Development and Demonstration of Oxy-fuel CFB Technology

Arto Hotta, Reijo Kuivalainen, Timo Eriksson,
Foster Wheeler Energy Oy
Finland

Andrés Sánchez-Biezma Sacristán, Jorge Martínez Jubitero, Juan Carlos Ballesteros
ENDESA Generación S.A.
Spain

Monica Lupion, Vicente Cortes
Fundación Ciudad del al Energía (CIUDEN)
Spain

Ban Anthony, Lufei Jia, David McCalden, Yewen Tan, Ian He, Yinghai Wu, Robert Symonds
CANMET Energy Technology Center
Ottawa, Canada

Presented at
Coal Gen Europe
Prague, Czech Republic
February 15 – 17, 2011
TP_CCS_11_01
Development and Demonstration of Oxy-fuel CFB Technology

Arto Hotta1a), Reijo Kuivalainen1), Timo Eriksson1), Andrés Sánchez-Biezma Sacristán2), Jorge Martínez Jubitero2), Juan Carlos Ballesteros2), Monica Lupion3), Vicente Cortes3), Ben Anthony4), Lufei Jia4), David McCalden4), Yewen Tan4), Ian He4), Yinghai Wu4) and Robert Symonds4)

1) Foster Wheeler Energia Oy, Finland; 2) ENDESA Generación S.A., Spain; 3) Fundación Ciudad de la Energía (CIUDEN), Spain; 4) CANMET Energy Technology Centre – Ottawa, Canada

a) arto.hotta@fwfin.fwc.com

ABSTRACT - Foster Wheeler’s Circulating Fluidized Bed (CFB) technology is today commercially available up to 800 MWₑ capacities with ultra-supercritical steam parameters. Simultaneously, the Flexi-Burn™ CFB* technology is being developed to provide capability to flexible operation in air firing and oxy-combustion for carbon capture.

CFB technology can offer alternative solutions for the reduction of CO₂ emissions. The main approaches to emissions reduction in energy production are the following:

- Increase in efficiency provides emissions cuts proportional to the rise in efficiency.
- Co-firing of solid fossil fuels with CO₂-neutral fuels like biomass in fuel-flexible CFB boilers.
- Flexi-Burn™ CFB for Carbon Capture and Storage (CCS)

The EU aims to support the construction of 10-12 commercial size CCS demonstration plants in order to prove the feasibility of CCS in fossil fuel power plants going into operation after 2020. The considered future OXY-CFB-300 project promoted by ENDESA Generación S.A. (ENDESA) and the state owned Fundacion Ciudad de la Energía (CIUDEN) in Spain, has been selected to be one of the six projects to receive early funding by the European Energy Program for Recovery (EEPR). The OXY-CFB-300 project aims to demonstrate fully integrated CCS power plant with approximately 300 MWₑ Oxyfuel-CFB boiler technology. The first phase of the project, granted by the EU EEPR will carry out work needed on the capture, transport and storage areas as well on the costs, financing and permitting required prior to the final investment decision of the plant by mid-2012. An essential part of the OXY-CFB-300 project is to demonstrate the feasibility of the oxyfuel-CFB technology in the 30 MWₑth Capture Technology Development Plant (TDP) built and operated by CIUDEN.

* “Flexi-Burn™” is a trademark of Foster Wheeler AG.
INTRODUCTION

Due to the uncertainties related to Carbon Capture and Storage (CCS), there is a need for flexible boilers that can be operated in either conventional or oxy-fuel combustion mode, preferably without any significant modifications needed to the plant. With such a concept based on high flue gas recycling rate, boilers can be built by modifying existing air-firing boilers.

Figure 1 shows a simplified process flow scheme of a power plant designed for both air-fired and oxygen-fired operation modes. It consists of an air separation unit (ASU), a high-efficiency steam cycle utilizing FW Flexi-Burn CFB (circulating fluidized bed) boiler technology and a CO2 compression and purification unit (CPU). For oxy-fuel combustion, which is the primary operation mode, oxygen is mixed with recycled flue gases, which creates a mixture of primarily O2 and CO2 (and H2O) used as oxidant in combustion instead of air. The absence of air nitrogen produces a flue gas stream with a high concentration of CO2, making it much easier to separate the CO2. In the air-firing mode, which serves risk mitigation purposes but may also be applied during high load demand, the ASU and CPU are out of service (or in stand-by) and the plant is operated like a conventional power plant, leading flue gases to the atmosphere.

ENDESA Generación together with CIUDEN is considering the promotion of a CCS integral Commercial Demonstration Plant (the OXY-CFB-300 project), including CO2 capture, transport and storage, based on a supercritical (SC) CFB oxy-combustion plant, with CO2 storage in a deep underground saline aquifer. The main target of this demonstration plant is to validate, at
commercial plant size, a CCS technology that will allow the renovation of the existing fossil thermal plants from 2020, using a wide range of domestic coals, as well as imported fuels (coals, pet coke…), and biomass. The today’s foreseen future plant’s location is the existing ENDESA’s Compostilla Power Plant, in El Bierzo (Northwest of Spain).

A key role in this development will be assumed by CIUDEN who is constructing an Integrated CCS Technology Development Plant (TDP) in El Bierzo featuring a 30MW\textsubscript{th} Flexi-Burn CFB using exactly the same technology to be incorporated by the commercial-scale demo plant. In that regard, Fundación Ciudad de la Energía (CIUDEN) has entered into a contract with FOSTER WHEELER ENERGÍA, S.L. ("FWES"), Madrid based company of the Foster Wheeler Global Power Group, for the supply by FWES of the Flexi-Burn CFB boiler for the TDP.

THE RESEARCH AND TECHNOLOGY DEVELOPMENT (RTD) ACTIVITIES FOR THE FLEXI-BURN CFB DEVELOPMENT

The RTD Framework

Foster Wheeler has been developing oxy-fuel CFB combustion since 2003 through:

- Knowledge and design tool development
- Test activities (bench-scale (VTT), small CFB test rig (VTT) and ~0.8 MW\textsubscript{th} CFB pilot (CANMET))
- Conceptual and feasibility studies (boiler design)

In the development of Flexi-Burn CFB technology, FW in cooperation with the Technical Research Centre of Finland (VTT) and the Lappeenranta University of Technology (LUT) applies a similar approach illustrated by Figure 2, which has been used in the scale-up of CFB boilers in the last two decades. Bench- and pilot-scale CFB furnaces provide well-controlled environments for studying of different phenomena related to combustion, heat transfer and emissions. Process understanding gained from small-scale experiments and modeling can be linked to designing of full-scale CFB boilers /1/.

Even though the Once-Through (OTU) CFB technology has been commercially demonstrated for conventional air firing, additional efforts are required to ensure the technological applicability to oxy-firing. For this purpose the framework of a powerful collaboration between ENDESA,
CIUDEN and FOSTER WHEELER has been established. Within this collaboration, the following main RTD activities will be executed:

- Test program in the air-fired reference plant (Lagisza 460 MW, OTU CFB)
- Small-scale pilot testing of oxy-combustion in the CFB process
- Characterization of the design fuels and limestone in air and oxy-fuel conditions in a lab-scale plant of around 0.8 MWt at CANMET in Canada
- Validation tests at CIUDEN’s oxy-fired CFB in 1:30 scale
- Development of operating modes and control strategies of the fully integrated Technology Development Plant at CIUDEN in Spain
- Developing models for optimising the final design for oxy-combustion
- Economic and Risk Assessment studies

Some of these activities are partially covered and funded by the ongoing FP7 project “FLEXIBURN CFB” sponsored by DG-TREN (European Commission), ENDESA (Spain), PKE (Poland), EDP (Portugal), CIUDEN (Spain), AICIA (Spain), Foster Wheeler (Spain/Finland),

\[ \text{Figure 2. Scale-up approach based on integrated experimental and modeling work /1/}. \]
PRAXAIR (Belgium), ADEX (Spain), CzUT (Poland), LITEC-UNZAR (Spain) and LUT (Finland) form the project consortium co-ordinated by VTT (Finland).

**Once-through CFB Technology Scale-up**

The Polish utility company Południowy Koncern Energetyczny SA (PKE) selected Foster Wheeler Energia Oy’s 460 MW<sub>e</sub> supercritical CFB boiler in 2003 for their Łagisza power plant. The new 460 MW<sub>e</sub> power unit of Łagisza was synchronized to the electrical network for the first time in 15th of February 2009. On the 10th of March the new Łagisza unit reached full output power of 460 MW<sub>e</sub>. Commissioning continued with fine tuning of the boiler controls and performance prior to start of a 720 h trial operation. The Łagisza CFB power plan was handed over to customer on 27th of June 2009.

After operating over 4000 hours, it can be stated that initial operation experience of the Łagisza boiler has been excellent. Over the whole load range, the boiler has performed as designed and operation has been steady and easily controllable. All performance values were already demonstrated during trial operation. Thus, Łagisza has validated Foster Wheeler’s supercritical CFB design platform providing a solid base for further units /3/.

Foster Wheeler has finalized the development of supercritical CFB up to the 800 MW<sub>e</sub> scale for bituminous coals, meeting the highest requirements for plant efficiency and environmental performance. The study has developed a basic conceptual boiler design to help understand the feasibility of a large CFB boiler of this size. Bituminous coal has been used as the base fuel in the study. Ultra-supercritical steam parameters, with a steam pressure of 300 bar, a superheated steam temperature of 600 °C, and a reheat steam temperature of 620 °C, to maximize the plant efficiency, have been used in the plant design. A predicted plant net efficiency of approximately 45% (LHV) has been calculated. Based on continuous development work including the experience of over 350 reference boilers in operation or under construction worldwide, the capability to offer supercritical CFB up to 800 MW<sub>e</sub> scale with full commercial guarantees has been created.

The design and operating experience of the Łagisza unit will form the foundation for the development of the Flexi-Burn CFB technology. In support of this development, a field test campaign has been planned together with project partners of the FP7 “FLEXIBURN CFB” project in 2010.
Small Pilot Testing of Oxy-combustion in the CFB Process

FW has carried out several test campaigns in bench scale and small pilot scale since 2004 at VTT. In addition, FW has participated in several public projects in which fundamental understanding has been created on the oxy-fuel process and related phenomena. Bench-scale testing is well suited for producing data on specific combustion phenomena, whereas the pilot tests give process data on actual circulating fluid bed conditions. Results of these tests are presented in previous conference papers and presentations (/1,2,4/).

Characterization of the Design Fuels in a 0.8 MWth Scale CFB Pilot Facility

CANMET Energy Technology Centre, Ottawa, (CETC-O) has retrofitted its 0.8 MWth CFB pilot plant for oxy-fuel combustion. The main components of the pilot (Figure 3) are the riser with an I.D. of 0.406 m and an internal height of 6.6 m, hot cyclone, return leg, flue gas cooler, baghouse, and feeders for fuel and sorbent. Riser temperature is controlled with up to four water-cooled bayonet tubes, which can be inserted or retracted during operation by a motorized winch system. A natural gas start-up burner preheats the CFBC to the ignition temperature of the test fuel.

Figure 3. CanmetENERGY 0.8 MWth Oxy-Fuel CFB Combustion Pilot Facility
During retrofitting, a flue gas recycle line was added, including a recycle blower, a flue gas condenser, and pressure control and safety equipment. The flue gas is drawn from the exit of the baghouse. Oxygen from a storage tank is mixed with the recycled flue gas to maintain combustion in the CFBC. Operating parameters remain basically the same as in the air-firing mode. However, the facility is run under slightly positive pressure to prevent air in-leakage, and oxygen level in the combustion gas can reach 29%. Flue gas from the CFBC is continuously analyzed for CO₂, CO, O₂, SO₂, and NOₓ. The system can operate at temperatures up to 1000 °C and superficial velocity of 4 - 6 m/s.

An extensive test program to characterize the potential design fuels and sulphur sorbents for the planned 300 MWₑ Flexi-Burn CFB demonstration boiler, was conducted with cooperation of FW, ENDESA and CETC-O. The test program commenced with one week of testing to validate the pilot plant operation against the preset criteria before deciding to proceed to the actual test program. The validation test was executed in September/October 2009. The criteria were passed successfully and the actual test campaign started in January 2010. The test program was completed as planned in the end of August 2010. Endesa provided the test materials for the testing as shown in Table 1. For sulfur sorbent, two limestone qualities were provided.

The realized test program shown in Figure 4 consisted total of 15 weeks of testing both in air and oxy combustion mode. Total of 88 test runs, duration of each being 6-8 hours, were carried out. The Figure 4 shows the overall schedule of the test program. The typical varied test parameters were: firing rate, limestone feed rate (Ca/S-ratio), combustion temperature, excess air, air distribution and oxygen/recycle gas ratio (oxidant O₂).

<table>
<thead>
<tr>
<th></th>
<th>Anthracite</th>
<th>Bit. coal</th>
<th>Lignite</th>
<th>Petcoke</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Proximate analysis</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moisture</td>
<td>6.1</td>
<td>6.0</td>
<td>21.8</td>
<td>6.2</td>
</tr>
<tr>
<td>Volatiles</td>
<td>7.3</td>
<td>25.9</td>
<td>30.8</td>
<td>10.1</td>
</tr>
<tr>
<td>Ash</td>
<td>34.3</td>
<td>14.9</td>
<td>33.0</td>
<td>0.8</td>
</tr>
<tr>
<td>Fixed carbon</td>
<td>52.3</td>
<td>53.2</td>
<td>14.4</td>
<td>82.9</td>
</tr>
<tr>
<td><strong>Ultimate analysis (as received)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>57.4</td>
<td>68.6</td>
<td>46.3</td>
<td>85.7</td>
</tr>
<tr>
<td>H</td>
<td>2.1</td>
<td>4.00</td>
<td>3.58</td>
<td>3.6</td>
</tr>
<tr>
<td>N</td>
<td>0.92</td>
<td>1.71</td>
<td>0.51</td>
<td>1.64</td>
</tr>
<tr>
<td>S</td>
<td>1.1</td>
<td>0.86</td>
<td>7.16</td>
<td>6.61</td>
</tr>
<tr>
<td>O</td>
<td>1.95</td>
<td>8.02</td>
<td>16.64</td>
<td>1.70</td>
</tr>
<tr>
<td><strong>Higher hear value</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H.H.V. MJ/kg, dry basis</td>
<td>21.7</td>
<td>27.3</td>
<td>17.9</td>
<td>34.6</td>
</tr>
</tbody>
</table>

Table 1. Preliminary analyses of test fuels
The project provided plenty of data about the differences between oxy-fuel combustion and conventional combustion of different fuels. During the forthcoming months, the results will be thoroughly analyzed by using the FW CFB boiler design model for creating understanding on oxy combustion performance and for validation of design model for oxy combustion conditions. Phenomena of interest include combustion, firing rate, emissions-related issues, mixing, heat transfer, fouling and corrosion.

CIUDEN’s Integrated Technology Development Plant (TDP)

CIUDEN’s TDP features all necessary equipment to provide the CO₂ stream ready for transport at a 1:30 scale. Testing campaigns are to be performed jointly by the partners, aiming to get a sound basis for the refinement of the incorporated technologies, specially the CFB under oxy-firing conditions, but also the dynamic behaviour of the complete unit is to be reached. Through this approach the risks associated with the design and construction of a first-of-its-kind Flexi-Burn CFB boiler will be greatly reduced, thus resulting in lower uncertainties about costs and availability.

Figure 5 shows the location of the TDP adjacent to the Compostilla II Power Plant.
The configuration of the TDP (Figures 6 and 7) is flexible, modular and versatile in order to test a wide range of operating conditions including different coals and combustion conditions from air mode to oxy mode in independent but interconnected modules for simultaneous or separate operation.

Figure 5: CIUDEN’s Technological Development Plant, near Compostilla II P.S.

Figure 6: CIUDEN’s TDP Configuration
Figure 7: Simplified flow-sheet of CIUDEN’s integrated TDP

Figure 8 shows a 3D model of the CFB boiler island with main design parameters.

<table>
<thead>
<tr>
<th>Dimensions (m)</th>
<th>21x2.7x2.4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power (MWth)</td>
<td>30 max</td>
</tr>
<tr>
<td>$O_2$ (kg/h)</td>
<td>8775</td>
</tr>
<tr>
<td>Flue gas recycle (kg/h)</td>
<td>25512</td>
</tr>
<tr>
<td>Flue gas (kg/h)</td>
<td>28800</td>
</tr>
<tr>
<td>Coal feed (kg/h)</td>
<td>5469</td>
</tr>
<tr>
<td>Limestone feed (kg/h)</td>
<td>720</td>
</tr>
<tr>
<td>Steam (t/h)</td>
<td>44.6</td>
</tr>
<tr>
<td>$P_{(bar)} / T$ (°C)</td>
<td>30 / 250</td>
</tr>
</tbody>
</table>

Figure 8: Flexi-Burn CFB Boiler at the TDP
In particular, anthracites, bituminous and sub-bituminous coals and pet coke will be tested. Table 3 shows the characteristics of the design fuels. However, the CFB boiler is designed with R&D versatility in mind, hence, allowing the testing of a variety of coals and biomass. This approach will provide strong support to the requirements of ENDESA regarding fuel utilisation at the 300 MW_{e} Flexi-Burn CFB Demo Plant, and will largely contribute to showing the capabilities of the Flexi-Burn CFB technology to efficiently process fuels of interest for other utilities in Europe.
THE 300 MW_e FLEXI-BURN CFB DEMONSTRATION PROJECT

A Feasibility Study for the Flexi-Burn CFB Technology Definition

FWES and ENDESA Generación signed an agreement in October 2007 for joint development of the Oxy-fuel CFB with indigenous coals, including all the validation steps. In order to support the development of the demonstration project, a feasibility study of a 500 MW_e Flexi-Burn CFB plant was carried out during 2007-2008 /4/.

For the boiler design, the 460 MW_e (gross) once-through supercritical, coal-fired CFB boiler plant designed and constructed by FW for the Polish utility PKE at Lagisza power plant was used as a starting point in the feasibility study. Praxair provided the technical and cost information for the ASU and CPU. ENDESA added other components such as the turbine island and prepared overall cost information. The oxygen supply system consists of two identical ASU trains, each individual unit having a capacity of 4277 t/d (contained). The ASU is based on advanced process and equipment technology designed to reduce the power consumption over current state of the art. The CPU consists of the following sections: flue gas cooling and condensate removal, raw gas compression, contaminant removal and drying system, CO₂ purification, and product compression. The Flexi-Burn CFB concept was introduced, combined with a firing-more fuel approach to increase the gross power in the oxy-fuel mode. FW offices in Finland, USA and Spain developed the Flexi-Burn CFB boiler design and performance estimates and ran a system level heat and mass balance model on an Aspen Plus platform, and the system performance was studied in both operation modes. With the selected approach, the gross power increased by about 100 MW_e in oxy-fuel mode, so that the reduction in net power output was only 6 % (from 436 to 410 MW_e), excluding product compression to pipeline pressure. The CO₂ capture rate is over 90 %. The net efficiency drops by 10 %-points, from 43.5 to 33.5 %. Further optimization will be carried out when advancing toward the design of commercial-scale demo plant, with several methods of efficiency improvement already identified.

The feasibility study was updated for the 300 MW_e-scale plant in 2009.

Description of the Future Project

The European Union selected the project as eligible for funding, the earlier studies and design stages, from the European Economic Package for Recovery (EEPR). The main target of the project consortium, coordinated by ENDESA, is to develop engineering FEED of a future
integrated CCS power plant in a 300 MW_e scale. Based on this work, techno-economic feasibility of the plant technology commercial application, CO_2 transportation and storage options will be evaluated for the basis of the Final Investment Decision (FID) in 2012. The technology provider is the Foster Wheeler Energia Oy that is responsible for fluidized bed technology within the Foster Wheeler Global Power Group.

The overall future project aims at a completely new supercritical CFB unit of about 320 MW_e (gross) sited at ENDESA´s Compostilla Power Station. Compostilla is located in Cubillos del Sil (León) in the Northwest of Spain. The selection of this site will help with the installation of the expected Demo Plant, thanks to the existing consolidated infrastructure, and a timetable for closing the oldest units of the site. So, in order to reduce the investment costs of the unit, some of the existing infrastructure of the power plant will be used. CIUDEN´s TDP plant is also located at the same site, offering synergy for the RTD and demonstration activities.

The design fuel for the plant is a mix of local Spanish anthracite and pet-coke (70%-30%) and the operational data presented in this document refer to this mix. The operating flexibility of the CFB technology will permit modifications of the fuel mix according to market prices and availability of fuels and specific requirements of a demonstration plant.

The technical risks associated with a demo plant will be reduced as the boiler will be based on technology similar to the air-fired once-thorugh supercritical CFB unit by Foster Wheeler. This plant features the most advanced design parameters and has recently been accepted for commercial operation by the plant owner.

**Capture Technology**

The basic principle of oxy-combustion is to replace the traditional oxidant (air: 21% oxygen, 79% nitrogen) with a mixture of pure oxygen and recycled CO_2-rich gas from the flue gas stream. Due to the absence of air nitrogen, the flue gas produced is for the most part CO_2 and H_2O. About 30% of the flue gas is led out of the process to a flue gas condenser, the remaining CO_2 is purified and compressed to liquid phase ready for transport. Eliminating the nitrogen component of air and recirculation of flue gases back to the combustor reduce NO_x emissions, and SO_2 is captured with limestone in the furnace, similar to normal CFB boilers. The CFB technology has been selected because of the relatively low and constant heat flux profile inside the combustion
chamber versus a PC boiler, owing to the circulation of solids, which facilitates the handling of the potentially high temperatures produced in oxy-combustion.

Other advantages of incorporating a CFB boiler with oxy-combustion, over traditional PC-fired boilers are considered to be:

- Capability of burning a wide range of fuels, including low-grade coals and biomass, due to the large heat capacity and mixing of the bed.
- Reduced combustion temperatures, and affordable furnace heat absorption rate.
- High combustion efficiency, due to turbulent mixing and long residence time in the circulating bed.
- Low NOx, SO2 and CO emissions, have onward savings with the CO2 compression unit.
- Stable operating conditions, boiler response and good turn-down rates provide flexibility of operation allowing optimization of downstream equipment sizing.

Figure 9 shows the simplified process flow diagram of the proposed plant.

*Figure 9: Simplified process flow diagram of the 300 MW, Flexi-Burn CFB plant*
The pure oxygen from an Air Separation Unit (ASU), must be mixed with recycled flue gas to form an oxidant suitable for stable combustion. This oxidant stream is then divided and distributed to the boiler in convenient proportions.

The primary oxidant is preheated before it is utilized as a fluidising stream, while the secondary oxidant, also preheated, is injected above the bed to complete the combustion. A third high-pressure oxidant stream is used as a fluidising medium to control the Intrex heat exchanger. The gases coming from combustion are cooled down and, in order to improve boiler efficiency, a low-pressure economizer is used in parallel with a regenerative air preheater. Later, the gas passes through a cleaning device for particle removal and a cold-end heat exchanger is used to recover heat and further improve plant efficiency before gases are sent to the Compression and Purification Unit (CPU).

Oxygen is provided by an ASU, which utilizes a series of cooling and compression stages to achieve the separation of oxygen. The ASU consists of two identical trains of air separation units. Each individual unit will have a capacity of 2542 tO₂/d. The ASU is based on advanced process and equipment technology designed to reduce the power consumption over current state of the art. The unit design stresses reliability, efficiency and safety.

The CPU consists of the following sections: flue gas cooling and condensate removal, raw gas compression, contaminant removal and drying system, CO₂ purification, and product compression. Purification of the CO₂ takes place in a unique cold box process design. The design cools the compressed, dry CO₂ stream to a temperature at which a majority of the CO₂ condenses. Most of the inert substances in the stream, including oxygen, nitrogen, argon, etc., remain in the vapour phase, and are removed using a separator. The CO₂-rich liquid stream is then expanded to provide refrigeration in the cold box. Both the CO₂-rich stream and the waste inert stream are warmed against the incoming feed stream. The CO₂ rich product stream exiting the cold box is compressed using one train of multi stage, centrifugal, electric motor driven compression to a pressure of 180 bar.

The CPU will treat 100% of the total combustion gases produced in the plant. Over 91% of the CO₂ produced will be captured and stored.
The Flexi-Burn CFB design is based on an equivalent 250 MW<sub>e</sub> (net) air-fired plant. It is able to operate both in oxy-combustion mode with an actual net output of 234 MW<sub>e</sub> and eventually in air mode (necessary for start-up), with an actual net output of 250 MW<sub>e</sub>. Due to increased auxiliary power consumption by the ASU and CPU units, the efficiency penalty is 10 %-units in oxy-fuel operation compared to air firing, which is partly accounted for the high compression pressure of CO<sub>2</sub>.

In the preliminary studies for plant definition, an availability of 4400 equivalent annual operational hours for the first five years has been considered, resulting in capture and storage of around 5.02 million tonnes of CO<sub>2</sub> by the plant. This value is based on the first operation stage of the plant, which will have a lower utilization rate due to non-programmed shut-down and research or design modification activities in the plant.

**SUMMARY AND CONCLUSIONS**

In support of the concepts and design development, FW has conducted an extensive R&D program including testing campaigns in bench scale and small pilot scale. Fuels and sorbent characterization tests in the 0.8 MW<sub>e</sub>-scale oxy-combustion CFB pilot plant has recently been completed at CETC-O, and generated data for validation of the process models and design tools necessary for reliable performance predictions of the Flexi-Burn CFB demonstration plant.

Fundación Ciudad de la Energía (CIUDEN) is constructing an Integrated CCS Technology Development Plant (TDP) El Bierzo (Northwestern Spain) featuring a 30 MW<sub>th</sub> CFB boiler (Flexi-Burn CFB) using exactly the same technology to be incorporated by the commercial-scale demo plant (Demo Plant). The configuration of the TDP is flexible, modular and versatile in order to test a wide range of operating conditions including different coals and combustion conditions from air mode to oxy mode in independent but interconnected modules for simultaneous or separate operation. The TDP will be ready for testing in the second half of 2011.

ENDESA Generación together with CIUDEN is considering the promotion of a future CCS integral commercial demonstration project, including CO<sub>2</sub> capture, transport and storage, based on a circa 320 MW<sub>e</sub> gross Circulating Fluidised Bed (CFB) supercritical oxy-combustion plant, with CO<sub>2</sub> storage in a saline aquifer. The main target of the future demo project will be to
validate, at commercial plant size, a CCS technology that will allow the renovation of existing fossil thermal plants from 2020, using a wide range of domestic coals, as well as imported fuels (coals, petcoke, etc.), and biomass. The proposed location of the plant is ENDESA’s Compostilla Power Plant, in the Northwest of Spain.

The Lagisza 460-MWₑ (gross) SC-OTU CFB boiler was used as a starting point for the boiler design, and the Flexi-Burn CFB concept and increased fuel firing in the oxy-fuel mode were adopted. The Flexi-Burn CFB design will be based on a 250 MWₑ (net) air-fired plant. It is able to operate both in oxy-combustion mode with an actual net output of 223.8 MWₑ and eventually in air mode (necessary for start-up), with an actual net output of 250 MWₑ.

The ASU consists of two identical trains of air separation units. Each individual unit will have a capacity of 2542 tO₂/d. The ASU is based on advanced process and equipment technology designed to reduce power consumption over current state of the art. The unit design stresses reliability, efficiency and safety. The CPU consists of the following sections: flue gas cooling and condensate removal, raw gas compression, contaminant removal and drying system, CO₂ purification, and product compression. Purification of the CO₂ takes place in a unique cold box process design.

ACKNOWLEDGEMENT

The research leading to these results has received funding from the European Community’s Seventh Framework Programme (FP7/2007-2013) under grant agreement n° TREN/FP7EN/239188/”FLEXI BURN CFB”.

REFERENCES:

