



Utility CFB goes “Supercritical” – Foster Wheeler’s Lagisza 460 MWe Operating Experience and 600-800 MWe Designs

James Utt, Arto Hotta, Stephen Goidich
Foster Wheeler North America Corp.
Clinton, New Jersey 08809

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***“UTILITY CFB GOES SUPERCRITICAL” - FOSTER WHEELER’S LAGISZA 460 MWE
OPERATING EXPERIENCE AND NEW 600 - 800 MWE DESIGNS***



ABSTRACT

When the Lagisza supercritical unit commences commercial operation in mid 2009, it will demonstrate a new era in the evolution of Circulating Fluidized Bed (CFB) technology. It is currently the world's largest CFB boiler at 460 MWe, and the world's first once-through unit (OTU) supercritical CFB boiler. The unit successfully demonstrates the integrated features of both technologies. OTU technology features include the BENSON Vertical evaporator with Supercritical steam conditions (4000 psia, 1050/1075°F) with an overall net plant efficiency of 41.6% (HHV basis). Low mass flux BENSON once-through technology is ideal for CFB boilers as it utilizes vertical tubes as opposed to spiral wound tubing used in many other once-through designs. The furnace heat flux (heat absorbed per surface area) is very low and uniform. Additionally, BENSON low mass flux design provides a unique “self compensating” feature reducing the risk of overheating any one particular tube. The CFB process includes features such as in-furnace sulfur capture by simple injection of crushed limestone, low NO_x emissions because of an inherently low furnace temperature, staged combustion and fuel firing flexibility because of the vigorous mixing resulting from the flywheel of circulating solids.

Described in this paper is a summary of the CFB and OTU design features that make the Lagisza unit a highly efficient state-of-the-art power production facility. Commissioning experience and data from operation of the unit as compared to design and dynamic simulations will be presented along with performance test summaries. Using the Lagisza model as a baseline along with data collected during operation, Foster Wheeler has completed the design of both 600 and 800 MWe CFB supercritical units and is now offering these designs with full commercial guarantees. An overview of these evolutionary designs is also presented in the paper.

1. EVOLUTION TO LAGISZA

Foster Wheeler Global Power Group supplies a wide range of industrial and utility scale steam generators to the power industry. Among other products, the company offers state-of-the-art boilers for heat and electricity generation based on circulating fluidized bed (CFB) technology. Boilers are offered for a variety of fuels and mixes, including fossil-derived fuels (e.g. coal, waste coal, petcoke), peat, biomass-derived fuels (e.g. wood, agricultural residue, bio-sludge), and waste fuels (e.g. contaminated wood, REF, TDF).

During the past 30 years Foster Wheeler has designed and supplied nearly 350 CFB boilers, of which almost 240 are designed for coal and wastes from the coal mining industry with total thermal capacity of 47,000 MWth (~15,600 MWe) (Figure 1). All the boilers share the same circulating fluidization principle; however, depending on the quality of fuel, the boilers differ significantly in design and operation.

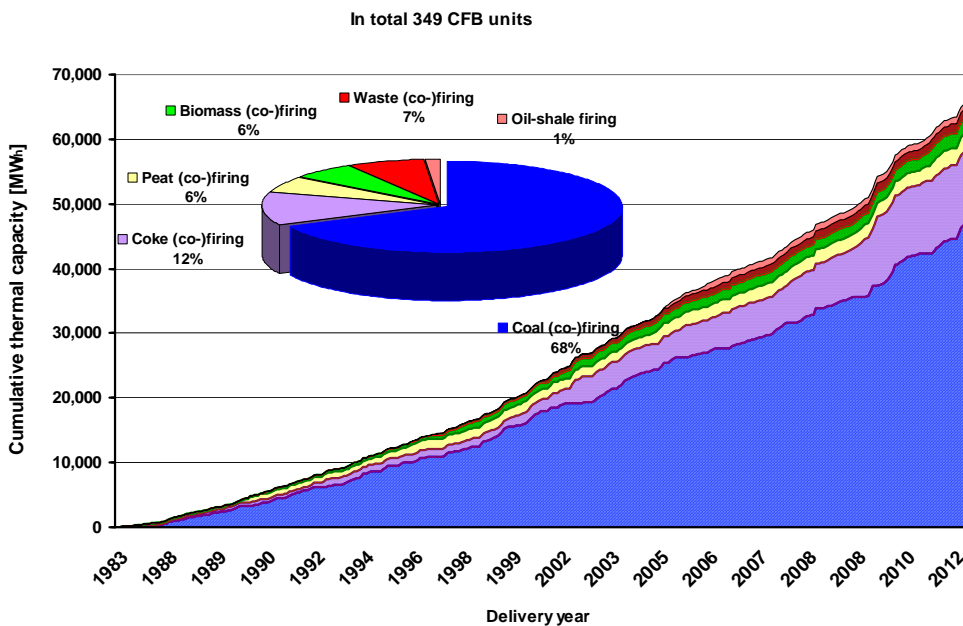


Figure 1. Foster Wheeler's CFB references (as of 02.09.2008)

Power generation based on the combustion of solid fuels is expected to remain as mainstream technology for the foreseeable future. Fuel resources are abundant and widely distributed, which tends to provide price stability and security of supply. At modern power plants, the traditional pollutants are well under control. When considering either new plants or repowering of old plants, efficiency and environmental performance are key issues. High efficiency means lower fuel requirements and lower levels of ash and emissions, including CO₂. Utilization of proven high efficiency CFB technology is an ideal solution both for repowering and for new plants. CFB technology has proven excellent fuel flexibility and also offers the option to co-combust biofuels with different grades of coals, which can further reduce CO₂ emissions (Jäntti T et al., 2006).

1.1 Scale-up

Responding to an ever-growing demand for power generation, Foster Wheeler's CFB boiler technology has been developed to meet utility-scale requirements (Figure 2). Today, Foster Wheeler's largest CFB units, based on natural circulation, in operation are two 300 MWe CFB boilers at Jacksonville Energy Authority in Jacksonville, Florida, U.S.A. These boilers burn either 100% coal or 100% petroleum coke or any combination of the two. Additionally, the 2 x 330 MWe CLECO Rodemacher sub-critical CFB units in Louisiana are scheduled for commercial operation later in 2009. These units are designed in a "2 on 1" configuration which means the two boilers supply steam to a single 600 MWe turbine. The boilers are designed to burn 100% petroleum coke, 100% bituminous coal, or 100% Powder River basin coal (PRB) in any combination, as well as a percentage of biomass, truly demonstrating the fuel flexibility of the CFB. The largest units in terms of physical dimensions are three 262 MWe CFB boilers at Turow power plant in Poland. The fuel for these boilers is lignite with moisture content of 45 wt-%, which increases the flue gas flow considerably. The net efficiency of conventional sub-critical designs is approximately 38–40%, depending on fuel and condenser conditions.

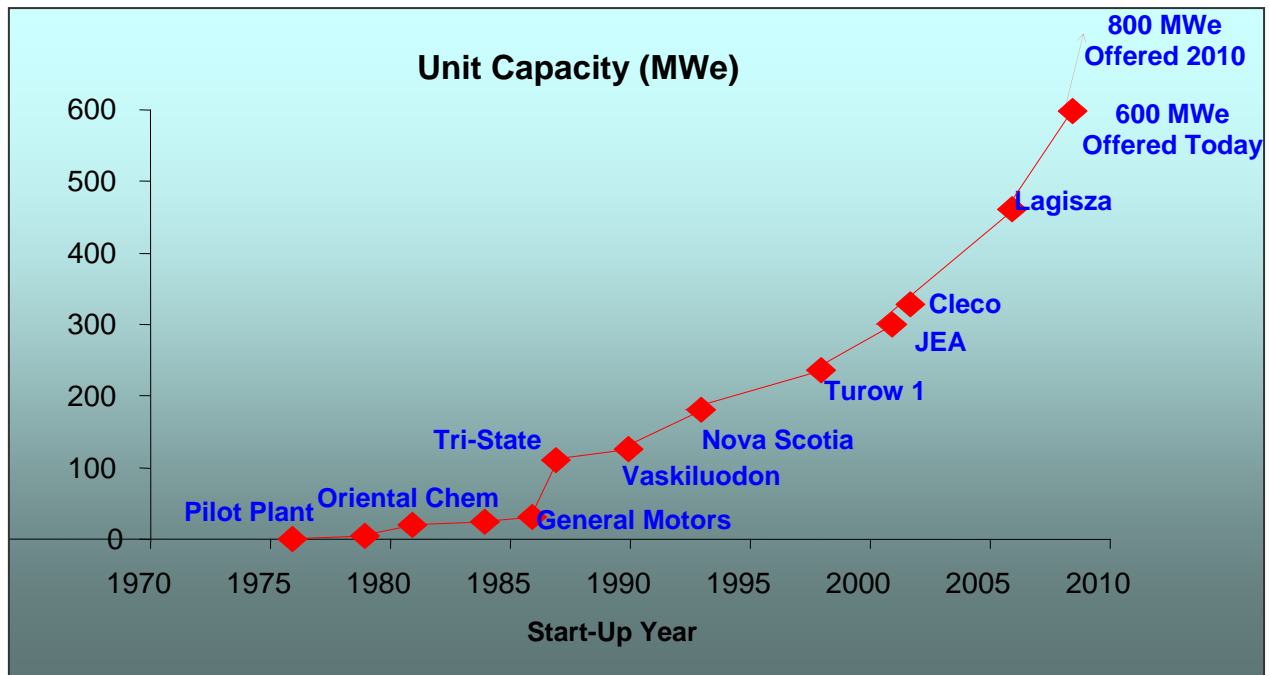


Figure 2. Scaling-up of Foster Wheeler's CFB boilers

Scaling-up of Foster Wheeler's CFB boiler technology has been achieved through continuous development. For the supercritical units, the design features integration of the cyclone separator for circulating solids and the furnace (Figure 3a). A water/steam cooled compact separator replaced the hot cyclone with heavy refractory lining, which was distinctive for the earlier designs. This concept offers several advantages, such as:

- Less refractory in the system, thus reducing maintenance cost
- Shorter start-up time due to less temperature sensitivity in the refractory
- No expansion joints between the separator and the combustion chamber
- Smaller foot-print of the boiler, which can be very important in re-powering schemes where the new boiler has to fit into an existing building or existing site.

The compact separator design was enhanced with introduction of INTREX™ – integrated heat exchanger located in the furnace (Figure 3b). INTREX™ extracts heat from the hot circulating material that is returned from the separator, or solids are taken directly from the lower part of the furnace. Continuous flow of dense solids enables high heat-rate coefficients within a small physical space and prevents formation of deposits on tube surfaces. No mechanical devices are needed and all required controls are performed by air fluidization. Superheaters and reheaters of INTREX™ type are particularly effective in designs for fuels that can cause corrosion on conventional heat surfaces and for large-scale utility boilers.

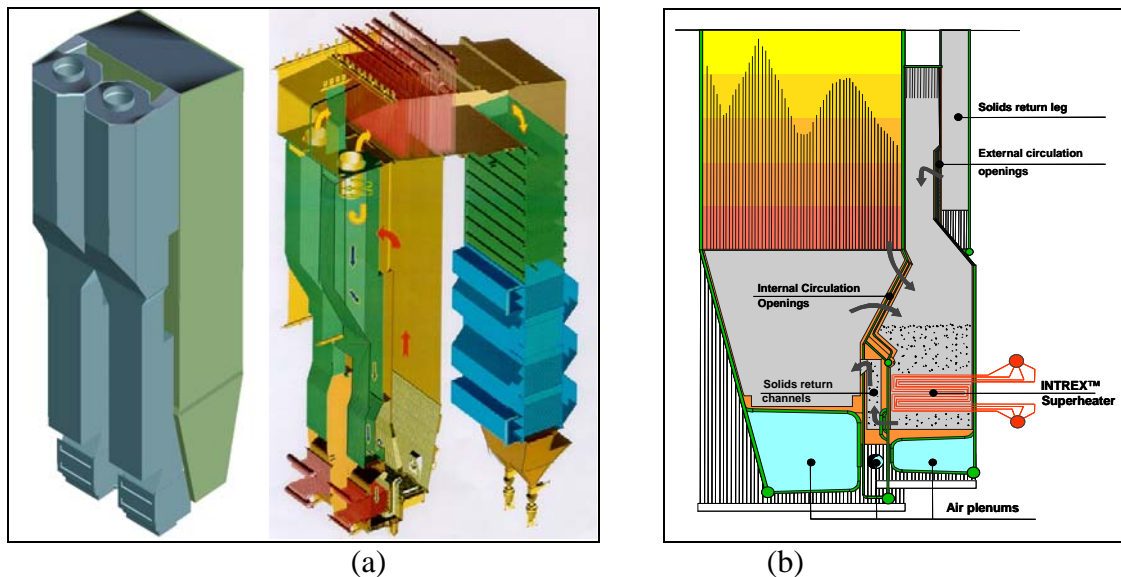


Figure 3. Features of Foster Wheeler's CFB boiler design: a) Water/steam cooled integrated separator, b) INTREX™ Superheater

CFB technology is now proven at utility-scale. The net efficiency of those conventional sub-critical designs is approximately 38-40%, depending on fuel and condenser conditions. During recent years, Foster Wheeler has developed once-through supercritical (OTSC) CFB technology, enabling the next stage in CFB development to proceed medium-scale (<500 MWe) utility projects such as Lagisza, with net efficiencies near 45%. Additionally, the once-through steam cycle utilizing Siemens' BENSON technology has performed as predicted in a CFB process. Foster Wheeler has further developed the CFB design up to 800 MWe with net efficiency of >45% to be commercially offered during late 2009 early 2010.

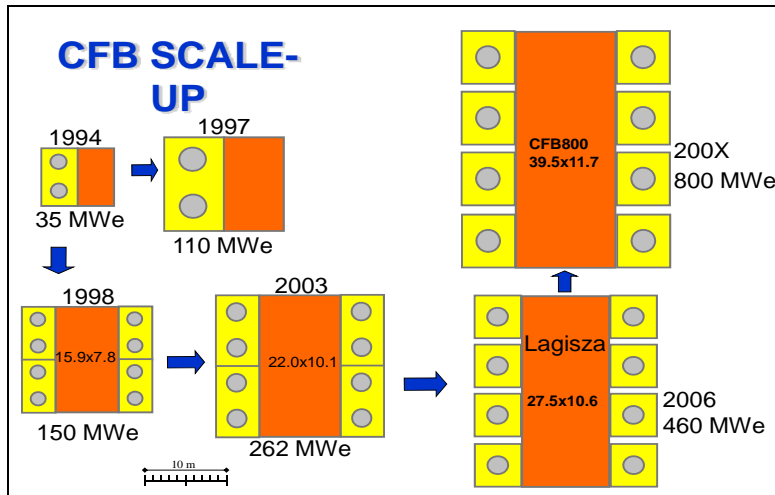


Figure 4. CFB Scale up – modular approach

2. LAGIZA 460 MWe CFB BOILER

The Lagisza unit utilizes Siemens' BENSON low mass-flux vertical tubing technology which offers some clear advantages for CFB technology, including a lower pressure drop over the furnace tubing, resulting in less power needed for feed water pumps resulting in lower auxiliary power consumption. The combustion temperature in a CFB is homogenous both vertically and horizontally, which means that the heat flux is relatively uniform and the risk of overheating is not present as it is in conventional pulverized firing technology with a heat flux that can be up to three times higher in the firing zones.

The first company to benefit from OTU CFB technology with supercritical steam parameters is the Polish utility, Poludniowy Koncern Energetyczny S.A. (PKE). The new 460 MWe (gross) unit replaces old power blocks of Lagisza power plant. The existing blocks were erected in the 1960's and consist of seven units (110-125 MWe each). Two of them will be shut down after the new 460 MWe unit is accepted for commercial operation. The new boiler has been constructed adjacent to the old boilers and many of the existing plant systems, like coal handling and water treatment, have been renovated and utilized for the new CFB unit.

Primary fuel for the boiler is Polish bituminous coal. The source of fuel consists of ten local coal mines with a wide range of coal parameters, further verifying the fuel flexibility of CFB technology. Table 1 summarizes parameters of design fuel and overall fuel range. Boiler design is optimized with a possibility for combustion of additional fuels. The boiler is designed to co-fire coal slurry that is available in large amounts in local coal mines. Because of CFB technology inherent characteristics, wet coal slurry can be co-fired with a 30% share by fuel heat input. Coal washing rejects can also be burned in the form of dry coal slurry granulates with a share up to 50% of heat input. The boiler is designed to also co-fire biomass fuels up to 10% of fuel heat input. The biomass feeding equipment is included in the delivery as an option to be installed later.

Table 1. Fuel properties for the Lagisza Project

		Coal range	Coal slurry range (max 30% input)
Lower heat value	MJ/kg	18–23	7–17
Moisture content	%	6–23	27–45
Total ash content	%	10–25	28–65
Sulfur content	%	0.6–1.4	0.6–1.6

Table 2. Boiler data for the Lagisza 460 MWe CFB Boiler

	kg/s	359.8
Maximum continuous flow		
Minimum continuous flow	kg/s	143.9
HP steam pressure at turbine inlet	MPa	27.50
HP steam temperature at turbine inlet	°C	560
Cold reheated steam flow	kg/s	306.9
Cold reheated steam pressure	MPa	5.46
Cold reheated steam temperature	°C	314.3
RH steam temperature at IP turbine inlet	°C	580
Feed water temperature	°C	289.7

The Lagisza CFB boiler has been designed to parameters shown in Table 2. The general boiler layout was based on the conventional in-line arrangement already applied for Units 4–6 of the Turów power plant. Figure 5 shows an illustration of the boiler. Detailed description of the once-through boiler design and related aspects can be found in Venäläinen, Psik, 2004.

The emission requirements for the Lagisza boiler are according to European Union directive for large combustion plants, and considerable emission reduction is expected compared to existing PF units. The emissions of sulfur dioxide are controlled with limestone feeding into the furnace. With the design coal a sulfur reduction of 94% is required, and that shall be achieved in the CFB with a calcium to sulfur molar ratio of 2.0–2.4. The nitrogen oxide emissions are controlled with low combustion temperature and staged combustion. There are also provisions made for a simple ammonia injection system (SNCR), however, that is not required on design coals. Compared to original plants, NO_x is expected to be reduced by 71% and CO₂ by 28%. Particulate emissions are controlled by electrostatic precipitator. The plant efficiency is expected to be improved from 34.7% to nearly 44%.

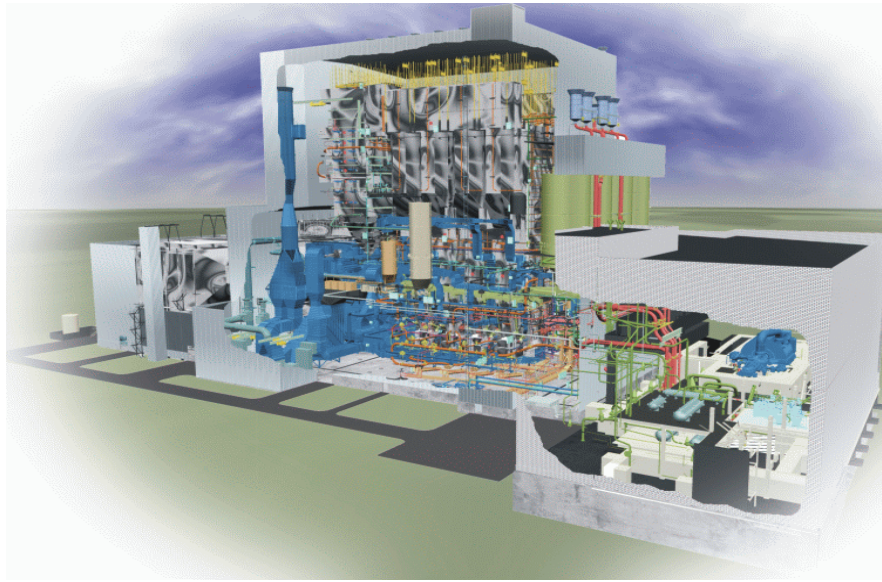


Figure 5. The 460 MWe once-through CFB at PKE, Lagisza

2.1 Operational Performance

The Lagisza power plant achieved full load steam conditions on 100% coal on March 2009 running at the designed supercritical steam pressure and temperature. The boiler has been running in stable operation on coal from 25% to 100 % MCR and has shown to operate as designed and predicted. The emissions of SO₂, NO_x and CO have to date tested below guaranteed and permitted values. Combustion efficiency also appears to be very good. The unburned carbon in ash has remained well below 5% at all loads. Basic process parameters on different load points are shown on the following table.

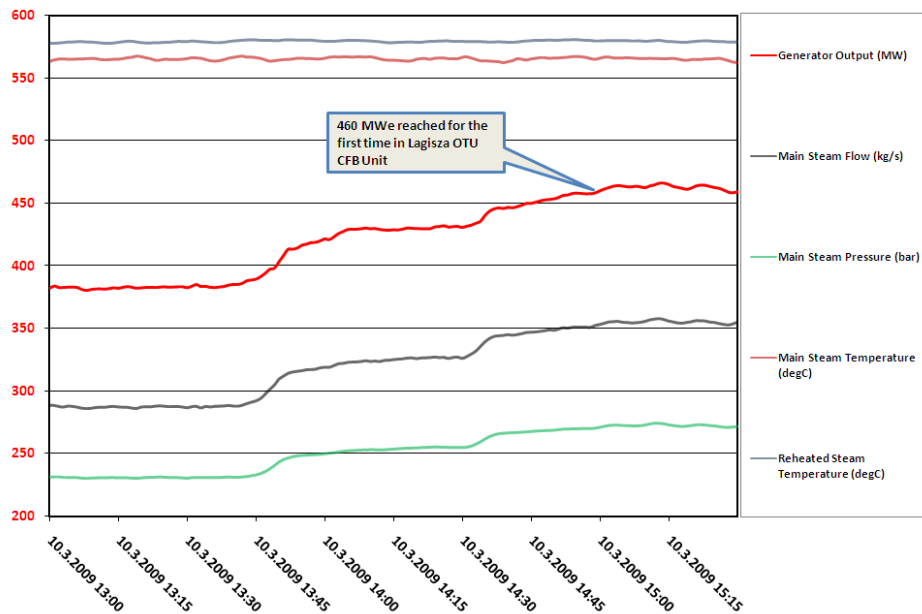
Table 3. Process parameters on different load levels

		40 %MCR	65 %MCR	80 %MCR	100 %MCR
Main steam flow	kg/s	144	235	287	361
Main steam pressure	Bar	131	186	231	271
Main steam temperature	°C	560	560	560	560
Reheat temperature	°C	550	572	580	580
Bed temperature	°C	753	835	853	889
Flue gas exit temperature	°C	80	81	86	88

The once-through steam cycle utilizing Siemens' BENSON technology has performed as predicted by Foster Wheeler's model for the CFB process and Siemens's prediction tools for the once-through steam cycle. An extensive dynamic process modeling and simulation training program, which was developed by Foster Wheeler during the design and engineering of the boiler, has now shown its merits;

- All boiler control tuning parameters were derived from the control simulations in the process model and then uploaded to the DCS at site so only minor tuning has been required during the actual operation.
- The overall operation of the large CFB has been very smooth and it has been easy to operate. As an example, the first time the boiler was taken to full load on March 10, 2009, the boiler was ramped from 65% load to 100% load on automatic ramp and sliding pressure control @ 2%/minute ramp rate with a resulting deviation in main steam and reheat temperature of only 1 °C.
- A training simulation program was developed utilizing this process model as input into the actual DCS used for the project. All operations personnel were trained on the simulator months in advance of commissioning activities which help improve operations from the very beginning of commissioning.
- On-line DCS process optimization (advanced control) is also utilized to constantly "learn" and improve control of all of the systems.

Load increase to MCR for the first time in Lagisza



2.2 Evaporator Operation

Peak heat fluxes in a CFB boiler are clearly lower than experienced in PC boilers. In the CFB, highest heat flux occurs just above the refractory covered zone in the lower furnace. At that level the fluid is at a low temperature at supercritical pressures and is a sub-cooled liquid at reduced loads (sub-critical steam pressure). Because of the low heat fluxes in a CFB furnace, the full load water-steam mass flow rate can be in the 550 – 650 kg/m²s range. This low mass flux creates a “natural circulation” characteristic that together with stable circulation of the solids results in a more uniform heat flux distribution, which in turn gives a reduced tube to tube temperature differential.

Based on the first analysis result from Lagisza CFB, heat flux profiles to furnace walls have been low and uniform during coal firing. Highest heat fluxes have been measured above the refractory lining in lower furnace as it was expected. Due to uniform heat fluxes to furnace walls, steam temperature variations after evaporator have been minimal when operating above BENSON point. Somewhat higher but still controllable variation in heat fluxes have been observed when firing light fuel oil (LFO) during boiler start-up.

2.3 Process Behavior

The Lagisza boiler has shown an excellent environmental and economical performance as it has been operated on full load range firing coal. Emissions have been lower than set by the on Large Combustion Plant (LCP) directive and a low flue gas exit temperature together with good combustion efficiency are guaranteeing high thermal efficiency.

Control concepts designed for the Lagisza boiler have demonstrated success. The boiler operates and responds well to transient conditions and is extremely stable as the boiler is operated in steady state conditions.

2.4 Mechanical Scale Up

The boiler’s general layout was based on the conventional in-line arrangement that has been applied in Units 4 – 6 at the Turów power plant. Mechanical scale up was also reasonably modest since physical size of the Lagisza boiler is not significantly bigger than boilers already in operation for lower grade fuels like brown coal in Turów units. This far no problems regarding mechanical design of the boiler have occurred during boiler start-up.

2.5 Auxiliary Equipment Operation

Boiler auxiliary equipments have worked without major problems from minimum up to maximum boiler load.

2.6 Field Testing

As Foster Wheeler is heading for larger boiler sizes and higher efficiencies, it is important to collect all possible information from Lagisza to achieve a better understanding of large CFB boilers.

During the course of the final boiler commissioning and trial operation, Foster Wheeler will conduct an extensive testing program on the Lagisza boiler. Performance of the boiler will be tested on steady state operation, as well as in dynamic conditions, and data from the measurements will be used for validation of the process and dynamic models for development of our 600–800 MWe CFB OTU designs.

3. FLEXI-BURN™ CFB – SOLUTION FOR CARBON CAPTURE

When larger emission reductions are required, CCS offers potential for near zero emission power production from fossil fuels albeit at the expense of efficiency and costs. Foster Wheeler is developing oxy-fuel CFB technology, which is seen to be the most feasible alternative for CCS at the moment.

Figure 6 shows a simplified process flow scheme of an oxy-combustion power plant, which consists of an air separation unit (ASU), a power plant with O₂-blown combustion, and a CO₂ treatment unit. Oxygen is mixed with re-circulated flue gases, which creates a mixture of primarily O₂ and CO₂ (and H₂O) used as oxidant in combustion instead of air. The absence of air nitrogen produces a flue gas stream with a high concentration of CO₂, making it much easier to separate the CO₂. CFB technology appears to be ideally suited for oxy-fuel combustion, and as a longer term activity, Foster Wheeler is developing its CFB for oxy-combustion to provide the potential for nearly 100% reduction of CO₂ (Eriksson, T. et. al, 2007).

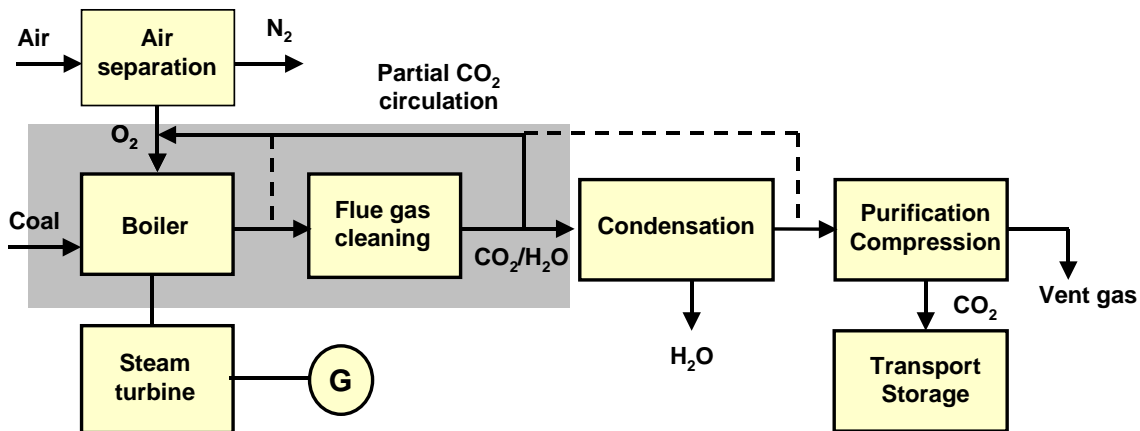


Figure 6. Schematic of an Oxy-combustion Power Plant

Oxy-CFB technology, the Flexi-Burn™ CFB, is being developed for existing boilers as a retrofit solution, for new "capture ready" boilers to be modified for CCS in the future, and for integrated Greenfield power plants with CCS from the beginning. Designing an oxy-fuel power plant calls for case-specific optimization of the performance and economics. Normal boiler designs with reasonable modifications can be applied if the mixing ratio of oxygen and recycled flue gas ratio is chosen so that the adiabatic combustion temperature is close to that of air firing. Such a plant could even be operated either with or without carbon capture and thus with lower or higher output, for instance, depending on the price of CO₂ allowances and electricity (Eriksson, T. et. al, 2007).

The 460 MWe once-through supercritical coal fired CFB boiler plant being designed and constructed by Foster Wheeler for the Polish utility PKE at Lagisza power plant has been used as a starting point and reference in a study that considers plant optimization items and aims to generate knowledge about boiler conversions for oxy-firing and design of new "capture ready" boiler plants. High O₂ designs provide potential for cost savings and higher efficiency, but require an entirely new boiler concept and will be the subject of future studies (Eriksson, T. et. al, 2007).

4. CONCLUSION

The Lagisza boiler design is based on well proven Foster Wheeler CFB technology. The design of the new Lagisza boiler is based on Foster Wheeler's utility scale CFB technology with the solids separators built of steam-cooled panels integrated with the combustion chamber. Lagisza boiler utilizes low mass flux BENSON vertical once-through technology developed and licensed by Siemens AG, Germany. CFB boiler with low and uniform furnace heat flux is extremely well suited for the BENSON technology.

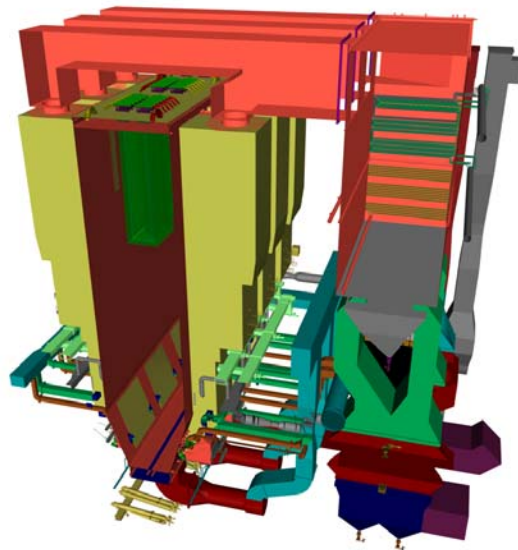
Erection of the boiler plant was completed in July of 2008. Commissioning of the boiler plant proceeded from cold commissioning to acid cleaning and steam blowing and initial firing. The steam blowing of all systems was actually performed on solid fuel which demonstrates the turndown capability of the unit. Steam was introduced to the turbine for the first time on the 7th of February, 2009 and synchronization took place the 15th of February. Full power output of the plant, 460 MW_e, was achieved on the 10th of March, 2009. After fine tuning of controls and optimization of the boiler performance, a 720 h trial operation will begin followed by plant take-over and start of the commercial operation.

Operational experiences of the 460 MW_e OTU CFB has been excellent. All operating parameters of the unit have been stable and easily adjustable. Heat fluxes to furnace walls on coal firing have been low and uniform as expected. Emissions and load performance of the large boiler with numerous fuel feeding points has turned meet or exceed expectations.

- FW's Large Scale CFB OTU Design Platform Verified by Lagisza Initial Performance (no scale up issues discovered).

- FW Utility Scale Supercritical Technology allows for Fuel Flexibility while providing Reliable, Highly Efficient, and Cost Effective Power Generation. This ability to fuel arbitrage could save \$/Millions.
- FW CFB Technology - Ideally Suited for Re-powering or New Installations and available in sizes up to 800 MWe.
- FW CFB Technology - The perfect choice for Flexi-Burn™ which provides an Exit Flue Gas ready for Sequestration.

Foster Wheeler now offers 600 – 800 MWe CFB OTU Designs as a Positive Alternative to Conventional PC Technology Bringing Unmatched Fuel Flexibility, Economic, and Environmental Advantages to the Utility Power Sector.



Foster Wheeler 800 MWe Design

REFERENCES

Arto Hotta, FW Global Power Group “Features and Operational Performance of Lagisza 460 MWe CFB Boiler” Presented at 20th International Conference on Fluidized Bed, Xian, China, May 18th 2009

Timo Jantti, Krister Sundquist, Rikku Parkkonen, Rafal Psik, Foster Wheeler Global Power Group, “Lagisza 460 MWe Super Critical CFB- Design, Start-up and Initial Operation Experience” Present at PowerGen Europe, Cologne, Germany, May 26, 2009

Jäntti, T.; Eriksson, T.; Hotta, A.; Hyppänen, T.; Nuortimo, K. Circulating Fluidized-bed Technology – toward zero CO₂ Emissions. POWER-GEN Europe 2006, Cologne, Germany.

Eriksson T., Sippu O., Hotta A., Zhen Fan, Myöhänen K., Hyppänen T., Pikkarainen T.: Oxyfuel CFB Boiler as a Route to Near Zero CO₂ Emission Coal Firing. POWER-GEN Europe 2007, June 26-28, 2007, Madrid, Spain