Co-Firing Biomass in large Scale CFBC
Biomass Combustion in CFBC

Presentation Topics:

- Why Biomass Combustion?
- Advantages of Co-Firing Biomass & Coal
- Specific Implications firing Biomass
- References
- Experiences
- Outlook
CFB Power Plant
CFB Combustion Process
Solid Fuels

CO2 in Atmosphere [ppm]

CO2 Reduction by Fuel Substitution with Biomass

Example Calculation:
300 MWe CFB Power Plant
SubCritical lignite fired ~37% Plant Efficiency
SuperCritical coal fired ~43% Plant Efficiency
CO2 Reduction by Fuel Substitution with Biomass

Tons of fuel per h

Example Calculation:
300 MWe CFB Power Plant
SubCritical lignite fired ~37% Plant Efficiency
SuperCritical coal fired ~43% Plant Efficiency

Remark:
Typical Fuel Density
Coal 700-900 kg/m$^3$
Lignite 650-850 kg/m$^3$
Biomass 250-400 kg/m$^3$
CO2 Reduction & Fuel Substitution by Biomass

Example Calculation:

300 MWe CFB Power Plant
Subcritical lignite fired, ~37% Plant Efficiency
SC coal fired with ~43% Plant Efficiency

CO2 Emission in g/kWh

% of Heat Input by Biomass

Tons of fuel per h

Remark:
Typical Fuel Density

Coal  700-900 kg/m³
Lignite  650-850 kg/m³
Biomass  250-400 kg/m³
CFB Fuels and Experience

- PC boiler (for hard coal)
- DL CFB boilers
- Hard coal
- Dry biomass
- Wet biomass
- Lignite
- Sewage sludge
- Discard / high ash coals washery rejects
- Oil sand
- Pet coke
Fuels and Design Challenges

- pet coke
- anthracite
- bituminous hard coals
- dry biomass
- natural (wet) biomass
- brown coal
- lignite
- sewage sludge
- discard / high ash coals
- washery rejects
- high ash & high moisture lignite

NCV [MJ/kg] as fired

Standard Design → Specific Design Challenges
Example Biomass : typical Properties

<table>
<thead>
<tr>
<th>Fuels</th>
<th>C</th>
<th>H2</th>
<th>S</th>
<th>O2</th>
<th>N2</th>
<th>Ash</th>
<th>Cl</th>
<th>Na</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%-daf</td>
<td>%-daf</td>
<td>%-daf</td>
<td>%-daf</td>
<td>%-daf</td>
<td>%-%dry</td>
<td>%-%daf</td>
<td>mg/kg-d</td>
<td>mg/kg-d</td>
</tr>
<tr>
<td>Peat</td>
<td>55</td>
<td>5,5</td>
<td>0,2</td>
<td>33</td>
<td>1,7</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Wood, coniferous</td>
<td>51</td>
<td>6,3</td>
<td>0,02</td>
<td>42</td>
<td>0,1</td>
<td>0,3</td>
<td>0,01</td>
<td>20</td>
<td>400</td>
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<tr>
<td>Wood, deciduous</td>
<td>49</td>
<td>6,2</td>
<td>0,02</td>
<td>44</td>
<td>0,1</td>
<td>0,3</td>
<td>0,01</td>
<td>50</td>
<td>800</td>
</tr>
<tr>
<td>Bark, coniferous</td>
<td>54</td>
<td>6,1</td>
<td>0,1</td>
<td>40</td>
<td>0,5</td>
<td>4</td>
<td>0,02</td>
<td>300</td>
<td>2000</td>
</tr>
<tr>
<td>Bark, deciduous</td>
<td>55</td>
<td>6,1</td>
<td>0,1</td>
<td>40</td>
<td>0,3</td>
<td>5</td>
<td>0,02</td>
<td>100</td>
<td>2000</td>
</tr>
<tr>
<td>Willow</td>
<td>49</td>
<td>6,2</td>
<td>0,05</td>
<td>44</td>
<td>0,5</td>
<td>2</td>
<td>0,03</td>
<td>200</td>
<td>3000</td>
</tr>
<tr>
<td>Poplar</td>
<td>49</td>
<td>6,3</td>
<td>0,03</td>
<td>44</td>
<td>0,4</td>
<td>2</td>
<td>0,01</td>
<td></td>
<td>3000</td>
</tr>
<tr>
<td>Straw, wheat, rye, barley</td>
<td>49</td>
<td>6,3</td>
<td>0,1</td>
<td>43</td>
<td>0,5</td>
<td>5</td>
<td>0,4</td>
<td>500</td>
<td>10000</td>
</tr>
<tr>
<td>Straw, rape</td>
<td>50</td>
<td>6,3</td>
<td>0,3</td>
<td>43</td>
<td>0,8</td>
<td>5</td>
<td>0,5</td>
<td>500</td>
<td>10000</td>
</tr>
<tr>
<td>Reed canary grass, summer harv.</td>
<td>49</td>
<td>6,1</td>
<td>0,2</td>
<td>43</td>
<td>1,4</td>
<td>6,4</td>
<td>0,6</td>
<td>200</td>
<td>12000</td>
</tr>
<tr>
<td>Reed canary grass, delayed harv.</td>
<td>49</td>
<td>5,8</td>
<td>0,1</td>
<td>44</td>
<td>0,9</td>
<td>5,6</td>
<td>0,1</td>
<td>200</td>
<td>2700</td>
</tr>
</tbody>
</table>

Most Critical Biomass Elements:

- **Chlorine:** high temp. Corrosion / Fouling / HCl emission / Dioxines
- **Alkaline Metals:** Fouling, Slagging / Bed Sintering / Corrosion
- **Heavy Metals:** Corrosion, Emissions / Ash Treatment
- **Nitrogen:** NO\textsubscript{x} Emission

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Boiler Corrosion Risk

- **Low temperature corrosion**
- **SO₂ / SO₃**
- **CI**
- **High temperature corrosion**

Graph showing the relationship between fuel sulfur to chlorine ratio and corrosion risk. The graph indicates that a ratio of S/CI ≥ 4 is corrosion resistant, while a ratio of S/CI ≤ 2 indicates a risk of corrosion.
Corrosion Mechanism

Within the deposit layer a cycle process takes place.

In the presence of chlorine iron is dissolved and penetrates to the surface.

Here oxidation causes the iron to convert to iron oxide.

Thereby chlorine is released again and can start the cycle again.
Corrosion Mechanism Analysis (elementry Distribution)

2 KCl + SO₂ + O₂ → K₂SO₄ + Cl₂

Chlorine, Sulphur and Alkali metals play an important role in the chemical reaction chain.

Energy dispersive X-ray spectroscopy give an insight into the layer structure of a corrosive deposit layer.

Oxygen
Sulphur
Chlorine

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High Temperature Chlorine Corrosion

- High chlorine (Cl) content together with low sulfur (S) content promotes high temperature corrosion
- High alkali content (Na and K) increases the risk
- Alkalis together with chlorine forms alkali-chorides NaCl and KCl
- If the tube surface temperature is >450°C
  => alkali-chloride deposit
  => corrosion
Initial Biomass Experience in CFB

5 Units in California / USA
- Rocklin
- Fresno
- Mecca I + II
- Ione (after conversion)

1988 / 89 / 92 & 2010

Steam Parameters
Pressure  80 - 90 bar
Temperature  480-510 °C
Efficiency  29 – 31 %
Wood Waste Combustion (Rio Bravo, Fresno, Rocklin / Ca, US)
Modern Biomass CFB Strongoli

Year of Commissioning  2003

- Electrical Output  50 MWe

- Technical Boiler Data (per 1 Boiler)
  - Number of Boilers  2
  - Live Steam  79 t/h
    515 °C
    95 bar
  - Feedwater  160 °C
  - Biomass Flow  21 t/h
  - Flue Gas  94,000 m³/h (STP)
  - Thermal Capacity  60 MWth

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Design Fuel Data

<table>
<thead>
<tr>
<th></th>
<th>Imported wood chips</th>
<th>Local stem wood / branches</th>
</tr>
</thead>
<tbody>
<tr>
<td>L H V (a.r.)</td>
<td>8,0</td>
<td>13,3 MJ/kg</td>
</tr>
<tr>
<td>Ash</td>
<td>3,0</td>
<td>8,0 wt.-%</td>
</tr>
<tr>
<td>Moisture</td>
<td>25,0</td>
<td>50,0 wt.-%</td>
</tr>
<tr>
<td>Sulphur</td>
<td>0,00</td>
<td>0,05 wt.-%</td>
</tr>
<tr>
<td>Chlorine</td>
<td>0,01</td>
<td>0,1 wt.-%</td>
</tr>
<tr>
<td>Alkali</td>
<td>0,0</td>
<td>0,5 wt.-%</td>
</tr>
</tbody>
</table>
Guarantee Data

Emissions (based on 11 % O2,dry)

- SO2  50  mg/m³ (STP)
- NOx  200 mg/m³ (STP)
- CO   50  mg/m³ (STP)
- TOC  10  mg/m³ (STP)
- Dust 10  mg/m³ (STP)
- HCl  10  mg/m³ (STP)
- Flue-Gas Stack
- Temperature  130 °C

Thermal Efficiency (DIN 1942)  91,7  %
Example of Wood Fuels as delivered (partly out of Specification)
Wood Storage at Site
Wood Pellets
Supply by Trucks & Site Handling
Co-Firing Biomass in large Scale CFBC 2018

Reference Berlin, Fuels and Experience

CHALLENGES

- Benson boiler at 196 bar
- Water-cooled cyclone – low refractory

KEY PROJECT DATA

Customer: Vattenfall
Location of power station: Berlin Moabit, Germany
Main fuels: Hard coal and lignite
Boiler type: CFB-Benson with reheat
Live steam: 326 / 269 t/h
Steam pressure: 196 / 42 bar
Steam temperature: 540 / 540°C
Feedwater: 300°C
Minimum load: 40%
Flue gas exit temperature: 130°C
Thermal efficiency (acc to DIN 1942): 92.3%

Design fuel: bituminous coal

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>LHV</td>
<td>30 MJ/kg</td>
</tr>
<tr>
<td>Ash</td>
<td>6.7%</td>
</tr>
<tr>
<td>Moisture</td>
<td>7.2%</td>
</tr>
<tr>
<td>Sulphur</td>
<td>1.1%</td>
</tr>
<tr>
<td>Emissions (acc to 7% O₂, dry)</td>
<td></td>
</tr>
<tr>
<td>SO₂</td>
<td>200 mg/m³ (STP)</td>
</tr>
<tr>
<td>NOₓ</td>
<td>200 mg/m³ (STP)</td>
</tr>
<tr>
<td>CO</td>
<td>250 mg/m³ (STP)</td>
</tr>
<tr>
<td>Dust</td>
<td>20 mg/m³ (STP)</td>
</tr>
</tbody>
</table>

PC boiler (for hard coal)

DL CFB boilers

hard coal

dry biomass

PC boiler (for lignite)

lignite

sewage sludge

wet biomass

discard / high ash coals

washery rejects

oil sand

Petcoke

Tire-derived fuel (TDF)
Berlin, Moabit (Vattenfall) – Commissioned 1990

World’s 1st CFB with cooled cyclones

1st CFB with almost 200 bar, Benson (once-through) principle
### CFB Berlin – Technical Data

**Commissioning:** 1990

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Thermal Capacity</strong></td>
<td>242 MW</td>
</tr>
<tr>
<td><strong>Live Steam</strong></td>
<td>326 t/h</td>
</tr>
<tr>
<td><strong>Feedwater</strong></td>
<td>300 °C</td>
</tr>
<tr>
<td><strong>Min. Load</strong></td>
<td>40 %</td>
</tr>
<tr>
<td><strong>Design Fuel</strong></td>
<td>Lignite, Subbit.Coal</td>
</tr>
<tr>
<td><strong>LHV</strong></td>
<td>30.0 MJ/kg</td>
</tr>
<tr>
<td><strong>Ash</strong></td>
<td>6.7 %</td>
</tr>
<tr>
<td><strong>Moisture</strong></td>
<td>7.2 %</td>
</tr>
<tr>
<td><strong>Volatiles</strong></td>
<td>13.0 %</td>
</tr>
<tr>
<td><strong>Sulphur</strong></td>
<td>1.1 %</td>
</tr>
</tbody>
</table>

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Berlin Plant Site through the Years: 1930 / 1990
Power Plant Site in Berlin City
Berlin additional Biomass System
Reference Gardanne, Fuels and Experience

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**World's first 250 MW<sub>e</sub> CFB plant**

**Provence 4bis, Gardanne, France**

- **Year of Commissioning**: 1995
- **Thermal Capacity**: 557 MW
- **Power Capacity**: 250 MWe
- **Live / Reheat Steam**:
  - 700 / 651 t/h
  - 565 / 565 °C
  - 163 / 34.3 bar
- **Feedwater**: 249 °C
- **Design Fuel**
  - Lignite: 14.8
  - Bit. Coal: 25.7
  - Petcoke: 32
  - Ash(%): 28 / 13 / 0.6
  - Moisture(%): 11 / 7 / 6
  - Sulphur(%): 3.7 / 0.4 / 7
- **Emission limits**
  - SO<sub>2</sub>: 200 mg/Nm³
  - NO<sub>x</sub>: 250 mg/Nm³
  - Dust: 30 mg/Nm³

Currently converted to Biomass firing by Doosan Group
### Gardanne, France – Overview Conversion of CFB Plant

<table>
<thead>
<tr>
<th>Original Design (Bituminous Coal &amp; Lignite)</th>
<th>Conversion to Biomass</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Capacity:</strong> 100 % MCR</td>
<td>App. 70% original capacity</td>
</tr>
<tr>
<td>250 MWe</td>
<td>170 MWe</td>
</tr>
<tr>
<td>557 MWth</td>
<td>380 MWth</td>
</tr>
<tr>
<td><strong>Fuel:</strong> Lignite, Bit. Coal</td>
<td>Wood, Coal</td>
</tr>
<tr>
<td><strong>Heating Value:</strong> 14.8 -25 MJ/kg</td>
<td>10.3 MJ/kg</td>
</tr>
<tr>
<td><strong>HP Steam:</strong> 565°C, 163 bar</td>
<td>565°C, 163 bar</td>
</tr>
<tr>
<td><strong>Reheat Steam:</strong> 565°C, 34 bar</td>
<td>565°C, 34 bar</td>
</tr>
<tr>
<td><strong>Gas Cleaning:</strong> limestone injection into furnace</td>
<td>External addition of hydrated lime in duct upfront of new bag house filter</td>
</tr>
<tr>
<td><strong>Bed material:</strong> ensured by fuel</td>
<td>Ensured by co-firing of coal</td>
</tr>
</tbody>
</table>
Gardanne, France – Biomass Retrofit Overview
Advantages of Co-Combustion in CFB (in Comparison to Biomass Combustion only)

- **Higher Efficiency** due to larger Boiler and higher Steam Parameters (up to USC, e.g. 620°C, 280 bar)
- **Sufficient Coal Ash**, no **Sand Addition** required
- **Dilution of Biomass Alkaline Content by Coal Ash**, less **Risk of Fouling**
- **S/Cl ratio >4**, no **Risk of Cl Corrosion**
- **Reduced Ash Discharge**
- **Less Limestone Consumption**
Conclusions / Outlook

✓ CFB is the most **Fuel flexible** Combustion Technology
✓ CFB provides **highest Efficiency** while having **lowest Emissions**
✓ Biomass Combustion reduces the **CO₂** Footprint (& **CO₂** Fee)
✓ Existing CFB´s can be **upgraded to Biomass**
✓ Biomass Addition to large Scale CFB is more **safe, flexible, efficient and economic** than small scale Biomass Combustion, having similar **CO₂** reduction
Thank You!
Any Questions?

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Pioneering energy solutions since 1928

Doosan Lentjes is a global provider of processes and technologies for energy production from renewable and fossil fuels.

We are a technology company with in-house proprietary processes — our areas of expertise include:

- Circulating fluidised bed boiler technologies (CFB)
- Waste-to-energy (WtE)
- Air quality control systems (AQCS)

Doosan Lentjes is the global center of competence for CFB, WtE and AQCS within DHI and has its own R&D center for these technologies.
Fluidization

(2.3 – 3.0 m/s)

(4.6 – 7.0 m/s)

(4.6 – 10.0 m/s)

CLASSICAL FLUID BED

CIRCULATING FLUID BED

TRANSPORT REACTOR

Mean Gas Velocity

Mean Solids Velocity

Slip Velocity

Increased Solids Loading

Increasing Expansion

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CFB Market Players & History of CFBC

1922
60-ties
70-ties
80-ties
1985
SGP
Austria
EVT
Germany

1986
Combustion Engineering
USA
MHI
Japan
Lentjes
Germany

1987
Hyundai
HI; Korea

1988
1989

1990
Rafako
Poland

1991
EVT
Germany
Beijing
BW

1992
1993
1994

1995
Dongfang
BW China

1996

1997

1998

1999

2000

2001

2002

2003

2004

2005

2006

2007

2008

2009

2010

2011

2012

2013

2014

2015

2016

2017

2018

CFB 40 Years

Legend

- main technology developer
- Licensee
- follow-up License
- use of Technology after License End
- joint Cooperation
- offering similar tech., without licensed rights and support
# Fuel Properties

## Coal Characteristics I

<table>
<thead>
<tr>
<th>Description</th>
<th>Unit</th>
<th>Performance Fuel</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PROXIMATE ANALYSIS (As Received)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Moisture</td>
<td>% by weight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ash</td>
<td>% by weight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volatile Matter</td>
<td>% by weight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fixed Carbon</td>
<td>% by weight</td>
<td></td>
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<tr>
<td><strong>ULTIMATE ANALYSIS (As Received)</strong></td>
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<td></td>
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<tr>
<td>Carbon</td>
<td>% by weight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrogen</td>
<td>% by weight</td>
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<tr>
<td>Oxygen</td>
<td>% by weight</td>
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<tr>
<td>Nitrogen</td>
<td>% by weight</td>
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<tr>
<td>Total Sulphur</td>
<td>% by weight</td>
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<tr>
<td>Combustible sulphur</td>
<td>% by weight</td>
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<tr>
<td>- organic sulphur</td>
<td>% by weight</td>
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<td></td>
</tr>
<tr>
<td>- pyritic sulphur</td>
<td>% by weight</td>
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</tr>
<tr>
<td>Others</td>
<td>% by weight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ash</td>
<td>% by weight</td>
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<tr>
<td><strong>CALORIFIC VALUE (As Received)</strong></td>
<td></td>
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<tr>
<td>LHV</td>
<td>kJ/kg</td>
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</tr>
<tr>
<td>HHV</td>
<td>kJ/kg</td>
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## Coal Characteristics II

<table>
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<th>Description</th>
<th>Unit</th>
<th>Performance Fuel</th>
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<td><strong>FUEL IGNITION</strong></td>
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<tr>
<td>Coal ignition temperature</td>
<td>°C</td>
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<tr>
<td><strong>PARTICLE PROPERTIES</strong></td>
<td></td>
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</tr>
<tr>
<td>Grindability</td>
<td>HGI</td>
<td></td>
<td></td>
</tr>
<tr>
<td>In case of slurries or Sludges particl size distribution</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td><strong>ASH ANALYSIS</strong></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>SiO2</td>
<td>% by weight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Al2O3</td>
<td>% by weight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fe2O3</td>
<td>% by weight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CaO</td>
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<td>MgO</td>
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<tr>
<td>Na2O</td>
<td>% by weight</td>
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<tr>
<td>K2O</td>
<td>% by weight</td>
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<tr>
<td>SO3</td>
<td>% by weight</td>
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<tr>
<td>CO2</td>
<td>% by weight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TiO2</td>
<td>% by weight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P2O5</td>
<td>% by weight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MnO2</td>
<td>% by weight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>V2O5</td>
<td>% by weight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Others</td>
<td>% by weight</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>ASH FUSIBILITY CHARACTERISTICS (Oxidizing Atmosphere)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Softening</td>
<td>°C</td>
<td></td>
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</tr>
<tr>
<td>Hemi-spherical</td>
<td>°C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fluid</td>
<td>°C</td>
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</tr>
</tbody>
</table>

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Doosan Lentjes
Features of 75 MW\textsubscript{e} highly efficient Biomass CFB

- Fully integrated Combustor Design
- high eff. Steam cooled Cyclones
- Full redundant Biomass Feeding
- integrated FBHE
- Bicarbonate Injection (optional)
- SCR (optional)
- Low Pressure Puls Jet Filter (optional)
- Bed Ash Cooling Screws
Active Bed Temperature Control with integrated FBHE
Integrated Concept – Physical CFB Model
Animation of CFBC Loop

CFBC Loop

Cut through middle