Updated Overview of Alstom’s Efforts to Commercialize Oxy-Combustion for Steam Power Plants

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Alstom Leader in Clean Power

Alstom is a full scope supplier of all major power plant components and turnkey plants.

13 CCS pilots
several large-scale demo projects in development

North America
12%

Europe
44%

Asia Pacific
25%

Latin America
6%

Africa – Middle East
13%

92,600 employees worldwide in 100 countries
Why Oxy-Combustion:

- **Robust** - developed from existing components
- **Flexible**:
  - Applicable all types of boilers, firing systems and fuels
  - Options for operational flexibility
  - Retrofit and “Oxy-Ready” can be addressed
- **Scale-up**:
  - No constraints anticipated for large commercial units up to 1000 MWe, high efficiency with ultra-supercritical cycles
- **Cost competitive** - with other CCS as well as other low carbon technologies
- **Environmentally-friendly**:
  - Emissions: No new chemicals introduced to plant
  - High CO2 capture rates (>90%)

Source: Alstom analysis – 2013– New PC power plants with CCS including transport and storage. NEurope
Alstom Oxy-Combustion Technology Development Steps

Reference Design Studies

Lab Scale <3 MWth

Large Pilot Plants 15-30 MWth

Demonstration 150-400 MWe

Scale-up 2012

2008

1990s

Full-Scale 600-1100 MWe

Modeling & Tool Dev.

Alstom is a full scope supplier of all major power plant components and turnkey plants
First **oxy pilot plant** with complete train for CO₂ separation and capture

- Alstom supplied the Boiler, ESP and other components of the flue gas path
- Technology Partnership with Vattenfall to advance of the Oxyfuel technology

**Operation started September 2008**

- More than 10,000 operation hours and 10,000 tons of CO₂ >10,000 tons
- Tests with two lignites (low/high sulfur)
- Test phases with Alstom Burners (Design A+B) finished

**Wealth of knowledge gained on design, performance and operation**

Uwe Burchhardt & other Vattenfall presentations; also F. Kluger
15 MWth Oxyfuel Pilot Plant
Alstom Labs, Windsor, CT, USA

Comprehensive Program:
- **5 Years** (Sept. 2008 – April 2014)
- **~21.5 MUSD**

Large Pilot Completed:
- Evaluated the impacts of different oxy process options and boiler design parameters
- (combustion, heat transfer, pollutant emissions, deposition, corrosion ... )
- **Coals tested** (low S Bit (WV), high S Bit (III), Sub-bit (WY), Lignite (ND, DE))
- Evaluated, improved, and validated engineering and computational tools

Scale-Up Completed:
- Development of design guidelines
- Commercial **Reference Designs**
- **Demonstration Design**
- Ready for large demonstration
Oxy T-Fired Boiler Development Project Status

Accomplished

- Process and CFD Screening **Completed**
- Modifications For Oxy-Firing **Completed**
- Campaign 1 **Completed**
  Sept. 2009 – PRB subbituminous coal
- Campaign 2 **Completed**
  Feb. 2010 - Low S bituminous coal
- Campaign 3 **Completed**
  April 2010 - High S Illinois Bit coal
- Campaign 4 **Completed**
  2010 - North Dakota lignite
- Campaign 5 **Completed**
  Aug. 2011- Schwarze Pumpe lignite
- Campaign 6 – Test 1-3 **Completed**
  Dec.11, Sept.12, Nov.12 – Advanced Concepts and Pollutant Control

On-Going

- Tools & Modeling Refinement and Validation
- Design Guidelines
- Reference & Demo Designs
Oxy 15 MW T-fired Testing in BSF
Example of Results: Combustion and Emissions

**NOx Spiking Tests**

- NOx returned to windbox reburned
- NOx returned to SOFA not destroyed

**Pollutant Control**

- **Hg control** injection of PAC Optimize between Boiler and GPU
- **SO3 control** injection of Na-based and Ca-based additives

**Sorbents Behavior Similar During Oxy-firing**
Oxy 15 MW T-fired Testing in BSF
Example of Results

Optimize Thermal Performance
Ability to control heat flux profile with recycle flow rates and with oxygen distribution into furnace

Minimize difference between average and peak values enables lower recycle rates

Advanced Concepts

Close Coupled Recycle
- Enables downstream equipment savings
- Eductors
  - Able to achieve 100% secondary gas recycle with single eductor and O2 motive gas. Ideal for high temp recycle applications.

Detailed In-Furnace Mapping
- Gas Temperature
- Gas Composition
- Heat Flux

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CFD Model Development

LES Modeling Evaluation

U of Utah Results and Animations of Unsteady Combustion (O2 conc.)

FLUENT - Validation and Scale-up

- Upgrade of Model Subroutines
- Evaluation and Refinement Using Experimental Data
- Verification and Uncertainty Analysis with U of Utah
Dynamic Model Development

Aspen Dynamics Platform
- Detailed boiler model
- Overall oxy capture plant model

Dynamic Simulation
- Assess transient response
  - Operating modes
  - Load changes
  - Failure behavior
- Design advanced controls

Detailed Oxy Boiler Model

Total Oxy Capture Plant Model
Oxy-PC Pilot Testing - Optimized Integration with Boiler, AQCS, FGC, and GPU
GPU Pilot Tests in Alstom’s CCS test centers
Sweden (Vaxjo) and USA (Windsor)

• Evaluation of Drying, Compression and Cryogenic-Purification
• Behavior of SOx and NOx during each process step
• Behavior of SOx in Direct Contact Condenser
• Behavior of Ash, Hg and other heavy metals, VOC during each process step

Tested under actual oxy coal-fired conditions

Wuyin Wang - Session 4b Thursday (09:30) and Olaf Stallmann - Session 5b Thursday (12:10)
Oxy-firing Integrated Approach
Reference Plant work

- Globally optimize cost of electricity
- Balance trade-offs between main subsystems (performance and costs)
- Determine specification for the new subsystems
- Optimize power plant operation behaviour
- Optimize arrangement and minimize footprint

Guides the oxy-program and defines future commercial
Demonstration Unit Boiler Design

Specifications

- 425 MWe gross
- Supercritical, sliding pressure with spiral wall evaporator
- USC – 279/52 bar, 600/620 C
- Direct pulverized coal firing, Tilting-tangential firing system

Design Fuel

- Range of Bituminous Coals

Operation

- Dual 100% Air / 100% Oxy
- Cycling load operation
- Min. Load 25%

Materials & Corrosion - Bettina Bordenet - Workshop 1 Wednesday 14:00

Low NOx T-Fired System With CCOFA & 2-Levels SOFA

O2 Injection before gas-gas heater and into windbox

SCR (with economizer and gas bypasses)

Ljungstrom gas-gas heater with special sealing to minimize leakage
About the White Rose project

• The White Rose partners – Alstom, Drax and BOC – are planning to build a 426MW oxy-combustion carbon capture and storage (CCS) demonstration project

• The project will comprise a state-of-the-art new build coal-fired power station that will be fully equipped with CCS technology

• It will be built at the existing Drax power station site, near Selby, North Yorkshire, and will capture around 90% of emissions

• Around two million tonnes of CO$_2$ will be transported through the proposed National Grid pipeline for permanent storage under the North Sea

• On March 20$^{th}$ 2013, the project was selected as one of two preferred bidders remaining in the UK Government’s CCS Commercialisation programme

• The Project has now entered a risk reduction phase for which a Front End Engineering and Design (FEED) contract will be concluded with DECC
Power plant appearance
Project’s Objectives

• To demonstrate Oxy-combustion CCS technology as a reliable, flexible and affordable low-carbon technology

• To help reduce CO₂ emissions in order to meet future environmental legislation and to help combat climate change

• To improve the UK’s security of electricity supply by providing a coal-based low-carbon electricity generation option

• To generate enough low-carbon electricity to meet the energy needs of more than 630,000 homes

• To act as an anchor project for the development of a CO₂ transportation and storage network in the UK’s most energy intensive region
## Project participants

<table>
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<th>Company</th>
<th>Description</th>
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| **Alstom**   | A global leader in the world of power generation, power transmission and rail infrastructure  
                A pioneer in large-scale and efficient CCS technologies |
| **Drax**     | Owner and operator of the UK’s largest, cleanest, most efficient coal-fired power station; meets 7% of the UK’s electricity needs  
                Committed to reducing Drax & UK power generation carbon footprint |
| **BOC**      | The largest provider of industrial gases in UK, and a leader in clean energy technologies  
                A member of the Linde Group, a world leading gases and engineering company |
| **National Grid** | An international electricity and gas company and one of the largest investor-owned energy companies in the world.  
                        Expert in running high pressure natural gas system in a safe, reliably and efficient manner. |
Participants’ roles

Location: Drax Power Station, Selby, North Yorkshire, UK

Project Promoters

- Oxy-combustion Power Plant & CO₂ Capture
  - Alstom
  - Drax
  - BOC

- CO₂ Transportation & Storage
  - National Grid
CO₂ Transportation and Storage

Transport Development

- **R&D programme**
  - Vapour phase programme completed
  - Dense phase programme underway
- **Onshore route planning**
  - Public consultation underway
- **Offshore route planning on-going**

Storage Development

- Regional assessment completed
- 257 wells assessed in target area
- Key sites shortlisted
- Technical programme to identify prime target (two front runners) developed
- Developing appraisal plan (to include drilling)
Project Development Status

• Bid submitted for funding under UK CCS Commercialisation programme

• Selected as preferred bidder for the risk reduction phase of the programme (FEED Contract)
  - Permitting process for the Oxy-combustion power plant on-going
  - Engaged with National Grid Carbon on project CO₂ transportation and storage solution development, and on development of Humber cluster

• Competition winner will be selected after FEED and awarded Project Contracts:
  - Final Investment Decision (FID) and construction start expected in 2015
  - Project completion and commencement of operation in 2019

• Application for funding under Phase II of the European NER-300 programme submitted by the UK government
Chemical Looping
Fossil fuel Power with CCS at lower cost than alternates

“Breakthrough CCS Technology”

“Transformational Coal Power Technology”

CO₂ capture process in oxy-combustion using solid oxygen carriers rather than an ASU (cryogenic O₂ production), avoiding related cost & energy penalty
Alstom - Chemical Looping Process
Managed Development and Scale-up Steps

We are here, Significant progress made

1st Worldwide to achieve “Auto Thermal Operation”
Metal Oxide Based (MeOx)

ECLAIR Program - EU RFCS co-funded

Main Features:
- Metal Based Oxygen Carriers
  ilmenite (FeTiO$_3$) - iron-titanium ore
- Process based on CFB solids transport
- Carbon stripper for minimizing UBC

Limestone Based (LCL™)

US-DOE co-funded

Main Features:
- Limestone based oxygen carrier - CaS, CaSO$_4$
- “Fast” CFB solids transport
- Sorbent reactivation for increased limestone utilization
- Same materials in commercial CFBs
Concluding Remarks

• Oxy-combustion successfully developed over the past ten years
• Alstom and other oxy pilots across the world provide design data and confirm the robustness of the process
• Alstom has addressed all major components and their integration
• Total plant integration is needed to optimize performance and minimize the CoE of oxy power plants
• Alstom is ready to demonstrate oxy-combustion at large-scale under real commercial conditions
• The White Rose project in UK is a promising opportunity providing a key step for commercialization
• Long term, advanced technologies like Chemical Looping may offer improved performance and cost

Please attend Alstom presentations and speak with Alstom representatives at OCC3
THANKS TO MANY PARTNERS WHO HAVE SUPPORTED AND/OR WORKED WITH ALSTOM ON THE EFFORTS PRESENTED. PARTICULAR ACKNOWLEDGEMENT TO THE US DOE NETL AND TO THE EU RFCS.