WORLD'S LARGEST GREENFIELD
100% BIOMASS FIRED POWER
PLANT

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ABSTRACT

Major incentives on wind and solar power and decreasing consumption have nearly stalled thermal power investments in Europe. While fossil fuels are facing strong political pressures there seems to be a market for CO₂ neutral thermal power and heat production. Today's market situation calls for fuel flexible technologies, coordinated efforts in the integration of contractual and financial structures and several power generation technologies, while maximum efficiency and economics of scale drive towards utility size solutions. MGT Teesside Limited has selected Técnicas Reunidas (TR), in a consortium with Samsung C&T, for the execution of a contract to build a new 299-MWₑ combined heat and power (CHP) plant within the Teesport Estate near Middlesbrough, U.K.

Amec Foster Wheeler will design and supply the single circulating fluidized bed (CFB) boiler of the CHP plant, taking the CFB to the 299-MWₑ scale with 100% biomass fuels, i.e. wood pellets that will be sourced from sustainable forest by-products in North America and sustainable wood chips mainly from the United Kingdom. Besides providing nearly CO₂ free energy by using renewable fuels, the plant will fulfil the most stringent emission limits set for traditional (SOₓ, NOₓ, dust) as well as previously unlimited pollutants, such as NH₃, Hg, HCl and HF.

High-efficiency biomass power plants need to utilize advanced steam parameters and in Tees REP they are 176 / 43.8 bar(a), 568 / 568 °C. With sufficiently clean biomass and a state-of-the-art design, high availability and acceptable lifetimes of boiler pressure parts can be maintained. When this CHP plant enters commercial operation in January 2020, it will introduce the world’s largest and most advanced 100% biomass fired CFB based power plant. This paper reviews the challenges to build up a bankable EPC solution capable of reaching financial closure and presents the key technical features and performance estimates of the high-efficiency process and state-of-the-art CFB boiler based power plant.

Keywords: EPC, CFB, Biomass, Renewable Energy, Emissions
INTRODUCTION

MGT Teesside Limited has selected Técnicas Reunidas (TR), in a consortium with Samsung C&T, for the execution of a contract to build a new 299-MWe combined heat and power (CHP) plant within the Teesport Estate near Middlesbrough, U.K.. Reaching this stage took a significant coordinated effort in the integration of contractual and financial structures as well as several power generation technologies. Along with the EPC project development, solutions had to be found for a number of other types of challenges, e.g. fulfilling the new BREF emission limits covering multiple pollutants, reaching high efficiency in energy production and adapting the design to the variable properties of biomass from international sustainable sources.

The project equity owners are Macquarie Group and Danish pension fund PKA in a 50/50% partnership. Construction is taking place under a lump sum turnkey EPC contract with a joint venture of Tecnicas Reunidas and Samsung C&T, and it is scheduled to take approximately 3.5 years. The project will receive revenue fundamentally from the sale of electricity under a combination of a market price power purchase agreement (PPA) and a contract for difference (CfD), which provides a variable top-up between the market price and a fixed strike price.

The Tees Renewable Energy Plant is taking 100% biomass fired CFB combustion technology to a new scale at 299 MWₑ. It will be the largest of its kind, though not physically bigger than the latest CFB units firing fossil fuels. Also the steam parameters will rise to a new level in fully biomass-fired greenfield power plant, paving the way toward higher efficiencies. Technical readiness exists to even double the unit size if new opportunities come up, and further increases in efficiency are pursued.

This paper reviews the challenges to build up a bankable EPC solution capable of reaching financial closure and presents the key technical features and performance estimates of the high-efficiency process and state-of-the-art CFB boiler based power plant.

PROJECT OVERVIEW

Project Basics

The Tees REP power plant in Teesside, UK is a 299 MW dedicated biomass project with combined heat and power (CHP) located in Teesport in England’s north east, near Middlesborough. The project was developed originally by MGT Power Limited (MGT). At a given moment in time, Macquarie Group (Macquarie) entered in the development, and partnering with MGT and with the support of all involved stakeholders, managed to successfully commercialise, structure and finance the project through development to financial
close. Macquarie owns 50 per cent of the equity in the Project, with Macquarie introducing Danish pension fund PKA as an equity co-investor and partner who owns the remaining 50 per cent stake.

The project is being built on a brownfield site at the Teesport port facilities. The site has been secured under a long-term lease agreement with PD Ports. Construction is taking place under a Lump Sum Turn Key - EPC contract with a joint venture of Tecnicas Reunidas and Samsung C&T. The project will include an Amec Foster Wheeler CFB boiler and a proven design steam turbine generator, along with a fuel storage and conveyor system, a wood chip drier and air cooled condenser. Construction is scheduled to take approximately 3.5 years.

Project Fundamentals

The project will receive revenue fundamentally from the sale of electricity under a combination of a market price power purchase agreement (PPA) and a contract for difference (CfD), which running for 15 years from the commencement of operations act as the primary lever to ensure the stream of revenues for the project. Under the UK CfD scheme, the project receives a variable top-up between the market price and a fixed strike price that will grow with inflation over time. The CfD counterparty is the Low Carbon Contract Company (LCCC), a private company that is 100% owned by the UK government that has been set up as counterparty for these types of contract.

The plant will contract most operations and management to an O&M contractor.

Biomass Fuel

The project will be fuelled primarily by virgin wood pellets, as well as wood chips. The pellets will be supplied under a contract covering the majority of fuel requirements; the plant requires more than 1 million tonnes per year. The fuel contract defines the price for delivered fuel to the port of Teesport and the commercial terms for delivery.

The plant is also expected to use a smaller amount of local UK-sourced virgin wood chips that will be dried in an on-site chip drier before being used as fuel. There will be no onsite wood chipper – rather the wood chips will go through a quality inspection at delivery and oversized chips will be rejected.

Fuel must meet a sustainability threshold in terms of sustainable timber harvesting and CO₂ footprint, which is guaranteed by the fuel supplier.

The plant will be technically able to run from 70% to 100% on pellets with the remainder in the form of wood chips.
Pellets and some chips will be delivered to the immediately adjacent quay, which is a deepwater jetty capable of handling up to Supramax size vessels (50000 dead weight tonnage, about 200 meters long). Remaining woodchips will be delivered by truck.

The project will include a continuous ship unloader for discharge of pellets along with a substantial conveyor system and 16 separate storage silos. The plant can be fed from any silo and this allows separation of different cargoes along with fuel blending ability.

Figure 1. Tees REP.

**Business Case Demands from the EPC**

The materialization of the business case of MGT, with the given boundary conditions of the project, was a challenging journey, from a contractual and technical perspective – both sharing deep roots, on the risk allocation and management measures. Key technical challenges and enablers related to the biomass fuel handling, CFB boiler and water steam cycle are discussed in detail in the next sections of this paper. Regarding the wide range of contractual challenges needed to materialize the project, three main topics that deserve attention are:

- Financing requiring Investment Grade Rating (IGR) from the construction phase. The financing plan of the developer required a strong, experienced and consolidated contractor,
allowing the IGR to the project from the construction phase.

− Technical complexity and business case logics requiring a demanding technical risk coverage enabling a project financing operation involving multiple international lenders.

− Project location and local UK execution, with the particular circumstances encountered at the doors of Financial Closure: UK’s referendum vote to withdraw from the EU ("Brexit").

**TR-SCT EPC Providing Answers to the Challenges**

The challenges posted by the business case developed by MGT required a full suite of solutions to the different challenges. TR-SCT worked closely with MGT and Macquarie to develop solutions within the EPC framework. As for the topics pointed out in the paragraph above:

− In order to address MGT’s needs in respect to the contractor profile TR and SCT joined forces in a consortium, thus bringing the robustness, experience, engineering capabilities and local presence in the UK needed for the execution of the project. The participation of TR is approx. 70%, being the rest SCT.

− The technical challenges associated with the fulfilment of the technical output demands, needed to support the business case, are fundamentally covered by the EPC, and required:
  
  o Endorsement – after a multidimensional risk analysis and embedment of an agreed mitigation plan – of the guarantees needed to enable/ensure the key business case requirements in terms of, among others, **efficiency** (of paramount importance due to the high cost of the fuel used) and **delivery time**, given the fixed delivery date predefined in the CfD contract of MGT with LCCC.

  o Guaranteeing plant efficiency is a considerable engineering effort due to the complex process integration considerations that were to be reflected, and the coordinated harmonization of different OEM’s and process integration elements in the power plant. To this end TR was capable, thanks to its in-house power devoted engineering resources, to assemble a team, comprising the different engineering disciplines, which took over successfully the challenge of such integration engineering effort.

  o Closely related are the considerations for translating the process engineering output into the power plant construction phase. The integration effort went beyond process/performance guarantees assembly, and into the execution dimension. To this end key OEM’s involvement – in particular Amec Foster Wheeler as supplier of the CFB boiler, which was hitting directly the project’s critical path – was needed. This involvement was carefully designed and meticulously translated to the procurement conditions of the different plant components. In a general manner, all this was a
coordinated effort of the EPC contractor process engineering, construction and planning teams in order to tackle the critical path challenges by mainly: (i) deliver early sound engineering outputs, (ii) design the procurement/fabrication conditions of the different components in harmony with (iii) the results of the multiple constructability studies developed.

- Materialization of the project in the UK has required from the early stages of the planning and strategy set up, an in deep consideration of the local execution conditions for procurement and construction, fundamentally because the main driver of such strategy has been the execution under local conditions and maximizing local involvement. The fundamental differential factor is the harmonization of the complex project needs and EPC contractor policies and procedures with the local idiosyncrasy. Additionally, in the midst of financial closure, Brexit happened. The Developer group made contingency in the overall structures of the operation and was able to trigger solutions, but the new uncertain scenario was a challenge to the EPC contractor. TR-SCT worked out in an agile set up coordinated with the developer a global solution to the challenge, which facilitated the reaching of financial closure in the early days of August 2016.

HIGH-EFFICIENCY WATER-STEAM CYCLE

The plant design is based on a regenerative steam cycle with reheat. It comprises the boiler itself, one three pressure two body condensing steam turbine-generator (STG) with reheat, condensate extraction pumps, a feedwater tank with integral deaerator, steam driven boiler feedwater pump and an electrical driven feedwater pump (back-up of the previous one) and feedwater heaters. An air cooled condenser is used to cool and condense the turbine exhaust steam.

The configuration of the system, the definition of the steam parameters and the sizing of the equipment have been selected and optimized to achieve a high efficiency of the plant and to comply with the high reliability required by MGT.
The steam from the CFB boiler feeds the high pressure (HP) steam turbine at 174 bar(a) and 567 °C. The exhaust of the HP body is returned to the boiler at around 46 bar(a) and 363 °C and after passing through the boiler reheaters is another time led to the intermediate pressure (IP) turbine at around 42 bar(a) and 567 °C.

The exhaust of the steam turbine is led to the air cooled condenser (ACC), which has 40 cells and is designed for an ambient temperature of 10 °C. 2x100% condensate pumps extract the condensate from the ACC hotwell and feed the feedwater tank through 4 feedwater heaters. The tank operates at 13.5 bar(a) and 194 °C. From this point, the boiler feedwater pumps (2x100%, one of them turbine driven) feed the boiler through three heaters at approximately 203 bar(a) and 262 °C.

The design includes the delivery of low pressure steam to the wood chip dryer (approximately 6 MW\textsubscript{a}) in order to reduce the humidity of the incoming wood chips. The steam system also includes spare connections to feed other steam consumers of the area in case MGT considers it economically feasible. Also other consumers of the plant such as the steam ejectors for the air cooled condenser, the gland steam for the turbine and the deaerator are supplied from the steam system. Two by pass stations for HP (2x50%) and for IP system (1x100%) complete the system.

The Tees REP plant is designed to operate in coordinated control mode where the STG leads the power control of the plant and the CFB boiler leads the HP header pressure, and to work
between 40% and 100% load. The CFB boiler and the steam turbine are designed to work under modified sliding pressure mode. The HP steam pressure is set depending upon the plant load as shown in Figure 3. These pressure values derive from a transient study of the plant developed to fulfil the requirements about frequency response from national grid code of the United Kingdom.

![Figure 3. HP steam pressure set points.](image)

In order to comply with these frequency response requirements, the HP steam header pressure must be controlled over the natural sliding pressure value so that the HP steam header can have enough back-up pressure upstream of the turbine control valves, which can let a quick increase of power when the turbine control valves open. This quick power increase requirement (primary response) happens when there is a grid frequency drop scenario.

The CFB boiler will be able to respond with the load ramp with overfiring as required to meet the steam conditions necessary to comply with the primary and secondary response requirement. Moreover, the steam turbine will be able to respond with the power generation output within the required time to meet all the grid code requirements.

**FUEL STORAGE AND HANDLING SYSTEM**

Another key feature of the plant is the design of the fuel storage and handling system, which is one of the largest in the world for a biomass power plant.

The system includes a ship unloader of 1600 ton/h of rated capacity, conveyors to take the fuel from the quay up to the boiler feeding, and a storage of about 260000 m³ of capacity by means
of sixteen circular silos 27 m in diameter and 30 meters in height, and is capable to operate with both fuels (wood pellets and wood chips) and a mixture of them. The system is designed to supply to the boiler wood pellets and chips at a rate of 660 tons/h.

The silos will include a sloped bottom to accommodate the vibrating floor, necessary for the correct reclaiming of the fuel from the silos. Laboratory tests of the flow ability of the fuels have been carried out to optimize the slope of the belts and to avoid any future problem during operation.

The risk of fire on this kind of plants is a strong concern for project developers and owners. In the design, the fire risk of this kind of fuel has been considered from the beginning, and the system includes features to minimize the level of dust release, the root cause of the fire risk, by the use of high performance filters in the areas where dust creation is possible (transfer points mainly). Also separate surveys have been made to achieve the maximum level of protection against fire by an extensive study of the potential areas where an explosive atmosphere could be created and with a detailed analysis of the active and passive protection systems and also fire suppression for each case.

**TEES CFB BOILER DESIGN**

**Large Scale CFB for Biomass Combustion – ABC Technology**

The Amec Foster Wheeler ABC (Advanced Bio CFB) technology not only addresses the fuel issues related to biomass firing, but also adopts plant requirements and optimizes the investment factors. Plant requirements include the type of the boiler i.e. utility or industrial boiler, capacity, operational load range, steam data, emission limits and other requirements set by legislation. Investment factors include plant availability, fuel flexibility requirements, the investment costs and operation costs. Consequently, economical boiler designs have been developed to fire easy-to-burn biomass, while more robust solutions are implemented as the biomass quality degrades and becomes more challenging to burn reliably.

Key design features of the ABC technology are summarized in Figure 4. This concept has already been utilized in several references, such as the following ones [1]:

- GS E&C in Dangjin, South Korea
  - 253 MWth, main steam 390 t/h, 540 °C, 130 bar, a
  - 110 MWth, 35 MWel, main steam 154 t/h, 540 °C, 113 bar, a
  - Design fuels woody biomass, demolition wood, peat
– GDF SUEZ, Polaniec, Poland
  o 447 MW\textsubscript{th}, main/reheat steam 569/486 t/h, 535/535 °C, 128/20 bar, a
  o Design fuels wood chips, agro biomass
– ZE PAK, S.A., Konin, Poland
  o 154 MW\textsubscript{th}, 215 t/h, main steam 540 °C, 97 bar, a
  o Design fuels wood, crop waste

The well proven ABC technology forms the basis also for the new concept with higher steam parameters in the Tees Renewable Energy Plant described in the next chapter.

\textbf{Figure 4. Key features of the ABC technology.}

\textbf{Tees Boiler Design}

\textit{General [3, 4]}

CFB boilers operating on biomass only have typically used steam temperatures of approx. 540 °C and live steam pressures up to about 140 bar. Besides historical reasons – previously biomass was burned in relatively small units – the steam parameters have been limited due to commonly identified corrosion issues in combustion of biomass and waste derived fuels, attributed to the ash forming elements that largely define the degree of challenges in combustion, such as halogens (notably chlorine), alkali metals (mainly sodium and potassium), phosphorous and heavy metals (e.g. lead, zinc). Although higher steam parameters have been applied to some extent in smaller industrial boilers, it has become more important in large utility size boilers firing biomass. Reaching such high steam temperatures without major corrosion
issues already calls for austenitic superheater and reheater materials, and applying these heat exchangers as fluidized bed units such as INTREX™. Limitations to steam pressure can be influenced by waterwall corrosion: the metal temperature of the evaporator tubes depends directly on the steam pressure. In a drum boiler the pressure is usually essentially constant through the load range and temperature distribution along waterwalls is uniform, near the temperature of saturated steam at the operating pressure.

For cost and manufacturing reasons the waterwalls are normally made of low alloyed steels, which are susceptible to e.g. chlorine corrosion. In coal-fired CFB boilers, with less concerns of corrosion, steam side oxidation being the mechanism limiting use of materials, such steels have been applied even with supercritical steam parameters. The low and uniform heat flux distribution in a CFB furnace provides certain advantage in this respect compared with PC boilers, i.e. lower grade materials can be applied with similar steam parameters.

Utility size biomass plants are aiming at maximum steam cycle efficiency, therefore live steam parameters in the order of 170 bar, 570 °C were selected for the Teesside boiler with clean biomass. Biomass in this case may be virgin wood pellets or chips, the origin varying in a wide range. With sufficiently clean fuel such a high steam pressure, which is about the maximum applicable in natural circulation boilers, is considered feasible with normally applied waterwall materials. Correspondingly, acceptable SH/RH lifetimes can be achieved with clean biomass. With clean woody biomass sand not only acts as circulating material but also serves as alkali getter, binding and purging away potassium with ashes. With more challenging type biomass, additives such as kaolin and elemental sulfur may be fed into combustor to control bed agglomeration, fouling and hot corrosion; the additive type and feed rate depending on fuel quality. Contaminated fuel such as recycled wood may contain high levels of halogens and alkali metals and also heavy metals, therefore such high steam parameters are not considered feasible as it would lead into inadequate lifetime, or call for special solutions with significant cost impact.

**Fuels [2]**

The design fuel is a mixture of virgin wood pellets (70 wt-%) and virgin wood chips (30 wt-%), therefore the moisture is quite low, but the mixing ratio is highly variable and the boiler is capable of burning up to 100 % pellets at full load. This means that the design shall be able to adapt to wide variations in heat value, and also in the chemical properties as a result of international fuel sourcing. Generally, boilers sized to handle the modest amounts of flue gas from dry pellets may have difficulties managing the considerably larger volumes of flue gas.
from wet chips. Conversely, furnaces designed to handle the moderate heat from wet chips may suffer overheating from drier and more calorific biomass and residue [1].

Biomass properties vary considerably depending on their biological origin, location, seasonality, farming and harvesting practices, and ultimately their preparation and processing. This leads to broad variations in chemical composition and physical properties across different biomass types and even within the same type. The related issues such as agglomeration, fouling and corrosion have been discussed in [1] and [2].

The fuels specified for the Tees project, in spite of being virgin woody biomass, may have elevated chlorine contents (max. 0.1 %dry). Such fuels have been characterized with various methods mentioned in [1], ranging from laboratory tests to pilot tests. Numerous challenging biomass fuels have also been burned in existing CFB (and BFB) boilers, and studied with in-house models.

*Water–Steam Circuitry*

The Tees CFB boiler features the following design parameters: approx. 650 MWth, 230/207 kg/s, 568/568 ºC and 176/43 bar, a.

Figure 5 illustrates the water – steam circuitry of the Tees biomass CFB boiler. The feed water is led to a series of conventional feed water heaters that use steam extracted from the turbine. Next, the feed water stream enters the boiler at a temperature of about 260 ºC for preheating in a bare tube economizer. Thereafter water is taken to water-cooled hanger tubes and further to the drum; the boiler is of natural circulation type. From the drum water is led via downcomers and distribution headers to the evaporator (furnace) walls. The water is heated in the evaporator wall tubes, turning partly into steam at constant temperature and the water–steam mixture is taken from the evaporator outlet to the drum where water and steam are separated.

Steam from the drum is led to superheating in the first part of superheating system (SH I) that consists of several sections, starting from steam-cooled flue gas inlet channels. Thereafter, steam is further heated up in four steam-cooled solids separators, the enclosure walls of the INTREX fluidized bed heat exchangers, the crossover duct (COD) and the convection pass walls. The first water spray desuperheater (DSH) is located after the convection pass walls. Next, steam flows into platen type panels hung from the top of the furnace (SH II), followed by the second water spray DSH. The third stage of superheating occurs in tube coils of the convective superheater, and the third effective water spray is located after the SH III stage. The fourth and final superheating stage occurs in two parallel INTREX superheaters on opposite
sides of the furnace below the separators.

The main steam temperature is controlled with feed water sprays. Steam after the high-pressure turbine is brought back to the boiler for reheating. The first stage reheater is located in the convection pass and it is equipped with a steam side bypass used for reheat steam temperature control. At higher loads part of the reheat steam bypasses the RH I, which reduces the heat pick-up and hence the inlet steam temperature to RH II is decreased. With this patented reheat steam control method spray control is normally not required on the reheat side, and therefore the related decrease in plant efficiency is avoided. Also the second stage reheater is located in the convection pass, and it is followed by the DSH (that is normally closed). Final reheating (RH III) is performed in two INTREX units on opposite sides of the furnace below the separators [2].

![Water-steam circuitry of the Tees CFB boiler.](image)

The Tees CFB boiler is designed for sliding pressure operation in order to maximize the efficiency within the load range; besides base load operation the boiler shall be capable of rapid load changes.

_Dynamics [2]_

Load change flexibility of thermal power plants can be maximized by joint operation of the boiler (steam generator), the turbine system and the balance-of-plant (BOP) system; e.g.
condensate throttling. The performance of the boiler depends on the type of steam generation
process (drum or once-through boiler), the operation mode (constant or sliding pressure), and
the thermal (combustion) capacity of the plant. The constant pressure drum boilers are capable
for 3 – 4 %/min ramp due to the large throttling reserve of the turbine valve and the large stored
energy.

The dynamics of the steam generation can be further improved by over-firing the boiler; i.e. the
maximum heat input to the boiler temporarily exceeds that of the nominal MCR. The load
change capability of the Tees 299 MW_{e} unit is demonstrated by dynamic simulation in Figure
6; a 10 % step change in the generated power in 10 seconds is achievable. This quick change is
due to the large storage capacity of the steam generator. The recovery time of the main steam
pressure – which is the long term operation – was improved by the over-firing of the boiler.
Note, that the initial pressure drop is independent of the combustion capacity.

![Figure 6. Improved performance by over-firing the boiler; steam mass flow to the turbine and main steam pressure.](image)

**Furnace Design**

Figure 7 shows a 3D view of the CFB boiler's furnace and back pass area. The furnace has a
single water-cooled fluidizing grid with combination of AmecFW step grid and novel design
grid nozzles. It is provided with refractory protection on the upper side, and bottom ash
discharge openings distributed across the grid ensure efficient removal of bottom ash and
foreign material from the grid. Under the grid there are four separate plenums (windboxes) with
uncooled steel plate structure. The primary air flow to these four air plenums is measured and controlled separately to ensure equal flow to all sections of the grid and uniform fluidization. Primary air provides less than half of the total combustion air. The single continuous fluidizing grid ensures simple control as well as a stable and uniform operation of the furnace.

Figure 7. Tees 299-MWe biomass CFB boiler.

The lower furnace is refractory-lined and tapered so that the grid area is smaller than that of the upper furnace cross section, which provides high internal turbulence of the fluidized bed and enables efficient mixing of fuel and secondary air. Secondary air nozzles are located at two different elevations of the refractory-lined section, and they provide approx. half of the combustion air.

The flue gas side furnace design is based on extensive analysis of the fuels that are going to be used. This has given the required data for the design models to make predictions for circulating material particle size distribution, solids densities and finally the heat transfer and gas temperatures within the entire load range and specified range of fuels.

From the top of the furnace, through openings in the front and rear wall the flue gas flows into four steam-cooled high-efficiency solids separators, two on each side. The separators are
formed of gas tight membrane walls covered with a thin refractory lining with high heat conductivity. Separated solids are discharged from the bottom via non-mechanical gas seal into INTREX units, one below each separator. Two INTREX units serve as the final SH, and the other two as the final RH stage [2].

Table 1 shows a comparison of the design steam parameters of the Tees 299-MW<sub>e</sub> biomass CFB boiler, the GDF Suez Energia Polska S.A. Polaniec CFB boiler (205 MW<sub>e, gross</sub>) that has been successfully operated since 2012, the Kaukas 125-MW<sub>e</sub> (152 MW<sub>steam</sub>, 110 MW<sub>DH</sub>) CFB in Finland that entered commercial operation in 2009, as well as the Samcheok (4 * 550 MW<sub>e, gross</sub>) CFB boilers designed to fire moist, low-ash, high-volatile Indonesian coal and biomass.

Table 1. Scale-up of biomass CFB vs. the largest utility-size CFB.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Tees</th>
<th>Polaniec</th>
<th>Kaukas</th>
<th>Samcheok</th>
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<td>242</td>
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Layout of the Boiler Island

Figure 8 shows a 3D view of the boiler island. The boiler is located in a closed building. After the convective heat exchangers and catalyst, the flue gas stream is divided for the rotary air preheater (RAPH) and an additional heat exchanger called bypass economizer, which heats up part of condensate extracted from the turbine island, thereby reducing need for turbine steam extractions. These parallel streams are joined before the flue gases are cleaned in a high-efficiency baghouse. Between ID fans and stack, further cooling of gases takes place in a Heat Recovery System (HRS). At the HRS, gases are cooled down to a potentially corrosive temperature, nevertheless far above water dew point, in a corrosion resistant flue gas heat exchanger provided with plastic tubes. A closed cooling water circuit transfers heat into combustion air upstream of the RAPH, replacing auxiliary steam normally needed in the first stage of air preheating. As a result of lower flue gas exit temperature, lesser steam extractions and auxiliary steam consumption, the boiler efficiency and overall process efficiency are improved. A similar system has been in operation e.g. at the 458-MW<sub>th</sub> biomass CFB boiler in
Jyväskylä, Finland since 2010.

Figure 8. View of the boiler island.

Emissions Control

The emission limits set for this project are in line with the new IED and anticipated LCP-BREF requirements. The controlled pollutants include sulfur dioxide/trioxide (SO$_x$), nitrogen oxides (NO$_x$), dust, carbon monoxide (CO), ammonia (NH$_3$) slip, mercury (Hg), hydrogen chloride (HCl) and fluoride (HF). The CFB combustion technology provides inherent mechanisms to reduce various pollutants to a low level; however the strict limits based on BREF call also for additional measures. Several technologies are available for control of acid gases (SO$_x$, HCl, HF) and heavy metals (Hg), e.g. CFB scrubbers and spray dry absorbers (SDA), but in biomass combustion the simple and proven dry sorbent injection (DSI) technology is considered more economical.

In DSI, powdered sorbent is pneumatically injected into the flue gas, acid gas is adsorbed onto the sorbent and dry waste product is removed via a particulate removal device. It is a simple system with low capital cost and also low operation cost when the required level of acid gas removal is moderate. DSI provides efficient control of the acid gases HCl, HF and SO$_3$ and acid
dew point by calcium hydroxide or sodium bicarbonate sorbents, but limited SO\textsubscript{2} removal capability. By injecting also powdered activated carbon (PAC), also mercury and dioxins and furans can be absorbed.

The emissions control concept selected for the Tees project includes the following gas clean-up facilities:

- High-efficiency fabric filter combined with DSI to control
  - Particulate matter
  - SO\textsubscript{x} with hydrated lime (not needed with normal clean biomass but could be required with some high-S biomass)
  - Hg with activated carbon injection (if required)
  - HCl with hydrated lime (is expected to be needed due to high-Cl fuels)
  - HF with hydrated lime
- Selective non-catalytic reduction, SNCR, i.e. ammonia injection into separators and/or into furnace depending on load, for NO\textsubscript{x} control
- A slip catalyst in-between two economizer stages to minimize NH\textsubscript{3} slip while utilizing SNCR for DeNO\textsubscript{x} [2].

SUMMARY

Today's market situation for thermal power in Europe calls for CO\textsubscript{2} neutral and fuel-flexible technologies capable of grid control, while maximum efficiency and economics of scale drive towards utility size solutions. Conventional thermal power generation has an increased role to compensate for the variation of renewable power generation. Simultaneously, tightening emission regulations also sets new requirements for thermal power project developers and technology vendors. Amec Foster Wheeler has continued the development of its innovative circulating fluidized bed (CFB) combustion technology as well as back end emission control systems and combinations of those in order to meet the increasing challenges.

Reflecting the above-mentioned trends in power production, MGT Teesside Limited has selected Técnicas Reunidas (TR), in a consortium with Samsung C&T, for the execution of a contract to build a new 299-MW\textsubscript{e} combined heat and power (CHP) plant within the Teesport Estate near Middlesbrough, U.K.. Reaching this stage took a significant coordinated effort in the integration of contractual and financial structures as well as several power generation technologies.

The Tees Renewable Energy Plant is taking the Circulating Fluidized Bed (CFB) combustion technology to the new 299-MW\textsubscript{e} scale with 100% biomass fuels. The steam parameters (SH/RH
176 / 40.4 bara, 568 / 568 °C) will rise to a new level in fully biomass-fired greenfield power plants, which together with an optimized process design will enable high efficiency in power production. Technical readiness exists to even double the unit size if new opportunities come up, and further increases in efficiency are pursued.

This paper reviews the challenges to build up a bankable EPC solution capable of reaching financial closure and presents the key technical features and performance estimates of the high-efficiency process and state-of-the-art CFB boiler based power plant.

REFERENCES


