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CIRCULATING FLUIDIZED BED BOILERS

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The development of atmospheric bubbling fluidized bed (BFB) combustion between 1950 and 1960 led to the workout of a new type of fluid-bed process – circulating fluidized bed (CFB) combustion.

In the Europe, the leadership in the development of CFB technology between 1975 and 1985 belonged to Lurgi Lentjes Babcock (LLB, Germany) and Research and Development Center of Ahlstrom (Hans Ahlstrom Laboratory, Finland; since 1995 Foster Wheeler).

The analysis following below is based on the data of Foster Wheeler (FW) and LLB Lurgi.

The first CFB boiler at Research and Development Center of Ahlstrom (Pyroflow process) was built in 1976. First commercial CFB boilers of thermal capacity 7-15 MW burning peat, wood waste or coal went into operation since 1979 in Finland. The first industrial size unit of thermal capacity 65 MW went into operation at paper mill at Kauttua, Finland in 1981. One of the first industrial applications was the 55 MW boiler at Kemira Oy chemical plant in Oulu, Finland, started in 1983. By end of 1996 the 143 FW boilers of total thermal capacity 16,195 MW ranging in unit capacity from 7 MW to 409 MW were in operation, of average unit capacity 113.3 MW. At the end of 1998, the total number of boilers will increase up to 157 and total thermal capacity up to 19,556.5 MW (Figs. 1 and 2).

The first industrial CFB boiler of Deutsche Babcock (Circufluid process) with thermal output 84 MW burning bituminous coal with high ash content started operation in Lünen, Germany in 1982 (Fig. 1). Between 1982 and 1995, LLB with its partners has designed and manufactured 69 CFB units for industrial and utility applications of total thermal capacity 10,347 MW, ranging in size from 44 MW to 650 MW. In 1996-1998, 16 boilers will be added to them. At the end of 1998, the

total number of boilers will increase up to 85 and total capacity up to 12.488 GW (Figs. 1 and 2).

In these CFB boilers fuels with variable particle size and high ash, moisture and sulphur content have been burned. These boilers can burn besides high-grade coals a broad band of cheap fuels such as high-sulphur and high-ash coals, lignite, anthracite culm, petroleum coke, oil shale, wood waste, bark, peat, wide range of different industrial sludge, sulfite liquor as well as different mixtures of coal with wood, peat, wastes and other, including oil and gas, etc.

Based on the above-given survey, between 1979 and 1998 Foster Wheeler and LLB Lurgi with their cooperation partners have installed or will install worldwide 242 CFB boilers of total thermal capacity about 32 GW ranging in unit size from 7 MW to 650 MW (Table 1).

Average unit capacity per year has been increased from 29.3 MW in 1979 up to 100-150 MW during last 10 years. Change of average unit capacity per year for Foster Wheeler and LLB Lurgi is shown in Figure 1.

Table 1. **CFB Boilers 1979-1998. Foster Wheeler & LLB Lurgi**

		Capacity	
Year	Number of units	Total MW_{th}	Average MW_{th}
1979	3	88.0	29.3
1981	3	97.0	32.3
1982	2	136.0	68.0
1983	4	150.0	37.5
1984	1	97.0	97.0
1985	9	652.0	72.4
1986	5	558.0	111.6
1987	6	771.0	128.5
1988	31	3118.0	100.6
1989	20	3071.0	153.6
1990	29	4382.0	151.1
1991	10	1499.0	149.9
1992	21	2727.3	129.9
1993	11	1348.3	122.6
1994	16	2362.5	147.7
1995	23	3190.5	138.7
1996	25	2914.5	116.6
1997	15	1990.4	132.7
1998	8	2892.0	361.5
SUM 1993	**155**	**18509.6**	**119.4**
SUM 1995	**194**	**24062.6**	**124.0**
TOTAL 1998	***242***	***32044.5***	***132.4***

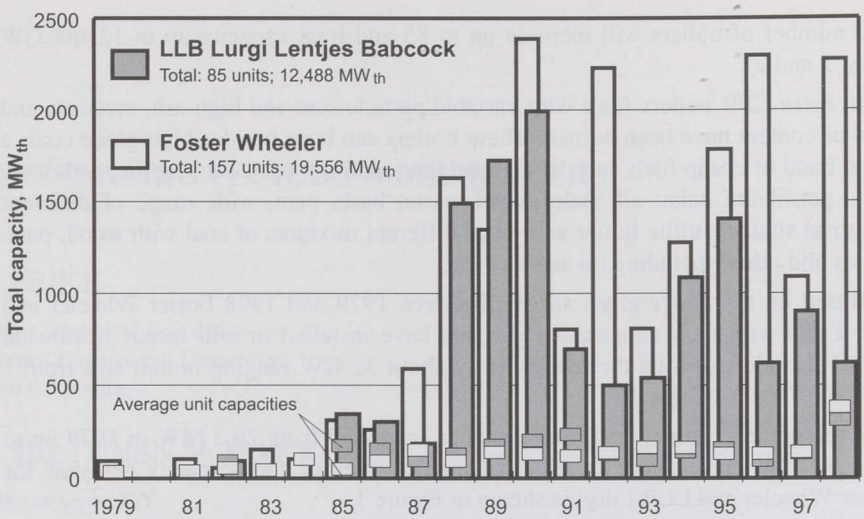

Figure 1. Total and average capacity of CFB boilers installed by LLB Lurgi and Foster Wheeler between 1979 and 1998

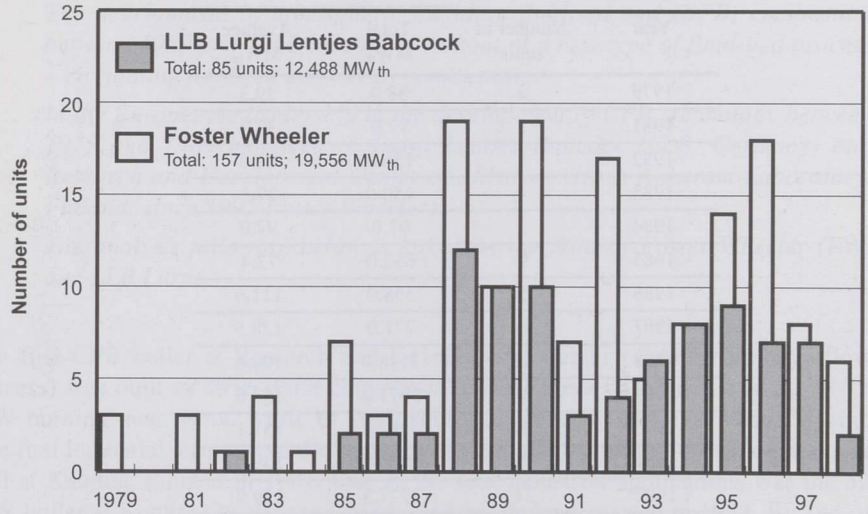

Figure 2. Number of CFB boilers manufactured by LLB Lurgi and Foster Wheeler between 1979 and 1998

BOILERS FOR EUROPEAN COUNTRIES

For European countries between 1979 and 1998 by Foster Wheeler and LLB Lurgi 93 units for industrial and utility applications of total thermal capacity 11,390 MW, ranging in size from 44 MW to 650 MW were installed or designed (Fig. 3). Foster Wheeler has installed in 12 European countries 60 CFB boilers (6,192 MW_{th}) and LLB Lurgi in 5 countries 33 units (5,198 MW_{th}) of average unit capacity 103.2 and 157.5 MW_{th}. The part of Foster Wheeler in Europe made 54.4%.

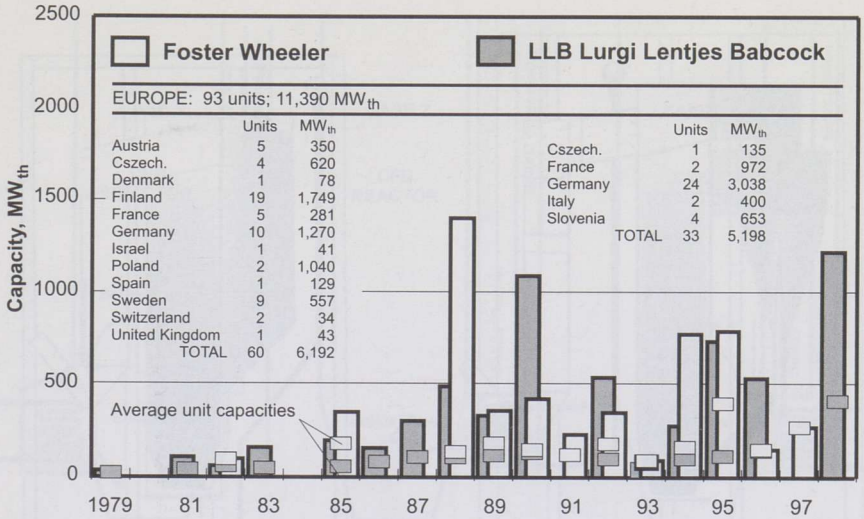

Figure 3. Capacity of CFB boilers installed by LLB Lurgi and Foster Wheeler for European countries between 1979 and 1998

Figure 4 shows the distribution of capacity percentage in the European countries. As it can be seen, 64% of capacity is distributed in three countries: Germany (37.82%), Finland (15.36%) and France (11%).

Foster Wheeler, besides Finnish manufacturers, has cooperation partners in Germany (EVT – Energie- und Verfahrenstechnik GmbH), Austria (AEE – Austrian Energy and Environment) and France (CNIM – Constructions Navales et Industrielles de la Mediterranee S.A.). Part of partners in production of CFB boilers for European countries was 21 boilers with total thermal capacity 2,357.3 MW.

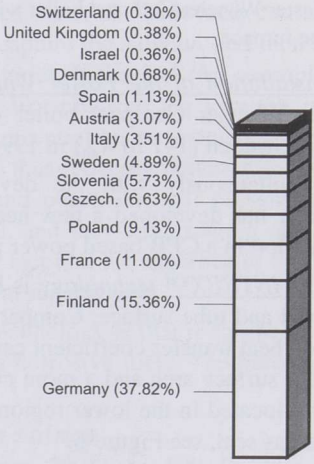

Figure 4. Distribution of installed boiler capacity between European countries

For Finland, between 1979 and 1995, FW has installed 16 Pyroflow and 3 Compact boilers of total thermal capacity 1,749.3 MW in the range from 7 MW to 299 MW (Fig. 3).

The principal schemes of Pyroflow and Foster Wheeler Compact boilers, worked out in the Foster Wheeler, are shown in Figures 5 and 6.

The Pyroflow boilers of the maximal size in Europe were installed in Seinajoki, Finland (249 MW_{th}) in 1990 for burning peat and coal, and in Essen, Germany (313 MW_{th}) in 1991 for burning German brown coal. In 1998, the installation in Bogatyna, Poland of two boilers of thermal capacity 520 MW for burning Polish brown coal is planned.

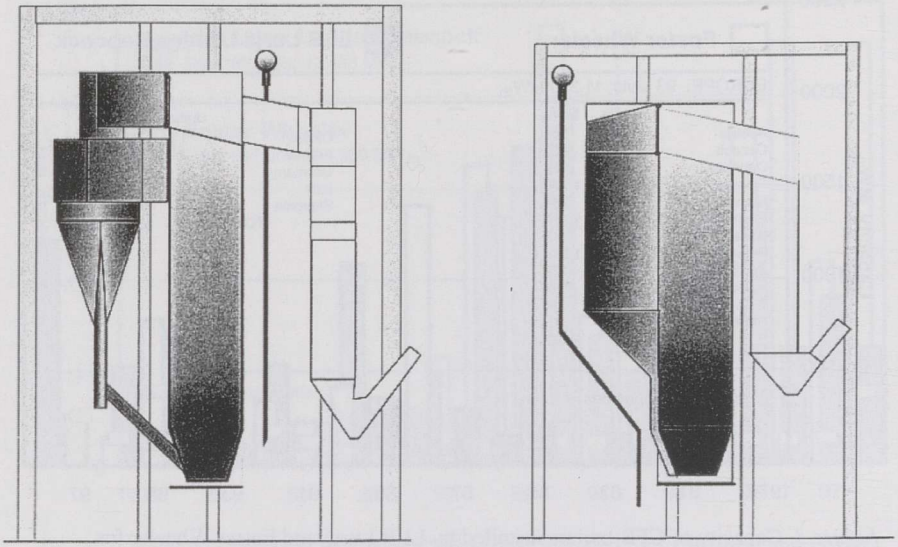

Figure 5. Foster Wheeler. The traditional boiler with round cyclone on the left and the Foster Wheeler Compact boiler with "square cyclone" – centrifugal separator – joined to the furnace

Installation of the Foster Wheeler Compact boilers was started in 1992. The Foster Wheeler Compact boiler of the maximal size in Europe was installed in Brista, Sweden (141 MW_{th}) in 1996 for burning wood waste.

Simultaneously with the development of the Compact CFB boiler, Foster Wheeler has developed a new heat exchanger design which can be used for steam production in a CFB based power plant.

The INTREX™ technology is based on the heat transfer between fluidized solid material and tube surface. Compared to conventional gas phase heat exchangers, the outside heat transfer coefficient can be up to six times higher. This allows lower heat transfer surface area and a more compact design. The INTREX™ heat exchanger is usually located in the lower region of the furnace, or in the solids return in the place of the gas seal, see Figure 6.

The solids can be introduced from the solids separator or from the combustor, and returned to the combustor. The heat recovery can be controlled by adjusting fluidization in the chamber, or by controlling the solids mass flow through the INTREX™ with non-mechanical valves. The temperature of solids entering the chamber is normally between 700°C and 900°C, depending on the boiler load.

Fluidizing is achieved by blowing air through the solid material lying on the grid acting as an air distributor. The INTREX™ operates at bubbling fluidized bed range; the superficial fluidization velocity is lower than 1 m/s during normal operation. With this fluidization rate, there exists a visible bed surface level which is kept above the highest heat exchange surface to avoid erosion caused by the entering solid material, and to reduce the risk of corrosion caused by the chlorine-containing gas atmosphere.

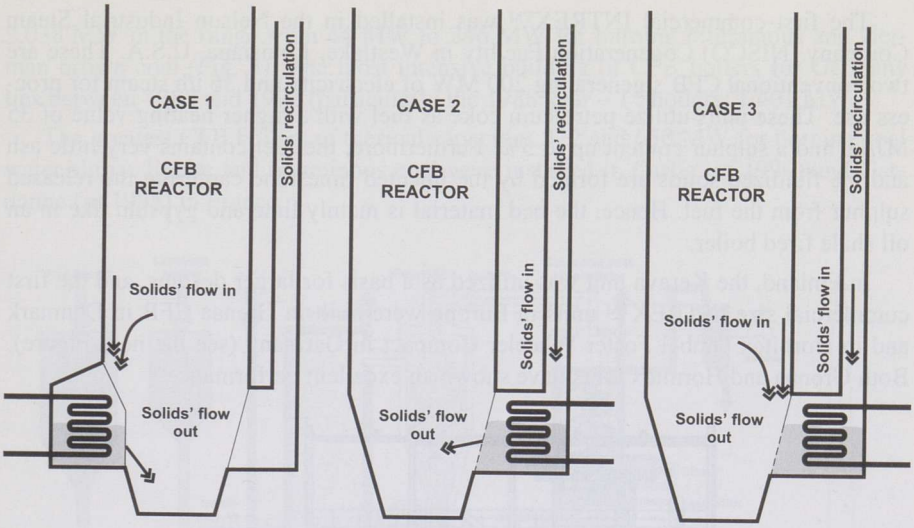

Figure 6. Possible locations for an INTREX™ superheater in a Foster Wheeler Compact boiler

To low ash fuels, sand is added to form the bed material. With fuels containing sulphur, limestone is often fed into the furnace to capture the sulphur, and then limestone together with fuel ash will form the bed material. If the fuel (for example the Estonian oil shale), contains harmful impurities, like chlorine the location in the return line of the solids separator decreases the concentration of impurities entering the region of the INTREX™ heat transfer surface, thus reducing potential for corrosion. However, the small amounts of chlorine and potassium still present in the circulating solids will be released in the loop seal, and they will create a corrosive environment in the gas above the solids level. The fact that the superheater tubes are inside the solids will reduce the corrosion rate of the superheater.

The major advantage of the new INTREX™ technology is that it can be used as final superheater or reheater in boilers combusting corrosive fuels. The benefits can be listed as follows:

- avoidance of corrosion of heat transfer surfaces,
- controllability, tested load range from 20 % to 100 % with non-mechanical valves,
- an efficient way of controlling bed temperature,
- lower heat transfer area than in the conventional heat exchangers,
- compact size.

The controllability of superheaters is a useful feature in regulating boilers which have to operate with large daily load changes. The INTREX™ can be utilized both for the steam temperature and bed material temperature control by utilizing a spray desuperheater for the steam temperature, and a INTREX™ for the bed temperature.

The heat transfer rate is higher than in conventional superheaters – so the heat transfer areas can be reduced. Various designs have been studied and the design parameters have been analyzed, first in cold models and then in hot pilot units during several test run periods.

The first commercial INTREX™ was installed in the Nelson Industrial Steam Company (NISCO) Cogeneration Facility in Westlake. Louisiana, U.S.A. These are two conventional CFB's generating 200 MW of electricity and 36 t/h steam for process use. These units utilize petroleum coke as fuel with a higher heating value of 35 MJ/kg and a sulphur content up to 5%. Furthermore, the fuel contains very little ash and the fluidized solids are formed by the injected limestone capturing the released sulphur from the fuel. Hence, the bed material is mainly lime and gypsum like in an oil shale fired boiler.

In Finland, the Kerava unit was utilized as a basis for larger designs, and the first commercial size INTREX™ units in Europe were built in Grenaa CFB in Denmark and in Hornitex GmbH Foster Wheeler Compact in Germany (see the next Figure). Both Grenaa and Hornitex units have shown an excellent performance.

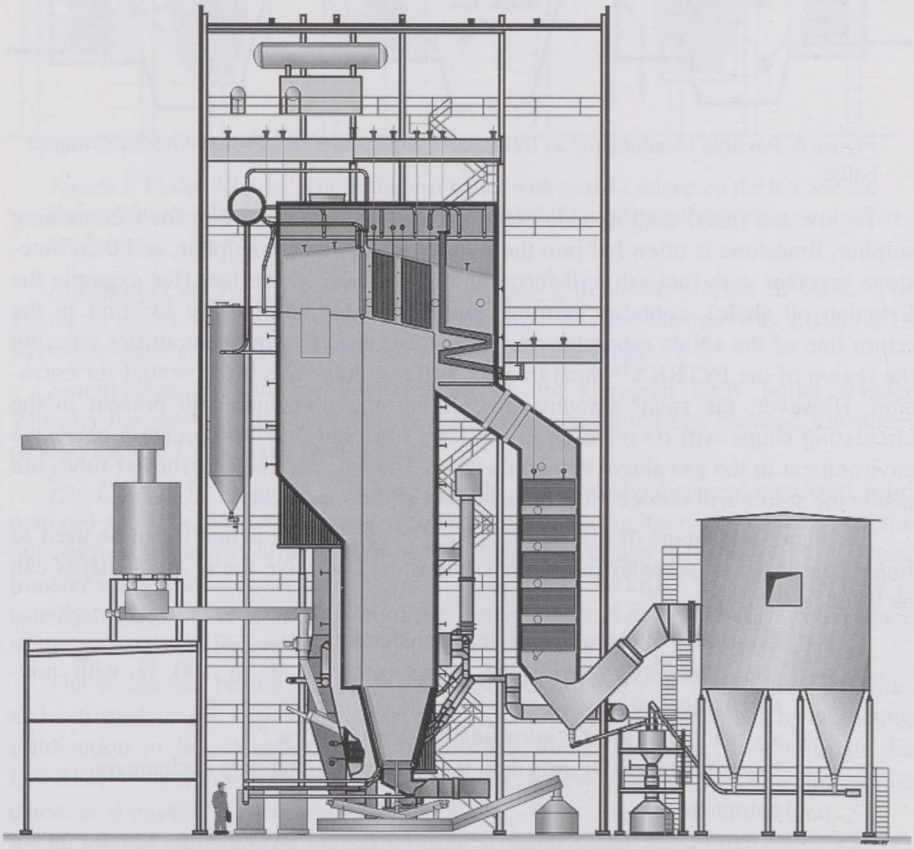

Figure 7. Hornitex GmbH Foster Wheeler Compact

European Cooperation Partners of LLB Lurgi in France (Stein Industry), Italy (Ansaldo), Slovenia (Slovenske Energeticke Strojane) and Czechoslovakia (Prvni Brnenska Strojirna) were installed 9 boilers of total thermal capacity 2,160 MW. LLB Lurgi (Deutsche Babcock, Lentjes and Steinmüller) for needs of Germany between 1982 and 1994 were installed 24 boilers of total thermal capacity

3,038 MW in the range from 44 MW to 246 MW for burning bituminous and German brown coal (Fig. 3). The most intensive building of CFB boilers for Germany lies between 1988 and 1992 (particularly the 1988 year – 11 boilers; 1,401 MW_{th}).

The greatest CFB boilers of thermal capacities 322 and 650 MW for burning coal water slurry, lignite and bituminous coal were installed in Carlig (in 1990) and Gardanne (in 1995) in France.

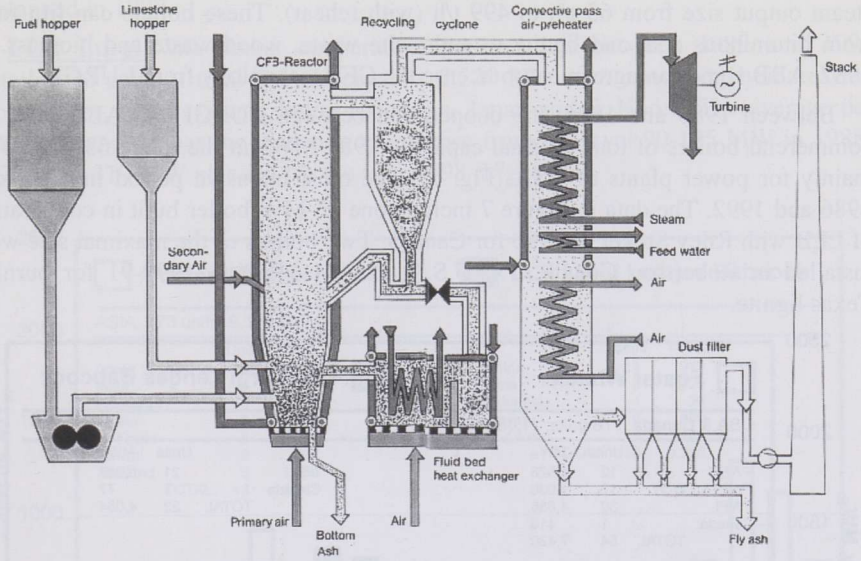

Figure 6. LLB Lurgi. The traditional CFB Boiler with round cyclone and FBHE

BOILERS FOR U.S.A

For U.S.A., between 1979 and 1997 by Foster Wheeler and LLB Lurgi 76 boilers of total thermal capacity 11,484 MW, ranging in size from 77 MW to 474 MW, were installed or designed (Fig. 7). 64.6% of them were installed by Foster Wheeler mainly between 1988 and 1995 (54 boilers of total thermal capacity 7,420 MW in 1979-1997).

The largest cooperation **Foster Wheeler** has been developed with the Pyropower Corporation in USA (subsidiary of Ahlstrom for the USA and Canada; since 1995 Foster Wheeler Pyropower).

Between 1988 and 1997 with continuous increasing of unit capacity 30 CFB boilers of total thermal capacity 4,856 MW in the range from 36 MW up to 409 MW were installed by FWPI (Foster Wheeler Pyropower Inc.) for power plants of USA and Canada (for Canada: Nowa Scotia Power Corp., 1 boiler in 1993, 409 MW. Between 1979 and 1997 by FWEC (Foster Wheeler Energy Corporation) 12 boilers of total thermal capacity 1,526 MW (66-285 MW) were installed for the needs of USA. By FWPI & FWOY in 1985-1988 12 boilers of total capacity 1,038 MW (27-294 MW) were installed. The most intensive building of CFB boilers for U.S.A. lies

between 1988 and 1995. Boiler of the maximal size was installed in Nova-Scotia, Canada (409 MW) in 1993 for burning coal.

The cooperation of **LLB Lurgi** with ABB-Combustion Engineering (ABB) in 1980. ABB was awarded a study to develop the design of a 200 MW boiler based on the LURGI's technology. The study led to a consortium agreement with LURGI in 1983 for the joint commercial offering of CFB boilers. ABB sold a large number of CFB units between 1983 and 1987 for industrial and utility applications ranging in steam output size from 68 t/h to 499 t/h (with reheat). These boilers can fire fuels from bituminous coal and lignite to anthracite waste, wood waste and biomass. In 1987, ABB signed an agreement to license the CFB technology from LURGI.

Between 1986 and 1996, the cooperation between LURGI and ABB gave 21 commercial boilers of total thermal capacity 3,987 MW (in the range 63-474 MW) mainly for power plants of USA (Fig. 7). The most intensive period lies between 1986 and 1992. The data in Figure 7 include one 73 MW boiler built in cooperation of LLB with Riley Stoker in 1990 for Canada. Two boilers of the maximal size were installed in Robertson County, Tx, U.S.A. (2x474 MW) in 1990-91 for burning Texas lignite.

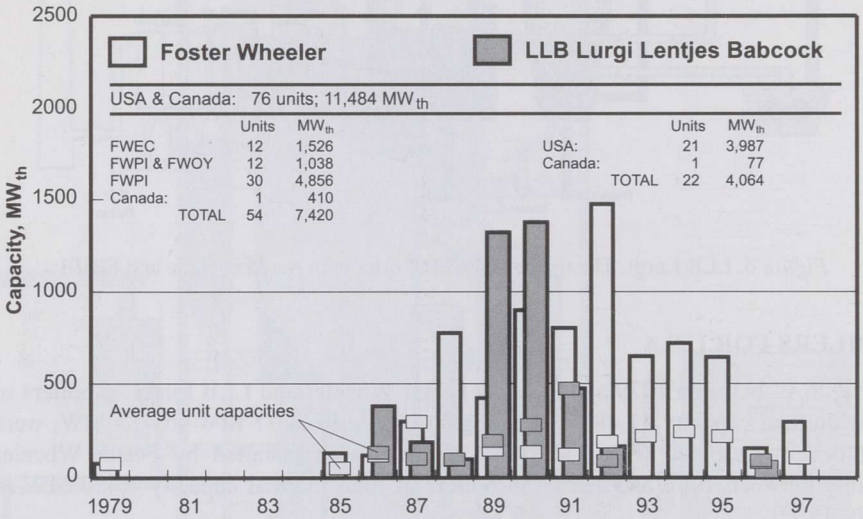

Figure 7. Capacity of CFB boilers installed by LLB Lurgi and Foster Wheeler for U.S.A. between 1979 and 1997

BOILERS FOR ASIA

Asia has been a considerably new region in energy consumption during last years.

For Asian countries (China, India, Indonesia, Japan, Korea, Taiwan and Thailand) between 1979 and 1997 by Foster Wheeler and LLB Lurgi 73 boilers of total thermal capacity 9,175 MW, ranging in size from 24 MW to 310 MW, were installed or designed (Fig. 8). 64.8% of these boilers were installed by Foster Wheeler mainly between 1988 and 1995 (54 boilers of total thermal capacity 7,420 MW in 1988-1998).

Foster Wheeler started CFB boiler production for Asian countries in 1984 – for burning lignite. FW Pyroflow K.K. has installed 97 MW_{th} boiler in Inchon, Republic of Korea. Between 1984 and 1998 Foster Wheeler has been installed 43 units of total thermal capacity 5,945 (Fig. 8) MW ranging in size from 28 MW to 314 MW. The average per year unit capacity has the tendency to increase from the level 75-150 MW in 1988-1995 up to 370 MW planned for the year 1998.

The start of two 156 MW boilers for burning local oil shale in Maoming, China is planned in 1997.

LLB Lurgi with Asian cooperation partners has between 1989 and 1998 installed 30 units of total thermal capacity 3,230 MW with continuously increasing capacity per year in China, India, Indonesia, Japan and S.-Korea. The average per year unit capacity has the tendency to increase from the level 90-125 MW in 1988-1995 up to 310 MW planned for the year 1998 (Fig. 8).

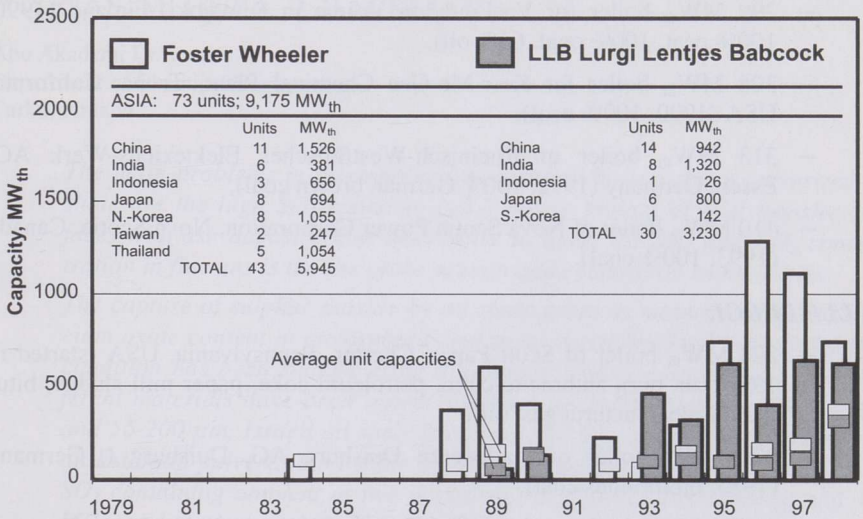

Figure 8. Capacity of CFB boilers installed by LLB Lurgi and Foster Wheeler for Asia between 1979 and 1998

Figure 9 shows the distribution of the capacity percentage in Asian countries. One can see that 64% of capacity are distributed between three countries: China (27.92%), India (19.24%) and Japan (16.89%).

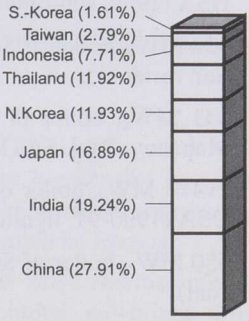

Figure 9. Distribution of installed boiler capacity between Asian countries

LARGEST CFB BOILERS IN OPERATION

FOSTER WHEELER:

- 164 MW_{th} boiler in Stockton, Corn Products, California, USA (started in 1988, 100% coal),
- 184 MW_{th} boiler of Nippon Steel Corporation, Hirohata, Japan (1989, 100% coal),
- 200 MW_{th} boiler of Ulsan Petrochemical Service Corporation, Ulsan, Republic of Korea (1990, 100% coal, 60% oil),
- 240 MW_{th} boiler of Kainuun Voima Oy, Kajaani, Finland (1989, 100 % PCWS: peat-coal-wood waste-sludge mixture),
- 291 MW_{th} boiler at Nucla Station in Colorado, USA of Colorado-Ute Electric Association (1987, 100% coal),
- 299 MW_{th} boiler for Vaskiluodon Voima in Seinäjoki, Finland (1990, 100% peat, 100% coal, 63% oil),
- 306 MW_{th} boiler for Kerr-Mc-Gee Chemical Plant, Trona, California, USA (1990, 100% coal),
- 313 MW_{th} boiler of Rheinisch-Westfälisches Elektezitäts-Werk AG, Essen, Germany (1992, 100% German brown coal),
- 410 MW_{th} boiler of Nova Scotia Power Corporation, Nova Scotia, Canada (1993, 100% coal).

LLB LURGI:

- 224 MW_{th} boiler of Scott Paper, Chester, Pennsylvania, USA (started in 1986, can burn anthracite culm, petroleum coke, paper mill sludge, bituminous coal, natural gas, oil),
- 226 MW_{th} boiler of Stadtwerke Duisburg AG, Duisburg I, Germany (1985, bituminous coal),
- 4x226 MW_{th} boilers of Applied Energy Services, Shady Point, Panama, Oklahoma, USA (1990, sub-bituminous coal),
- 2x253 MW_{th} boilers of Applied Energy Systems Thames, Monteville, Ct, USA (1989, sub-bituminous coal),
- 322 MW_{th} boiler of Sodelif, Carlig, France (1990, coal water slurry, flotation residues),
- 341 MW_{th} boiler of Schuylkill Energy Resources St., Nicholas, North Mahanoy, Pa, USA (1989, anthracite culm),
- 2x474 MW_{th} boiler of Texas – New Mexico I and II, Robertson, Texas, USA (1990-91, lignite)
- 650 MW_{th} boiler of Soprolif, Gardenne, France (1995, lignite, bituminous coal).

Presented by A. Ots
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