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Technology comparison of CFB versus pulverized-fuel firing for utility power generation

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Abstract—Recent developments in Circulating Fluidized Bed (CFB) once through supercritical technology (OTSC) have enabled this technology to be offered as utility-scale projects competing head to head with pulverized fuel (PF) once through supercritical offerings as evidenced by the Łagisza Power Plant in Poland owned by Południowy Koncern Energetyczny S.A. (PKE) . This unit has now been in commercial operation for two full years since initial full load operation showing very good performance and has confirmed Foster Wheeler's performance model at this utility scale as well as for units in the 600 MW_{el} and 800 MW_{el} size ranges offering net efficiency of ~43% (LHV basis). This operating unit also validated the use of the world's first FW/BENSON™ vertical tube OTSC low mass flux technology. Since the Łagisza original international tender was for OTSC PF technology it is of importance to note that the alternative selection of CFB OTSC technology over conventional PF technology is of historic significance not only for the validation of the CFB platform as a viable alternative to conventional PF technology but it also positions the CFB OTSC with fuel flexibility for offering of sizes up to and including 800 MW_{el} units.

This paper explores the differences between CFB OTSC technology and standard PF OTSC in utility power generation. Provided are selection criteria, fuel burning range in both technologies and other selection drivers. Economic analysis of both technologies based on existing built cases is also provided. Also discussed will be the technical advantages and uses of each technology. Foster Wheeler has just recently been awarded a contract for 4 units of CFB OTSC technology which utilizes a 2 on 1 configuration of 2×550MW_{el} CFB OTSC boilers on two single 1000 MW_{el} turbines. Essentially this provides a fuel flexible low emissions alternative for a 2×1000 MW_{el} solid fuel power block.

INTRODUCTION

Coal fired power plants account for over 40% of all electricity generation globally. Some countries have even higher percentages of coal electricity generation throughout the world as shown in Table 1.

Table 1. Coal in electricity generation, %.

South Africa	93	Poland	92	PR China	79
Australia	77	Kazkhstan	70	India	69
Israel	63	Czech Rep.	60	Morocco	55
Greece	52	USA	49	Germany	46

Source: IEA 2010

In today's global utility industry the most widely used technology for large scale utility coal fired steam generators has been pulverized fuel firing of so called "steam" quality coal. These pulverized fuel boilers fire coal in differing configurations including wall firing, corner firing and in some cases for low volatile fuels arch firing. The coal being fired in these boilers is generally a high to medium quality bituminous coal which in many cases beneficiated through some type of washing.

Foster Wheeler has designed and supplied over 130,000 MW's of the type of solid fuel steam generators discussed in this paper. These units include a) subcritical and supercritical pulverized fuel/coal (PF/PC) wall fired steam generators firing high to medium quality bituminous, sub bituminous coals b) subcritical and supercritical arch-fired units firing low volatile anthracite and c) subcritical and supercritical circulating fluidized bed (CFB) steam generators firing a wide array of solid fuels including; all coals, petroleum coke, biomass, waste coal and oil shale to name a few.

There have been three significant milestones related to utility steam generators achieved by Foster Wheeler in the last few years. The first came in 2009 with the successful completion and commercial operation of the world's largest and first super critical CFB, the Łagisza 460 MW_{el} CFB OTSC BENSON vertical tube design in Poland. The project was originally specified as a PF unit but was selected as an alternative due to the CFB's ability to burn a wider range of fuels which favorably impacted the life cycle economics. This project has now been in operation for over two years and has proven the design platform for Foster Wheeler's 550 MW_{el}, 660 MW_{el} and 800 MW_{el} BENSON vertical designs. The second is the Longview 760 MW_{el} super critical PF BENSON vertical ribbed tube (VRT) design which has just recently been put into successful commercial operation in Madisonville Virginia in the United States. The third is the recent contract award for 4×550 MW_{el} super critical CFB BENSON vertical units supplied by Foster Wheeler to the Kospo for the Samcheok project in South Korea. This project features a "2 on 1" configuration of 2 each 550 MW CFB units on a single 1000 MW turbine with two separate 1000 MW power blocks. The significance of the Samcheok Project is that it was awarded based upon the favorable environmental and economics of the CFB units in straight up competition with 2 single 1000 MW PC units on 2 single 1000 MW_{el} turbines.

TREND TO HIGHER EFFICIENCY GENERATION

In today's coal generation expansion markets the trend is to install larger 660 MW to 1000 MW single or multiple PF units with once through super critical (OTSC) technology with steam pressures approaching 300 bar and temperatures around 600°C. The advantage of using increasingly higher efficiency steam cycles is to improve net plant heat rate which essentially produces the same amount of electricity with reduced fuel usage, air emissions (CO_2, SO_x, NO_x, Hg and dust) while also reducing O&M cost. As illustrated in Figure 1 below, you can see the improvement in net plant heat rate as the steam temperature and pressure is increased from subcritical to supercritical conditions.

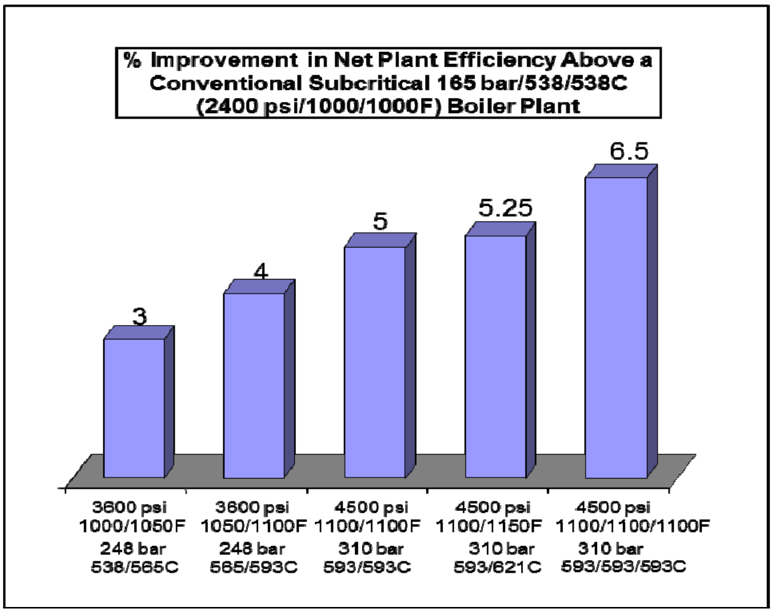

Figure 1. Improvement in net plant efficiency

TECHNOLOGY COMPARISONS

Graphic illustrations of the differences in the PC versus CFB are shown in Figure 2 for a supercritical design. Although the heat recovery areas of the boilers are similar with the exception of the reheat steam temperature control scheme, major differences can be seen in the furnace sections. One major difference is the CFB utilizes a continuous hot solids return system to the furnace which offers many advantages. The CFB hot solids circulating system acts as a thermal "flywheel" which increases solids retention time resulting in good carbon burnout and homogeneous heat flux throughout the furnace and return system. A couple of key benefits of this thermal flywheel effect are:

a) Capability of burning a wider range of fuel and

b) Ability to tolerate variations in fuel quality on an "real time" basis.

This alone favorably affects the variable O&M economics. While the PC uses rotating mills and transport air to deliver fuel to multiple levels of burners to fire the pulverized fuel, the CFB boiler uses startup burners for initial warm up then when reaching a solid fuel temperature permit the solid fuel is gravity fed to the units with virtually no flame present. The combustion temperature remains fairly constant between 875–925°C.

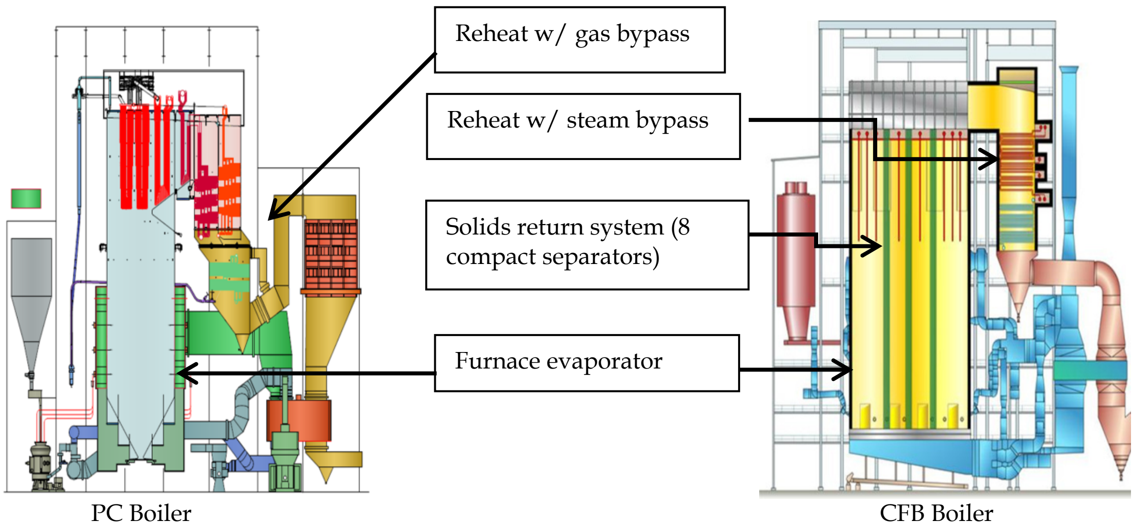

Figure 2. Large-scale OTSC PC versus CFB comparison

The difference in combustion temperature between the boilers is dramatic as shown in the first bullet of Tables 2 and 3. The lower combustion temperature in the CFB generates much less thermal NO_x while also producing an even temperature profile in the furnace as compared to the PC unit.

As you compare the attributes in Tables 2 and 3 many favor the CFB as a technology choice, especially in todays utility climate given the concerns for carbon emissions balanced against affordable power made available to the public.

The difference in the heat flux profiles between the two technologies are graphically shown in the following Figure 4. The heat flux comparison illustrates the difference in design requirements for evaporator tube cooling of the CFB versus the PC. Both units utilize Foster Wheeler's BENSON low mass flux evaporators although there is less tube to tube differential temperature in the CFB which reduces heat stresses to the boiler tubes producing a positive affect on long term reliability. The graphic shown on the right plots the heat flux input of the CFB compared to the percent of PC wall fired and PC arch unit heat flux as a function of furnace height. The peak fluxes of the PC units are in the burner zones while the CFB heat flux is fairly constant throughout the furnace.

Table 2. PC attributes

• Combustion temperature 1300-1400°C • In furnace soot blowers normal practice • Melting ash could cause potential slagging in furnace • Fast burn • Open flame • Achieving reasonable NO_x levels require low NO_x burners with SCR • No sulphur retention in the furnace • Greater possibility of heat related tube damage due to higher temperature Differentials between water and flame and high heat flux in the burner zone • Sensitive to sudden changes in fuel quality

Table 3. CFB Attributes

• Combustion temperature 850-900°C • No furnace slagging • No furnace soot blowing • NO_x formation reduced due to staged combustion – SNCR add on simple • SO_2 retention simple by adding limestone into the furnace • SO_x capture • Flue gas temperature profile homogenous throughout the furnace lowers stress due to reduced differential temperature between gas and water side • Insensitive to sudden changes in fuel quality • Long residence time for good carbon burn out

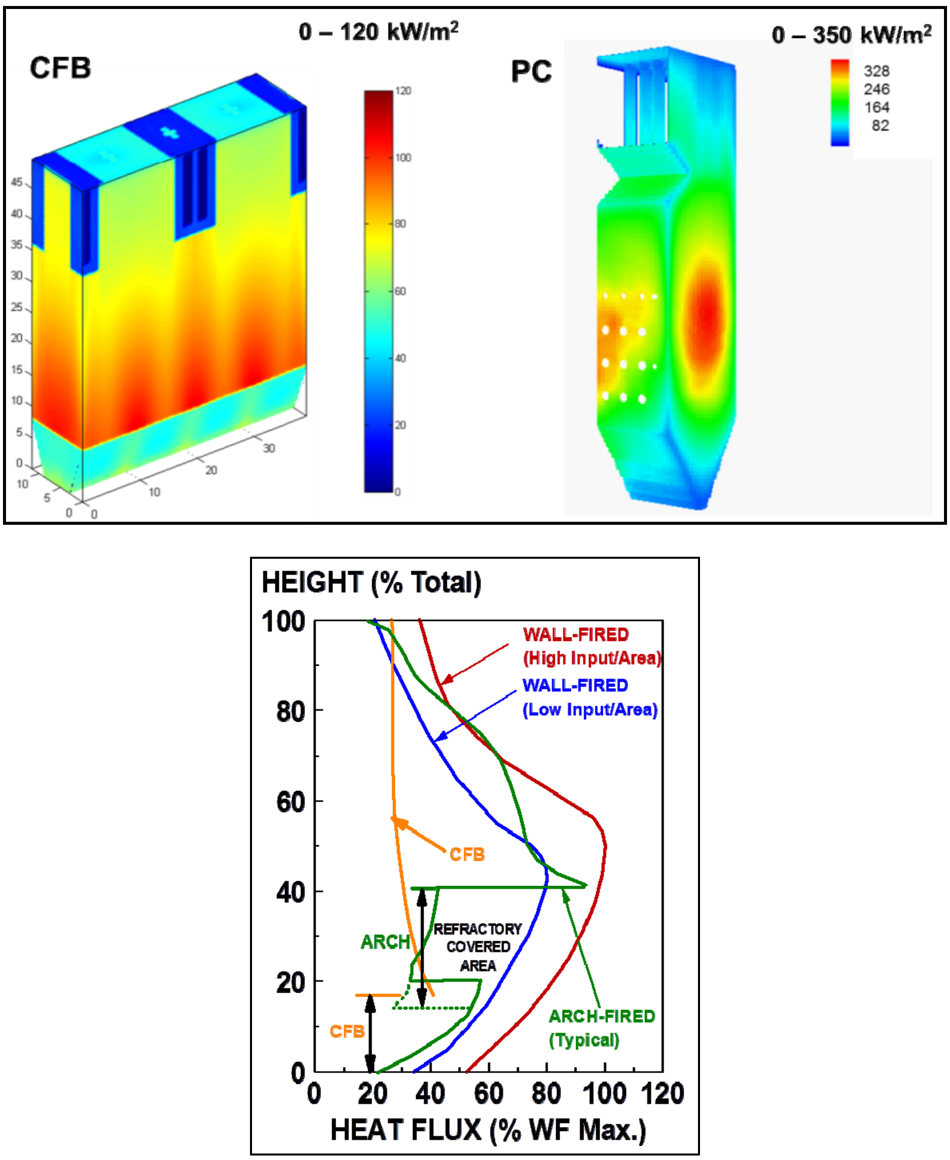

Figure 3. CFB versus PC heat flux comparison

DRIVERS TO CONSIDER

PC—Steam coal readily available

A good example of drivers which would influence the selection of a PC over a CFB would be high availabilty of a local steam quality low sulphur coal with relatively relaxed emission requirments (eg. SO_x limits above 2000 mg/nm3 and NO_x limits above 750 mg/nm3). In other words, no selective catalytic redcution system (SCR) or flue gas desulphurization (FGD) system would be required on the back end of the PC unit in this example. In this example there may be at a slight first cost advantage in selecting the PC over the CFB. However, if requirements to ratchet down emissions at some futuer date are required, there are substantial retrofit capital costs which would have to be accounted for in theanalysis of lifecycle costs of the plant. With scrubber costs in the $125/KW–$270/KW range for new units it could be as much as $500/KW if you had to retrofit units.

CFB—Low emission requirements/lower fuel quality available

On the other hand if the emission requirements were much lower eg. below 200 mg/nm3 and there is reasonable access to lower quality fuel with higher sulphur content and lower heating value or higher ash, this example could easily favor the CFB because of its ability to burn lower quality fuels while maintaining low emissions without the addition of SCR's or FGD systems which would be necessary for a PC. To more clearly understand the differences in fuel burning capability of both technologies, please see Figure 4 as it compares the fuel burning range in heating value versus burning difficulty of most of todays fuels. Note the PC fuel range in the black circle as compared to the range of the red rectangle for the CFB. This graphic clearly shows the fuel flexibility of the CFB. When you couple this flexibility with the ability to burn or blend lower cost fuels the economics will clearly favor the CFB.

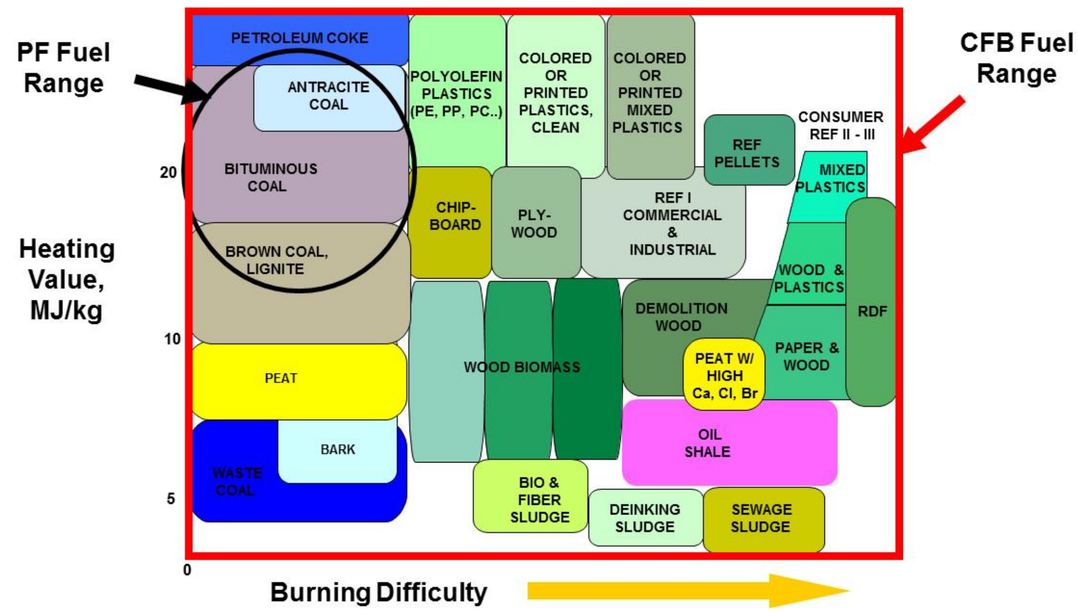

Figure 4. Fuels heating values versus burning difficulty

ECONOMIC ANALYSIS

A recent study was completed comparing PC and CFB economics. The results of this study "Power Plant Case Assumptions" analysis is shown below in Table 4. This analysis compares the two steam generator technologies for a plant configured for an output of 660 MW electric. The base technology is a PC with CFB compared in 3 different fuel cases all using super critical steam cycles.

The coal used in the example for the PC is a typical 6000 kcal/kg steam coal. The supercritical CFB comparison in column 2 is based upon utilizing the same coal as the supercritical PC. Note there is a few per percent decrease in electrical production costs but nearly $150/kW reduction in capex for the CFB because of an FGD system required for the PC. The economics of burning a lower heating value coal in a CFB is shown column 3 and a typical petroleum coke in column 4. It clearly shows the CFB option can offer the increased value for power production as compared to the PC especially when burning a lower grade fuel or a petroleum coke. The CFB petcoke fired unit production cost is $20/MWh less than that of the PC unit firing the 6000 kcal coal.

Table 4. “Power Plant Case Assumptions”analysis.

Case	Units	1"	2"	3"	4"
Plant Type		PC	CFB	CFB	CFB
Steam Cycle Technology		Supercritical OTU	Supercritical OTU	Supercritical OTU	Supercritical OTU
Additional Economical Fuels Plant can Utilize			All Coals, Petcoke, Biomass	All Coals, Petcoke, Biomass	All Coals, Petcoke, Biomass
Additional Pollution Control Required		Dry FGD + SCR			Dry FGD
Plant Gross Power Capacity	MWe	660	660	660	660
Plant Net Power Capacity	MWe	595	594	594	591
Plant Utilization Factor	%	90	90	90	90
Plant Net Efficiency	%HHV	40	40	40	40
Fuel		6000 kcal coal	6000 kcal coal	4900 kcal coal	Petcoke
Fuel Sulfur Content	%	0.8	0.8	0.2	6.0
Fuel Cost	$/Mbtu	4.2	4.2	3.9	2.0
Fuel Cost	$/tonne	100	100	75	60
Electricity Production Cost	$/MWh	101	96	92	81
Savings in Electricity Production Cost	$/MWh	Base	5	9	20
Annual Savings in Electricity Production Cost[1]	M$/year	Base	23.45	42.15	93.19
Plant EPC Capital Cost	$/KWe	2150	2000	2000	2100
Additional Plant EPC Cost Savings	B$	Base	-0.09	-0.09	-0.03
Note 1 - Assumes 595 MWe continuous output for 90% of the time					

When you add the advantage of fuel arbitrage as shown in Table 5 below 600 MW example, you not only see a reduction in capex due to less equipment required (no FGD + DeNOx) but there is a potential of $14.6 M per year fuel savings with a 10 year NPV of $95 M. This number can be even more pronounced when burning even lower grade fuels or blends of waste fuels and biomass for example.

Table 5. 600 MW net CFB supercritical plant operating at 90% capacity factor.

Plant Parameter	Units	6000 Kcal South African Coal	4900 kcal Indonesian Sub-bituminous Coal	Annual Fuel Arbitrage ($/yr)	10 yr NPV Fuel Arbitrage ($)
Plant Net Power	MWe	600	600		
Fuel Cost	$/ metric Ton	100	75		
Fuel Heating Value	kcal/kg	6000	4900		
Fuel Heating Value	MJ/Kg	25.1	20.5		
Plant Capacity Factor	%	90%	90%		
Fuel consumption	metric ton/year	1,689,152	2,057,166		
Fuel Cost	$/year	168,915,200	154,287,450		
Difference in Fuel Price				**$14,627,750**	**$95,008,129**

CONCLUSIONS

Historical pricing and future global coal price projections (Figure 5) suggest that in the long term, pricing will drop from the current peak of around $110/tonne FOB and settle inat around $80/tonne FOB in about 5 years and then be stablefor the next 15 years or so. Since fuel pricing is the largest component of a plants operating costs, it plays a significant role in the financial success of a coal project.

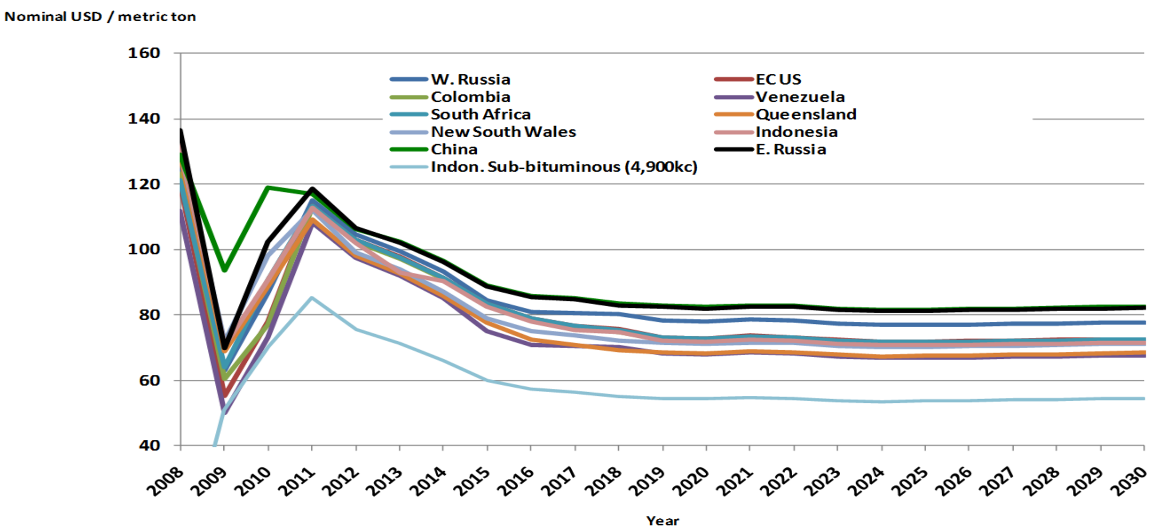

Figure 5. Recent and predicted global coal pricing.

THE CASE FOR PULVERIZED COAL

The PC boiler has been the standard for large coal fired utility plant applications for the last several decades. The units have proven reliability and coupled with the right air quality control systems (AQCS) can achieve the lower standards of emissions required in many of the utility markets today. Additionally, with the increasing demand for better efficiency they are readily avaialbe with super critical steam parameters. The success of the Longview 760 MW_{el} PC project has proven the BENSON VRT technolgoy is a viable solution for today's super critical PC application. In most developed country's the emissions requirements dictate the inclusion of a selective catalytic reduction (SCR) system as well as either a dry flue gas desulphurization system (FGD) or wet FGD in additon to back end particulate collection systems all of which collectively form the full AQCS. It is likely that the PC will continue to be strongly considered when looking at todays plant requirements and will continue to be favored when steam quality coal is readily available in long term contracts within the defined limits of heating values, ash contents, moisture content, sulphur content and especially ash fusion temperatures.

THE CASE FOR CFB

The CFB boiler has long been viewed and accepted in the industry as viable technolgy in the 20–350 MW_{el} subcritical class units. As shown in Figure 6 below the Foster Wheeler CFB has steadily grown to larger sizes with super critical steam values. It should also be noted that while incrementally increasing steam output, the Foster Wheeler CFB has never had an issue related to scale up in its development history.

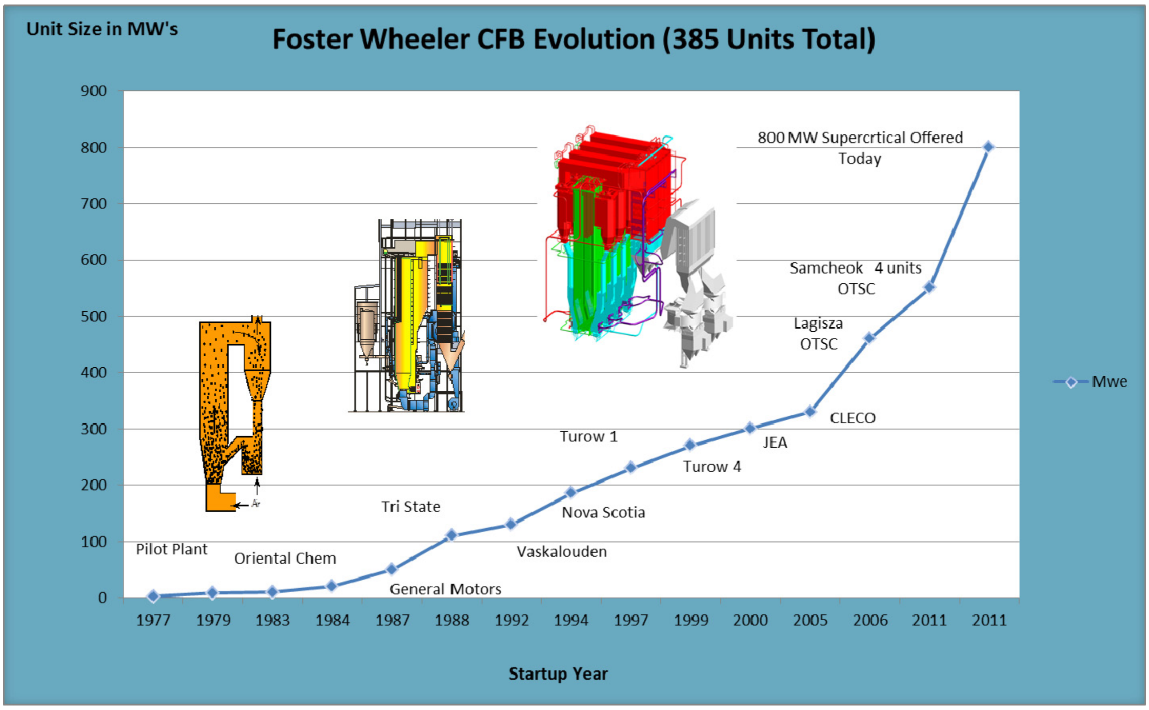

Figure 6. Evolution of Foster Wheeler CFB boilers

The Łagisza unit in Poland has demonstrated the technology and validated the Foster Wheeler design plaform for the larger 550, 660 and 800 MW_{el} units. While the Łagisza unit successfully competed with a PC unit in the intial international bid tender it is also significant to note that the Kospo Samcheok project CFB's (Figure 7) were selected as the preferred technology over PC due to the multiple fuel capability which allows for more favorable emission flexibility as well as reduced variable O&M costs.

With proven advances in super critical CFB technology which now allows direct competition for large scale utility PC offerings in the 500 MW to 1000 MW size ranges and while uncertainty may prevail in predicting future global fuel costs and availability, the selection of utility scale CFB super critical units can capitilize on fuel arbitrage and opportunity fuels while providing highly competitive value and reduced emissionsfor many years in to the future.

Figure 7. The Kospo Samcheok project—4×550 MW_{el} SC CFBs

- 4×550 MW_{el} CFBs powering 2×1000 MW_{el} steam turbines
- Advanced supercritical vertical tube steam technology
- 603/603°C steam temperatures
- Firing a wide range of imported and domestic coals
- Commercial operation expected: Units 1 and 2 mid 2015; units 3 and 4 end of 2015