Final Stage of First Supercritical 460 MWe CFB Boiler Construction – Project Update

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ABSTRACT

Circulating fluidized bed (CFB) boiler technology has been growing in size and number over the past two decades and it has established its position as utility scale boiler technology. Plant sizes up to 300 MW_e are in operation today and designs for larger boilers are being developed. The next natural step for CFB technology is to go for supercritical steam parameters and larger boiler sizes. A Polish utility company Południowy Koncern Energetyczny SA (PKE) placed an order to Foster Wheeler Energia Oy for a 460 MW_e supercritical CFB boiler for their Łagisza power plant. Contract was signed at the end of year 2002 and the engineering work is now ongoing. This will be the first supercritical once-through CFB boiler in the world.

A modern power plant is designed for high efficiency not only for economical reasons but also for enhanced environmental performance in terms of reduced emissions and quantity of ash generated due to lower fuel consumption. Cutting CO_2 emissions is one of the main drivers. To achieve these goals, supercritical steam parameters have been applied. Now this technology is available also for CFB technology. This combines a high plant efficiency with the other well known benefits of CFB technology, such as: fuel flexibility, low emissions and high availability.

The boiler design for 460 MW_e Łagisza power plant 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 providing a stable operation of the boiler also during load changes and abnormal operation conditions.

The paper describes the 460 MW_e supercritical CFB boiler concept and presents the technical solutions of the boiler design with auxiliary equipment, as well as first experiences from boiler erection period and commissioning.

In spite of achieving this remarkable milestone the development of the CFB technology is continuing to even larger plant sizes. Boiler designs in size range of 600 – 800 MW_e are being developed.

1 INTRODUCTION

Target for high efficiency in modern power plants is set not only because of economical reasons but also for enhanced environmental performance in terms of reduced fuel needs, quantity of ash generated and pollutants emitted. Cutting CO_2 -emission has become increasingly important after the Kyoto Protocol. As coal will remain an important source of energy the focus has been set to improve the efficiency of coal fired power plants. To achieve this goal, supercritical steam parameters have been applied. Most large European thermal power plants built for fossil fuels such as coal and brown coal over the last decade have had supercritical steam parameters and have been based on pulverized coal (PC) fired once-through boiler technology.

Circulating fluidized bed (CFB) technology has emerged as a growing challenger to conventional pulverized coal-fired boilers in energy generation. Over the last decade, CFB boiler technology based on natural circulation has reached utility scale. There are several CFB boilers in operation with sizes between 200 – 300 MW_e. The largest units in operation are two 300 MW_e CFB boilers at Jacksonville Energy Authority in Jacksonville, Florida, U.S.A delivered by Foster Wheeler. These boilers burn either 100% coal or 100% petroleum coke or any combination of the two. The largest units in terms of physical dimensions are two 262 MW_e CFB boilers at Turow power plant in Poland (units 4 and 5, unit 6 under construction). The fuel for these boilers is brown coal with 45 % moisture content, which increases the flue gas flow considerably.

Foster Wheeler is now taking CFB technology a step further, to larger sizes with supercritical steam parameters and once-through technology. The construction works for a 460 MW_e supercritical CFB boiler for Południowy Koncern Energetyczny SA (PKE) in Poland are about to be finalized. This is a result of continuous and determined development work conducted by Foster Wheeler including an experience database of over 200 reference boilers in operation. Emphasis has been given to mechanical design issues and understanding the process conditions affecting heat transfer, flow dynamics, combustion characteristics, gaseous emission control and thermohydraulics among others. Understanding these processes has been gained by the work done in bench-scale test rigs, pilot plants, field testing of operating units, model development, and simulation using developed semi-empirical models or more theoretical models. Design criterias for larger units have been developed and successfully implemented on the basis of data collected, model development work, and correlations with conventional boiler design.

PKE (Part of TAURON GROUP) is located in southern Poland in Katowice and it is the largest utility in Poland, operating eight power plants within a 50 km radius from Katowice. The company has installed capacity of over 5055 MW_e, which is approximately 17 % of Poland's total generating capacity. In addition, the company has over 2541 MW_{th} of district heating capacity, which accounts for 16 % of the local heat generating requirements of the Katowice area. In year 2001, PKE announced a bidding process for supercritical once-through boiler delivery for 460 MW_e unit in their Łagisza plant, with two alternative combustion technologies: pulverized combustion and circulating fluidized bed combustion. Foster Wheeler submitted proposals for both combustion alternatives. Both boiler proposals were based on BENSON technology with vertical tubing and low mass flux. Foster Wheeler was selected as the boiler supplier on December 30, 2002, with both combustion technologies. Finally CFB technology was chosen by PKE for Łagisza OTU boiler after additional two months of detailed technical comparisons, as well as economical studies with following conclusions:

- Total plant investment cost is lower for CFB alternative. The installation of wet desulfurization and SCR systems that are essential for a PC-based solution can be eliminated, and all emissions requirement are still fulfilled.
- Overall plant performance is better. Net plant efficiency using CFB technology and an advanced flue gas heat recovery system is approximately 0.3 %-unit better than with PC solution with similar heat recovery system.
- Fuel flexibility provides a useful safety margin for the future. The unique multi-fuel capability of the CFB boiler provides a wider fuel range and the additional possibility of using opportunity fuels.

2 PKE LAGISZA 460 MW PROJECT

The new 460 MW_e (gross) unit will replace old power blocks of Łagisza Power Plant. The existing blocks were erected in 1960's and consist of seven units (110-125 MW_e each). Two of them will be shut down after the new 460 MW_e unit is commissioned. The new boiler will be built adjacent to the old boilers and many of existing plant systems like coal handling and water treatment will be renovated and utilized for the new CFB unit.

Table 1. Project execution schedule

Contract Signing	December 30, 2002
Notice to Proceed:	
I Stage – Basic Engineering	March 1, 2003
II Stage – Execution	December 31, 2005

Hand Over	38,5 months after start of Stage II (March 2009)

The Foster Wheeler's delivery comprises turnkey boiler island including engineering and design, civil works and foundations for the boiler, boiler house enclosure with steel structures, boiler pressure parts, auxiliary equipment, main steam piping to turbine and reheated steam piping, coal bunkers and fuel feeding equipment, electrostatic precipitator and cold end flue gas heat recovery system, erection, construction, start-up, and commissioning. The time schedule of the project is presented in Table 1

Table 2. Fuel specification

		Bituminous Coal	
		Design fuel	Range
LHV (a.r.)	MJ/kg	20	18 - 23
Moisture	%	12	6 - 23
Ash (a.r.)	%	23	10 - 25
Sulfur (a.r.)	%	1.4	0.6-1.4
Chlorine (dry.)	%	< 0.4	< 0.4

a.r. = as received

Main fuel for the boiler is bituminous coal. The source of fuel consists of 10 local coal mines with wide range of coal parameters, proving once more the fuel flexibility of the CFB technology. Table 2 is presenting parameters of design fuel and overall fuel range. The steam parameters for the boiler were specified by the PKE. The selected steam pressure and temperature are proven in other supercritical units and conventional boiler steel materials can be used. Table 3 presents main steam parameters of this 460 MW_e CFB boiler.

Table 3. Steam parameters at 100 % load

SH flow	kg/s	361
SH pressure	MPa	27.5
SH temperature	°C	560
RH pressure	MPa	5.48
RH temperature	°C	580

The plant net efficiency is naturally dictated by the selected steam parameters, steam cycle configuration, cooling tower conditions and boiler efficiency. In Łagisza design the boiler efficiency is improved by flue gas heat recovery system, which cools the flue gases down to 85 °C thus improving the plant net efficiency. The calculated net plant efficiency for Łagisza is 43.3 % and net power output is 439 MW_e.

The emission requirements for Łagisza boiler are according to European Union directive for Large Combustion Plants. The emissions for sulfur dioxide are controlled with limestone feeding into the furnace. 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. Particulate emissions are controlled by electrostatic precipitator.

Table 4. Emission limits

Emission (6% O_2, dry)	mg/m^3n
SO_2	200
NO_x	200
Particulates	30

3 ŁAGISZA CFB BOILER DESIGN

3.1 General

The boiler design for Łagisza design is based on well proven Foster Wheeler CFB – technology. It utilizes the experience of over 200 reference units starting from the first generation CFB boilers with conventional cyclone design which typically had a thick multi-layer refractory linings. These heavy refractory linings are known to cause high maintenance, decreased availability and limiting operational flexibility, such as long start-up times. Few of these first generation units have been made with a steam or water cooled structure, however the manufacturing of such construction is laborious and some sections with thick refractory linings remained together with few expansion joints.

The second generation CFB technology was developed to integrate solids separator with combustion chamber and to get rid of heavy multi-layer refractory linings. This was achieved with water or steam cooled panel wall construction that allowed the whole solids separator construction including the solids return channels to be made of panel walls with thin refractory linings. Also the number and size of expansion joints could be minimized, with water cooled separator construction no expansion joints are needed. The first of the second generation CFB boilers was started already 1992 and thereafter the number and size of this advanced technology grown steadily. The largest of the second generation CFB boiler are the units delivered to Turow power plant in Poland for units 4, 5 and 6. The power output of these units is 262 MW_e.

3.2 Water and Steam circuitry

In Łagisza CFB boiler the feed water enters the boiler at a temperature of 290 °C for preheating in a bare tube economizer. Thereafter water is divided to the enclosure walls of the INTREX™ fluidized bed heat exchangers and further to distribution headers of the evaporator (furnace) walls. The water is heated in the evaporator wall tubes and eventually converted to superheated steam before the evaporator outlet. Therefore there is dry-out occurring (as in all once through designs) at a certain elevation of the evaporator causing a decrease internal heat transfer coefficient and locally increased tube and fin temperatures. In CFB boilers the furnace heat flux is considerably lower than in PC boilers and the highest heat flux occurs in the lower furnace where water is always sub cooled. Detail studies have proved that in CFB conditions proper cooling of the evaporator wall tubes is achieved at wide load range using normal smooth tubes with mass flux of 550 – 650 kg/m^2s at full load.

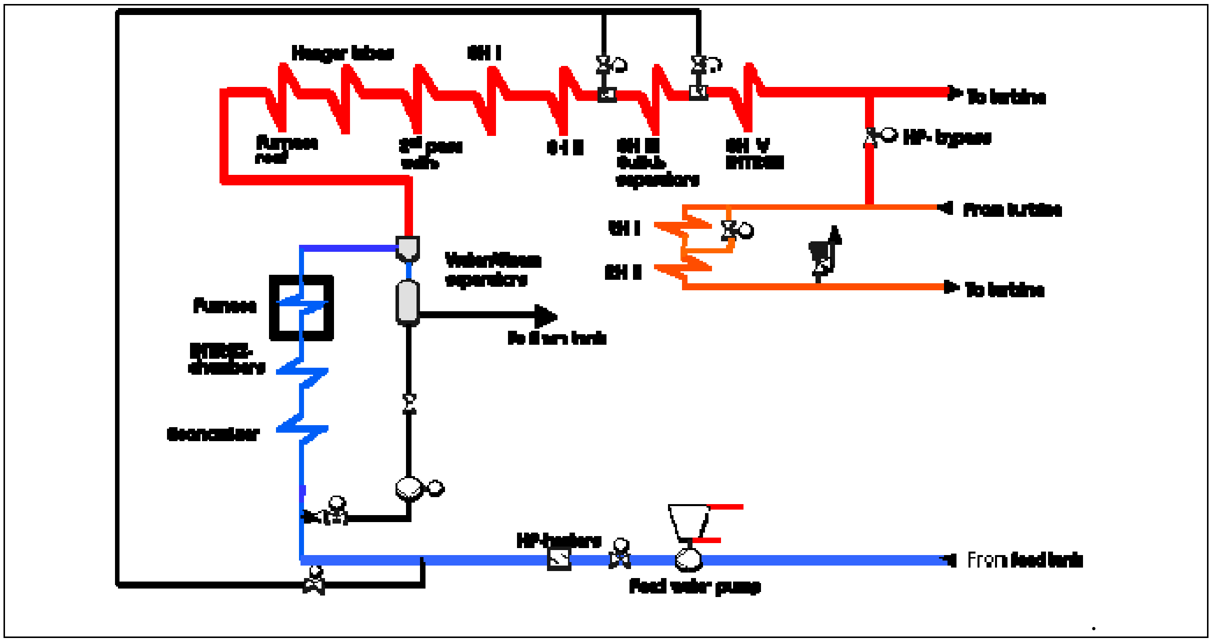

Figure 1. Steam circuitry.

During boiler start-up and shut down a circulation pump is used to secure minimum water flow through the evaporator. The two-phase flow from the outlet headers of the evaporator walls is collected to vertical water/steam separators where the water is separated from the steam and led to a single the water-collecting vessel, see figure 1.

When the boiler load exceeds the so called BENSON -point at approximately 32 % load the steam exiting the evaporator walls is slightly superheated. Hence the circulation system can be closed and the boiler has achieved once-through operation mode.

Dry steam from the water/steam separators is led to the furnace roof which is the first part of superheating system. After the furnace roof steam is taken to superheater support tubes, walls of the convection pass and tube coils of the convective superheater I. Superheater II is located in the upper furnace in areas where the solids densities are low and its lower ends are protected against any possible erosion.

After superheater II the steam is divided to eight parallel solids separators that form the superheater III. The separator walls are formed of the gas tight membrane walls and they are covered with a thin refractory lining with high heat conductivity.

Final superheating is performed in superheater IV located in four INTREX superheaters at the one side of the furnace. The INTREX superheater is a fluidized bed heat exchanger that is integrated to the lower part of the furnace. The main steam temperature is controlled with a two stage feed water spray as well as by adjusting fuel feeding.

Steam after the high pressure turbine is brought back to the boiler for reheating. The first stage reheater is located in the convection pass. The reheater I (RH I) is equipped with a steam side bypass which is used for reheat steam temperature control. At higher loads part of the reheat steam is bypassed the RH I which reduces the heat pick-up and hence the inlet steam temperature to RH II is decreased. This patented reheat steam control method avoids using a spray control for reheat side and therefore do not cause a decrease in plant efficiency. There are over 20 CFB boilers utilizing this control method, e.g. Turow CFB boilers in Poland. In Łagisza the final reheater stage is located in INTREX heat exchanger similar to the final superheater.

The plant is operated with sliding steam pressure so the boiler pressure is following the turbine load. Hence at lower loads (below 75 %) the main steam pressure below critical pressure (221 bar) and at higher loads the boiler is operating at supercritical pressures.

3.3 Furnace design

3.3.1 Flue gas side

The flue gas side furnace design for Łagisza CFB boiler is based on extensive analysis of the fuels and limestones that are going to be used. These have given the required data for the design models to make predictions for circulating material particle size distribution, solids densities and finally the heat transfer with gas temperatures. The design resulted with a furnace cross section of 27.6 x 10.6 m and height of 48.0 m. The furnace dimensions are only slightly larger than the experience from the operating units, see comparison to the key reference boilers shown in Table 5.

Table 5. Comparison of furnace dimensions

		Łagisza	Turow 4-6	JEA	Turow 1-3
Furnace					
- Width	m	27.6	22.0	26.0	21.2
- Depth	m	10.6	10.1	6.7	9.9
- Height	m	48.0	42.0	35.1	43.5

The furnace has one single fluidizing grid under which there are four separate air plenums introducing primary air to furnace. The primary air flow for these four air plenums is measured and controlled separately to insure equal air flow to all sections of the grid and uniform fluidization. The single continuous fluidizing grid ensures simple control as well as a stable and uniform operation of the furnace.

Fuel feeding is arranged on the long walls of the furnace. The grid area per one fuel feed point is the same as used in other boilers. Secondary air is introduced also on long furnace walls at three elevations to provide staged combustion for minimizing the NO_x emissions. Figure 2 is presenting general 3D view of Łagisza CFB boiler

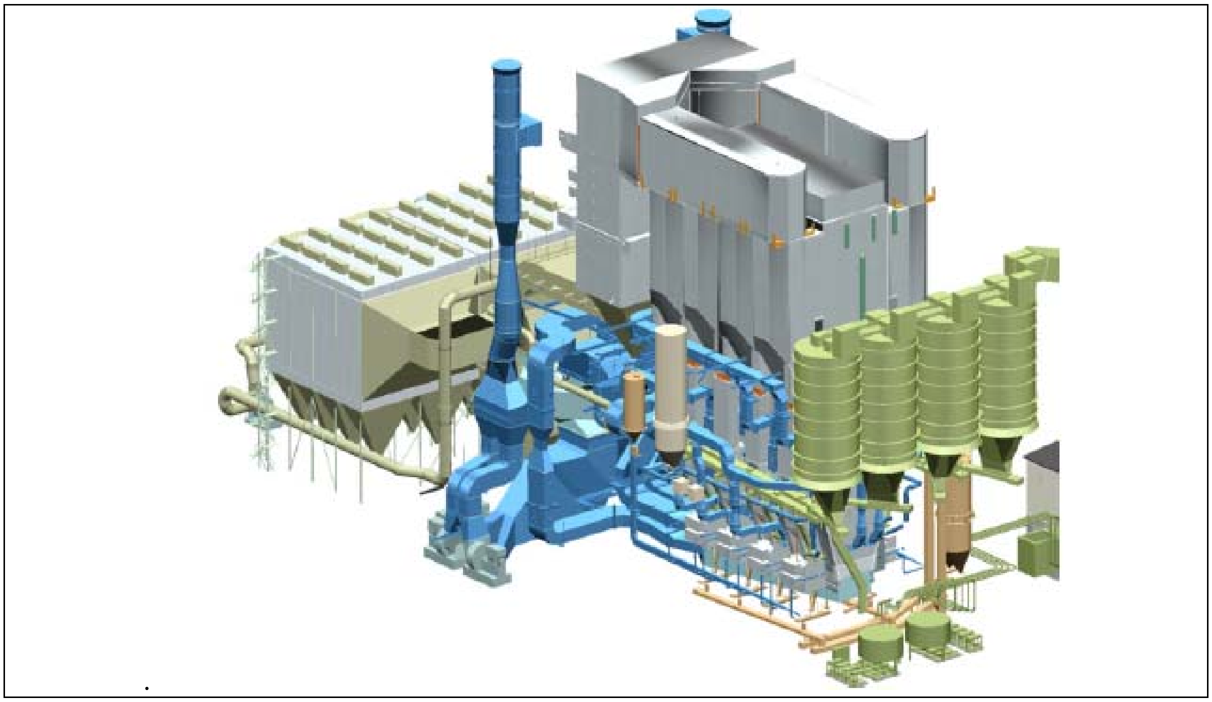

Figure 2. View of the Łagisza CFB boiler.

3.4 Solids separator design

The solids separator design for Łagisza CFB boiler is based on the second generation CFB design with steam cooled panel wall construction. The solids separator design is optimized for high collection efficiency with low flue gas pressure loss. The advanced separator inlet design with tall and narrow shape provides a uniform flow of flue gas and solids avoiding high local velocities. This results in equal collection efficiency as the best conventional cyclones with considerably lower pressure loss.

There are eight (8) solids separators arranged in parallel, four (4) separators on two opposite furnace walls. The separator size is only slightly larger than in Turow units 4-6 and even larger separators are in commercial operation. Hence there is no scale-up in the separator size.

The separators are designed with panel wall sections and have a thin refractory lining anchored with dense studding. This minimizes the required amount of refractories. The separators are manufactured with panel welding machines eliminating need for extensive manual welding. The separator tubes are steam cooled forming a third superheater stage. Also the flue gas ducts (two pcs) after the solids separators are steam cooled and connected to the separator tubing.

3.5 INTREX™ Heat Exchanger Design

INTREX is an fluidized bed heat exchanger extracting heat from the hot circulating bed material that is collected in the solid separators. Additional bed material is taken to INTREX chambers directly from the lower part of the furnace. This provides sufficient amount of bed material at wide load range. A unique feature of the INTREX superheater is its ability to control the heat transfer by changing the fluidization velocities. This special capability is utilized for example during load changes to trim the steam temperatures and to control reheat steam temperature. Also in case of fuels having high chlorine contents INTREX superheater provides enhanced protection against corrosion.

Łagisza boiler design incorporates altogether eight INTREX heat exchangers, one for each solids separator. Four of the INTREX heat surfaces are serving as final superheater and other four as final reheater. Also this part of the boiler the refractory linings are minimized due to water cooled casing of the INTREX surfaces. This allows the integration of the INTREX casings to the furnace thus eliminating expansion joints and minimizing distances to transfer hot solids. Controlling of the flow of hot solids is done only with fluidization, therefore no valves or other mechanical devices are required.

Another benefit of the INTREX heat exchanger is a high heat transfer rate, which decreases the amount of heat surface required thus making the actual dimensions smaller.

3.6 Auxiliary equipment

Combustion air system for Łagisza boiler consist of primary and secondary air system and separate air system for fluidizing the INTREX heat exchangers and sealing devises. Radial fans with inlet guide vane control are used for primary and secondary air fans, 2 pcs each. For induced draft (ID) fans two axial fans are used. A flue gas recirculation system is provided to accommodate the larger variations in the fuel quality.

Downstream the economizer flue gases are cooled in a tri-sector rotary air heater and in a parallel by-pass economizer. The tri-sector air heater was selected over a quad-sector alternative due to its smaller diameter of the heat surface, shorter sealing length and better mechanical rigidity.

Electrostatic precipitator (ESP) with four electrical fields in series is used to control dust emissions to 30 mg/m^{3}n. The separated fly ash is conveyed to fly ash silo using a dense phase ash conveying system.

Fuel handling equipment includes a coal screening and crushing station located at the fuel yard. The system consists of 2 x 100 % lines having a capacity of 900 t/h. Each line has a primary and secondary roller screen and a granulator type crusher. With this equipment the fuel is crushed to a maximum size of 8 mm.

Coal feeding system consists of four similar fuel feed lines, two fuel feed lines at both of the long walls of the furnace. One fuel feeding line includes fuel day bin (1 000 m^3), drag chain feeder, drag chain conveyor and discharge to the feeding points. Each feed point has a dosing screw, slide gate and wall feeding screw.

3.7 Flue Gas Heat Recovery System

The flue gas Heat Recovery System (HRS) improves the boiler and power plant efficiency by decreasing the flue gas temperature down to 85 °C. The system recovers heat from the flue gases which results in an improvement of 0.8 %-units in total plant efficiency.

HRS is operating in the clean gas after the ESP and ID fans. The cooling of the flue gas takes place in a heat exchanger made of PF-plastic tubing to avoid corrosion problems. After the HRS, the flue gas is conducted to the cooling tower via glass fiber duct.

A primary water circuit transfers the recovered heat to the combustion air system and heat is transferred to both primary and secondary air. As the combustion air temperature before the rotary air preheater is increased, the air flow is not able to absorb all the heat available from the flue gases. Therefore part of the flue gases is conducted to a separate low-pressure bypass economizer where the heat from the flue gases is used for heating of the main condensate, see figure 3.

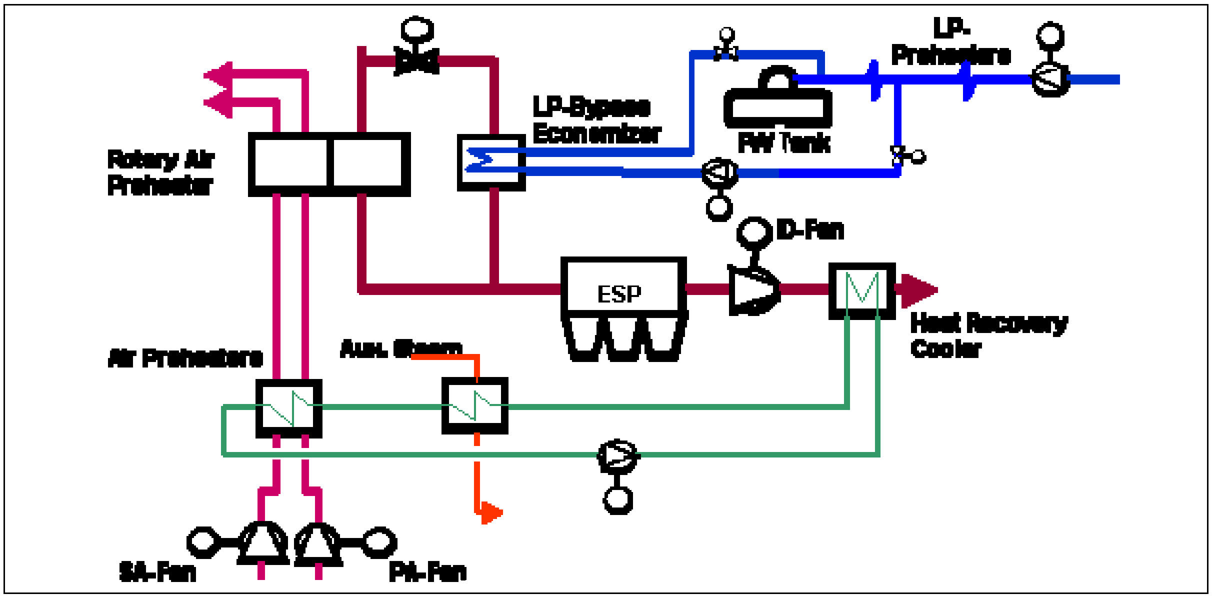

Figure 3 Flue Gas Heat Recovery System

4 PROJECT STATUS AT AUGUST 2008

Site works started on February 27, 2006 by taking over a site. Foster Wheeler as EPC contractor of boiler island was responsible also for excavation works and foundations. Immediately excavation work was started. Mid of May 2006 foundation was casting with using over 6 700 m^3 of concrete. On June 21st first steel structure columns were placed on foundation anchor bolts, this began erection of over 6 500 t of construction steel needed for this boiler island. The heaviest element, which was preassembled at ground level and then lifted, had over 60 t weights. In January 2007 steel structure was ready to take a load of first pressure parts, as a first elements compact separators was lifted and hanged steel structure grid by using hanger rods. Then over next 20 months of mechanical erection all pressure parts and auxiliary equipment was erected, as well as, walls cladding, roof, refractory and insulation, to allow starting in August 2008 cold commissioning activities. Construction management was very difficult, because of work force shortages in Poland that time, fortunately Foster Wheeler managed that obstacles and have been proceeding according to schedule.

In mid time also other PKE subcontractors of new power block were performing at site, among them were: external fuel handling contractor, fly ash handling contractor, electrification contractor, DCS supplier, and many other subcontractors responsible for small systems. PKE in this project have not employed EPCM, they decided to establish project site office, they pick up different fields engineers from own plans and they are performing by themselves a project coordination and coordination of those all subcontractors.

Foster Wheeler is the biggest contractor at site with the biggest amount of people, in peak time Foster Wheeler reported to PKE over 900 workers at site. Is worth to mention that over those 30 months of Foster Wheeler construction activities not even one significant SHE incident was recorded. Second big contractor at site is ALSTOM - turbine island supplier responsible also for cooling tower. Cooling tower constructed at site is currently the biggest cooling tower in Poland, with height of 133,2m. Cooling tower was casting 24/7 through 139 days using 6 000 m3 of concrete and 800 t of steel. Flue gas duct inserted to cooling tower on elevation of 17,1m and has a diameter of 6 m.

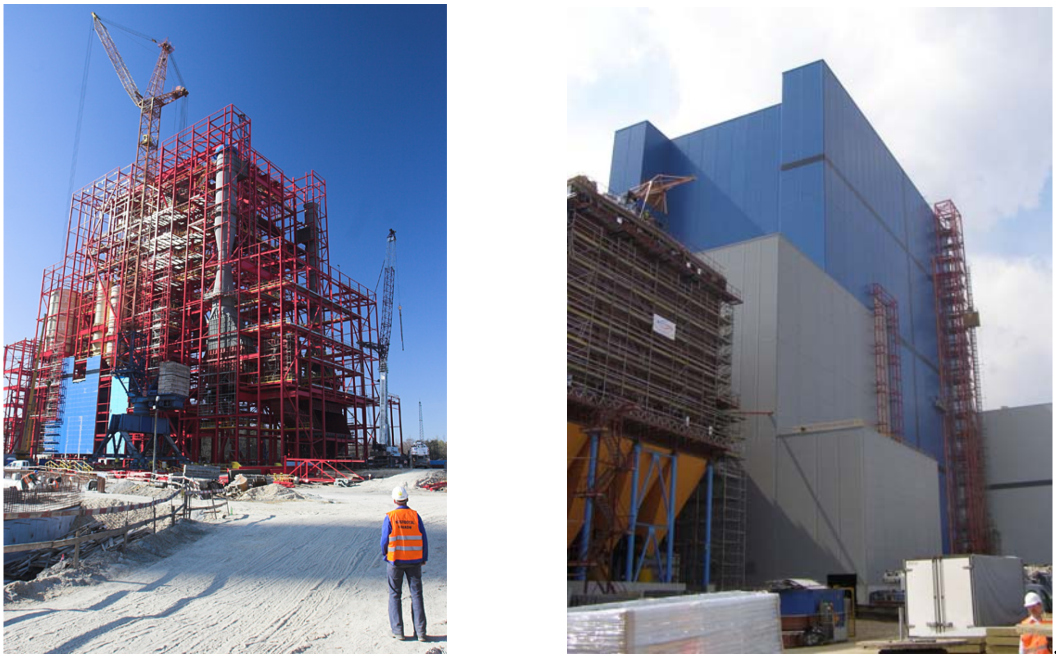

Figure 4. Łagisza CFB boiler under construction, April 2007(left) and April 2008(right).

Today, second half of September 2008 cold commissioning of boiler island and turbine island is ongoing. Control room and DCS system is already in operation, loops checking done. Fists starts of motors are ongoing, as a first was started one of the ID fans. As a next are planed cold starts of following auxiliary equipment, as other fans and coal sieving and crushing station. Crushing station is required to be ready to operation end of September 2008, because boiler steam blowing is planned to be performed also with solid fuel to reduce cost of light oil. Following big commissioning activity to be done in September, before steam blowing is boiler chemical cleaning. According to original schedule steam to turbine will be supplied begging of December 2008 and boiler take over will take place in March 2009.

Figure 5. Łagisza CFB boiler under construction, August 22nd, 2008.

5 FUTURE DESIGNS

Now when the design for Łagisza 460 MW_e CFB boiler is almost completed, the next step is to reach for even larger boiler sizes and higher plant efficiencies. To accomplish this goal Foster Wheeler together with few European partners has launched a development program to develop a CFB boiler design for 800 MW_e. The design for the 800 MW_e boiler will be based on the Łagisza design with the necessary scale-up modifications.

In this project the steam parameters are selected to represent the state-of-the-art material technology to maximize the plant efficiency. Using bituminous coal as a fuel and direct sea water cooling (18 °C), a net efficiency exceeding 45 % is estimated.

6 CONCLUSIONS

CFB technology has been considered a technology for niche applications. Today, however, the technology is challenging the conventional technology, with enhancements in terms of both scale and efficiency. CFB technology offers a number of advantages for refurbishment old power plants, such as fuel flexibility, multi-fuel capability, and emission control without the use of secondary systems. CFB boiler usally well fits to retrofited boiler room lay out allowing in many casest to increase power otput of block from the same avilable space. Integration of supercritical once-through boiler technology with CFB technology provides the best combination of features for efficient, cost effective, and environmentally safe power production.

With supercritical once through technology CFB boilers are able to provide a basis for high efficiency power plant with reduced emissions including CO_2 together with high fuel flexibility. The CFB boiler for Łagisza power plant utilizes a wide range of coals. The boiler design for 460 MW_e Łagisza power plant is based on proven solutions that are already used in other large CFB boilers delivered by Foster Wheeler. Only a modest scale-up has been required. It can be concluded that CFB technology is today commercial to boiler sizes of 500 MW_e and programs exist to scale-up the technology up to 800 MW_e. Next supercritical once through CFB boiler was sold by Foster Wheeler in January 2008 in Russia (Novocherkavskaya Power Plant) with capacity of 330MWe.