Oxy-Coal for Electric Power Generation: Status and Prospects

David Thimsen (dthimsen@epri.com)
Senior Project Manager
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Why would an Electric Utility Consider Oxy-Coal?

Oxy-coal is only relevant to electric utilities if there is a specific cost associated with emitting CO\textsubscript{2} or value for capturing CO\textsubscript{2}. 

- CO\textsubscript{2} capture from an oxy-coal plant does not seriously impact design or operation of the steam-electric power cycle.
- Unfamiliar power plant systems (Air Separation Unit, CO\textsubscript{2} Purification Unit) employ physical processes. Components of these systems are familiar to power plant operators: rotating machinery and heat exchangers.
- No need to inventory chemicals for the absorption processes associated with pre- and post-combustion capture. No air emissions of these.

Cost-Cost-Cost will be determinative!
Preliminary Look at Comparative Costs for CO$_2$ Capture

• The most definitive comparative cost study to date was done by Worley Parsons for USDoE (2008 update) with a follow-up for GCCSI (2009).

• Three broad CO$_2$ capture options:
  – Pre-combustion CO$_2$ capture (IGCC)
  – Post-combustion CO$_2$ capture (USC steam cycle)
  – Oxy-coal with CO$_2$ purification (USC steam cycle)

• Conclusion: Oxy-coal COE and cost of avoided CO$_2$ emissions are incrementally lower than costs for either pre- or post-combustion capture.

Caveats:
• Oxy-coal COE and cost of avoided CO$_2$ emissions are sensitive to design basis CO$_2$ purity.
• Considerable oxy-coal flow sheet development has occurred since the original studies.
Oxy-Coal Technology Modules

- Air Separation Unit (ASU)
- Steam generator
- Steam turbine cycle / electrical generator
- Air Quality Control System (AQCS, including flue gas recycle)
- CO$_2$ Purification Unit (CPU)
- CO$_2$ Storage
Air Separation Unit

- Full Scale Module Capacity: 5,000 t/day
- Product O₂ Purity: 95–98%
- Delivery Pressure: 10 psig (1.7 bar), 130 psig (10 bar)

Delivery of large O₂ volumes with indicated purity at low pressure is a new wrinkle on air separation technology.
Steam Generator

- Oxy-PC Combustion
- Oxy-CFB Combustion
- Pressurized Oxy-Combustion (10 bar)

- Includes:
  - Coal preparation/feed
  - Limestone preparation/feed (for CFB)
  - Burner technology
  - O$_2$/flue gas recycle mixing
  - Steam/water heat exchange surface
  - Air/recycle heater
Air Quality Control System

• NO$_X$
  – Inherently lower than air-fired coal units; minor thermal NO$_X$ production along with reburning NO$_X$ in recycle flue gas
  – Staged combustion / low-NO$_X$ burners likely to be adequate for oxy-coal operations.
  – Polishing removal in the warm end of CPU
  – SCR (for PC) and SNCR (for CFB) may be required if air-fired operation is part of the plan.

• SO$_2$
  – Furnace limestone addition / Spray-dryer absorption (for CFB)
  – Wet FGD (for PC) May need to be put inside the recycle loop if high S coal is fired.
  – Polishing Removal in the warm end of CPU

• Particulate Matter
  – ESP
  – Fabric filter (baghouse)
CO₂ Purification Unit

- **Warm End**
  - Flue gas cooling/water wash
  - SOₓ/NOₓ removal during compression
- **Cold Box (if required)**
  - Full scale will use liquid CO₂ as the refrigerant
  - Cold box design vs. required CO₂ purity
- **Vent Gas CO₂ Recovery**
  - Membrane
  - Adsorbent
- **Pipeline compression**

*CPU design will be a strong function of design basis CO₂ purity specification.*
Scope of Full-Scale Oxy-Coal Power Plant

• Electrical Capacity: 800 MWe (gross)
  ~ 600 MWe (net)
• Thermal Input: ~ 1,800 MWth (USC steam cycle)
• ASU Capacity: ~ 11,800 t/day (3 x 4000 t/day)
• CPU Capacity: ~ 17,200 t/day (4 x 4500 t/day)

This scale is typical of the coal-fired power plants that electric utilities have purchased in the last few years.
# Commercial Pilot Plants* in Planning

<table>
<thead>
<tr>
<th>Project, Utility</th>
<th>Location</th>
<th>Electrical Output (Oxy, net)</th>
<th>In Service</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jänschwalde, Vattenfall</td>
<td>Peitz, Germany</td>
<td>250 MWe (40% full scale)</td>
<td>2015</td>
</tr>
<tr>
<td>Compostilla, Endesa</td>
<td>El Bierzo, Spain</td>
<td>300 MWe (50% full scale)</td>
<td>2015</td>
</tr>
<tr>
<td>Yong Dong, KOSEP</td>
<td>South Korea</td>
<td>100 MWe (17% full scale)</td>
<td>2018</td>
</tr>
<tr>
<td>Meredosia #4, Ameren</td>
<td>Meredosia, Illinois</td>
<td>200 MWe (33% full scale)</td>
<td>2015</td>
</tr>
</tbody>
</table>

*Commercial Pilot Plant: >25% full scale, revenue generation
Proposed Commercial Pilot Plant: 250 MWe Oxy-PC Boiler at Vattenfall Jänschwalde

Lignite Dryer → CO₂ Purification → CO₂ Compression

Oxy-PC Steam Generator → ASUs

Cost pushing €1,000 million

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# Oxy-Coal Pilot Plants* in Service or in Construction

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<th>Location</th>
<th>Thermal Output</th>
<th>ASU</th>
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</thead>
<tbody>
<tr>
<td>ITEA</td>
<td>Gioia del Colle, Italy</td>
<td>5 MWth (10%@4 bar)</td>
<td>LO$_2$</td>
<td>2006</td>
</tr>
<tr>
<td>Jupiter Oxygen</td>
<td>Hammond, IN</td>
<td>15 MWth (30% – PC)</td>
<td>(3%)</td>
<td>2006</td>
</tr>
<tr>
<td>B&amp;W</td>
<td>Alliance, OH</td>
<td>30 MWth (60% – PC)</td>
<td>LO$_2$</td>
<td>2008</td>
</tr>
<tr>
<td>Schwarze Pumpe, Vattenfall **</td>
<td>Schwarze Pumpe, Germany</td>
<td>30 MWth (60% – PC)</td>
<td>(6%)</td>
<td>2009</td>
</tr>
<tr>
<td>Oxy-Coal UK, Doosan Power</td>
<td>Renfrew, Scotland</td>
<td>40 MWth (80% – PC)</td>
<td>LO$_2$</td>
<td>2009</td>
</tr>
<tr>
<td>Alstom</td>
<td>Windsor, CT</td>
<td>15 MWth (1% – T-fired)</td>
<td>LO$_2$</td>
<td>2009</td>
</tr>
<tr>
<td>Callide A, CS Energy **</td>
<td>Biloela, Australia</td>
<td>80 MWth, 25 MWe</td>
<td>(2x8%)</td>
<td>2010</td>
</tr>
<tr>
<td>CIUDEN **</td>
<td>El Bierzo, Spain</td>
<td>20 MWth – PC (40%) 30 MWth – CFB (2%)</td>
<td>LO$_2$</td>
<td>2010 2011</td>
</tr>
<tr>
<td>Enel</td>
<td>Brindisi, Italy</td>
<td>48 MWth (100%@10 bar)</td>
<td>O$_2$ (g)</td>
<td>2012</td>
</tr>
</tbody>
</table>

* Pilot Plant: >5% full scale, little or no revenue generation

** Pilot Plants integrating a CO$_2$ Purification Unit

Numerous university process development unit - scale and flow sheet design studies are in progress
Vatenfall’s Schwarze Pumpe Oxy-PC Pilot Plant in support of Jänschwalde

Steam produced is routed to a 120 bar export line serving industries to the south.

ALSTOM Oxy-PC boiler

Air Products PDU (to remove SO\textsubscript{X}/NO\textsubscript{X} from CO\textsubscript{2}) will go here. Startup in late 2010.

Cost > €80 million

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B&W’s 30 MWth Burner Test Facility

Operations focused on combustion, heat transfer and Air Quality Control Systems
Challenges for Oxy-Coal Development and Deployment

• **Oxy-coal is only relevant to electric utilities if there is a specific cost associated with emitting CO\textsubscript{2} or value associated with capturing CO\textsubscript{2}.**

• No realistic way to do incremental development of oxy-coal with CCS. (Pre- and post-combustion CO\textsubscript{2} capture can be developed incrementally by treating flue gas slipstreams.)

• Commercial Pilot Plant projects are required to advance oxy-coal technology. Capex for these push ~$1 billion. Similar projects for pre- and post-combustion CO\textsubscript{2} capture cost half this, still significant money.

• In order for a commercial project to proceed in 2020, at least two commercial pilot plant projects need to be underway through one maintenance cycle. During these operations, significant Opex associated with CO\textsubscript{2} capture (ASU and CPU power use) is incurred.

• Refer to bullet #1 above. Absent a clear public policy that rewards CO\textsubscript{2} capture and storage, utilities are highly unlikely to incur the Capex and Opex associated with oxy-coal/CCS plants.
Improving Oxy-Coal (for Full Scale Deployment Beyond 2020)

• Achieve criteria pollutant emissions sufficient low to permit the plant as a “minor source”.

• Reduce steam generator size (cost) by reducing flue gas recycle. CFBs may be particularly suitable for this.

• Conduct oxy-coal combustion and heat transfer under ~10 atmospheres gas pressure to increase boiler efficiency (reduced latent heat losses).

• Replace the cryogenic ASU with:
  – Effusion membrane separation
  – Ion Transfer Membrane separation
  – Chemical Looping Combustion
Conclusions

• Pilot Plant activity to date has been primarily oriented to oxy-combustion component testing
  – B&W has completed a successful burner test program as have other equipment vendors.
  – Schwarze Pumpe pilot plant is underway and has achieved thousands of hours of operation
  – CIUDEN pilot plant is scheduled to start oxy-PC operation in 2010, and oxy-CFB operations in 2011
  – Callide-A plant (25 MWe) has restarted operation with air-firing of coal. Oxy-coal operations will commence late 2010 or early 2011.
• Commercial Pilot Plant operations will not commence before 2015. Four (4) projects are “on the table”, PC and CFB. All are awaiting finalization of their funding plans before receiving the “green light” to go.
• Successful operation of multiple Commercial Pilot Plants through one maintenance cycle are likely needed to pave the way for the 1st Full-Scale Commercial Plant in 2020.
• There are opportunities for improving oxy-coal technology (lower cost / higher efficiency) beyond that envisioned for commercial deployment in 2020.
Questions?

Together…Shaping the Future of Electricity

David Thimsen
(651) 766-8826
dthimsen@epri.com