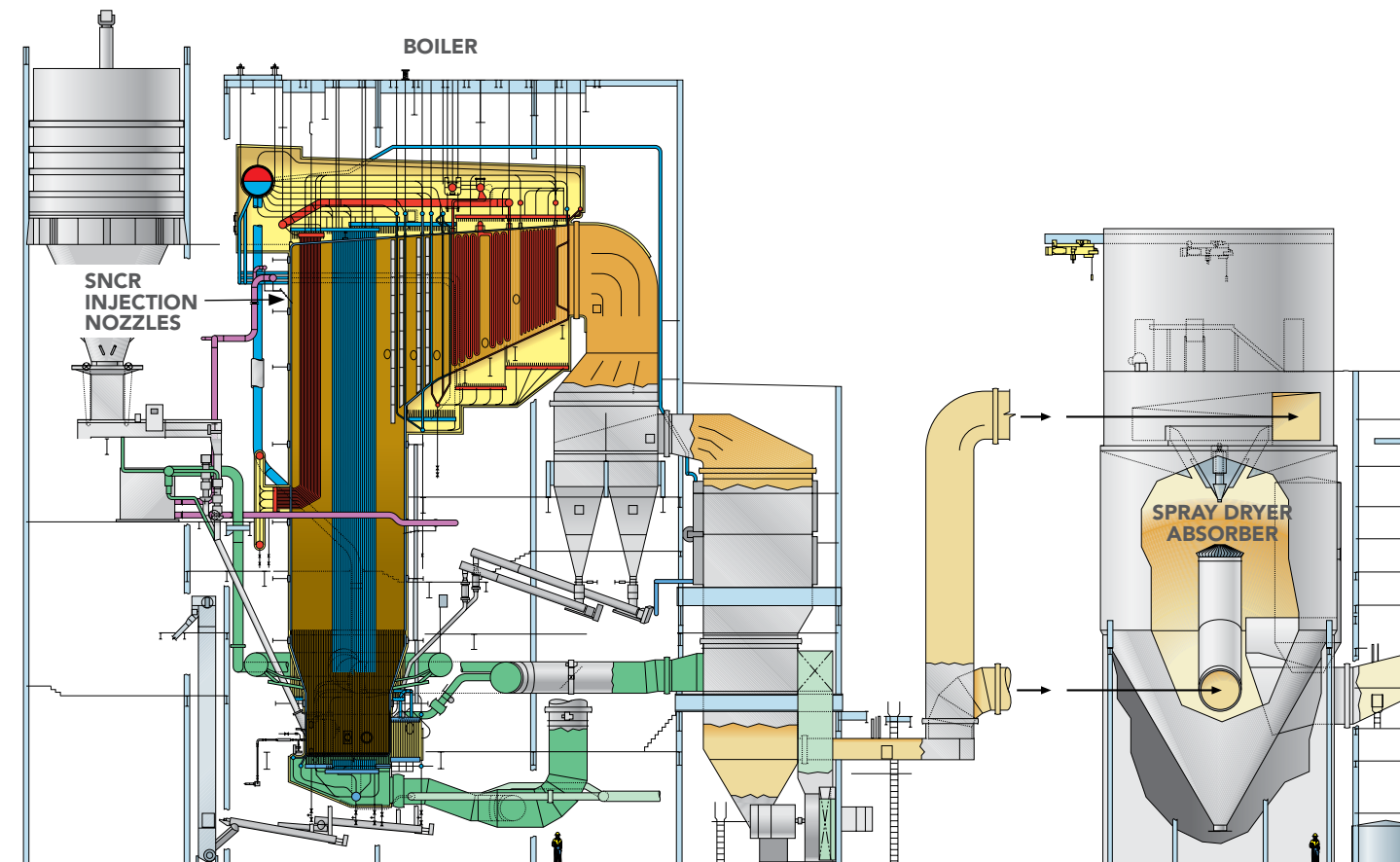
- Bituminous coal
- Bituminous gob or high-ash waste coal
- Subbituminous coal
- Lignite and brown coal
- Anthracite culm
- Coal cleaning tailings
- Petroleum coke
- Biomass

In addition, IR-CFBs allow the use of coals with a wide range of characteristics, as well as flexibility with sorbent choices:

HHV:	3500 to 12,000 Btu/lb (8.1 to 29.1 MJ/kg)
Ash:	Up to 60%
Moisture:	Up to 50%
Sorbents:	Limestone, dolomite, other low grade sorbents



In addition to coals, fuels such as wood, biomass, shredded tires and sludge are also candidates, depending on their percentage of heat input, moisture content and emissions requirements. The IR-CFB boiler also can be designed to burn several specified fuels in the same unit. This provides the additional flexibility needed to respond to changes in the fuel markets.

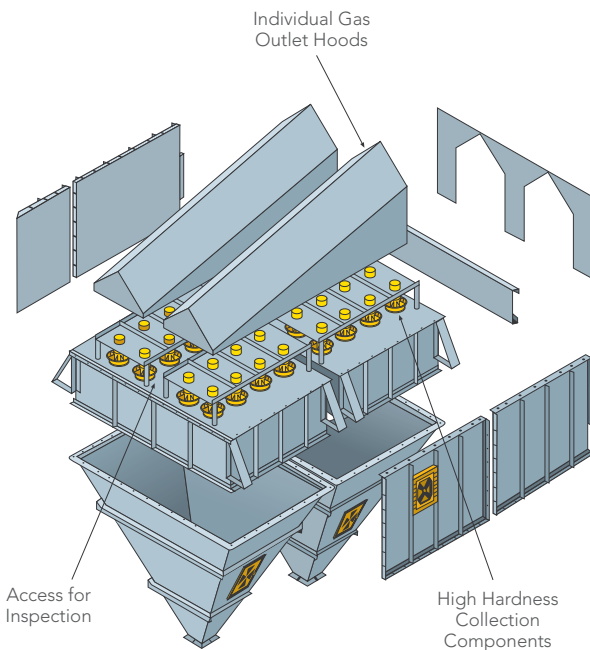


Emissions Control

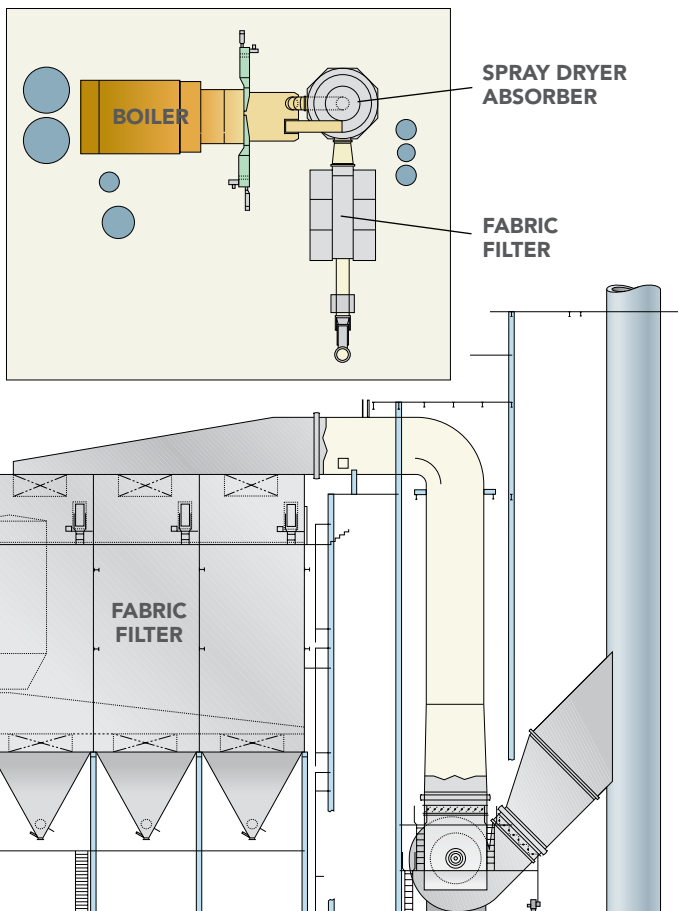
The IR-CFB boiler can control SO_2 emissions by injecting limestone into the lower furnace. Relatively low NO_x emissions are inherent in the IR-CFB due to low furnace temperatures and staged combustion. NO_x emissions can be further reduced by using a selective non-catalytic reduction (SNCR) system. In addition, the IR-CFB's secondary particle recycle system provides increased control, not found in other CFB technologies, to maintain an optimum uniform furnace temperature which is essential for low SO_2 and NO_x emissions.

When additional control of acid gases and particulate is required, B&W can integrate its state-of-the-art dry scrubbing and fabric filter technologies into the overall plant design. Our spray dryer absorber, circulating dry scrubbing, and dry sorbent injection technologies have proven successful in power generation applications as well as installations controlling emissions from industrial processes, district heating and waste-to-energy applications.

Our pulse jet fabric filters are available in various styles for maximum particulate collection efficiency and design flexibility to address site-specific arrangement requirements.



The secondary multi-cyclone dust collector in B&W's two-stage particle separation system provides increased collection efficiency of fine particles. By locating the dust collector upstream of the economizer in a region of cooler flue gas, and by using high hardness, wear-resistant material, maintenance is minimized. The design also permits easy access to all internal components.



Experience and Results Matter

There is no substitute for actual operating experience. B&W has that experience and a proven track record of high availability for all types of boiler technologies – including both our circulating and bubbling fluidized-bed combustion technologies.

Breadth

84 units have been installed using B&W's IR-CFB technology

Longevity

First unit started up in 1986

Availability

Proven reliable; typical availability of installed units is above 95%

IR-CFB Design Features and Benefits

Features	Benefits and Operating Results
Two-stage particle separation system	▪ Greater than 99.8% particle collection efficiency ▪ Provides a means to control particle density in furnace, which results in improved emissions and heat transfer ▪ Reduces operating costs ▪ Precise furnace temperature control ▪ Extended turndown ratio
All-internal primary solids recirculation (U-beams)	▪ Eliminates hot cyclone and its vortex finder, loop seal and loop seal blower ▪ Compact design requires less building volume than cyclone-based CFB boilers — critical for repowering projects
Low, uniform velocities at the furnace exit, U-beam separators, and the superheater	▪ Significantly reduces erosion in upper furnace and superheater compared with cyclone designs ▪ To date, no major U-beam erosion maintenance required in B&W's coal-fired CFBs since going into operation in 1989
No thick refractory due to elimination of hot cyclones and hot return legs	▪ Thin, cooled refractory used by B&W results in no boiler start-up or shut-down rate restrictions due to refractory heating or cooling ▪ Significantly reduces need for refractory maintenance ▪ Virtually eliminates forced outages due to refractory failures ▪ Requires only 10 to 25% of the total refractory compared with hot-cyclone CFB designs
In-furnace heat transfer surface	▪ Vertical, flat membraned tube panels within furnace perform evaporative or superheat duty ▪ Proven reliability and low maintenance



Features	Benefits and Operating Results
In-bed heat exchanger (IBHX)	▪ Faster load-following capability ▪ Controls steam temperature over a wide load range ▪ Low maintenance ▪ Compact design with less surface area of superheater and reheater tubes when compared to designs with final superheater in the waterwall or convection pass
Primary air nozzles (bubble caps)	▪ Reduces back sifting of solids during low-load operation ▪ Reduces need for periodic cleaning of nozzles and primary air windbox ▪ Minimizes erosion inside nozzle caused by the re-entrainment of back-sifted solids
Sootblowers usually not required upstream of MDC	▪ Eliminates maintenance costs and forced outages typically associated with sootblowers
Gravity fuel feed and fly ash recycle system	▪ Reduces maintenance, forced outages and auxiliary power requirements by eliminating the mechanical fuel injection and pneumatic fly ash recycle systems
High turndown (up to 5:1) without auxiliary fuel support	▪ Allows wider load swings ▪ Reduces operating costs (no auxiliary fuel) during low-load operation
Reduced diameter zone	▪ Less erosion of membrane walls

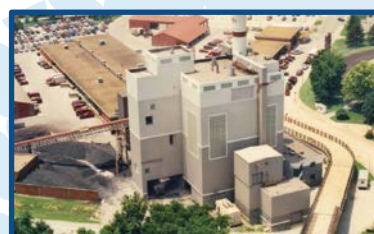
IR-CFB boiler owners and operators gain these benefits:

- » Higher boiler availability
- » Less maintenance cost
- » More steam production
- » Greater revenue



Through our experience, expertise and total-scope services, B&W is dedicated to providing engineered solutions in an environmentally safe, efficient and economical manner.

Our internal recirculation circulating fluidized-bed boiler is the technology of choice for power plant owners seeking reliability and flexibility.



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