TURÓW REHABILITATION PROJECT. THE WORLD'S LARGEST CFB REPOWERING PROJECT

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ABSTRACT

The Turów Power Plant Rehabilitation Project has made an important contribution to efforts to improve the quality of the environment in area what use to be known as the "Black Triangle" on the borders of Poland, the Czech Republic and Germany. Back at the beginning of the 1990s, there was up to 14.000MW of generating capacity within 50km radius. As the largest single unit, Turów became very much identified with pollution problem.

Turów Rehabilitation Project has covered the modernization of major part of the original 10-block plant, with six pulverized coal (PC) boiler island and turbine island being replaced by new CFB units and new turbines. Contract for the opening of retrofit works was signed in 1994. The first two block were handed over by Turów in 1998, the third in 2000, the fourth in March 2003, the fifth in February 2004, and the last sixth block in December 2004 - 4 months ahead the schedule.

The CFB boilers were chosen for all three stages of rehabilitation, base on the few important reasons. New units had to be build in the foot print of the demolished old PC boilers. There were not enough space for advanced FGD system, but strong emissions limits were set to bidders. Turów requested bigger output than 200MWe, as was getting from old boilers. Also wide fuel flexibility was expected from new boilers, because parameters of brown coal what comes to Power Plant can vary quite a lot. Finally, in foot print of six old PC boilers with capacity of 1200MWe, six CFB boilers were installed with the total capacity of 1491MWe. The new block offer a net efficiency of 39 % compared to the 32% of the original design.

Turów's new CFB's have cut the plant's emissions dramatically. Now when the project is finished SO_x emissions is 87.000 t/a lower than before, NO_x emissions are 5.220 t/a lower, and particulates are down 36.500 t/a. In addition to CFB repowering project, Turów Power Plant has also already installed desulphurisation equipment and low-NOx burners on its other PC boilers. Seven measurement stations are installed in the surrounding area today, monitoring emission levels continuously and sending data booth to Power Plant and to state authorities. Following the closure of old capacity in Germany and commissioning of new cleaner plants in Poland, and improvement in the Czech Republic too, the "Black Triangle" has ceased to exist. In 2002 Turów Power Plant received the Polish Ecology Leader Prize in recognition of environmental achievements. In 2004 "White Tiger Laurels" was awarded to Turów in field of technical and ecological retrofit of Power Plant. Now after 10 year of

Rehabilitation Project going on, is the time to use name of “Green Triangle” for that Europe area.

1 INTRODUCTION

Elektrownia Turów, Poland, (Turów Power Plant) was constructed in 50’s and 60’s previous century, first of six Units, 200MWe each, was commissioned in 1962, that time it was one of the biggest power project in Europe. In 1971 was finished second phase of project, with another 4 Units, finally total power of plant achieves 2000MWe. In beginning of 90’s oldest Units exceed the 200.000 hours of operation, all equipment was worked out, mainly boiler, turbine and piping, what could lead to serious breakdowns, and additionally efficiency of power production continuously decreasing. To avoid shut down of following Units after 1995, was taken decision about beginning of Rehabilitation Project. After deep consideration about fuel sources size and quality and combustion technology for new Units, CFB technology was chosen as best technology for new efficiency and environmental requirements. Elektrownia Turów modernization started in 1995. The first phase was rehabilitation of Units 1 and 2, that were commissioned in 1998, the second-phase Unit 3 was commissioned during April 2000, third-phase Units 4-6 were commissioned respectively: March 2003, February 2004 and December 2004. The project has been presented to the public on various occasions, thus the objective of this paper will be to show summary of whole modernization of Elektrownia Turów and present some operational experience form six CFB boilers working in one plant. In the first and second-phase, three old 200 MWe (Units 1, 2 and 3) pulverized brown coal fired boilers were replace with circulating fluidized bed (CFB) boilers each of capacity of 235 MWe. Those three CFB units in Elektrownia Turow represent conventional CFB technology - the separators are round hot cyclones with heavy refractory lining. In order to minimize the maintenance needs related and simplify the overall design, for third-phase Foster Wheeler has developed the Compact design where the traditional cyclones have been replaced with a cooled, rectangular solids’ separators. Primarily, these changes were results of technology and design development but there were also changes resulting from experience gained on the first three units. While the Compact design is already proven FW solution in CFB technology, its Turów application represents biggest CFB with Compact design in the world. Other up to date design used in Turow boilers was INTREX™ superheater design. Coming back to the Compact solution: the reduced space requirement is demonstrated in Turów’s case. With Compact design and steam parameters upgrade it has been possible to increase the output of each new Unit 4-6 to 261.6 MWe from 235 Mwe

(Units 1-3) utilizing the same footprint available from old 200 MWe boilers. Last Unit - Unit 6 was hand over in December 2004. Now Elektrownia Turow is the world's biggest utility-size power plant utilizing CFB technology with almost 1,500 MWe installed CFB capacity.

2 PROJECT FINANCING SOURCESS AND REHABILITATION STAGES

Commencement of the Rehabilitation Project depended mainly on work progress in the gaining of financing for deliveries and services. The only one realistic possibility to gather founds in amount proper to finance 6 units modernization, was the bank credits. Rehabilitation Project schedule was an outcome of negotiations with credits grantors and Polish Energy Grid operator (PSE S.A.), who guaranteed suitable plant revenues, base on long-term energy sell contract. In the first financial stage, was organized Polish and foreign banks consortium, which grant a credit of total value 363 MUSD, enough to cover costs of first-phase of rehabilitation of oldest Unit 1 and 2.

In October 1992, was finished bid procedure to choose boiler and turbine island supplier, the best offers delivered consortium ABB and Alhstrom Pyropower Corp., next two years expired on negotiations on required set of documents to put in motion Rehabilitation Project:

- Long-term contract for energy sell with PSE S.A., signed in August, 1994.
- Contract for Rehabilitation of Units 1-2, with option for rehabilitation Units 3-4 in second-phase and Units 5-6 in third-phase, contract signed in November 1994. (during 10 years of Rehabilitation Project, because of ownership transformations, instead of ABB, came Alstom, and instead of Alhstrom Pyropower, came Foster Wheeler Pyropower).
- Long-term contract for lignite supplies with Turów lignite mine (KWB Turów), signed in April, 1995.
- Series of bank credits contracts, last one signed in June 6th, 1995.

2.1 First phase (Units 1 and 2)

Real date of the Rehabilitation Project beginning, was Unit 1 shut down for demolition, in June, 1995. Unit 2 was shut down in September 1995. PAC (Provisional Acceptance Certificate) for new Units with CFB boilers were sign in December, 1998. Guaranty measurements performed couple of month later, proved that performance data fulfilled all conditions promised in contract.

2.2 Second-phase, (Unit 3)

Second-phase originally should includes modernization of Units 3 and 4, but finally, because of difficulties with financial closing, cover only Unit 3 (196,5 MUSD). In 1997 Elektrownia

Turów sign with consortium ABB – Alhstrom Pyropower Corp. Annex no1 to Contract, commenced second-phase of modernization. In September, 1997 Unit 3 was shut down for demolition. Experience gathered by Consortium during construction of Units 1 and 2, caused that PAC for Unit 3 was signed in May, 2000, six months faster than for Units 1-2.

2.3 Third -phase (Units 4, 5 and 6)

Working on third-phase of modernization, Elektrownia Turów signed credits in amount enough to perform modernization of following three Units, 4-6. Total value of this modernization phase was 667,5 MUSD, this also included 70 MUSD of Elektrownia Turów own founds. In December 1999 signed Annex no2 to Contract with Consortium ABB Alstom Power and Foster Wheeler Pyropower Corp., covering Rehabilitation of Units 4-6. Because in December 1998 on old Unit 5 was a serious damage of generator and control room, third-phase of modernization begins from this Unit. In succession following Units were shut down for demolition and new Units commissioned, i.e. Unit 5 shut down December 1999, PAC signed March 2003; Unit 4 shut down march 2000, PAC signed March 2001; Unit 6 shut down February 2002, PAC signed December 2004.

3 CFB BOILER DESIGN

CFB boilers for the first stage had lower steam parameter requirements, because there were assumption to use as much as possible of existing equipment, mainly in turbine hall, steam parameter were not set on high level. Although in the third stage, base on the wide experience gathered during stage I and II, was taken decision about increasing of power output and steam

Table 1. Comparison of main boiler data.

		Boilers	
		# 1-3	# 4-6
Main Steam flow	kg/s	185.4	195.5
Capacity	MW_t	528.9	
Main Steam Pressure	bar	131	169
Main Steam Temperature	^oC	540	565
Reheated Steam Pressure	bar	24	39
Reheated Steam Temperature	^oC	540	585

parameters, because was not assumed that old auxiliary equipment will be used in such a scope like for Units 4-6. Table 1. presents parameters sheet for Units 1-3 and 4-6. Together with increasing of steam parameters, was change also boiler concept, instead of design with

round heavy cyclones, Foster Wheeler offered, so called "compact" design boiler. This design is characterized by rectangular separators adjacent to furnace, it lead to further increasing of power output up to 261.6MWe, from pitch where originally was installed 200MWe PC boilers. Design fuel was the same for all three stages of rehabilitation, for both boiler concepts. Fuel is local lignite from local open pit coalmine, located not more than 10km from power plant; fuel is transported to fuel yard by belt conveyors. Tables 2. presents fuel sheet for Turów Rehabilitation Project. High moisture content of design fuel, case that furnace size of Turów CFB was that time biggest among ever delivered Foster Wheeler CFB boilers.

Table 2. Fuel parameters

		Fuel - lignite	
		Design	Range
LHV	kJ/kg	8250	16 - 19
Moisture	%	44	40 - 48
Ash (a.f.)	%	22.5	6.5 – 31.5
Sulfur (d.s.)	%	0.6	0.4 – 0.8

3.1 First and second stage of rehabilitation, boilers no 1-3

The boilers include a water-cooled furnace, brick lined cyclone and a conventional back pass with superheater III, reheater II and reheater I enclosed in a steam cooled convection cage. Below there are an economizer and tubular air heater. The furnace includes 14 omega superheater panels and 14 superheater wing walls. Coal is supplied to the furnace through feed points penetrating the furnace wall. Limestone is injected from two feed systems to the injection points. Boiler is equipped with 10 heavy oil fired start-up burners. Bottom ash is removed with water-cooled screw coolers and side ash coolers. The space restrictions imposed necessitated configuring the boiler with two (2) large diameter cyclone separators that represented a significant scale-up from previous experience. A three-cyclone design would have required increase in boiler island width for which there was not sufficient space. Performance with the large diameter cyclones was as

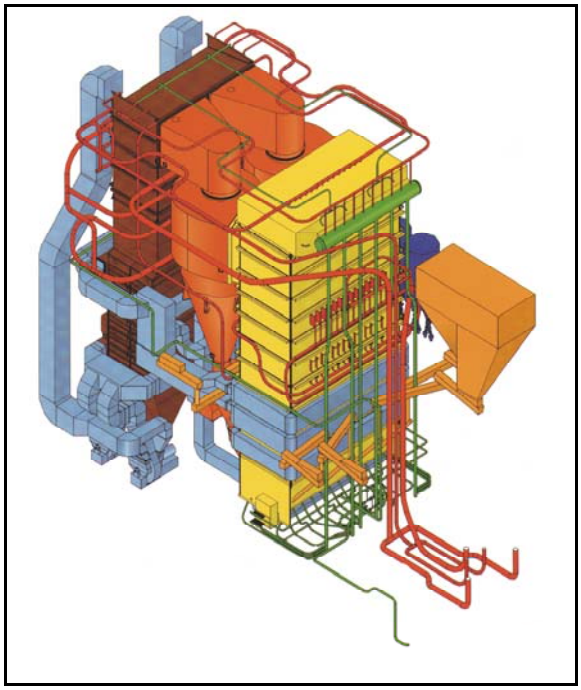

Figure 1. View of Turów phase I-II boiler.

expected with all performance guarantees. All plant performance guarantees had to be demonstrated including the requirements of the Union for the Coordination of Production and transmission of Energy (UCPTE) which is the European utility power plant standard that contains guidelines for load ramp changes and plant dispatching.

All three units met or exceeded the trial run requirements, demonstrating that the large scale-up of CFB boilers can meet utility market requirements for cycling and that the scale-up of the furnace solids circulation loop beyond previous experience was successful. The trial run and performance tests together confirmed that:

- CFB boilers were in full compliance with UCPTE criteria.
- Guaranteed parameters were met in a wide range of load conditions.
- Full capacity can be reached without any problems.
- Emission guarantees are clearly met with significant margins.
- The boilers are flexible in a wide range of loads.
- The plant availability was achieved.

As indicated above, the performance test results confirmed the design assumptions and met the requirements of the contract.

3.2 Third stage of rehabilitation, boilers no 4-6

"Compact" design has been selected for the boiler 4-6 with an incentive of having higher power generation for each unit: 261.6 MWe instead of 235 Mwe within the same space restrictions that previously accommodated old, pulverized coal 200 MWe units. The Foster Wheeler CFB boilers for blocks 4, 5 and 6 are designed for fixed pressure, natural circulation, lignite firing units with live steam maximum continuous rating of 195.5 kg/s. Estimated boiler efficiency for the phase III is 91 %, LHV based with stack temperature lowered down to 130 °C compared to 157 °C for units 1–3. Required emissions level from CFB boilers 4-6 is achieved by low combustion temperature and even temperature profile through the height of the furnace, a staged combustion, good residence times and mixing conditions. It should be noted that further lowering of the emission limits to the future EU requirements could be easily obtained with only minor adjustments. For example, for the NO_x limit of 200 mg/Nm^3 solution will be adding a simple system of weak water-solution of ammonia spraying into the separators. Lowering the sulfur dioxide emission can be achieved with more limestone injection to the furnace or with ash activation solutions. Units are be compatible with UCPTE and PSE (Polish Power Grid Company) requirements regarding their operation for the grid and are able to work on house-load.

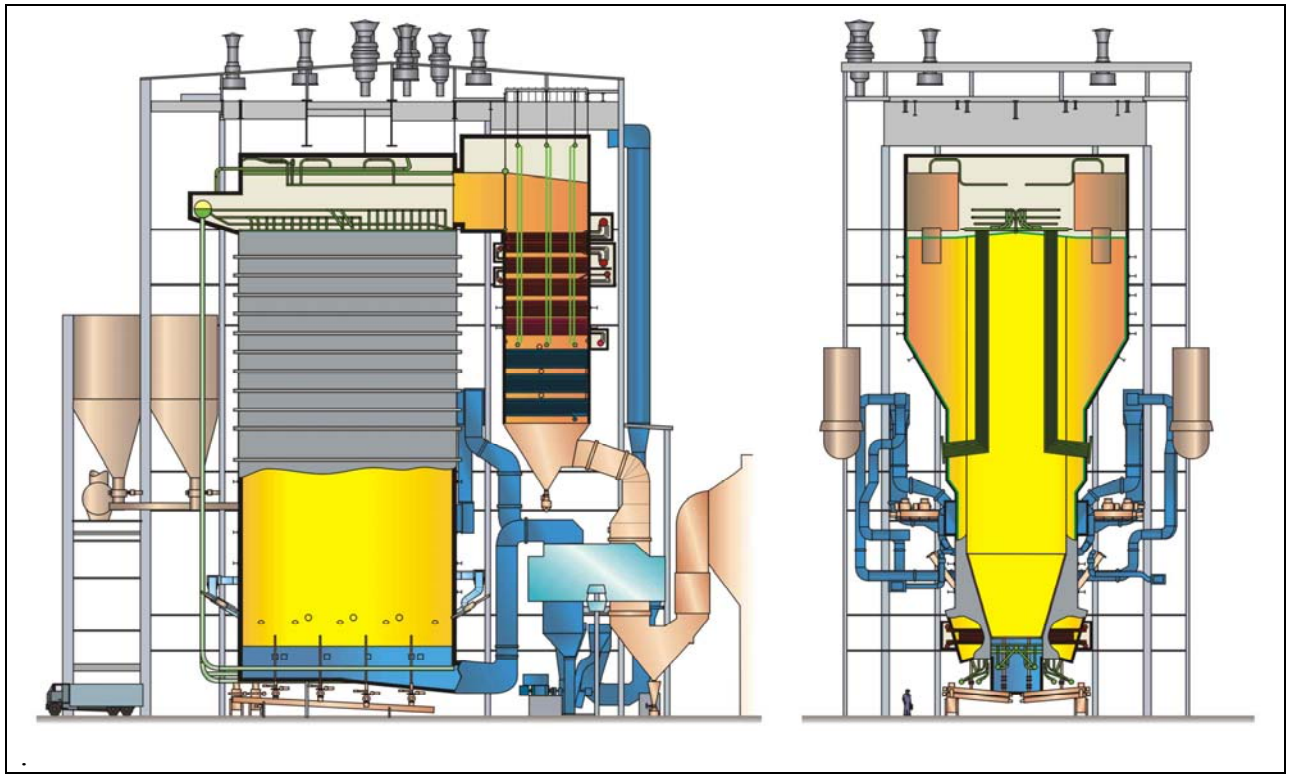

Figure 2. View of Turów phase III boiler.

Designed stable operation range of the boilers without auxiliary firing is from 40 % to 100 % MCR. Steam temperature control range is from 60 % - 100 % of the full load. Increase of the unit capacity was achieved thanks to higher steam parameters selected, application of Compact boiler concept, the INTREX™ heat exchangers and rotary airpreheaters.

4 ENVIROMENTAL EFFECTS OF MODERNISATION

In the beginning of 90's region on the Germany, Czech Republic and Poland border cross-section, where Elektrownia Turów is located, was terribly polluted, gathered in that area thermal power plant of three countries, produced a lots of pollutants. Forest in neighbor started to die, because of acid rain precipitation. Finally region started to be internationally

Table 3. Emissions Units 1-3

			SOx g/GJ	NOx g/GJ	Dust mg/Nm^3
Guaranteed in dry gas 6%O_2			150	150	50
Unit 1	100	%MCR	114.2	122.5	17.5
Unit 2	100	%MCR	126.0	126.0	3.5
Unit 3	100	%MCR	84.0	111.0	6.0

called „BLACK TRIANGLE". As a modernization effect, power plant has got six modern Units, which fulfilled all EU requirements in respect to dust, SO_x and NO_x emission. Also all CFB Units fulfilled CO emission requirement, although contract for first three CFB Units not guaranteed CO emission, according to contemporary legal status in Poland.

Table 4. Emissions Units 4-6

			SOx mg/Nm^3	NOx mg/Nm^3	CO mg/Nm^3	Dust mg/Nm^3
Guaranteed in dry gas 6%O_2			347	371	150	50
Unit 4	100	%MCR	316	239	6.8	16
Unit 5	100	%MCR	287	275	4.3	21
Unit 6	100	%MCR	Measurements not performed jet.			

Guarantee measurements of Unit 6 will be performed in year 2005, preliminary measurements, done during trial run, proved that also this Unit will not have any problem to fulfilled guaranteed emissions levels.

New CFB Units in respect to old PC produces 87.000 ton/a less SO_2 (93% reduction/MWe), 5.220 ton/a less NO_X (50% reduction/MWe), 36.500 ton/a less dust (94% reduction/MWe, 100 ton/day less).

Seven measurement stations are installed in the surrounding area today, monitoring emission levels continuously and sending data booth to Power Plant and to state authorities. In 2002 Turów Power Plant received the Polish Ecology Leader Prize in recognition of environmental achievements. In 2004 "White Tiger Laurels" was awarded to Turów in field of technical and ecological retrofit of Power Plant.

Following the closure of old capacity in Germany and commissioning of new cleaner plants in Poland, and improvement in the Czech Republic too, the "Black Triangle" has ceased to exist. Those environmental friendly activities have converted region name to **GREEN TRIANGLE.**

5 ECONOMICAL EFFECTS OF MODERNIZATION

New Units with the power output much higher than old Units (before modernization all old Units, had power output 200MWe each, now 235MWe in case of Units 1-3 and 260MWe in case of Units 4-6), has also higher power production efficiency. Demolished Units equipped with PC's had net efficiency on the level of 32-33%, present Units 1-3 has net efficiency higher than 37%, and Units 4-6 higher than 39%. Flexibility of new Units, allow having a

beneficial energy-selling contract, because of Units load controlling by central energy distribution system. As a result of significant efficiency increasing, with similar fuel input to all six units, their total power output increased by 285MWe, effecting reduction of CO_2 per MWe almost by 20%.

Important effect of modernization is social issue and economical activation of region, thru 10 years of project executions, unemployment in region significantly reduced. Plenty of companies what came to plant, employed local staff for modernization works. In case if this, project would not happened, and in beginning of 90's would be taken decision that Elektrownia Turow will not be modernized but shut down including closing of open pit lignite mine, local authorities would face with social disaster.

6 OPERATIONAL EXPIRIENCE

Almost thirty years technical stuff in Elektrownia Turów was dealing with PC combustion technology, new CFB Units has brought new challenges, minds of many people had to be changed. New technology brought new requirement for power plant staff skills. Operational staff was trained at reference Foster Wheeler boilers and intensively during start up by commissioning team. That was successful training program, well prepared people of Elektrownia Turów, very easy handled new knowledge and skills. Finally it leads to on-time performed hand-over of Units to Elektrownia Turów. During guarantee measurements each unit was controlled fully only by plant stuff, performance data what was achieved during guarantee measurement can be found in table 5.

Table 5. Units 1-6 performance

Units 1-3	**Guaranteed**	**Operational average**
Boiler efficiency	90%	91.2%
Unit efficiency (gross)	-	40.8%
Net heat rate	9795 kJ/kWh	9556kJ/kWh

Units 4-5	**Guaranteed**	Unit 5*	Unit 4*
Boiler efficiency	91%	92.54%	93.19%
Unit efficiency (gross)	-	41.89%	41.94%
Net heat rate	9211 kJ/kWh	8922kJ/kWh	8827kJ/kWh

* Data from guarantee measurements

6.1 Operational experience, Units 1-3

On the each Unit after signing PAC began 18 months long guarantee period, during that period guarantee measurements were performed. Energopomiar-Gliwice as a third independent party was an executor of measurements. All parameters guaranteed in the contract, booth performance and environmental were fulfilled with significant reserve (environmental effects look chapter 4). Expected boiler efficiency was 90%, operational experience shows that average boiler efficiency is around 91,2%. Despite, that units fulfilled requirements of Elektrownia Turów and contract parameters, there occurred some number of mechanical defects and faults. The major works what Foster Wheeler had to performed during guarantee time of Units 1-2 were:

- Replacement of PA and SA fans.
- Reductions of ID fan vibrations.
- Corrections on main stem piping hangers.
- Burner management system corrections.
- Windbox mechanical tunig for even air flow distribution.

There were also some minor issues to correct, but in "baby age" of boiler, is a normal situation that some malfunctioning occurs, Foster Wheeler fixed them in guarantee period. All of issues (major and minor) were already corrected during erection of Unit 3.

Elektrownia Turów continuously working on improvement of Units 1-3 performance, availability and reduction of maintenance costs. There is an improvement program for:

- Investigation of further emission reduction.
- Investigation for further limestone consumption reduction.
- Increasing of boilers efficiency.
- Increasing of refractory life time.
- Decreasing of power consumption for own needs, mainly for lower loads of boilers.
- Implementation of long-term maintenance program for maintenance cost reduction.

Summarizing boilers 1-3 operational experience since 1998, can be said: boilers are working with high efficiency, availability is very high, emissions are on proper level with reserve for future stronger limits, boilers are flexible for fast load changes, continuously cost of maintenance is reduced, failures were removed during guarantee period by boiler supplier. Following schedule is set for maintenance (same is assumed for Units 4-6): one outage for 16 days for one unit every one year, one outage for 45 (target is to cut it for 35 days) days for one unit every 5 years, one outage for 65 days for one unit every 10 years. According to Senior Boiler Manager: "I state that boilers 1-3 are very good product, and we as power plant will be at least so happy with Boilers 4-6 like with 1-3."

6.2 Operational experience, Units 4-6

Presently all six Units are in operation, Units 5 and 4 passed guarantee test, performed by same company like on boilers 1-3. All parameters guaranteed in the contract, booth performance and environmental were fulfilled with significant reserve (environmental effects look chapter 4). Guarantee test for Units 6 will be performed in July 2005; preliminary operational data are showing that this unit will not have also any difficulties to fulfill requirements with some reserve. Expected boiler efficiency for Unit 4-6 is 91%, measured indicate 93.19% for Unit no 4 and 92.54% for Unit no 5. Experience gathered on erection of Units 1-3 and 4-5 allow to sign PAC of Unit no5 almost three months ahead schedule. Compare operational experience from Units 4-6 with Units1-3 can be recognized:

- Higher availability.
- No erosion problems.
- Higher efficiency.
- Lower maintenance cost.

Although, after long experience from Units 1-3, on Units 4-5 Foster Wheeler did not avoid some troubles while Stage III of modernization. During guarantee period some repairs work were performed on Units 4-5: replacement of rotary air preheater seals, antyvibration shield in back pass modernization, main stem pipe line supports modernization, ash handling system form ESP hoppers modernization.

7 FUTURE OF ELEKTROWNIA TURÓW

Now at power plant exist four old PC boilers. Boiler no 7 is not in operation anymore, for last 2 years. Units 8-10 were modernized in the years 1994-1996. Modernization comprised following systems: turbine and turbine controller, boiler start-up system, electrical system, control system and unit protections and dry DESOX installation. Those units will be in operation till achievement of 250 thousands hours, what is going to happened around 2008-2011. After this moment Units 8-10 will be shut down. Because of already performed shut down of Unit no7 and future shut down of Units 8-10, there is possibility to install on their foot print, modern power unit. Lignite sources are enough to ensure continuous fuel supplies for that unit for next 25-30 years. Beginning of that investment depends only on possibility for gathered necessary financing for investment. Presently different technical solution for new unit are considered, one of them is installation on the place of Unit 7-10, one Unit equipped with 460 MWe turbine and supercritical once-thru CFB boiler. In Poland two Units with

power output 460MWe each, are under construction in Poland, one base on lignite and one base on bituminous coal, this is going to be standard size of middle size utility power unit for Polish energy sector.

8 CONCLUSIONS

Now Elektrownia Turow is the world's biggest utility-size power plant utilizing state of the art CFB technology with almost 1,500 MWe installed as a CFB capacity. This ambitious Rehabilitation Project with project value of total $US 1.7 billion was the biggest rehabilitation program in Polish energy sector. This project has brought for Elektrownia Turów success in many areas: successful financing gaining, master new technology in-house, fulfilling project execution requirements, keep continuously financial safety of project and financial partners. Surrounding environment is clean, and name of region has been converted to GREEN TRIANGLE. Elektrownia Turów has got plenty Polish and European of environmental awards, which ascertained that all what was done, was done properly and in such a way is received by inhabitants and authorities. Socially, region is safe and developed. Units 7 is already shut down, Units 8-10, has to be shut down by 2011, quite soon we could hear again about Turów Rehabilitation Project, that time it will be called Stage IV.

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