Integration of Oxy Combustion in a Large Size USC PC Plant for a Competitive Solution

Thierry POURCHOT
Bénédicte PRODHOMME, François GRANIER,
Patrick MÖNCKERT, Olaf STALLMANN

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Alstom Power Sectors
Technologies adapted to all thermal energy sources

Gas
Coal
Oil

Hydro
Nuclear (turbine island)
Wind

Solar
Geothermal
Biomass

... for new power plants and the installed base
Alstom Plant Integrator™ concept
Creating value for customers

Customer’s business objectives

- Increased cash flow – lowest cost of electricity
- Higher power output
- Increased installation efficiency
- Reduced fuel consumption
- Increased operational flexibility
- Minimal environmental impact

Components

Integrated Systems

EPC

Operation & Maintenance

Working to achieve customer’s business objectives
The reference plant benefits from feedback experience of many tendered and executed large supercritical plants, as for example in Europe:

- Belchatow in Poland: 1x900MW supercritical
- RDK8 in Germany: first project based on RP900
- Neurath in Germany: 2x1100MW supercritical
- Sostanj in Slovenia: 1x600MW supercritical
- Niederaußem in Germany: 1x1000MW supercritical
Oxy-PC CO2 Capture Reference Plant
Main Plant Scope

Full turnkey steam plant 1 x 900 MW class (gross) including oxy extra features:

1. Air Separation Units (ASU) - 3x33%
2. Once-through Oxy-Boiler Pulverised Coal
3. Turbine hall
4. Air quality Control Systems
5. Flue Gas Recycle ducts
6. Gas Processing Unit (GPU)
7. Balance of plant
8. Fuel storage & Handling Plant
9. Electrical Systems

... and Oxy Integration Systems!

Oxy PC Reference Plant developed on basis of RP 900MW Class Cycle C Product
The integrated approach is key to integrate at best new oxy systems.

Strong and multiple interconnections with conventional plant components.

Main areas for integrations are:

- Plant arrangement / Mechanical integration: optimal layout, study of alternative compressor drive solutions.
- Operation & Control / Electrical integration: global plant load & transient operation control, dynamic behaviour simulation.

This integration approach should therefore be started very early in a project development to maximise its benefits.

An integrated approach will allow minimizing cost of electricity.
Oxy-PC CO2 Capture Reference Plant
Oxy-Combustion Integrated Approach

Multiple options and areas of integration evaluated for Oxy PC Reference Plant
Oxy-PC CO₂ Capture Reference Plant
Oxy-firing Integration Assumptions

DESIGN BASIS

- Oxy-Combustion Power Plant 900 MW class (90% CO₂ capture)
- Steam Cycle: 600 °C / 620 °C / 275 bara
- Bituminous Coal
- Direct cooling (power plant, ASU, GPU)
- CO₂ Specification for storage in a Saline Aquifer (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
- Parity factor for integration: 5300 €/kW

ESTIMATED PLANT PERFORMANCE (BASELINE FOR INTEGRATION)

<table>
<thead>
<tr>
<th></th>
<th>Net Eff. (LHV)</th>
<th>Net Output (MW)</th>
</tr>
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<tbody>
<tr>
<td>Conventional Air-Fired Plant (No Capture)</td>
<td>46.2%</td>
<td>836 MW</td>
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<td>Oxy Capture Plant - Not Integrated</td>
<td>33.4%</td>
<td>606 MW</td>
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</tbody>
</table>

Not- integrated Oxy Plant efficiency ~13% pts below Non-Capture Plant
Oxy-PC CO2 Capture Reference Plant
Air Separation Unit Integration

DESIGN BASIS – Non-Integrated Baseline

- 3 x 4400 tpd ASU trains (max. size today)
- 95% O2 Purity
- Low-pressure O2 production (~1.3 bara)

- State-of-the-art double-column Process
- In-line Centrifugal MAC (P/R ~5)

OXY-INTEGRATED HIGH EFFICIENCY ASU

- Low-energy process (triple-column, multiple LP reboilers)
- Axial MAC (P/R ~3) & Heat Exchangers for Integration
- GOX & LOX storage for Plant Operability & Flexibility

ESTIMATED HIGH EFFICIENCY ASU INTEGRATION VALUE*

<table>
<thead>
<tr>
<th></th>
<th>ASU Power (MW)</th>
<th>Power Value (M€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-integrated ASU</td>
<td>ref</td>
<td>ref</td>
</tr>
<tr>
<td>Oxy Integrated ASU</td>
<td>- 13.3 MW</td>
<td>+71 M€</td>
</tr>
</tbody>
</table>

Value of Power Gain for High efficiency ASU >> Expected ASU Cost Increase

*excluding heat integration
Oxy-PC CO2 Capture Reference Plant
Flue Gas Path Integration – ASU Oxygen Purity

DESIGN BASIS

- 95% O2 Purity (conventional “low purity” Oxygen)
- Maximum 96.5% O2 purity capability for « Low Energy » ASU process (avoidance of Argon distillation)
- GPU multi-flash process for Saline Aquifer storage

OPTIMAL O2 PURITY

- 96.3% O2 purity:
  - slight increase of ASU consumption (≤+1 %)
  - significant decrease of GPU Consumption (~-3%)

ESTIMATED O2 PURITY INTEGRATION VALUE

<table>
<thead>
<tr>
<th>ASU+GPU Power (MW)</th>
<th>Power Value (M€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>95% O2 purity</td>
<td>ref</td>
</tr>
<tr>
<td>96.3% O2 purity</td>
<td>- 1.4 MW</td>
</tr>
<tr>
<td>ref</td>
<td>+7 M€</td>
</tr>
</tbody>
</table>

O2 Purity Optimisation Provides Added Value at no (or negative) Additional Cost
Oxy-PC CO2 Capture Reference Plant
Flue Gas Path Integration – FG Recycle, O2 Injection & RGH

**DESIGN BASIS**

- AQCS: ESP + WFGD – Flue Gas Condenser (FGC)
- Secondary Recycle after ESP & Primary after FGC
- O2 Injection after Recycle Gas Heater – standard RGH
- Operation up to max. 1.5% S in coal (design 0.6%)

**FLUE GAS PATH RECYCLE & O2 INJECTION OPTIMISATION**

- 6 Flue Gas Recycle topologies evaluated, 9 Evaluation criteria: SO2 concentration, Flue Gas & Recycle Gas Temperatures, etc.
- 3 Injection options evaluated, 6 Evaluation criteria: RGH O2 limit, O2 & Coal consumptions, etc.
- RGH: Optimization of leak rate – purging & pressurized sealing

**ESTIMATED FG RECYCLE OPTIMISATION VALUE**

<table>
<thead>
<tr>
<th></th>
<th>Net Power (MW)</th>
<th>Power Value (M€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Case ref</td>
<td></td>
<td>ref</td>
</tr>
<tr>
<td>Best Topology</td>
<td>+ 9.8 MW</td>
<td>+52 M€</td>
</tr>
</tbody>
</table>

Optimization of recirculation provides Fuel/Operation Flexibility and Power Value
**Oxy-PC CO2 Capture Reference Plant**

**Flue Gas Path Integration – Oxy-PC Boiler**

**AIR-FIRED DESIGN BASIS**

- ALSTOM USC PC Tower-type Boiler, 900 MW class
- ~700 kg/s air intake, ~3% air in-leakage

**OXY-PC BOILER**

- ALSTOM USC Oxy-PC Boiler, Same rating/size as air-fired
- Improved sealing

**ESTIMATED REDUCED AIR-INLEAKAGE INTEGRATION VALUE**

<table>
<thead>
<tr>
<th></th>
<th>Net Power (MW)</th>
<th>Power Value (M€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional sealing</td>
<td>ref</td>
<td>ref</td>
</tr>
<tr>
<td>Oxy improved sealing</td>
<td>+ 7.6 MW</td>
<td>+40 M€</td>
</tr>
</tbody>
</table>

Reduced Oxy-Boiler Air In-leakage provides High Value at Low Cost
Oxy-PC CO2 Capture Reference Plant
Flue Gas Path Integration – Gas Processing Unit

**GPU DESIGN BASIS**

- 90% CO2 Capture Rate, 110 bar CO2 product pressure
- Saline Aquifer CO2 specification (CO2 > 95%, O2 < 3% vol.)
- Vent Gas Emission: NOx < 150 mg/Nm³ (air fired basis)

**GPU FLUE GAS PATH INTEGRATION**

- Energy optimisation
- Maximized CO2 content
- Direct Cooling integration

**ESTIMATED GPU COOLING INTEGRATION VALUE**

<table>
<thead>
<tr>
<th>No cooling integration</th>
<th>GPU Power (MW)</th>
<th>Power Value (M€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPU direct cooling</td>
<td>- 4.7 MW</td>
<td>+25 M€</td>
</tr>
</tbody>
</table>

Integrated GPU Cooling provides High Value at Low Cost
Oxy-PC CO2 Capture Reference Plant
Process Heat Integration - Air Separation Unit Dryer

**DESIGN BASIS – “STAND-ALONE” ASU**

- 3 x 4400 tpd ASU trains
- Molecular sieve dryers
- Heat needed for periodic ASU Dryer regeneration
- Electrical heating,

**ASU DRYER REGENERATION INTEGRATION**

- Steam heating supply from W&S cycle

**ESTIMATED ASU PROCESS HEAT INTEGRATION VALUE**

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<tr>
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<th>NET Power (MW)</th>
<th>Power Value (M€)</th>
</tr>
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<tbody>
<tr>
<td>Electrical heating</td>
<td>ref</td>
<td></td>
</tr>
<tr>
<td>Steam Integrated heating</td>
<td>+5.1 MW</td>
<td>+27 M€</td>
</tr>
</tbody>
</table>

High Value of Dryer Heating Integration at Low Cost
Oxy-PC CO2 Capture Reference Plant
Heat Integration - Water&Steam Cycle & Flue Gas Path

Heat Integration Loop** (condensates)

W&S CYCLE HEAT INTEGRATION
- Recovery of Oxy-systems available Heat into Condensate Loop
- Reduction of LP Heaters extraction
- Increased Steam Turbine Power

4 HEAT INTEGRATION SOURCES
- ASU Main Air Compressor
- Flue Gas Condenser
- Flue Gas Heat Recovery
- GPU Flue Gas Compressor
Oxy-PC CO2 Capture Reference Plant
Heat Integration

**ASU MAIN AIR COMPRESSOR**
Axial MAC & Coil-wound HX
**Power delta**
> 8.5 MW

**FLUE GAS CONDENSER INTEGRATION**
Direct Contact Cooler after WFGD
> 1.2 MW

**FGHRS INTEGRATION IN OXY PLANT**
Flue Gas Cooling upstream WFGD
> 7.1 MW

**GPU FLUE GAS COMPRESSOR**
Axial-radial compressor
> 4.5 MW

**OPTIMIZED WATER AND STEAM CYCLE CONFIGURATION**
- Optimal cycle design, to take in account Performance, Operability, Process control and Reliability
- 7 configurations evaluated

**ESTIMATED HEAT INTEGRATION VALUE**

<table>
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<th>Total Heat Integration</th>
<th>NET Power (MW)</th>
<th>Power Value (M€)</th>
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<tr>
<td></td>
<td>+ 25.7 MW</td>
<td>136 M€</td>
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Integration Oxy Plant - T. Pourniot – IEA OCC3 – Ponferrada, Spain, 12 Sept. 2013 – slide #16
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**Oxy-PC CO2 Capture Reference Plant**

**TOTAL INTEGRATION VALUE**

### ESTIMATED TOTAL INTEGRATION VALUE

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<th>Net Power (MW)</th>
<th>Net Efficiency (%)</th>
<th>Power Value (M€)</th>
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<tr>
<td>Not Integrated Oxy</td>
<td>ref</td>
<td>ref</td>
<td>ref</td>
</tr>
<tr>
<td>High efficiency ASU</td>
<td>+13.3 MW</td>
<td>+0.7%</td>
<td>+71 M€</td>
</tr>
<tr>
<td>Integrated Flue Gas Path</td>
<td>+23.5 MW</td>
<td>+1.3%</td>
<td>+125 M€</td>
</tr>
<tr>
<td>ASU Dryer Steam Supply</td>
<td>+5.1 MW</td>
<td>+0.3%</td>
<td>+27 M€</td>
</tr>
<tr>
<td>Optimal Heat Integration</td>
<td>+25.7 MW</td>
<td>+1.4%</td>
<td>+136 M€</td>
</tr>
<tr>
<td><strong>Total Oxy Integration</strong></td>
<td>+67.7 MW</td>
<td>+3.7%</td>
<td>+359 M€</td>
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<td>37.1%</td>
<td>673 MW</td>
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Total Integration provides 3.7% pts Efficiency Improvement and High Power Value

Integrated Oxy Plant efficiency ~9% pts below Non-Capture Plant
Alstom Cost of Electricity study on CCS

13 pilots, several demo projects in development

Global supply of turnkey power plants

CCS experience

Plant Integration experience

Robust CCS-CoE study built on Alstom know-how

Key component OEM

- Independent Validation of methodology and hypothesis;
- Update of assumptions every year
Results for bituminous coal Europe LCoE (No CO₂ price)

All technologies are in the same cost range: differences will be site-specific.

Coal price = 70.9 EUR/t

Source: Alstom cost of electricity study 2013
Thank you!

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