Costs of Emission Control Technologies

Jim Staudt, Ph.D.
Andover Technology Partners
ICAC-MARAMA Meeting
May 18-19, 2011
What ATP Does

What ATP does

• Consulting
  • Focused on Air Pollution Control/Monitoring
• Software and licensed reports

Clients

• Government
• Facility Owners
• Equipment suppliers
• Investment Community
Current/Planned ATP Activities of Interest . . .

- Support of US EPA (CAMD, OAQPS, ORD)
- Developing Models for US EPA Industrial Sector Integrated Solutions (ISIS) Model
  - Cement, Iron & Steel, Pulp & Paper Sectors
- US EPA’s Greenhouse Gas Mitigation Options Database (G-MOD)
  - EGU’s, Cement, Iron & Steel, Pulp & Paper, Refining Sectors
Sources of Interest

• EGU’s
• ICI Boilers
• Cement Kilns
Electric Generating Units . . .

Control Technologies to Reduce Conventional and Hazardous Air Pollutants from Coal-Fired Power Plants

March 31, 2011

Report prepared with MJ Bradley and Associates
### Control Technologies / Emission Reduction

<table>
<thead>
<tr>
<th>Control Technology Emission Reduction Effect</th>
<th>( \text{SO}_2 )</th>
<th>( \text{NO}_x )</th>
<th>( \text{Mercury (Hg)} )</th>
<th>( \text{HCl} )</th>
<th>( \text{PM} )</th>
<th>( \text{CO} )</th>
<th>Dioxins/ Furans</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combustion Controls</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Selective Non-Catalytic Reduction (SNCR)</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Selective Catalytic Reduction (SCR)</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>C</td>
</tr>
<tr>
<td>Particle Matter Controls (i.e., ESP or baghouse)</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Low Sulfur Fuel</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>C</td>
</tr>
<tr>
<td>Dry Scrubber</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>C</td>
<td>N</td>
</tr>
<tr>
<td>Wet Scrubber</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>C</td>
<td>N</td>
<td>C</td>
</tr>
<tr>
<td>Dry Sorbent Injection (DSI)</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>C</td>
<td>N</td>
<td>C</td>
</tr>
<tr>
<td>Activated Carbon Injection (ACI)</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
</tr>
</tbody>
</table>

N = Technology has little or no emission reduction effect  
Y = Technology reduces emissions  
C = Technology is normally used for other pollutants, but has a co-benefit emission reduction effect  
* = When used in combination with a downstream particle matter control device, such as a baghouse
Sources of Interest

- EGU’s
- ICI Boilers
- Cement Kilns
Caveats Regarding Cost Estimates

- All cost estimates presented here, except where stated otherwise, were developed by J. Staudt
  - Using proprietary algorithms, or
  - Using algorithms developed for others (EPA), and
  - All benchmarked against independent data, and
  - Escalated to late 2009 costs, except where stated otherwise

- All cost estimates presented here, except where stated otherwise, are intended to be “typical” and are not for any specific facility.
ICI Boilers - NOx

- Combustion Controls
  - LNB
  - ULNB
  - OFA
- Post Combustion Controls
  - SNCR
  - SCR
Combustion Controls - Coal

Coal, Uncontrolled NOx
= 0.70 lb/MMBtu

- Coal LNB 50% NOx Redn
- Coal OFA 25% NOx Redn
- Coal LNB/OFA 65% NOx Redn

0.35 lb/MMBtu
0.52 lb/MMBtu
0.25 lb/MMBtu
Combustion Controls – No. 6 Fuel Oil

No. 6 Oil, Uncontrolled
NOx = 0.37 lb/MMBtu

- Oil LNB 50% NOx Redn
  0.25 lb/MMBtu
- Oil OFA 25% NOx Redn
  0.28 lb/MMBtu
- Oil LNB/OFA 65% NOx Redn
  0.13 lb/MMBtu
Combustion Controls – Natural Gas

![Graph showing the cost of natural gas emissions reduction]

- **Nat. Gas, Uncontrolled NOx = 0.20 lb/MMBtu**
- **Gas LNB 50% NOx Redn 0.10 lb/MMBtu**
- **Gas OFA 25% NOx Redn 0.15 lb/MMBtu**
- **Gas ULNB 75% NOx Redn 0.05 lb/MMBtu**
ICI Boilers - SNCR

- Applicable to most boilers
- Especially well suited to solid fuel boilers
  - Can be combined with combustion controls
- Extremely effective on CFB boilers (50%+ reduction)
SNCR – Capital Costs

Installed Capital Costs ($/MMBtu/hr)

Unit Size (MMBtu/hr)

$/MMBTU/hr  Log. ($/MMBTU/hr)

ICAC Letter to OTC, 2006
SNCR - $/ton NOx removed

ICAC Letter to OTC, 2006

Andover Technology Partners
Consulting to the Air Pollution Control Industry
Combustion Controls & SNCR

Coal, Uncontrolled NO\textsubscript{x}

\[ = 0.70 \text{ lb/MMBtu} \]

- Coal LNB 50% NO\textsubscript{x} Redn 0.35 lb/MMBtu
- Coal OFA 25% NO\textsubscript{x} Redn 0.52 lb/MMBtu
- Coal LNB/OFA 65% NO\textsubscript{x} Redn 0.25 lb/MMBtu
- Coal LNB/OFA/SNCR 75% NO\textsubscript{x} Redn 0.18 lb/MMBtu
SCR

- High Dust Systems
  - Many existing ICI boilers are tight on space where the SCR would be installed
  - Cost estimates are limited – based on “scaling” from utility projects
- “Tail End” System
  - More likely to find space
  - Actual projects to base costs on
  - Clean gas needs reheating
Regenerative SCR (RSCR)

Abrams, et. al. 2008
RSCR cost effectiveness

Cost effectiveness curve developed by J. Staudt based upon a very conservative budgetary estimate from Babcock Power

Andover Technology Partners  
Consulting to the Air Pollution Control Industry
ICI Boilers – SO$_2$

- Dry Sorbent Injection
- Dry Scrubber/FF
- Caustic Scrubber
ICI Boilers – Sorbent Injection

Diagram:
- Sorbent Storage
- Existing ESP or FF
- Stack
- Toxecon II
- Boiler
ICI Boilers – Sorbent Injection (ESP)

Assume Trona delivered price at $150/ton
ICI Boilers – Sorbent Injection (FF)

Assume Trona delivered price at $150/ton

Includes Cost of New Fabric Filter! Scaling of Utility Fabric Filter cost algorithms.
More on DSI

- Reagents – Trona, Sodium Bicarbonate, Hydrated Lime
- Reagent selection will depend upon control objective and limitations
  - SO2 control, HCl control, or SO3 control
  - Fly ash stabilization
ICI Boilers – Dry Scrubber(s)

Figures from
Babcock Power
Alstom
Babcock & Wilcox
ICI Boilers – Dry Scrubber Cost Effectiveness

Note: Costs scaled from utility projects and benchmarked against actual equipment estimates.
ICI Boilers – Caustic Scrubber(s)

Figure 2B is an equipment representation of the system shown in Configuration 2.2., consisting of a horizontal T.O., firetube boiler, quench column, acid-absorber, caustic scrubber, and integral stack.

ICI Boilers – Caustic Scrubber Cost Effectiveness

Costs shown do not include water treatment or disposal cost. Based on caustic soda at $400/ton delivered.
SO$_2$ Controls – Other Factors

- **Cobenefit controls**
  - Dry scrubber/fabric filter has high mercury, HCl and PM cobenefit capture
  - Wet scrubber has high HCl and Hg capture

- **Waste Disposal**
  - Caustic scrubbers well suited for pulp mills where sodium is reused

- **Acid Mist**
  - Wet scrubbers may promote acid mist if significant SO$_3$ is present in the gas

- **Reagent Cost**
  - Caustic prices can be volatile
Cement Kilns – NOx, SO$_2$, and HAP Controls
Cement Kilns - NOx

Averages/Medians of NOx emissions developed from 2002 NEI data – all US kilns

<table>
<thead>
<tr>
<th></th>
<th>PC</th>
<th>PH</th>
<th>Dry</th>
<th>Wet</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOx, lb/ton clinker (average)</td>
<td>3.69</td>
<td>7.06</td>
<td>8.86</td>
<td>8.40</td>
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<tr>
<td>NOx, lb/MMBtu (average)</td>
<td>1.08</td>
<td>1.78</td>
<td>1.85</td>
<td>2.07</td>
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<tr>
<td>NOx, lb/ton clinker (median)</td>
<td>3.37</td>
<td>4.68</td>
<td>7.19</td>
<td>7.71</td>
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<tr>
<td>NOx, lb/MMBtu (median)</td>
<td>0.99</td>
<td>1.27</td>
<td>1.38</td>
<td>1.99</td>
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</tbody>
</table>
Cement Kilns – SO$_2$ Emissions

Average SO$_2$ emissions (in lbs/ton clinker) by kiln type and market

Developed from 2002 NEI
Cement Kilns – Case Study

- 500,000 TPY Dry Kiln
- 7 lb/tonne clinker uncontrolled NOx
- 12 lb/tonne clinker uncontrolled SO₂
- Heat input 4.75 million Btu/tonne
Cement Kilns - NOx

- Combustion Controls
  - Low NOx Burners
  - Mid Kiln Firing
- Post Combustion Controls
  - SNCR
  - SCR*
- Fuel Switching
  - Coal produces lower NOx than natural gas

* Experience with SCR on cement kilns is fairly limited
## Cement Kilns – Case Study NOx

<table>
<thead>
<tr>
<th></th>
<th>Low NOx Burner/Ind Firing</th>
<th>Mid Kiln Firing</th>
<th>LNB w/ mid kiln firing</th>
<th>SNCR</th>
<th>SNCR + LNB/Ind Firing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital (USD)</td>
<td>1,404,606</td>
<td>4,833,663</td>
<td>6,238,269</td>
<td>1,191,393</td>
<td>2,595,999</td>
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<tr>
<td>Annual (USD)</td>
<td>269,891</td>
<td>784,249</td>
<td>1,054,140</td>
<td>515,576</td>
<td>646,633</td>
</tr>
<tr>
<td>Uncontrolled NOx, TPY</td>
<td>1,575</td>
<td>1,575</td>
<td>1,575</td>
<td>1,575</td>
<td>1,575</td>
</tr>
<tr>
<td>TPY Removed</td>
<td>788</td>
<td>473</td>
<td>1,024</td>
<td>473</td>
<td>1,024</td>
</tr>
<tr>
<td>$/ton</td>
<td>$343</td>
<td>$1,660</td>
<td>$1,030</td>
<td>$1,091</td>
<td>$632</td>
</tr>
</tbody>
</table>
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<th></th>
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<tr>
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</tr>
<tr>
<td><strong>Uncontrolled NOx, TPY</strong></td>
<td>1,575</td>
<td>1,575</td>
<td>1,575</td>
<td>1,575</td>
<td>1,575</td>
</tr>
<tr>
<td><strong>TPY Removed</strong></td>
<td>788</td>
<td>473</td>
<td>1,024</td>
<td>473</td>
<td>1,024</td>
</tr>
<tr>
<td><strong>$/ton</strong></td>
<td>$343</td>
<td>$1,660</td>
<td>$1,030</td>
<td>$1,091</td>
<td>$632</td>
</tr>
</tbody>
</table>

Not factoring in tipping fee from tires
## Cement Kilns – Case Study NOx

<table>
<thead>
<tr>
<th></th>
<th>Low NOx Burner/Ind Firing</th>
<th>SCR</th>
<th>LNB/Ind Firing + SCR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Capital</strong></td>
<td>1,404,606</td>
<td>$5,171,528</td>
<td>$6,576,134</td>
</tr>
<tr>
<td><strong>Annual</strong></td>
<td>269,891</td>
<td>$1,663,140</td>
<td>$1,750,565</td>
</tr>
<tr>
<td><strong>Uncontrolled NOx</strong></td>
<td>1,575</td>
<td>1,575</td>
<td>1,575</td>
</tr>
<tr>
<td><strong>Tons Removed</strong></td>
<td>788</td>
<td>1,260</td>
<td>1,418</td>
</tr>
<tr>
<td><strong>$/ton</strong></td>
<td>$343</td>
<td>$1,320</td>
<td>$1,235</td>
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</tbody>
</table>
Cement Kilns – SO$_2$ Emissions

- **SO$_2$ Emissions primarily determined by**
  - Kiln type
  - Raw material composition
- **Less affected by fuel sulfur**
  - Fuel changes have limited impact
Cement Kilns – SO$_2$ Control Options

- In Line Raw Mill
- Dry Lime Injection
- Lime Dry Scrubber
- Limestone Wet Scrubber
Cement Kilns – Scrubbers

- Limited data on scrubber retrofit costs
  - Only a few actual scrubbers in cement industry
  - Many on new facilities
  - Very reliant on industry BACT/BART estimates
## Cement Kiln Case Study – Wet Scrubber Cost

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncontrolled SO₂, TPY</td>
<td>3,000</td>
</tr>
<tr>
<td>Capital Cost of Scrubber</td>
<td>$13,952,308</td>
</tr>
<tr>
<td>Annual Cost</td>
<td>$2,449,786</td>
</tr>
<tr>
<td>SO₂ Removed, TPY</td>
<td>2,850</td>
</tr>
<tr>
<td>$/ton removed</td>
<td>$860</td>
</tr>
</tbody>
</table>
Many facilities looking to retrofit baghouses and perhaps ACI for MACT compliance

Enables separation of CKD from activated carbon
Questions?

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