



The value proposition of circulating fluidized-bed technology for the utility power sector

by R. Giglio* and N.J. Castilla*

Synopsis

Circulating fluidized-bed (CFB) combustion technology has been around for over 40 years, but over the last 6 years it has been commercially demonstrated at the 500 MW_e scale at the Łagisza plant located in Będzin, Poland. The CFB at the Łagisza plant has unique first-of-a-kind design features, such as vertical-tube supercritical steam technology and a low-temperature flue-gas heat extraction that allows the plant to achieve high plant efficiencies of over 43% (net lower heating value). Another unusual feature for a coal power plant is that this plant meets all its atmospheric emission permit levels without any post-combustion de-NO_x or de-SO_x equipment such as selective catalytic reduction (SCR) or flue-gas desulphurization (FGD).

CFB clean coal power technology is entering the utility power sector just in time to help deal with declining quality in internationally traded coals and to promote the large-scale use of economic, low-quality domestic fuels. Owing to the very attractive price discounts, growing supplies of low-quality Indonesian coals are outpacing the supply of high-quality Australian, Russian, and US coals. In Germany and Turkey, the use of domestic lignites for power production provides a secure and economic energy solution while creating domestic jobs.

Conventional pulverized coal (PC) boilers will have trouble accepting these off-specification coals because of their narrow fuel specifications; they typically call for heating values above 5500 kcal/kg. This limitation is not an issue for CFB technology because of its ability to burn the worst and best of coals with heating values ranging from 3900 to 8000 kcal/kg.

This paper provides an outlook for future coal supply, quality, and price, as well as a review of the technical and economic benefits of CFB technology firing low-quality fuels for utility power generation.

Keywords

value proposition, CFB, flexibility, lignite, Łagisza, circulating fluidized-bed, power generation.

Advanced CFB boilers for utility power generation

When the Łagisza power plant (Figure 1), located in the Katowice area of southern Poland, began commercial operation in June 2009, it marked a new era in the evolution of circulating fluidized-bed (CFB) technology. The plant is now celebrating its sixth year of successful commercial operation.

Besides being the most advanced operating CFB steam generator in the world, the CFB at the Łagisza plant has unique first-of-a-kind design features, such as vertical-tube supercritical steam technology and low-temperature flue-gas heat recovery system that allows the plant to achieve a very high net plant efficiency of 43.3% (based on the fuel's

lower heating value). A notable feature of the Łagisza CFB is that it meets all atmospheric emission permit levels without post-combustion de-NO_x or de-SO_x equipment such as selective catalytic reduction (SCR) or flue-gas desulphurization (FGD).

Like the Łagisza plant owners (PKE), Korean Southern Power Company (KOSPO) also saw value in CFB technology when it chose the technology for its 2200 MW_e Green Power Plant project in Samcheok, Korea (Figure 2). The Samcheok plant, which is now under construction, will utilize four larger 550 MW_e CFB boilers featuring ultra-supercritical steam conditions (257 barg, 603/603°C). These CFB boilers will be the most advanced units in the world when the plant comes on line as expected in 2016.

Both PKE and KOSPO first considered conventional pulverized coal (PC) technology for their projects, but after studying the additional technical and economic benefits that a CFB brings, they ultimately chose CFB technology. The CFB boilers offer many benefits, but two in particular played a big role in their decision. They were:

- The CFB's ability to reliably burn both low-rank and high-quality coals besides biomass and waste coal slurries (Łagisza only) dramatically improved the potential for huge fuel cost savings and high fuel procurement security
- The CFB's ability to meet atmospheric emission goals without FGD or SCR technology saved on capital, operating costs and water.

* Amec Foster Wheeler Global Power Group, Hampton, NJA, USA

© The Southern African Institute of Mining and Metallurgy, 2015. ISSN 2225-6253. This paper was first presented at IFSA 2014, Industrial Fluidization South Africa, Glenburn Lodge, Cradle of Humankind, 19–20 November 2014

The value proposition of circulating fluidized-bed technology for the utility power sector



Figure 1 – Łagisza CFB power plant located in Będzin, Poland



Figure 2 – 2200 MW_e Green Power CFB plant located in Samcheok, Korea

CFB's benefits are rooted in its unique combustion process

The CFB's advantages of reliability, low maintenance, a wide fuel range, and smaller and less costly boilers are rooted in its unique flameless, low-temperature combustion process. As Figure 3 summarizes, unlike conventional PC or oil/gas boilers, the fuel's ash does not melt or soften in a CFB, which allows the CFB to avoid many of the fouling and corrosion problems encountered in conventional boilers with an open flame.

Supercritical boiler design considerations

For once-through supercritical boiler designs (Figure 4), the low, even combustion temperature and heat flux throughout the CFB's furnace minimizes the risk of uneven tube-to-tube temperature variations, which permit the furnace walls to be constructed with cost-effective and easy-to-maintain smooth vertical tubes. For additional protection, Amec Foster Wheeler's once-through CFB boilers utilize a patented low-steam mass flux design providing a natural self-cooling characteristic that uses buoyancy forces to increase the water/steam flow in a tube proportionate to the amount of heat it receives. This further minimizes tube-to-tube temperature variations and ensures low mechanical stresses across the furnace, thereby extending furnace life.

To cope with the uneven temperatures and heat absorption in the furnace, most conventional PC and oil or gas once-through boilers incline and wrap the furnace wall tubes around the lower section of the furnace to even out tube-to-tube heat absorption and temperatures. Although this solves the heat imbalance problem, the spiral design has several disadvantages compared with Amec Foster Wheeler's CFB vertical-tube design. The spiral design requires a heavier, more complicated boiler and boiler support system

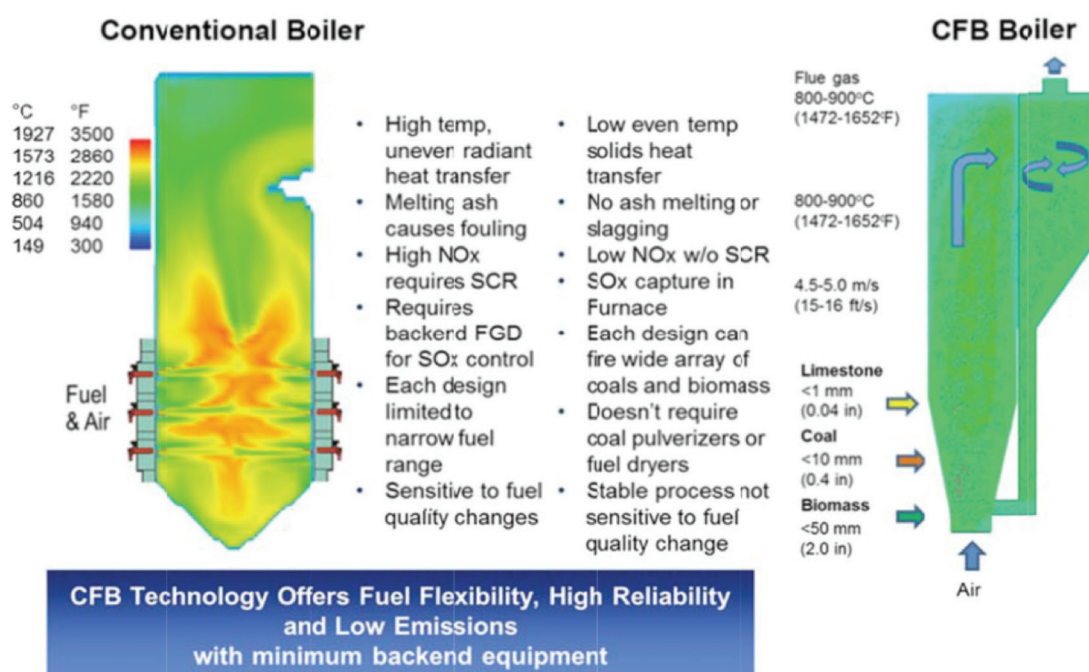


Figure 3 – Comparison of conventional *versus* CFB boiler technology

The value proposition of circulating fluidized-bed technology for the utility power sector

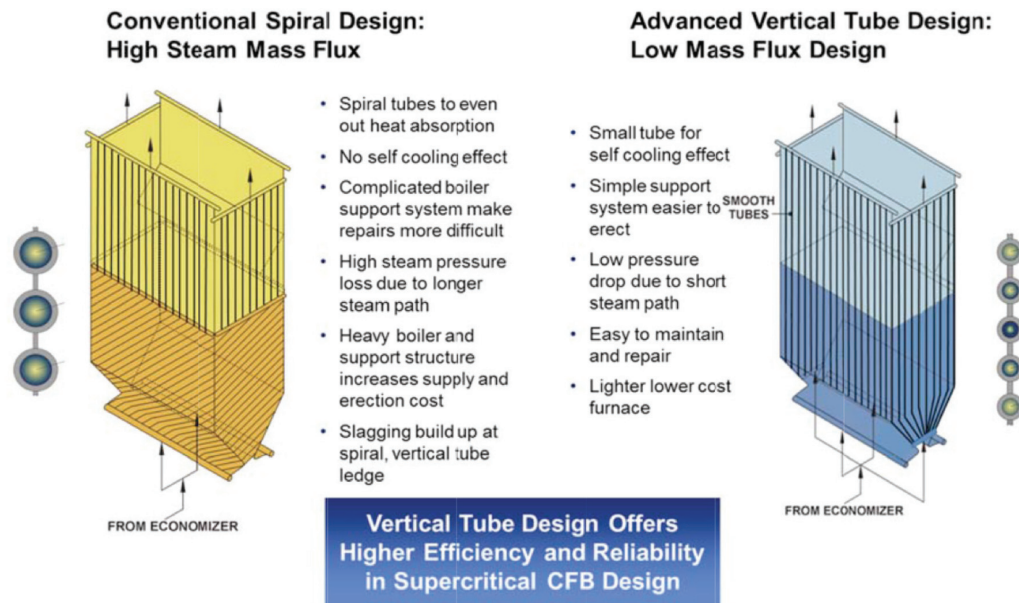


Figure 4 – Comparison of spiral versus vertical-tube once-through furnace design

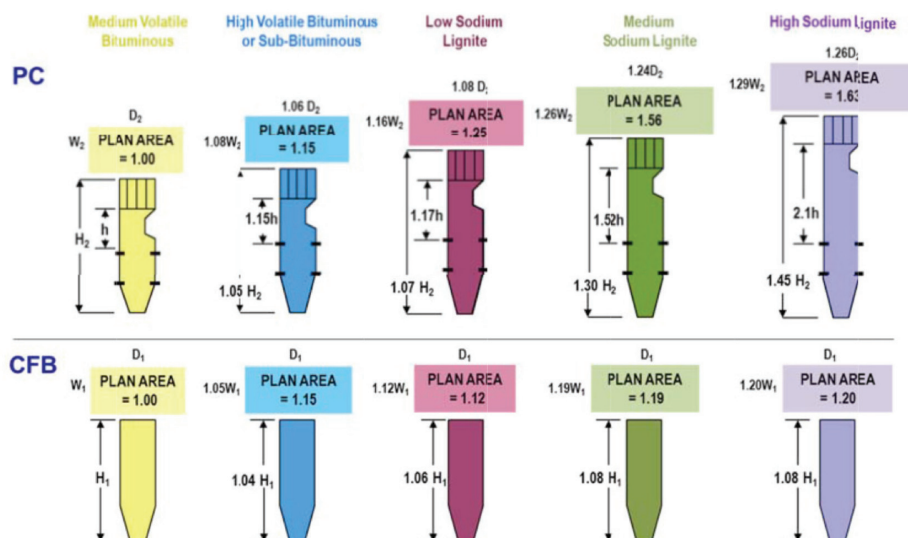


Figure 5 – Impact on furnace size as fuel quality degrades: PC versus CFB

which makes furnace tube repairs more difficult. Furthermore, the loss in steam pressure is high because the steam path is long and the ledge formed at the interface between the spiral and the vertical tube header is a natural location for build-up of slag.

Furnace size versus fuel quality

As ash does not soften or melt in a CFB, the size of the furnace does not increase as much as conventional boilers when firing lower quality fuels. As can be seen in Figure 5, in order to control fouling, slagging, and corrosion, the furnace height of a PC boiler doubles and its footprint increases by over 60% when firing a low-quality fuel such as high-sodium lignite, whereas the CFB boiler height increases by only 8% and its footprint increases by only 20%. This results in a CFB boiler that is smaller and costs less than a PC boiler.

Furthermore, unlike a PC boiler, a CFB boiler does not need soot blowers to control the build-up of deposits and slag in the furnace as the ash does not soften and the circulating solids themselves remove deposits and minimize their build-up on the furnace wall, panels and coils.

Superheater and reheater design considerations

Another very important feature of a CFB boiler involves the final superheat and reheat steam coils. These coils operate at the highest metal temperatures in the boiler, which makes them vulnerable to corrosion and fouling. This vulnerability increases significantly for supercritical boilers with high steam temperatures.

As shown in Figure 6, in a conventional PC or oil/gas boiler these coils are suspended from the furnace ceiling and are directly exposed to the slagging ash and corrosive gases

The value proposition of circulating fluidized-bed technology for the utility power sector

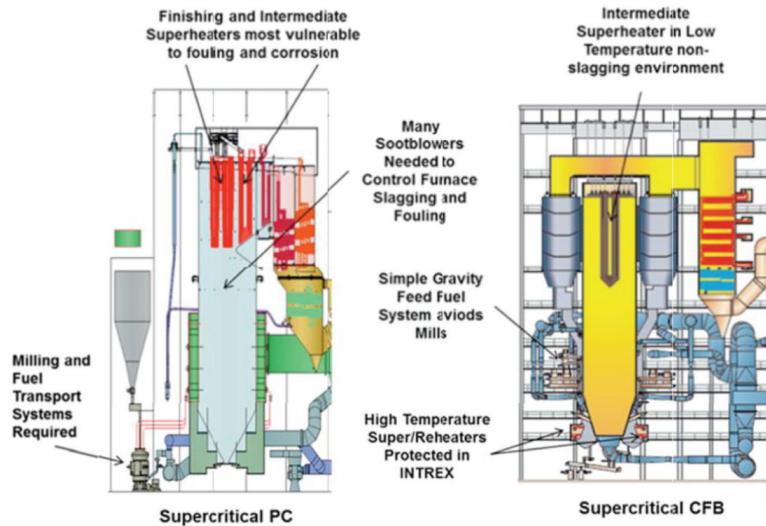


Figure 6 – A comparison of boiler design features: PC boilers versus CFB boiler

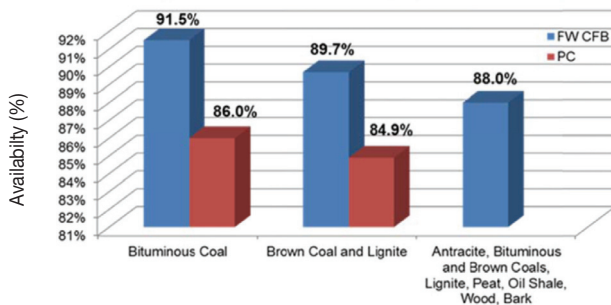


Figure 7 – Availabilities* of PC and CFB power plants. *Availability means total time plant is available to run accounting for both planned and unplanned downtime. The Amec Foster Wheeler CFB plant availability derives from client-supplied data reported over the period 2000–2008 for CFB plants located mainly in Europe. The PC values derive from client-supplied data over the period 2002–2011 for PC units that are mainly located in Europe ¹

(sodium and potassium chlorides) in the hot furnace flue-gas. To cope with this undesirable situation, boiler designers use expensive alloys and recommend a high level of cleaning and maintenance for these coils.

This design weakness is avoided in Amec Foster Wheeler's CFB boilers by submerging these coils in hot solids fluidized by clean air in heat exchangers called INTREX®, which protects them from the corrosive flue-gas (see Figure 6). The bubbling solids efficiently conduct their heat to the steam contained in the coils and as the solids never melt or soften, fouling and corrosion of these coils are minimal. Furthermore, because the high heat transfer rates of the solids (by conduction), the coil size is many times smaller than those in conventional boilers.

Fuel delivery system

A final important design issue involves the fuel delivery system to the boiler. A PC boiler requires the fuel to be finely ground and pneumatically transported and distributed to many burners. For low-quality, high-ash fuels such as brown coals and lignite, the power consumption of fuel pulverizers

increases dramatically and the fuel delivery system requires more maintenance as its reliability declines. A CFB boiler does not require pulverizers as its fuel is only coarsely crushed and fed to the CFB boiler directly from the fuel silos via a simple gravity feed system.

Overall plant reliability

Based on these process and design differences, CFB power plants have demonstrated plant availabilities well above conventional PC boilers, as shown by a recent study comparing PC plant availability to Amec Foster Wheeler CFB boilers (see Figure 7). Availability is defined as a percentage of 8760 hours, the total number of hours that a plant can be operationally available. The total includes both planned and unplanned downtime.

Power plants with CFB boilers had about a 5% (absolute) higher availability than PC plants, and this higher availability is maintained even for brown coals and lignites. For a 1000 MW_e supercritical coal power plant, this 5% difference in plant availability can translate into a \$160 million increase in power plant net income on a 10-year net present value (NPV) (see Figure 8).

Environmental performance and equipment requirements: PC versus CFB

From an environmental aspect, the low-temperature CFB combustion process (850°C for CFB versus 1500°C for PC/oil/gas) produces less NO_x and allows limestone to be fed directly into the furnace to capture SO_x as the fuel burns. In most cases SCR or a FGD is not needed, which dramatically reduces the plant installed and operating cost and water consumption while improving plant reliability and efficiency. For a 1000 MW_e power plant, the savings alone on the costs of SCR and FGD would be in the range of \$250 million–\$300 million.

¹ VGB PowerTech 2012. *Availability of Thermal Power Plants 2002-2011 – Report VGB-TW103Ve*

The value proposition of circulating fluidized-bed technology for the utility power sector

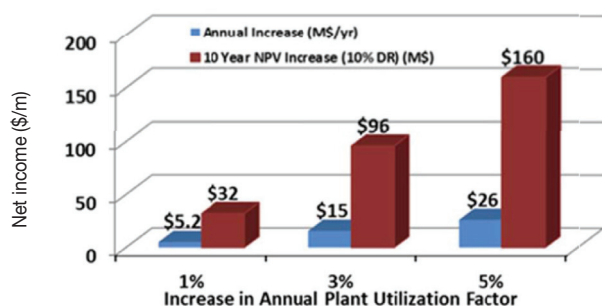


Figure 8 – Impact of plant utilization factor on annual plant net income for a 1000 MW_e supercritical steam power plant operating at a utilization factor of 90% and receiving a \$100 per MW_e electricity tariff based on buying coal at \$100 per ton

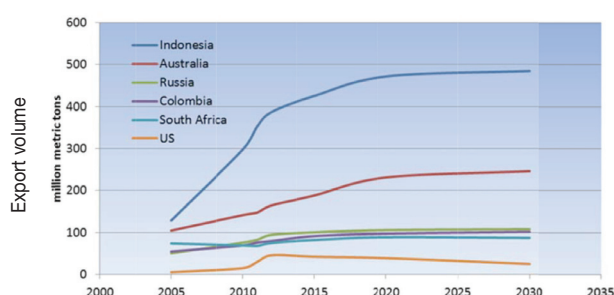


Figure 9 – Global coal exports. Source: historical data and Amec Foster Wheeler projections

A permanent change to the global coal market

Since 2005, Indonesian coal exports have grown faster than all other countries combined; nearly quadrupling to 400 Mt in 2013 (see Figure 9). Projections into the future predict Indonesian exports reaching nearly 500 Mt by 2030, about twice that of Australia, the world's second largest exporter of coal.

Today about 50% of the coal exported from Indonesia is low-quality, high-moisture sub-bituminous in quality with gross-as-received (GAR) higher heating values ranging from 3900 to 4200 kcal/kg, well below the 6000 kcal/kg benchmark used in the international coal market for the last 50 years.

Over the last 3 years, the quality of Indonesia's export coal has been declining, and this trend is expected to continue well into the future. Today about 60% of Indonesia's coal mines hold low-rank sub-bituminous coals. The other 40% hold bituminous coals estimated to have heating values less than 5200 kcal/kg. The heating value of Indonesia's export coals has been steadily declining and is forecast to continue, a trend that reflects the impact of mining this lower quality coal.

The primary driver for the ballooning share of Indonesian coal in the international coal market is simple economics. The current and forecast price discount between Indonesia's sub-bituminous 4200 kcal/kg Ecocoal and a 6000 kcal/kg Australian thermal coal, both on a net-as-received basis (NAR), shows a steady pattern: a 48% or \$55 per metric ton average discount for the lower quality Indonesia coal over the period from 2012 to 2020 (see Figure 11). The difference in

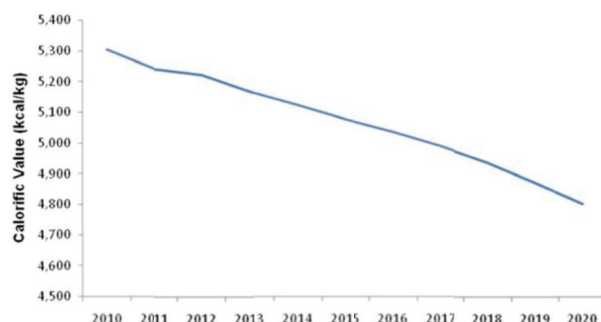


Figure 10 – Average gross heating value of Indonesian export coal. Source: marketing, sales and logistics analyst, Banpu PCL

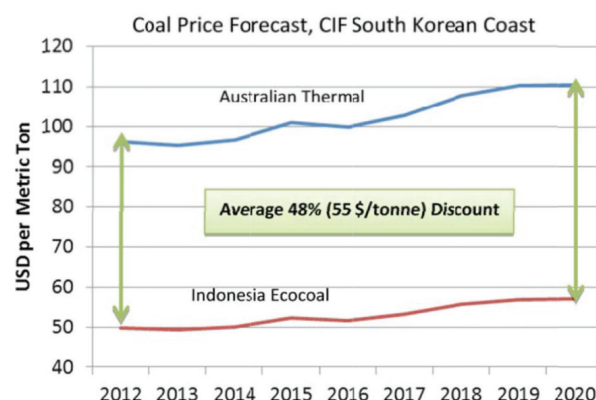


Figure 11 – Difference in prices between Indonesian Ecocoal and Australian thermal coal delivered (CIF) to the coast of South Korea. Prices shown are nominal. Source: Amec Foster Wheeler forecast

heating value, which amounts to 30% on a comparative energy basis, translates into a very attractive net 18% discount for the Ecocoal, a benefit that goes right to the bottom line of a power plant's balance sheet.

Since fuel cost makes up about 85–90% of the total operating cost of a large power plant, it would be foolish to ignore the economic benefits of using low-quality fuels. We can see this in several domestic markets, where low-quality coals and lignites play a major role in power production. For example, 77% of Germany's solid fuel power is produced from lignite; only 23% is produced from hard coal. In the USA, 54% of the solid fuel power comes from low-quality sub-bituminous coals. Use of low-rank coals and lignites for power production is growing in Turkey, India, China, Indonesia, Australia, South Africa, and Mozambique, a trend driven by the very low cost of these fuels relative to premium coals.

Until recently, low-quality coals and lignites have been confined to domestic markets and have not been part of the international coal market. This is because their economic benefit is quickly eroded by their transportation costs, owing to the lower energy contents of the coals. But today we see more low-quality coals and even lignites coming into the global coal market, a move that is driven by steep price discounts in a tight market for premium coals. From 2001 to 2010 for example, Korean imports of Indonesian coals (mostly sub-bituminous) increased sevenfold by 38 Mt, while imports from Australia coal grew by only 13 Mt.

The value proposition of circulating fluidized-bed technology for the utility power sector

This trend is not expected to change any time soon. Instead, it looks to be a permanent shift towards a more flexible coal market, where buyers and sellers trade price for coal quality, similar to markets in many other commodities and finished goods.

The impact of the changing coal market on coal boiler technology

This price *versus* quality shift in the global coal market will likely be viewed as good news by some observers and bad news by others, with the responses depending on their power plant technology position. PC power plants with tight coal specifications (here one thinks of supercritical designs) will have a limited ability to use the discounted coals. These plants will have to choose either to stay within the tightening premium coal market or to venture into the broader coal market and trade lower plant outputs, reduced reliability, and higher maintenance costs for discounts in the cost of fuel.

On the other hand, the shift will come as good news for power generators utilizing CFB technology. Owing to the CFB's fuel flexibility, plant owners can access the full range of discount coals (even for ultra-supercritical designs), buying fuels for maximum economic benefit while avoiding the high-priced premium coals. Furthermore, the impact of declining coal quality on plant output, reliability, and maintenance is minimized with a CFB, and the risk of future carbon regulation is lessened because of the CFB's ability to utilize biomass and other carbon-neutral fuels.

For new power plants, this trend clearly increases the value of fuel-flexible coal plants such as those utilizing CFB technology and will likely push towards (if not accelerate) the adoption of CFB technology in large coal-fired utility plants. The timing seems right, as CFB technology has demonstrated its capabilities in serving the utility power sector. This is not to say that new PC boiler power plants cannot be designed to burn low-rank fuels. They can. The point for consideration is that once a PC is designed to use a specific low-rank fuel, the

plant has difficulty burning other fuels without adversely affecting plant performance, reliability, and maintenance.

The economic benefits of CFB technology at the utility scale

To quantify the benefits of CFB technology on a large utility-plant scale, Amec Foster Wheeler conducted a study comparing both the technical and economic performances of two supercritical 1100 MW_e (gross) power plants. One of the plants used conventional PC technology and the other CFB technology. The study involved the development of full power-plant financial models, heat and material balances, as well as conceptual plant designs for plant layout, sizing, and cost estimation purposes. For the purpose of comparison, a number of performance metrics were evaluated. They included plant capital and operating costs, plant height and footprint, reliability, atmospheric emissions, solid and liquid inputs, and waste streams.

The PC plant was configured with a single 1100 MW_e ultra-supercritical boiler that provided its steam to a single 1100 MW_e steam turbine generator. The plant fired an Australian bituminous thermal coal with an NAR heating value of 5500 kcal/kg and a sulphur content of 0.35%. The coal was priced at \$95 per metric ton. SCR was installed in the boiler to control stack NO_x emissions to 50 ppmv (6% O₂ dry) and wet limestone FGD was installed behind the boiler to control stack SO_x to 50 ppmv (6% O₂ dry).

The CFB plant was configured with two 550 MW_e ultra-supercritical boilers that provided steam to a single 1100 MW_e steam turbine generator. The CFB plant fired an Indonesian sub-bituminous thermal coal (Ecocoal) with an NAR heating value of 4200 kcal/kg and sulphur content of 0.27%. The coal was priced at \$55 per metric ton. SCR was installed in the boiler to control NO_x emissions to 50 ppmv (6% O₂ dry), but no separate FGD was installed behind the CFB boiler, for the boiler itself used limestone to control stack SO_x to 50 ppmv (6% O₂ dry).

Table I

A comparison of capital costs of 1100 MW_e supercritical PC and CFB power plants

Note: Absolute design and supply boiler cost depends on scope. Source: Amec Foster Wheeler study

Case	1	2
Boiler Technology	USC PC	USC CFB
Boiler and Steam Turbine Configuration	1 x 1100 MW _e PC Boiler on 1 x 1100 MW _e STG	2 x 550 MW _e CFB Boilers on 1 x 1100 STG
AQCS Equipment Configuration	SCR + Wet FGD	SCR Only
Plant Fuel	5500 kcal/kg Bituminous Coal	4200 kcal/kg Indonesian Sub- Bituminous Coal
D&S Boiler Cost Index (Two CFBs burning lower quality fuel are more costly than PC)	1.000	1.106
D&S Coal Mill Cost Index (no mills needed for CFB)	Included in Boiler Price	0.0
D&S FGD Cost Index (130 \$/KWe for WFGD, no FGD for CFB)	0.37	0.0
Total D&S Cost Index	1.37	1.106
Total Boiler + FGD D&S Cost (M\$) (assuming 350 M\$ D&S Boiler Cost ¹)	480	387

The value proposition of circulating fluidized-bed technology for the utility power sector

Table II

A comparison of costs of 1100 MW_e supercritical PC and CFB power plants.

Source: Amec Foster Wheeler study

Case	Units	1	2
Boiler Technology		USC PC	USC CFB
Boiler and Steam Turbine Configuration		1 x 1100 MW _e PC Boiler on 1 x 1100 MW _e STG	2 x 550 MW _e CFB Boilers on 1 x 1100 STG
AQCS Equipment Configuration		SCR + WetFGD	SCR Only
Plant Fuel		5500 kcal/kg Bituminous Coal	4200 kcal/kg Indonesian Sub- Bituminous Coal
Coal	M\$/yr	299	233
Limestone	M\$/yr	1.4	3.3
Boiler Ash Disposal/Sales	M\$/yr	0.27	1.3
Other Variable O&M Costs	M\$/yr	36.6	31.3
Total Annual Cost	M\$/yr	338	269
Total Savings in OPEX	M\$/yr	Base	69
OPEX Savings 10 yr NPV	M\$	Base	424

\$66M/yr in Fuel Cost alone

Table III

A comparison of annual and NPV electricity production costs for 1100 MW_e supercritical PC and CFB power plants. Source: Amec Foster Wheeler study

Case	Units	1	2
Plant Technology		USC PC	USC CFB
Plant Configuration		1 x 1100 MW _e PC Boiler on 1 x 1100 MW _e STG	2 x 550 MW _e CFB Boilers on 1 x 1100 STG
Power Plant Fuels		5500 kcal/kg Bituminous Coal	4200 kcal/kg Indonesian Sub-Bituminous Coal
Fuel Cost (Delivered)		95 \$/tonne	55 \$/tonne
Plant EPC Specific Capital Cost	\$/net KWe	1,828	1,754
Plant EPC Capital Cost	B\$	1.886	1.821
Savings in Cost of Electricity from USC PC Plant	\$/MWh	Base	10
Savings in Cost of Electricity from USC PC Plant	M\$/yr	Base	81.8
10 yr Total NPV Value at 10% DR	M\$	Base	503

Fuel cost savings contributes most value

We compare the capital costs of boiler and pollution control equipment on a design and supply basis, excluding erection (see Table I). Even though the cost of two CFB boilers burning a low-rank coal is about 11% higher than the cost of a single large PC boiler burning a high-quality coal, meeting emission targets without installing an FGD for the CFB boilers resulted in a net \$93 million savings in capital for the CFB plant configuration.

As for operating costs (see Table II), using the discounted Indonesian coal, the CFB plant saves \$66 million annually in fuel costs. Adding in other operating costs such as limestone, ash disposal, gypsum sales, and maintenance increases savings to \$69 million. These savings are worth \$424 million in NPV over a 10-year period.

A full financial proforma model for both the PC and CFB plant configurations was developed to calculate the levelized electricity production cost for each plant configuration. In addition to total capital and operating costs, the proforma analysis takes into account plant utilization, financing conditions and terms.

Figure 12 compares the proforma analyses and the components that make up electricity production costs. The smaller capital and fuel cost components for the CFB plant results in a net savings of \$10 per megawatt-hour of electricity produced. This translates into \$82 million annually based on 90% plant utilization: the savings are worth \$503 million NPV over a 10-year period (see Table III).

The value proposition of circulating fluidized-bed technology for the utility power sector

Table IV

A comparison of emissions, plant efficiency, fuel, limestone, ash, and FGD water flow in 1100 MW_e supercritical PC and CFB power plants. Source: Amec Foster Wheeler study

Case	Units	1	2
Boiler Technology		USC PC	USC CFB
Boiler and Steam Turbine Configuration		1 x 1100 MW _e PC Boiler on 1 x 1100 MW _e STG	2 x 550 MW _e CFB Boilers on 1 x 1100 STG
AQCS Equipment Configuration		SCR + Wet FGD	SCR Only
Plant Fuel		5500 kcal/kg Bituminous Coal	4200 kcal/kg Indones Sub-Bituminous Co
Plant Air Emissions (SO _x /NO _x /PM)	ppm mg/Nm ³	50ppm/50ppm/ 30 Mg/nm ³	50ppm/50ppm/ 30 mg/nm ³
Net Power Plant Output	MWe	1032	1038
Total Plant Auxiliary Load	% Gross Power	6.2	5.6
Net Power Production Efficiency	%LHV	43	43.3
Fuel Flow	tonne/hr	400	538
Limestone Flow	tonne/hr	4.3	10.4
Plant Ash/Scrubber Product Flow	tonne/hr	32	34
FGD Water Requirement	Kgal/hr	66	0

Same Stack Emissions

Lower Aux Load since no FGD

About same plant solid byproduct

2 million m³/yr water savings

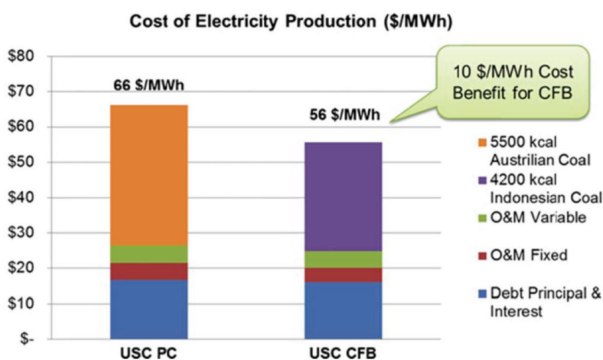


Figure 12 – A comparison of levelized electricity production costs for 1100 MW_e supercritical PC and CFB power plants. Source: Amec Foster Wheeler study

Finally, Table IV compares other plant parameters and performance metrics, highlighting that both the CFB and PC plants meet the same stack emission limits, but as the CFB plant does not have a separate wet FGD for SO_x control, it saves about 2 × 10⁶ m³ of water annually.

Conclusions and observations

Six years of successful operation of the large supercritical once-through CFB boiler at the Łagisza power plant in Poland has demonstrated CFB technology for utility power generation. KOSPO reinforces this conclusion by selecting Amec Foster Wheeler CFB technology for its 2200 MW_e Green Power Project in Samcheok, Korea.

Because combustion is flameless and occurs at low temperatures, CFB technology offers many benefits for utility power generation. Its fuel flexibility, reliability, and ability to meet strict environmental standards with minimal post-

combustion pollution control equipment are highly valued benefits for utilities. Additionally, the CFB's load-following flexibility (CFB has the same load ramp rates as a PC, but better turndown) is another important value for grids containing a high level of intermittent renewable power. As an example, the Łagisza unit cycles daily between 40 and 100% MCR to meet the requirements of the Polish national grid.

The CFB benefits become more compelling when considering low-quality fuels. The technology is able to provide smaller, less costly boilers as fuel quality declines, while achieving plant availabilities well beyond conventional PC boiler technology.

The global coal market is moving away from traditionally rigid, single-specification coal towards a more flexible price-for-coal-quality market. The convergence of the coal market shift with the CFB's entry into utility power application is expected to speed up the adoption of CFB technology in the large utility power sector.

Owing to the large economic benefit, the use of domestic brown coal and lignite for utility power generation is growing in Germany, Turkey, and Indonesia, all of which have abundant supplies of economical low-quality coal and lignites. It is expected that CFBs will be utilized more in these markets.

A technical and economic study conducted by Amec Foster Wheeler showed that a large utility CFB power plant has a compelling economic advantage over a traditional PC power plant, mainly because the CFB plant does not require post-combustion FGD equipment and can utilize a low-quality Indonesian coal. The numbers indicate that a 1100 MW_e CFB power plant would cost \$93 million less to build and would produce a net saving in the cost of producing electricity of about \$82 million annually, worth \$503 million on a 10-year NPV basis. In today's price-sensitive global utility market these numbers deserve serious consideration. ♦