Recovery Act: Oxy-Combustion Technology Development For Industrial-Scale Boiler Applications
DE NT-0005290

Armand Levasseur
Alstom Power, Windsor, CT

NETL CO2 Capture Technology Conference
Pittsburgh, PA
July 11, 2013
Why Oxy-Combustion:

- Robust - developed from existing components
- Environmentally friendly - near zero emissions
- Options for operational flexibility
- Rapid scale-up to 1000 MWe
- Retrofit and “Oxy-Ready” can be addressed
- High efficiency with supercritical/ultra-supercritical cycles
- High CO₂ capture rates (>90%)
- Cost competitive with other CCS as well as other low carbon technologies

A robust and competitive solution
Alstom Oxy-Combustion Technology Development Steps

- **Reference Design Studies**
- **Scale-Up**
  - 1990s
  - 2008
- **Lab Scale**
  - <3 MWth
- **Large Pilot Plants**
  - 15-30 MWth
- **Demonstration**
  - 150-400 MWe
- **Full-Scale**
  - 600-1100 MWe

Development Dates:
- **Reference Design Studies**
  - 2012
- **Demonstration**
  - 2018/2019

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Oxy T-Fired Boiler Development

Project Objectives

Develop and validate an oxyfuel T-fired boiler system as part of commercially attractive CO$_2$ capture solutions.

• Design and develop an oxyfuel firing system for T-fired boilers

• Evaluate the performance in pilot scale tests at 15 MW$_{th}$ testing
  - operation, combustion, heat transfer, pollutants, ash deposition and corrosion

• Evaluate and improve engineering and simulation tools for oxy-combustion by applying detailed test data obtained

• Develop design guidelines

• Develop the design, performance and costs for a demonstration-scale oxyfuel boiler and auxiliary systems.

• Develop the design and costs for both industrial and utility commercial-scale reference oxyfuel boilers
Oxy T-Fired Boiler Development
Budget & Schedule

Total Budget: $21.5 M
Project Team:
Alstom
DOE–NETL
ICCI
NDIC
Utilities

Utility Advisory Group
Ameren
ATCO
Dominion Energy
Great River Energy
Luminant (TXU)
LCRA and Austin Energy
MidWest Generation
NB Power
OG&E
Vattenfall

Project Start: Oct 2008  Duration: 5.75 Yrs

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<th>Task Description</th>
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<th>DOE FY10 Period 2</th>
<th>DOE FY11 Period 3</th>
<th>DOE FY12 Period 4</th>
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Task 1 - Project Management: 85% Completed
Task 2 - Bench Testing: 70% Completed
Task 3 – Screening Evaluations: 100% Completed
Task 4 - 15 MWth Testing: 100% Completed
Task 5 - Test Data Analysis: 90% Completed
Task 6 – Model Simulations: 70% Completed
Task 7 – Oxy Guidelines: Milestone Completed
Task 8 - Oxy Boiler Demo Design: Milestone Scheduled
Task 9 – Commercial Ref. Designs: 75% Completed
15 MWth Oxyfuel Pilot Plant: Alstom Boiler Laboratories, Windsor, CT

15 MWth Boiler Simulation Facility
- Multi-burner, Tangentially-fired

Flexible operating conditions
- air & oxy-firing, gas recycle configuration, oxygen injection, firing system design

Generation of detailed design and performance data
- combustion, emissions, heat transfer, deposition, corrosion
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

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

Windbox SOFA
- NOx returned to windbox burned
- NOx returned to SOFA not destroyed

NOx Spiking Tests
- NOx in SOFA in flue gas
- NOx in SOFA returned to windbox

Pollutant Control

- PAC Injection Rate (kg PAC / gm Hg)
- % Hg Capture

Sorbents Behavior Similar During Oxy-firing

Hydrated Lime
- % Capture
- Molar Ratio

2013 NETL CO2 Capture Technology Meeting
Optimize Thermal Performance

Ability to control heat flux profile with recycle flow rates and with oxygen distribution into furnace.

Advanced Concepts

Minimize difference between average and peak values enables lower recycle rates.

Close Coupled Recycle

- Enables downstream equipment savings
- 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
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
Dynamic Modeling
Example of Results

Oxy Boiler Simulation
During Transition from Air to Oxy-Firing

Oxy Plant Simulation
During Load Change (2% per Minute)
Oxy T-Fired Boiler Designs

Oxy Reference Plant and Demonstration Designs

- Application of test results and design tools
- Development of reference oxy-fired design – 900 MWe gross USC bituminous coal
- Development of oxy-fired designs for demonstration – 400 MWe gross – Dual Air/Oxy - USC
- Optimization, detailed design, performance assessment and costing
Large Commercial Reference Boiler Design

Boiler Specifications

- 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

- Optimized for Oxy
- Base load operation
- Minimum Load 40%

Boiler Design Optimized for Overall Plant Performance and Cost
A global approach to design of an oxy capture plant is necessary to optimize Performance and Cost of Electricity

- Integration of flue gas cleaning strategy
- Optimization of the arrangement and
- Minimize overall energy consumption by
  - Optimize heat integration
  - Optimize O₂ concentration from ASU
  - Balance O₂ concentration in oxidant to burner
- Optimize safety margins on each component to improve power plant performance
- Minimize air ingress/leakage

An integrated approach minimizes the cost of electricity
Oxy-firing Integrated Approach
Reference concept with integration

DESIGN BASIS

- Oxy-Combustion Power Plant 900 MW (90% CO₂ capture)
- Steam Cycle: 600°C / 620°C / 275 bar
- Bituminous Coal
- Direct cooling (power plant, ASU, GPU)
- CO₂ Specification for Storage (CO₂ > 95% vol, O₂ < 3% vol)
- Base load operating regime
- Flexibility in oxy-mode down to 40%
- Grid code compliance: 5% primary response in 30s at 90% load

ESTIMATED PERFORMANCE

<table>
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<tr>
<th>Plant Type</th>
<th>Net Plant Efficiency (LHV)</th>
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<tr>
<td>Conventional Air-Fired Plant (No Capture)</td>
<td>46.2%</td>
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<tr>
<td>Oxy Capture Plant - Not Integated</td>
<td>34.5%</td>
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<tr>
<td>Oxy Capture Plant – Integated</td>
<td>37.1%</td>
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Demonstration Unit Design

Boiler Specifications

- 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%

Boiler Design Optimized for Overall Plant Performance and Cost
White Rose Large Scale Oxy-Demo Project

Largest Oxyfuel CCS Demo

Location:
Drax Power Station,
North Yorkshire, UK

Project Promoters
Oxy-fuel Power Plant
CO₂ Transport & Storage

ALSTOM  DRAK  BOC-Linde  NATIONAL GRID

• New ultra-supercritical 426 MWe Gross Oxy-fuel Power Plant
• Clean power with entire flue gas treated to capture 2 Mt/y CO₂
• Biomass co-firing option leading to zero (or negative!) CO₂ emissions
• Anchor project for National Grid’s regional CO₂ transport & offshore storage network
• Project development on-going
  – Selected for award of FEED under the UK CCS competition (1 B£)
Concluding Remarks

Program has been very successful – Wealth of detailed information and know-how obtained.

- No technical barriers restrict the continued development and commercialization of oxy-combustion
- Combustion performance, emissions, and thermal behavior (temperature, heat flux intensity, heat flux profile) controlled to similar levels or better as air firing
- Oxy boiler design concepts to improve overall plant performance and cost are being investigated

Results from this project and other Alstom R&D programs have:

- Refined and validated design tools and design procedures
- Supported overall oxy plant integration and optimization efforts
- Developed and optimized designs for demonstration opportunities and future commercial plants

Ready for next step of large-scale demonstration – White Rose Oxy Demonstration Project is a promising opportunity
Acknowledgements and Disclaimer

Acknowledgement
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