CFB Technology for Coal, Lignites and Petcokes

PowerGen Asia, Bangkok, Sept 19-21, 2017
We have been advancing CFB technology for 40 years
482 units (37 GWe) logging over 37 million hours of operation

Our CFB Technology Evolution
Unit Steam Capacity vs. Start-up Year

- **Global CFB Orders Over 2007-2016 Period**
- **Unit sizes over 200 MWe**
- **1st Ultra Supercritical CFBs**
  - 4 x 550 MWe
- **Longest Running Supercritical CFB**
  - 1 x 460 MWe
- **1st Large Petcoke CFBs**
  - 2 x 300 MWe

Today CFB technology available commercially up to scale 800MWₑ!
We have built more Large CFBs than Anyone Else
Supplied 42 CFBs over 200 MWe totaling over 12 GWe of electric capacity

<table>
<thead>
<tr>
<th>Commission Year</th>
<th>Customer</th>
<th>Plant</th>
<th># of Units</th>
<th>Unit Capacity MWe</th>
<th>Unit Steam Flow tph</th>
<th>Primary Fuel</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020</td>
<td>CPECC &amp; SWEPDI</td>
<td>Hai Duong, Vietnam</td>
<td>4</td>
<td>300</td>
<td>1004</td>
<td>Coal - Anthracite</td>
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<tr>
<td>2020</td>
<td>Guangdong Power Engineering Corporation</td>
<td>Attarat, Jordania</td>
<td>2</td>
<td>277</td>
<td>842</td>
<td>Oil shale</td>
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<td>2020</td>
<td>MGT Teesside Ltd.</td>
<td>Tees Renewable Energy Plant</td>
<td>1</td>
<td>299</td>
<td>824</td>
<td>Biomass</td>
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<td>2017</td>
<td>Harbin Electric International Co. Ltd</td>
<td>Soma Kolin Thermal Power Plant</td>
<td>2</td>
<td>255</td>
<td>716</td>
<td>Turkish Biomass</td>
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<td>2016</td>
<td>eTEC E&amp;C Limited</td>
<td>Seagull Cogeneration Power Plant</td>
<td>1</td>
<td>250</td>
<td>891</td>
<td>Indonesian Lignite</td>
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<tr>
<td>2015</td>
<td>Hyundai Engineering and Construction</td>
<td>Samcheok Green Power</td>
<td>4</td>
<td>550</td>
<td>1573</td>
<td>Coal</td>
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<tr>
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<td>Doosan Heavy Industries</td>
<td>Yeosu Thermal Power Plant 1 (KOSEP)</td>
<td>1</td>
<td>350</td>
<td>1027</td>
<td>Sub-bituminous Coal</td>
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<tr>
<td>2015</td>
<td>Hyundai Engineering and Construction</td>
<td>Mong Duong 1 Thermal Power Plant</td>
<td>4</td>
<td>250</td>
<td>918</td>
<td>Anthracite Coal</td>
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<tr>
<td>2014</td>
<td>PJSC EM Alliance</td>
<td>Novocherkasskaya GRES</td>
<td>1</td>
<td>330</td>
<td>1001</td>
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<tr>
<td>2012</td>
<td>Shaw Group, Inc.</td>
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<td>2</td>
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<td>974</td>
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<td>Wuhan Kaidi Electric Power Ltd.</td>
<td>Mao Khe Thermal</td>
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<td>716</td>
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<tr>
<td>2012</td>
<td>GDF Suez Energia Polska</td>
<td>Polaniec Power Station</td>
<td>1</td>
<td>205</td>
<td>569</td>
<td>Biomass - Wood</td>
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<tr>
<td>2011</td>
<td>Kosepco</td>
<td>Yeosu Thermal Power PLant 2 (KOSEP)</td>
<td>1</td>
<td>340</td>
<td>1027</td>
<td>Sub-bituminous Coal</td>
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<tr>
<td>2010</td>
<td>Jyväskylän Energia Oy</td>
<td>Jyväskylä</td>
<td>1</td>
<td>200</td>
<td>576</td>
<td>Peat</td>
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<td>2009</td>
<td>PKE – Elektrownia Lagisza</td>
<td>Lagisza</td>
<td>1</td>
<td>460</td>
<td>1298</td>
<td>Bituminous Coal</td>
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<tr>
<td>2009</td>
<td>Shaw Group/CLECO Power LLC</td>
<td>Madison Unit 3</td>
<td>2</td>
<td>330</td>
<td>973</td>
<td>Petroleum Coke</td>
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<tr>
<td>2009</td>
<td>Bechtel/TXU</td>
<td>Sandow Gen Station</td>
<td>2</td>
<td>315</td>
<td>944</td>
<td>Lignite</td>
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<tr>
<td>2008</td>
<td>Jin Shan Thermal Power Station</td>
<td>Shenyang</td>
<td>2</td>
<td>200</td>
<td>745</td>
<td>Bituminous Coal</td>
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<tr>
<td>2003-2004</td>
<td>BOT Elektrownia Turow S.A.</td>
<td>Turow</td>
<td>3</td>
<td>262</td>
<td>705</td>
<td>Brown Coal</td>
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<tr>
<td>2001</td>
<td>JEA Northside Gen. Station</td>
<td>Northside Generating</td>
<td>2</td>
<td>300</td>
<td>905</td>
<td>Petroleum Coke</td>
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<td>1998-2000</td>
<td>BOT Elektrownia Turow S.A.</td>
<td>Turow</td>
<td>3</td>
<td>235</td>
<td>669</td>
<td>Brown Coal</td>
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</tbody>
</table>
Why do clients choose our CFBs more than all others?
For their: High reliability, Low maintenance and Competitive cost

- High reliability achieved through long term R&D and field experience
  - Lessons learned from world’s largest CFB fleet totaling 466 units and 35 GWe
  - Over $200M in R&D investment
  - 40 years and 37 million hours of field experience

- Our designs are low in maintenance and high in reliability
  - Fully cooled cyclones, loop seals, return legs, cross-over ducts, HRA enclosures
  - Superheaters and reheaters protected from corrosive flue gases in INTREX
  - Minimum use of refractory and mechanical expansion joints
  - Engineered cooled thin-wall refractory
  - Optimized fuel feed and ash removal systems
  - Optimized process to minimize fouling, agglomeration and corrosion

Our CFBs are the most reliable on the market
Our CFBs stand above the others in reliability
Don’t take our word for it, see what others are saying

Average Annual Plant Availability* (% of 8760 hours)

- **Bituminous coal**
  - SFW - CFB: 90.8%
  - NERC - All Boilers: 87.0%
  - VGB - All Boilers: 85.6%
  - WEC - All Boilers: 85.3%

- **Brown coal and lignite**
  - SFW - CFB: 91.6%
  - NERC - All Boilers: 89.1%
  - VGB - All Boilers: 88.6%
  - WEC - All Boilers: 88.4%

- **Other fuels**
  - Petcoke: 93.3%
  - Clean Wood: 92.9%
  - Demolition Wood: 91.5%
  - Mixed Wood & Peat: 90.0%

*Note: Plant Availability means total time plant is available to run accounting for both planned and unplanned downtime. SFW CFB plant reliability values based on client supplied data reported over 2000-2015 period for CFB plants mainly located in Europe. NERC (North America Reliability Corp), VGB and WEC (World Energy Council) availability data based on thermal steam power plant (PC and CFB) data reported over 2000-2015 period. Since most of the large thermal plants globally are PC type plants they are a good representation for PC plant availability. Chart created on 22Jun17.
Boiler Reliability Matters
The boiler determines plant’s availability and project’s financial success

Loss in Plant Income for 600 MWe Coal Plant (M$)
(Energy Sales Revenue - Plant Operating Cost)

- Annual Loss (M$/yr)
- 30 year NPV Loss (M$)

<table>
<thead>
<tr>
<th>Plant Annual Capacity Factor (%)</th>
<th>0</th>
<th>6.9</th>
<th>13.8</th>
<th>20.7</th>
<th>27.6</th>
<th>34.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base (90%)</td>
<td>0</td>
<td>6.9</td>
<td>13.8</td>
<td>20.7</td>
<td>27.6</td>
<td>34.5</td>
</tr>
<tr>
<td>-2% (88%)</td>
<td>106</td>
<td>13.8</td>
<td>20.7</td>
<td>27.6</td>
<td>34.5</td>
<td></td>
</tr>
<tr>
<td>-4% (86%)</td>
<td>212</td>
<td>20.7</td>
<td>27.6</td>
<td>34.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-6% (84%)</td>
<td>318</td>
<td>27.6</td>
<td>34.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-8% (82%)</td>
<td>424</td>
<td>34.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-10% (80%)</td>
<td>530</td>
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</tr>
</tbody>
</table>

A low boiler price can translate in huge losses over plant life

Note: 600 MWe supercritical coal plant firing 50 $/tonne (4500 kcal/kg) Indonesian coal, selling power at 100 $/MWh at a base 90% capacity factor. Plant Capacity Factor = Actual annual electricity produced by plant/possible maximum(600 MWe x 8760 hrs). NPV based on 30 year term and 5% discount rate.
Our CFB’s have proven fuel flexibility

Our CFB’s:

- Fire the widest range of fuels without a loss in reliability or performance
- Allow the maximum use of biomass fuels to reduce plant’s carbon footprint
- Tolerates declining coal mine quality
- Opens the door for plant owners to capture the high value of fuel market arbitrage
- Cleanly and reliably convert trash and waste into energy
- Maintain high combustion efficiency for low volatile fuels like petcoke and anthracite
- Fires high ash, moisture and sulfur lignites and waste coals without loss in plant reliability
- Have the most experience firing high alkali and chlorine biomasses

Our CFBs have the greatest fuel flexibility on the market
Our CFB technology has the widest fuel flexibility

**PC Fuel Range**

Fuels: PETROLEUM COKE, ANTRACITE COAL, BITUMINOUS COAL, BROWN COAL, LIGNITE, PEAT, WASTE COAL, BARK, POLYOLEFIN PLASTICS (PE, PP, PC..), WOOD BIOMASS, WOOD & PLASTICS, RDF, OIL SHALE, BIO & FIBER SLUDGE, DEINKING SLUDGE, SEWAGE SLUDGE.

**CFB Fuel Range**

Fuels: PETROLEUM COKE, ANTRACITE COAL, BITUMINOUS COAL, BROWN COAL, LIGNITE, PEAT, WASTE COAL, BARK, POLYOLEFIN PLASTICS (PE, PP, PC..), WOOD BIOMASS, WOOD & PLASTICS, RDF, OIL SHALE, BIO & FIBER SLUDGE, DEINKING SLUDGE, SEWAGE SLUDGE.

**Fuel Parameter (% As Received)**

<table>
<thead>
<tr>
<th>Fuel Parameter</th>
<th>Majority of Global PC Fleet</th>
<th>SHI FW CFB Fleet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture</td>
<td>5% - 35%</td>
<td>5% - 60%</td>
</tr>
<tr>
<td>Ash</td>
<td>1% - 30%</td>
<td>0.1% - 60%</td>
</tr>
<tr>
<td>Volatile Matter</td>
<td>20% - 45%</td>
<td>5% - 50%</td>
</tr>
<tr>
<td>Sulfur</td>
<td>0.1% - 4%</td>
<td>0% - 8%</td>
</tr>
</tbody>
</table>

The CFB provides the widest fuel flexibility with a single design.
Our CFBs can deliver huge operating cost savings
Proven to have widest fuel flexibility while maintaining high plant reliability

► CFBs provide a hedge against shifting fuel markets
► CFBs provide the best fuel security
► CFBs can utilize carbon neutral fuels:
  ► Meet carbon goals
  ► Qualify for subsidies
► CFBs minimizes biomass supply risk with coal back-up

Note: 600 MWe supercritical coal plant with 90% annual capacity factor firing 70 $/tonne (5500 kcal/kg) coal as base fuel and 60$/tonne (5000 kcal/kg), 50 $/tonne (4500 kcal/kg), and 40 $/tonne (4000 kcal/kg) as alternative fuels. NPV based on 30 year term and 5% discount rate.
# Summing up the Value for CFB

NPV savings provided by a generic 600 MWe CFB coal plant

<table>
<thead>
<tr>
<th>CFB Benefit over PC</th>
<th>Details of Benefit</th>
<th>NPV (M$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Higher plant reliability</td>
<td>A 600 MWe supercritical coal plant firing 50 $/tonne (4500 kcal/kg) Indonesian coal, selling power at 100 $/MWh at a 90% capacity factor can produce 17.25 M$ more income annually which amounts to a 265 M$ NPV over a 30 year term.</td>
<td>265</td>
</tr>
<tr>
<td>Fuel cost savings</td>
<td>A 600 MWe supercritical coal plant with a 90% annual capacity factor firing 50 $/tonne (4500 kcal/kg) Indonesian coal instead of 70 $/tonne (5500 kcal/kg) premium coal can save 15 M$/yr in plant operating cost which amounts to a 226 M$ NPV over a 30 year term.</td>
<td>226</td>
</tr>
<tr>
<td>Plant cost savings</td>
<td>A 600 MWe supercritical CFB coal plant doesn’t require SCR, FGD, mills and burners which can reduce plant EPC cost by roughly 100 $/KWe or 60 M$.</td>
<td>60</td>
</tr>
<tr>
<td>Reduced plant maintenance</td>
<td>Compared to a PC plant, CFB plant maintenance is lower since SCR, FGD, mills and burner equipment and systems are not needed. Further maintenance of a CFB boiler is lower than a PC boiler since the ash doesn’t melt avoiding the fouling and corrosion experienced in a PC boiler. The savings in maintenance and staff cost is estimated to be 1 M$/yr which amounts to a 15 M$ NPV over a 30 year term.</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>ünst to the CFB plant, CFB plant maintenance is lower since SCR, FGD, mills and burner equipment and systems are not needed. Further maintenance of a CFB boiler is lower than a PC boiler since the ash doesn’t melt avoiding the fouling and corrosion experienced in a PC boiler. The savings in maintenance and staff cost is estimated to be 1 M$/yr which amounts to a 15 M$ NPV over a 30 year term.</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Total Financial Value of CFB</strong></td>
<td>566</td>
</tr>
</tbody>
</table>
Our CFBs Opens the Door to Affordable and Reliable CO2 Reduction

- Co-Firing Carbon Neutral fuels in utility CFBs provides an optimum solution
  - Maximum environmental benefit since CFB is flexible to cope with seasonally varying biomass supply
  - Economical electricity due to large plant scale
  - Reliable electricity due to coal back-up
- CFB’s have proven themselves on 100% biomass and waste fuels up to 300 MWe unit sizes

![CO2 emissions from 600 MWe Plant (mtons/yr)](chart)

Note: PC coal plant assumed to have an annual capacity factor of 90% and a heat rate of 10,000 Btu/KWh, CFB plant assumed to have same capacity factor and a heat rate of 10,000 Btu/KWh (subcritical), 8200 Btu/KWh (supercritical)
CFB vs. PC Combustion Process

CFB’s flame free process has many benefits

**CFB Process & Design Benefits**

- Non-slagging uniform, low-temp combustion minimizes fouling, corrosion and OTU risk
- In-furnace SOx capture minimizes corrosion and fouling over entire gas path
- Circulating solids keep hot loop HX surfaces clean, no need for soot blowing
- SCR and full FGD not needed to meet low SOx and NOx
- Performance and reliability maintained over wide range of fuels
- Fuel milling, drying, and burners replaced by simple gravity fuel feed

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**CFB Process Video**

CFB vs. PC Combustion Process

Limestone
<1 mm (0.04 in)

Petcoke
<10 mm (0.4 in)

Biomass
<50 mm (2.0 in)

Air

<table>
<thead>
<tr>
<th>°C</th>
<th>°F</th>
</tr>
</thead>
<tbody>
<tr>
<td>1927</td>
<td>3500</td>
</tr>
<tr>
<td>1573</td>
<td>2860</td>
</tr>
<tr>
<td>1216</td>
<td>2220</td>
</tr>
<tr>
<td>860</td>
<td>1580</td>
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<tr>
<td>504</td>
<td>940</td>
</tr>
<tr>
<td>149</td>
<td>300</td>
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</tbody>
</table>

PC

Fuel & Air

Sumitomo SHI FW
CFB’s Low and Uniform Heat Flux Minimizes Risk of Furnace Tube Overheating

- CFB’s Low Risk of Furnace Tube Overheating allows for High Reliability and Long Furnace Life
- Furnace Design Optimized with 3D Computational Fluid and Heat Transfer Modeling

![Graph showing heat flux vs. furnace height for CFB and PC furnaces](image)

<table>
<thead>
<tr>
<th>Furnace Height [m]</th>
<th>Heat flux (average) [%]</th>
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<tbody>
<tr>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>45</td>
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<td>149</td>
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</tbody>
</table>
Conventional Spiral Design: High Steam Mass Flux

- Spiral tubes to even out heat absorption
- No self cooling effect
- Complicated boiler support system make repairs more difficult
- Heavy boiler increases supply and erection cost maintenance costs
- Slagging build up at spiral, vertical tube interface

Advanced Vertical Tube Design: Low Mass Flux Design

- Low mass flux and velocity for self cooling effect
- Simple support system
- Low pressure drop
- Easy to maintain

Supercritical Once-Through Boiler Design
Vertical tube offers benefits

Vertical Tube Design Offers Higher Efficiency and Reliability in supercritical Designs
Comparison of CFB vs. PC Technology

CFB boiler size and cost is least impacted by fuel changes

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>PC Plan Area</th>
<th>CFB Plan Area</th>
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<tbody>
<tr>
<td>Medium Volatile Bituminous</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>High Volatile Bituminous</td>
<td>1.14</td>
<td>1.25</td>
</tr>
<tr>
<td>or Sub-Bituminous</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low Sodium Lignite</td>
<td>1.25</td>
<td>1.56</td>
</tr>
<tr>
<td>Medium Sodium Lignite</td>
<td>1.56</td>
<td>1.63</td>
</tr>
<tr>
<td>High Sodium Lignite</td>
<td>1.63</td>
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</tr>
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CFB boiler size and cost is least impacted by fuel changes.
Comparing PC vs. CFB Designs

Coals

**PC**

- Fuel Milling & Drying
- Soot Blowers
- Final Superheaters
- Gravity Feed Fuel

**CFB**

- INTREX protects SHs RHs
- SNCR

**CFB Design Benefits**

- Fuel milling, drying, and burners replaced by simple gravity fuel feed system
- No furnace soot blowers needed, circulating solids keep HX surfaces clean
- High temp superheat coils protected by INTREX
- Non-slagging uniform, low-temp combustion minimizes fouling, corrosion and OTU risk
- No FGD or SCR catalyst needed for low SOx and NOx
- In-furnace SOx capture minimizes corrosion and fouling over entire gas path
- Performance and reliability maintained over wide fuel range
1000 MWe Anthracite Fired CFB Plant in Vietnam
4 x 250 MWe CFBs on 2 x 500 MWe Steam Turbines

► Owned and Operated by Electricity Vietnam, EPC by Hyundai Engineering & Construction
► Mong Duong Site located in Quang Ninh, Vietnam
► Each Unit produces 2.0 mpph (918 tph) of Steam at 2509 psig (173 bar) and 1006/1004F (541/540C)
► Designed to fire 100% Anthracite Coal
► Commercial Operation began in 2015

Successfully operating for 2 years
660 MWe Multi-Fuel CFB plant in Louisiana
Petcoke, Coal, Lignite, Biomass

- Plant located at CLECO’s Brame Energy Site in Boyce, Louisiana
- 2 x 330 MWe CFB Boilers on Single STG
- Each Unit produces 2.1 mpph (972 tph) of Steam at 2500/495 psig (172/34 bar) and 1055/1055F (568/568C)
- Plant designed for multiple fuels
  - 100% Petroleum Coke
  - 100% Illinois #6 Coal
  - 100% Sub-bituminous PRB coal
  - Co-fire up to 92% Lignite
  - Co-fire up to 5% paper sludge and Wood Waste (5%)
- CFB polishing scrubbers for very low, acid gas and metal emissions and improved limestone utilization
- Commercial Operation, Feb 2010

Successfully operating for 7 years
510 MWe Lignite Fired CFB plant in Turkey

Affordable power from local lignite

- Plant located in Soma region of Turkey owned by HIDRO-GEN Energy, a subsidiary of Kolin Group
- Plant EPC by Harbin Electric Intl’ Co. Ltd.
- 2 x 255 MWe CFBs + CFB scrubbers
- Each Unit produces 715/624 tph (1575/1376 kpph) of steam at 173/43 bar (2509/628 psig) and 565/565C (1049/1049F)
- Designed to fire 100% local Lignite at 1600 kcal/kg with 43% ash and 23% moisture
- Commercial Operation to begin in 2018

Largest CFB project awarded in Turkey
2200 MWe Most Advanced CFB Plant in World
4 x 550 MWe ultra supercritical CFBs at KOSPO’s Green Power Plant

Green power plant owned and operated by Korean Southern Power Company (KOSPO) located in Samcheok, Korea

Advanced 4 x 550 MWe Ultra Supercritical Vertical Tube CFBs on 2 x 1000 MWe STGs

Each CFB produces 1570/1275 tph steam at 257/53 bar, and 603/603 °C steam conditions

Fires a wide range of import coals spanning 3400-6000 kcal/kg heating values, 20-43% moisture, 1.5-17% ash and 0.1-1% sulfur levels

Co-fires biomasses up to 5% heat input

Achieves very low stack emissions (50 ppm SOx and NOx) without FGD scrubber

Commercial Operation began in Dec 2016

Korean Southern Power Company
Samcheok Green Power Plant
Samcheok, South Korea
2011-2016

Now in Full Commercial Operation

Samcheok Video
Our CFB’s

- Have the widest fuel flexibility
- Are the most reliable on the market today
- Are proven in the large utility ultra-supercritical scale
- Are selected more by clients than all other CFBs on the market

Our CFB’s are changing the solid fuel energy market by providing more flexibility and more value to plant owners.
Contact Us

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