2nd Oxyfuel Combustion Conference

Overview of a Manufacturer's Efforts to Commercialize Oxy-Combustion for Steam Power Plants

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Keywords: Alstom; Oxy-Combustion; Oxy-fuel; Carbon Capture Sequestration (CCS); Gas Processing Unit (GPU); Tilting-Tangential Firing; Plant Integration

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1. Introduction

A comprehensive updated overview of Alstom's development and commercialization of Oxy-Combustion technology for CO_2 capture from fossil fired power plants is given. Alstom's current development has completed extensive pilot testing establishing a firm foundation for large-scale demonstration plants (150 – 400 MWe) and subsequent commercial plants (450-1100 MWe). Oxy-Combustion technology builds upon proven coal-based power generation and is complementary with conventional boiler and steam power plant technology, including its evolution towards ultra-supercritical steam conditions, at very large sizes (>1000 MWe), and with advanced environmental controls. Alstom is a leader in the evaluation and commercialization of Oxy-Combustion with efforts on several technology platforms [Pulverized Coal (PC), Circulating Fluidized Bed (CFB), and Chemical Looping Combustion (CLC)] addressing all major components and their design and operational integration. Alstom has led 15 MW_{th} PC and 3 MW_{th} CFB pilot programs, was supplier of the 30 MW_{th} boiler, firing system and ESP for Schwarze Pumpe, and the supplier for the boiler modifications of the 30 MW Lacq project. Alstom has developed and pilot tested air pollution control equipment [Electrostatic Precipitator (ESP), Fabric Filter (FF), Flue Gas Desulferization (FGD), and flue gas condenser (FGC), and gas-processing unit (GPU)] relevant to the oxy

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combustion process applied to steam power. Alstom has completed comprehensive engineering and economic studies, and defined the optimized integration of oxy power plant components. The validity of the Oxy-Combustion process is now verified. Since September 2008, the full Oxy-Combustion PC boiler island capture chain, including the air separation unit (ASU) and the GPU, has been demonstrated at the Vattenfall 30 MW_{th} Schwarze Pumpe oxyfuel pilot plant where Alstom is a partner and a major equipment supplier. Considerable “know-how” has been acquired, and it is time for oxy-fuel technology to demonstrate commercial size integrated oxy-fired steam plants for future Carbon Capture and Sequestration (CCS) market

2.0 Oxygen Firing Concept

Oxygen firing is a promising near-term technology for CO_2 capture and sequestration from steam power plants. The basic concept of oxygen firing is to replace combustion air with a mixture of oxygen and recycled flue gas, thereby creating a high CO_2 content, nitrogen free, flue gas stream that can be processed for sequestration or high purity product. This technology is applicable to new units as well as to the large fleet of existing steam power plants. Economic evaluations show that purifying the flue gas from oxygen-fired systems is competitive with alternative CCS technologies.

By recirculating a part of the cooled flue gas back to the furnace, the furnace temperature is controlled and normal furnace temperatures are maintained without additional heat transfer surfaces (thus compatible for retrofit applications). Nominally, about 3 kg of flue gas are recycled for every 1-kg of net flue gas produced and mix with oxygen results in about a 30% oxygen concentration (by volume) oxidant mixture. This 30% mixture yields thermal conditions in the furnace similar to those with air firing (accounting for the different thermal properties of CO_2 and N_2). I1n a CFB boiler, the temperature control can be achieved by recirculating cooled solids to the furnace through a fluid bed heat exchanger (FBHE). With an oxygen-fired CFB, the additional required cooling duty can be achieved by recirculating cooled flue gas (as in the PC case), by increasing the circulation of cooled solids through an external heat exchanger, or by a combination of the two. This feature could allow for a reduction in furnace volume and reduction in ducting, fan, and gas cleaning equipment within the flue gas recycle loop.

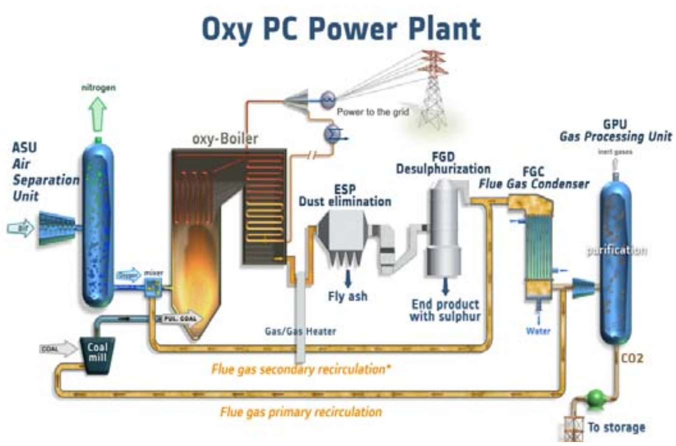

Figure 1: Oxy-Combustion Steam Power Plant

Alstom envisions that Oxy-Combustion technology will evolve as the industry gains experience and incorporates new innovations. Initial commercial designs will likely have dual capability to operate in either Oxy-Combustion mode or air-fired mode. This will provide a high degree of flexibility and reduce risk to the plant owner from the implementation of the first-of-a-kind oxygen-firing technology. Development of oxygen production will continue and will be integrated into Oxy-Combustion. Initially this will focus upon improvements to cryogenic oxygen production, reducing electrical consumption and CAPEX, but in the long term significant benefits could be gained by the development of oxygen transport membranes. The CO_2 gas-processing unit for compression and purification of CO2 will continue to be adapted to power generation and integrated in an optimized manner. No doubt performances and CAPEX for Oxy-Combustion will follow a learning curve and be optimised. Beyond this, solid oxygen carriers, which are in early stage development in Chemical Looping systems, could result, in the long term, in dramatic improvements to capital cost, efficiency, and overall economics. Although beyond the scope of this presentation, Alstom is the world leader in advancing chemical looping technology and is conducting two major on-going pilot test programs; one at 1 MW_{th}, and the second at 3 MW_{th}. Thus Oxy-Combustion technology appears to be an attractive option, both in the near-term as a fast track for steam power plants with CCS, and an attractive option in the long run with significant opportunity for further technological innovation.

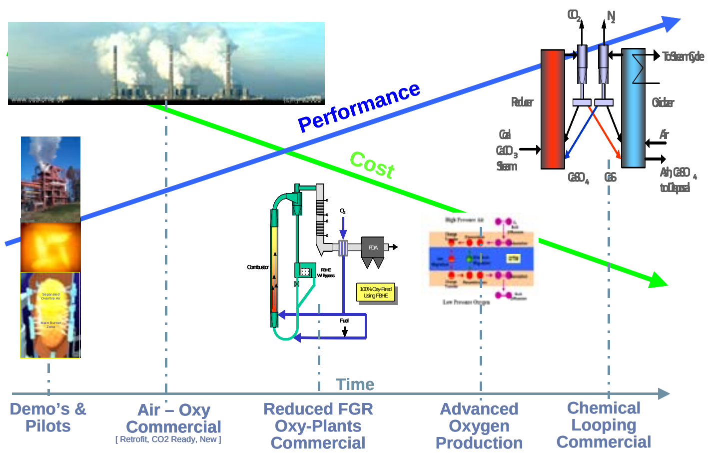

Figure 2: Alstom Oxy Combustion Technology Innovation Roadmap

3.0 Oxy Development Status

For Oxy-Combustion fundamentals, Alstom has been involved in the European research programs ENCAP (Enhanced Capture of CO_2), Oxy-Burner and was involved in the German research program ADECOS (Advance Development of the Coal-Fired Oxy-fuel Process with CO_2 Separation). These collaborative projects involved several research institutes with focus on oxy-fuel laboratory and small scale testing. Several tests at scales up to 0.5 MW_{th} were performed with different coals looking at combustion performance under oxy-fuel conditions. These tests supported the Alstom design and operating principles for the 30 MW_{th} pilot boiler at the Schwarze Pumpe Station in Spremberg, Germany (this project is covered in detail under a separate Alstom presentation, but is the first fully integrated Oxy-Combustion operating process applied to a steam power plant). Following the operational success of Schwarze Pumpe, the collaboration continues today with the development and validation of CFD modeling tools from the on-going pilot test and small-scale oxy-fuel tests and its application to scale the oxygen burner design concept for the 250 MWe oxygen demonstration plant at Jaenschwalde. Additionally, Alstom has completed a full and complete design for the demonstration plant and its major components.

Since October 2008, Alstom has conducted a multi-year program to develop and pilot test work for developing the Oxy-Combustion system for tangentially fired PC boilers with application to the broad range of global coals (including Bituminous, Sub-bituminous, and lignite type A). For this broad range of coal, as well as for oil and gas, Alstom employs titling tangential firing technology for optimum combustion, with low emissions, and to support steam temperature control. Schwarze Pumpe and Jaenschalde are applying Oxy-Combustion to lignite type B (i.e. "brown coal" which has also been dried). The Alstom Oxy-Combustion tangential boiler development program objectives are to: 1) design and develop an innovative oxy-fuel system for new and existing T-fired boiler units that minimizes overall capital investment and operating costs; 2) evaluate performance of oxy-fuel T-fired boiler systems in pilot scale tests at Alstom's 15 MWth T-Fired Boiler Simulation Facility (BSF) and 3) address optimization steps for design of oxy-fuel commercial utility boilers by focused testing in the BSF and improvement of engineering and CFD tools. This program is co-funded by Alstom, the US Department of Energy (US DOE)/National Energy Technology Laboratory (NETL), the State of Illinois, the State of North Dakota, and ten (10) electric utilities. This program has evaluated several Oxy-Combustion system design concepts including various flue gas recirculation scenarios and oxygen injection options using engineering and 3-D computational fluid dynamics (CFD) modeling tools. The most promising designs are being tested in the 15 MWth Boiler Simulation Facility. These tests include a range of operating conditions and a number of coal types and will continue in 2011. The test programs have validated Alstom modeling and design tools needed to optimize the Oxy-Combustion process.

For oxy-fuel Process and Steam Plant development, Alstom was involved in the European research program ENCAP (Enhanced Capture of CO_2), Process and Power Systems, and in the French research program éCO2 . These collaborative projects involved several research institutes with focus on oxy-fuel plant process development, performance and economic evaluation for various sizes and fuels, and comparison with other CO_2 capture technologies. On this basis, Alstom is conducting internal Plant Integration Concept studies, focused on oxy plant feasibility, process and performance optimization, and minimized avoided CO_2 cost. The steam conditions chosen are ultra-supercritical and in line with a future commercial scale Oxy-fuel Power Plant.

Alstom has followed a systematic approach (Figure 3) to scale-up oxy-combustion process technology starting with fundamental scale experiments, advancing to pilot-scale component testing, to integrated system pilots, to full scale demonstrations, and finally achieving utility scale commercialization. Supporting this scale-up has been validation and application of predictive and simulation tools, as well as the development of reference plant designs. Reference plant designs are defined early in Alstom's component technology development and set the vision for the development of the plant and its major components. The reference plant is updated over the development path to reflect the current component definition/validation and the current view of future CCS market requirements.

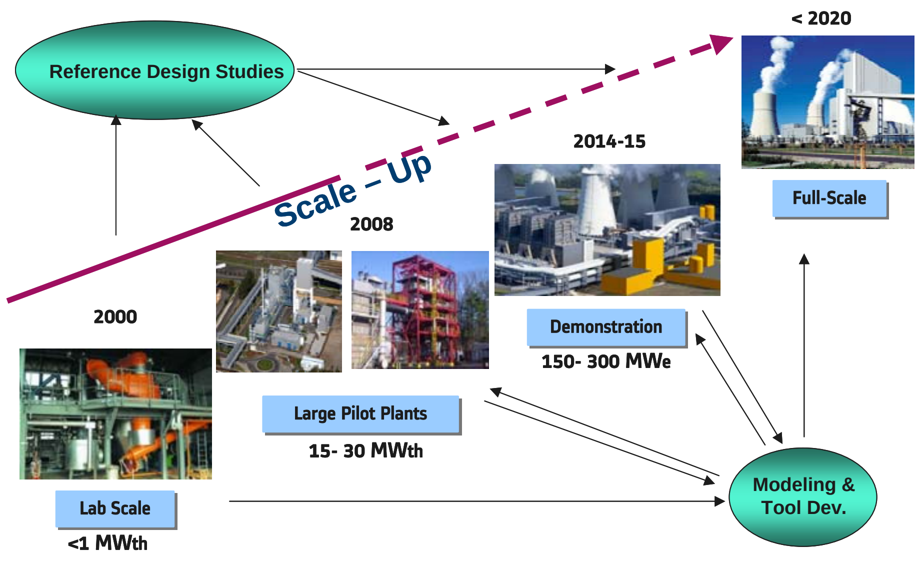

Figure 3: Alstom Oxy-Combustion Scale-Up and Commercialization Steps

Plant Integration –

The selection of the preferred flue gas recycling concept is strongly based on the fuel quality and the accordingly optimized level of integration. Alstom studies confirm the economical interest of high performance, high-efficiency processes for the Air Separation Unit (ASU) and Gas Processing Unit (GPU) systems, the significant impact of the flue gas path integration of the “Integrated Oxy-Boiler Island” (ASU, Oxy-Boiler, Air Quality Control System (AQCS), GPU) on gas-side performance (optimization of recirculation flows, O2 contents, excess O2 and air intake), and the major impact of the Heat Integration of all possible heat recovery from ASU and GPU compressors and flue gas coolers on the Water and Steam cycle. Integration Concept studies are used by Alstom for the development of Reference Plant designs for future commercial size Oxy-PC Steam Plants (“Oxy-effective” steam plants) and for “Oxy-ready” PC Steam plants which may be offered today for a possible future conversion in “Oxy-effective”.

Air Quality Control System (AQCS) -

The air quality control equipment for Oxy-Combustion applications designed and supplied by Alstom have been now proven and testing confirms Alstom performance expectations. In Schwarze Pumpe, the flue gas from the boiler is treated in a 3-field electrostatic precipitator. Gravimetric dust sampling and on-line particle size distribution measurements have been performed downstream of the precipitator, showing very low fly ash emissions. Even at reduced specific power input to the precipitator, the emission was below 10 Mg/Nm3. The particle size measurements showed very similar emission profiles for oxy-fuel combustion and air combustion in the size range of 0.015-10 μm.

Dry NID systems for flue gas desulphurization (FGD) were installed after the test facilities (3 MW_{th} & 15 MW_{th}) at Alstom’s Windsor, CT USA Boiler Laboratory. The dry FGD process exceeded performance expectations under oxy-firing conditions. Excessive carbonization of the lime fed to the FGD system did not occur and removal rates for SO2 was in the +95% range.

Flue Gas Condenser (FGC) -

Conventional, existing, installations for flue gas condensation are of two types, i.e., tube & shell and packed bed. The tube & shell condenser is a heat exchanger in which condensation takes place directly on tubes. In the packed-bed condenser, the flue gas contacts a circulating flow of water counter-currently. Heat is transferred to the cooling water, which is cooled through an external heat exchanger. Selection of the tube & shell condenser or the packed-bed condenser depends on size of the unit, the needs for cooling for polishing of pollutants, and for heat recovery.

Alstom’s Research and Development (R&D) for CCS set up a packed-bed type Flue Gas Condenser (FGC) pilot sized for 1 MWe at its Environmental Control Systems R&D laboratories in Växjö, Sweden. Since 2008, tests have been made on the FGC pilot to establish performance and design criteria. Tests were performed using synthetic gas consisting of air, moisture, CO2, SO2, SO3, NO, NO2 and other pollutants, as required. The FGC pilot facility has been employed to investigate cooling, condensation, heat recovery and polishing of the synthetic flue gas. Different parameters, including liquid flow rate, gas flow rate, water vapor content, CO2 content, SO2 concentration, NOx concentrations, pH and cooling water temperatures, were tested. The pilot was built with the additional purpose to test various design configurations. Tests have been made to optimize the design for packing type, packing height, liquid distribution, gas distribution, mist eliminator type and distribution. The FBC is now ready for full-scale demonstration.

Gas Processing Unit (GPU)-

The Gas Processing Unit (GPU) is located downstream of the Flue Gas Condenser. The purpose of the GPU is to compress and purify the CO2 rich flue gas and to provide a CO2 product that meets a certain specification as defined for storage or other purposes. The GPU is usually designed for a recovery rate of 90% of the inlet CO2 mass flow and dependant upon the quality of the inlet flue-gas and the requirements of the CO2.

For applications such as Enhanced Oil Recovery (EOR) with stringent requirements for the CO2 product purity, the GPU will be designed for product purity in excess of 99% CO2 with very low levels of O2, N2, and Ar. For CO2 storage, e.g. in saline aquifers, the requirements on the CO2 product quality are less stringent and product purity in excess of 95% CO2 is likely sufficient. For both cases, the remaining gas constituents will be mainly O2, N2 and Ar.

The Gas Processing Unit contains the following sub-systems:

- Flue Gas compression
- Conditioning and Drying
- Regeneration Gas System
- Chilling and CO2 Separation
- Off-gas System

- CO2 Recompression

The technical concept of the GPU has been developed with the objective of minimizing the energy consumption by Alstom in-house expertise of Alstom Carbon Capture unit (former Lummus Global) with extensive experience in numerous fields of chemical processing applications, especially for the oil and gas, petrochemical and Chemical Processing Industries. Alstom has developed a comprehensive development program to support the global Oxy-Combustion program, including optimization of its interfaces with other power plant subsystems and global evaluation of trade-offs and integration with the other components of the oxy-plant. Alstom is testing a 300 kW_{th} (equiv.) GPU pilot in its labs and is validating design tools and prediction models. Experimental data from this Compression and Purification pilot has been used in the GPU development. This unit has operated with a wide range of synthetic flue gas composition. The key results will be presented.

4. Summary

Significant know-how has been gained from Alstom studies, tests, and pilots. Oxygen-fired technology is now ready for large-scale (~150-400 MWe) CCS demonstration plants and subsequent commercialization. Alstom has been and will continue to be a leader in the development and commercialization of Oxy-Combustion for steam power plants.