CFB Technology for Biomass and Waste Fuels

PowerGen Asia, Bangkok, Sept 19-21, 2017
Our CFBs are Chosen the Most by Clients

We have supplied 482 Circulating Fluidized Bed (CFB) steam generators from 1975 - 2017

- Totaling 37.4 GWe in power capacity
  - 3 GWe Supercritical Once-Thru units
  - 33 GWe of Natural Circulation units
- Single unit capacities up to 550 MWe
- Proven by over 30 million hours of operation
- Burning a wide range of premium and waste coals, biomass, petroleum cokes, oil shale, and waste fuels

**World CFB Market**
**GPG Served Market**
**Orders Over 2007 - 2016 Period**

Total: 40 GWe, 415 Units

Source: GRDS 05Jun17, CFB Boiler, All sizes. Excludes domestic orders provided by domestic suppliers in China, and India. Market share based on steam capacity GWe. Project Scope EPC, D&E, D&S, Licensing. Other includes suppliers with less than 2% market share.
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**
  - Pet coke: 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.
We have the Widest Fuel Experience
- We know how to burn difficult fuels
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

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)
Biomass as Energy Source
Projected biomass and waste installed capacity for 2010-2030

► Biomass has an important role in reducing the environmental effects (CO2) of energy production

► Biomass fuel market has changed to global and makes possible large scale power generation of biomass alone

► In addition to the traditional clean and recycled biomasses, the trend today shows increasing interest to applying agricultural biomass & waste

Biomass and waste installed capacity
www.irena.org
“Many type of Solid Biomasses available”

HIERARCHY OF THE WOOD-DERIVED FUELS DEFINITIONS

FORESTRY
- Direct wood fuels
  - Timber or pulp wood for forest industry

INDUSTRY
- Indirect wood fuels
  - Pulp and paper industry
  - Mechanical wood industry

SOCIETY
- Recovered wood fuels
  - CONSUMERS OF WOOD AND PAPER PRODUCTS
    - Wood and paper products
    - Used paper and board
    - Recovered paper for recycling

WOOD FUELS
- Unmerchantable wood
  - Forest chips
    - Green chips
    - Brown chips
    - Whole tree
    - Other industrial wood residues
    - Sawdust
    - Cutter shavings
    - Grinding powder
    - Bark

FIELDS
- SHORT ROTATION FOREST (willow)
  - Regeneration stands (logging residues)
  - Young stands Thinnings (whole trees)
  - Delimbed trees
  - Stumps
  - Chips
  - Chips crushed
  - For paper industry
  - Pulp chips
  - Production of refined wood fuels
    - Pellets
    - Briquettes
  - Other industrial wood residues
  - Biobased slurges
  - Black liquor
  - Untreated wood
  - Building of new houses
  - Chemically treated wood
  - “Old wood” or used wood products

CONVERSION PROCESSES (COMBUSTION, GASIFICATION, PRODUCTION OF LIQUID BIOFUELS)

All fuels have they own Characteristics:

- Chemical characteristics
  - Na, K
  - Cl, P, heavy metals
  - Ash content
  - Etc..

- Physical characteristics
  - Bulk density
  - Sizing
  - Etc.
Biomass Properties Vary Greatly

<table>
<thead>
<tr>
<th></th>
<th>Timber pellets</th>
<th>Timber chips</th>
<th>Saw dust</th>
<th>Bagasse briquette</th>
<th>Straw pellets</th>
<th>Peat</th>
<th>Recycled wood</th>
<th>RDF fluff</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Moisture %</strong></td>
<td>5-10</td>
<td>20-50</td>
<td>45-60</td>
<td>8</td>
<td>12</td>
<td>50</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td><strong>Lower Heating Value</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>MJ/kg</strong></td>
<td>17</td>
<td>7,5-13,9</td>
<td>6-10</td>
<td>16</td>
<td>14,7</td>
<td>9,3</td>
<td>14</td>
<td>13</td>
</tr>
<tr>
<td><strong>Bulk Density kg/m³</strong></td>
<td>650</td>
<td>130-280</td>
<td>300-350</td>
<td>650</td>
<td>650</td>
<td>340</td>
<td>300-400</td>
<td>100</td>
</tr>
<tr>
<td><strong>Energy density</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>MWh/m³</strong></td>
<td>3</td>
<td>0,55</td>
<td>0,45-0,7</td>
<td>2,9</td>
<td>2,7</td>
<td>0,9</td>
<td>1,4</td>
<td>0,4</td>
</tr>
<tr>
<td><strong>Ash % ds</strong></td>
<td>0,9</td>
<td>0,4-5,3</td>
<td>0,4-0,5</td>
<td>6</td>
<td>7</td>
<td>5,1</td>
<td>5</td>
<td>10-20</td>
</tr>
<tr>
<td><strong>S % ds</strong></td>
<td>&lt;0,1</td>
<td>&lt;0,1</td>
<td>&lt;0,05</td>
<td>&lt;0,05</td>
<td>0,01-0,03</td>
<td>0,22</td>
<td>0,1</td>
<td>0,1-0,5</td>
</tr>
<tr>
<td><strong>Cl % ds</strong></td>
<td>&lt;0,03</td>
<td>&lt;0,05</td>
<td>&lt;0,03</td>
<td>&lt;0,03</td>
<td>0,1-0,8</td>
<td>0,02-0,06</td>
<td>0,1</td>
<td>0,3-1,2</td>
</tr>
<tr>
<td><strong>Alkali % ds</strong></td>
<td>0,1-0,3</td>
<td>0,1-0,3</td>
<td>0,1-0,3</td>
<td>0,4-0,7</td>
<td>0,3-1,7</td>
<td>0,1</td>
<td>0,1-0,5</td>
<td>0,4-1</td>
</tr>
<tr>
<td><strong>P % ds</strong></td>
<td>&lt;0,05</td>
<td>&lt;0,05</td>
<td>&lt;0,04</td>
<td>&lt;0,05</td>
<td>0,05-0,8</td>
<td>&lt;0,35</td>
<td>&lt;0,3</td>
<td>&lt;0,5</td>
</tr>
</tbody>
</table>

High concentrations of alkalis and chlorine increase risk for agglomeration, fouling and corrosion.
We have the knowhow to design CFBs for both easy and challenging fuels

SFW design model quantifies fuel risk to CFB
Our Advanced Bio CFB Design has evolved from Decades of R&D and Field Experience

- Correct flue gas temperature
- Correct design for convective heat transfer surfaces

Features to control Fouling & Corrosion

Integrated Water/Steam Cooled Solid Separator and Return Leg

Features to control Agglomeration & Fouling

- Effective temperature control
- Conservative flue gas velocity
- Possibility to use Additives with worst quality agros
- Active Bed Material

During Operation:
- Fuel quality management
- FW SmartBoiler datalog & Diagnostic tools

Kickout
Step Grid / Arrow head
Final SH & RH as INTREX
Our Biomass and Waste CFB experience is unmatched in the industry

57 (1.9 GWe) SFW CFBs firing biomass as a primary fuel

- Wood 46%
- Bark 14%
- Demo Wood 17%
- Palm Kernel Shell 5%
- Forest and Wood Residual 18%

13 (259 MWe) SFW CFBs firing waste fuels as a primary fuel

- RDF 42%
- Biosludge 8%
- MSW 19%
- REF 23%
- Tires 6%
- Paper 2%

Source: GRDS 06Jan16, CFBs firing biomass and waste as primary fuels for all years. Excludes domestic orders provided by domestic suppliers in China, and India. Market share based on steam production converted to electric capacity GWe.
GDF Suez built a state-of-the-art biomass power plant supplying over 200 MWe of renewable power to Poland’s power grid since 2012.

We provided the turnkey delivery of the boiler island, biomass processing, handling and storage facilities including civil work, equipment supply, erection and commissioning.

The advanced Bio-CFB utilizes cutting edge design features and materials to efficiently produce large scale power from a broad spectrum of wood biomass and agricultural crops and byproducts.

**Plant Electrical Output:**
- 205/190 MWe (Gross/Net)

**Net Plant Efficiency:**
- 36.5/31.4% (LHV/HHV)

**CFB Outlet Steam Conditions:**
- 570 tonnes/hr (1251 kpph)
- 126 barg (1828 psig)
- 535°C (995°F)
299 MWe Biomass CFB in the UK
Firing Wood Chips and Pellets

Will be World’s largest and most efficient biomass CFB plant in world

MGT Teesside Ltd. CFB Boiler
Planned for operation in 2020

<table>
<thead>
<tr>
<th>FUEL DATA</th>
<th>Wood Pellets</th>
<th>70% Wood Pellets</th>
<th>30% Wood Chips</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Blend</td>
<td>0-100%</td>
<td>0-100%</td>
<td></td>
</tr>
<tr>
<td>Sulphur (ds)</td>
<td>0.02%</td>
<td>0.03%</td>
<td>0.2%</td>
</tr>
<tr>
<td>Nitrogen (ds)</td>
<td>0.1%</td>
<td></td>
<td>0.2%</td>
</tr>
<tr>
<td>Moisture (ar)</td>
<td>5.0%</td>
<td>18.5%</td>
<td></td>
</tr>
<tr>
<td>Ash (ds)</td>
<td>5.0%</td>
<td>0.8%</td>
<td></td>
</tr>
<tr>
<td>LHV</td>
<td>17.8 MJ/kg</td>
<td>15.0 MJ/kg</td>
<td></td>
</tr>
<tr>
<td>(7652 btu/lbm)</td>
<td></td>
<td>(6426 btu/lbm)</td>
<td></td>
</tr>
</tbody>
</table>

Steam Capacity | Main Steam Flow | SH/RH Pressure | SH/RH Steam Temp. |
----------------|-----------------|----------------|-------------------|
299 MWe         | 824 tph         | 176/43.8 bar   | 568/568° C        |
105 MWe Multi Fuel CFB in South-Korea, Danjing
- Coal & Palm Kernel Shell & Wood Pellets

FUEL DATA

<table>
<thead>
<tr>
<th></th>
<th>Palm Kernel Shell</th>
<th>Bituminous coal</th>
<th>Wood Pellets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulphur (d.s.)</td>
<td>0.28%</td>
<td>0.22%</td>
<td>0.01%</td>
</tr>
<tr>
<td>Nitrogen (d.s.)</td>
<td>0.46%</td>
<td>0.61%</td>
<td>0.17%</td>
</tr>
<tr>
<td>Moisture</td>
<td>16.4%</td>
<td>6.4%</td>
<td>9.4%</td>
</tr>
<tr>
<td>Ash (d.s.)</td>
<td>2.97%</td>
<td>23.29%</td>
<td>0.88%</td>
</tr>
<tr>
<td>LHV</td>
<td>15.92 MJ/kg</td>
<td>24.9 MJ/kg</td>
<td>17.15 MJ/kg</td>
</tr>
</tbody>
</table>

DESIGN PERFORMANCE, O₂ 6% in dry gases

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flue Gas Exit Temperature</td>
<td>147 °C</td>
</tr>
<tr>
<td>Boiler Efficiency (ASME PTC 4)</td>
<td>85.10%</td>
</tr>
<tr>
<td>Emission Guarantees</td>
<td></td>
</tr>
<tr>
<td>- NOₓ</td>
<td>129 mg/Nm³</td>
</tr>
<tr>
<td>- SO₂</td>
<td>116 mg/Nm³</td>
</tr>
<tr>
<td>- CO</td>
<td>106 mg/Nm³</td>
</tr>
<tr>
<td>Particulate Matter (dry)</td>
<td>6 mg/Nm³</td>
</tr>
</tbody>
</table>

In commercial operation since August 2015.
70MWe Multifuel CFB, Lahti Energia, Finland
- 158 MWth, 56.5 kg/s, 120.9 bar, 540°C

Commercial operation in 2020

FUEL DATA

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass</td>
<td>0-100%</td>
</tr>
<tr>
<td>Recycled Wood</td>
<td>0-10%</td>
</tr>
<tr>
<td>Peat</td>
<td>0-100%</td>
</tr>
<tr>
<td>Coal</td>
<td>0-100%</td>
</tr>
</tbody>
</table>

DESIGN PERFORMANCE, O₂ 6% in dry gases

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flue Gas Exit Temperature</td>
<td>150 °C</td>
</tr>
<tr>
<td>Boiler Efficiency (ASME PTC 4)</td>
<td>90.29 %</td>
</tr>
<tr>
<td>Emission Guarantees</td>
<td></td>
</tr>
<tr>
<td>- NOₓ</td>
<td>50 mg/Nm³</td>
</tr>
<tr>
<td>- SO₂</td>
<td>20 mg/Nm³</td>
</tr>
<tr>
<td>Particulate Matter (dry)</td>
<td>5 mg/Nm³</td>
</tr>
</tbody>
</table>
85MW_e Multifuel CFB for Waste and Clean Biomass (CHP)
Igelsta (Söderenergi AB, Södertälje, Sweden)

240 MWth, 73 MWe-net, 209 MWDH, 92 kg/s, 90 bar, 540°C


### Fuel Mixes

<table>
<thead>
<tr>
<th></th>
<th>Mix 1</th>
<th>Mix 2</th>
<th>Mix 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass</td>
<td>75</td>
<td>30</td>
<td>100</td>
</tr>
<tr>
<td>Rec.wood</td>
<td>0</td>
<td>70</td>
<td>0</td>
</tr>
<tr>
<td>REF pellets</td>
<td>25</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Moisture</td>
<td>44.3</td>
<td>35.6</td>
<td>50.0</td>
</tr>
<tr>
<td>Ash</td>
<td>6.5</td>
<td>4.7</td>
<td>4.0</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>0.6</td>
<td>0.8</td>
<td>0.5</td>
</tr>
<tr>
<td>Sulfur</td>
<td>0.09</td>
<td>0.08</td>
<td>0.06</td>
</tr>
<tr>
<td>Chlorine</td>
<td>1200</td>
<td>800</td>
<td>200</td>
</tr>
<tr>
<td>LHV</td>
<td>9.7</td>
<td>11.0</td>
<td>8.3</td>
</tr>
</tbody>
</table>

### Emissions

<table>
<thead>
<tr>
<th></th>
<th>6%O₂, dry</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOx</td>
<td>35*</td>
</tr>
<tr>
<td>SO₂</td>
<td>75</td>
</tr>
<tr>
<td>CO</td>
<td>50*</td>
</tr>
<tr>
<td>Dust</td>
<td>10</td>
</tr>
<tr>
<td>NH₃</td>
<td>10</td>
</tr>
<tr>
<td>TOC</td>
<td>10</td>
</tr>
<tr>
<td>HCl / HF</td>
<td>10 / 1</td>
</tr>
<tr>
<td>Cd+Tl / Hg / HMs</td>
<td>0.05 / 0.05 / 0.5</td>
</tr>
<tr>
<td>PCDD+F</td>
<td>0.1</td>
</tr>
</tbody>
</table>

*) only at 100% load with Mix 1, 2, and 3
30 MWe WTE CFB in Sweden
- Firing Refuse Derived Fuel

FUEL DATA

<table>
<thead>
<tr>
<th>Property</th>
<th>RDF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulphur (as received)</td>
<td>0.08% (weekly average)</td>
</tr>
<tr>
<td>Nitrogen (as received)</td>
<td>0.22% (weekly average)</td>
</tr>
<tr>
<td>Moisture</td>
<td>27%</td>
</tr>
<tr>
<td>Ash (as received)</td>
<td>14.3%</td>
</tr>
<tr>
<td>LHV (as received)</td>
<td>12.9 MJ/kg (5546 btu/lbm)</td>
</tr>
<tr>
<td>Cl in dry solids</td>
<td>1.0 %</td>
</tr>
</tbody>
</table>

DESIGN PERFORMANCE, O₂ 11% in dry gases

<table>
<thead>
<tr>
<th>Property</th>
<th>RDF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flue Gas Exit Temperature</td>
<td>168 °C (334°F)</td>
</tr>
<tr>
<td>Boiler Efficiency</td>
<td>90.2%</td>
</tr>
<tr>
<td>Emissions</td>
<td></td>
</tr>
<tr>
<td>- NOₓ</td>
<td>&lt; 35 mg/MJ (0.081 lb/Mbtu)</td>
</tr>
<tr>
<td>- CO</td>
<td>&lt; 50 mg/Nm³</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Steam Capacity</th>
<th>Main Steam Flow</th>
<th>Main Steam Pressure</th>
<th>Main Steam Temp.</th>
<th>Feed-Water Temp.</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 MWe</td>
<td>246 kph</td>
<td>957 psi</td>
<td>842°F</td>
<td>275°F</td>
</tr>
<tr>
<td>85 MWth</td>
<td>31 kg/s</td>
<td>66 bar</td>
<td>450°C</td>
<td>135°C</td>
</tr>
</tbody>
</table>

E.ON Varme Sverige CFB Boiler
Operating since 2011
Our Value Points for Biomass and Waste Fuel CFB

- We are the CFB Market Leader
  - Advanced CFB designs with cooled solid separators
  - Proven high reliability with all fuels including aggressive biomass and waste fuels
  - Proven ability to meet strict environmental levels
- Most experience with CFBs firing biomass and waste fuels
  - We have the most experience firing demo woods, pellets, sewage sludge, biomass and RDF fuels in CFBs.
  - Pellets can soften, ignite, and agglomerate. We have the specialized know-how for designing pellet handling and boiler feeding systems.
- Extensive experience in Asia
  - We have a proven track record with clients, EPC and subcontractors in Asia
  - Flexible on scope to lower project cost, ease financing and minimize currency risk
Contact Us

Latin America & Iberia
John Hernandez
+1 858 205 2932
John.Hernandez@shi-g.com

Central & Eastern Europe
Boguslaw Krzton
+48 22 581 0038
Boguslaw.Krzton@shi-g.com

Russia & CIS
Anna Khryashcheva
+358 10 393 11
Anna.Khryashcheva@shi-g.com

Nordics
Markku Kostamo
+358 10 393 7520
Markku.Kostamo@shi-g.com

Western & Southern Europe
Kari Niemela
+358 10 393 11
Kari.Niemela@shi-g.com

Mid-East
Robert Giglio
+1 908 713 2561
Robert.Giglio@shi-g.com

North America, Africa & Indian Subcontinent
Caesar Hussain
+1 908 713 2500
Asif.Hussain@shi-g.com

East Asia, Southeast Asia & Asia Pacific
Nancy Qiu
+86 21 50583983
Nancy.Qiu@shi-g.com

Japan
Wataru Nagao
+81 50 2036 3705
Wataru.Nagao@shi-g.com

Kristofer Matsuo
+81 50 2036 3690
Kristofer.Matsuo@shi-g.com