Increases in NO\textsubscript{x} Emissions in Coal-Fired, SCR-Equipped Electric Generating Units

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January 14, 2015
Increases in NO$_x$ Emissions in Coal-Fired, SCR-Equipped Electric Generating Units

- Clean Air Act Amendments (1990)
  - NO$_x$ RACT
  - OTC NO$_x$ Budget Program (1999)
    - Northeast, Mid-Atlantic States
  - “NO$_x$ SIP Call” NO$_x$ Budget Program (2003-04)
    - 20 Eastern States
  - CAIR (2009)
  - CSAPR (2012.....)
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  – OTC $\text{NO}_x$ Budget Program (1999)
    • Northeast, Mid-Atlantic States
  – “$\text{NO}_x$ SIP Call” $\text{NO}_x$ Budget Program (2003-04)
    • 20 Eastern States
  – CAIR (2009)
  – CSAPR (2015.....)
What has been Happening?
What is NO$_x$?

- Oxides of Nitrogen

$$\text{N}_2 + \text{O}_2 \rightarrow \text{NO, NO}_2$$
What is NO\textsubscript{x}?  

- Oxides of Nitrogen

\[ \text{N}_2 + \text{O}_2 \rightarrow \text{NO}, \text{NO}_2 \]
Why is NO\textsubscript{x} a Concern?

Ozone formation

**Sunlight**

\(\text{Oxygen (O}_2\) + Volatile Organic Compounds (VOC) + Nitrogen Oxides (NO}_x\) \rightarrow \text{Ozone (O}_3)\)
What has been Happening?

• Hundreds of coal-fired EGUs have installed SCR
Selective Catalytic Reduction (SCR)

\[ \text{NO}_x + \text{NH}_3 \rightarrow \text{catalyst} \rightarrow \text{N}_2 + \text{H}_2\text{O} \]

TiO\textsubscript{2}, V\textsubscript{2}O\textsubscript{5}, WO\textsubscript{3},
Pt, Pd, zeolites

350° - ~1,100 °F

> 90% reduction
Coal-Fired EGUs in Eastern US
OTC Modeling Domain
CSAPR States

- States controlled for both fine particles (annual SO₂ and NOₓ) and ozone (ozone season NOₓ) (20 States)
- States controlled for fine particles only (annual SO₂ and NOₓ) (3 States)
- States controlled for ozone only (ozone season NOₓ) (5 States)
- States not covered by the Cross-State Air Pollution Rule
Eastern Half of US
2014 Ozone Season Excess $\text{NO}_x$ in Top 25 Emitters

- OTC Domain $\rightarrow$ 37,750 tons
- CAIR States $\rightarrow$ 36,626 tons
- CSAPR States $\rightarrow$ 32,403 tons
What has been Happening?

- Hundreds of coal boilers have installed SCR
- Emission rates fell dramatically 2003-09
Ozone Season NO$_x$ Emission Rates of SCR-Equipped Coal-Fired EGUs in Eastern US with Number of Units.
What has been Happening?

• Hundred of coal boilers have installed SCR

• Emission rates fell dramatically 2003-09

• Emission Rates began increasing after 2009
Ozone Season NO$_x$ Emission Rates of SCR-Equipped Coal-Fired EGUs in Eastern US with Number of Units.
2013 Ozone Season

• Top 200 Boilers = 66% of NO$_x$
  – 198 Coal-fired EGUs
  – 79 SCR Equipped
  • Best Observed Rate (BOR), lb/mmBTU
    – ≈68%, 2013 Emission Rate > BOR
    – Ratio (79 Units): 1.0 – 9.2, Mean = 3.3
Ozone Season NOₓ Emission Rates of Coal-Fired Units in OTC Modeling Domain with Reduced SCR Operations within the 2013 Top 200 Emitters.
Ozone Season NO\textsubscript{x} Emission Rates of Coal-Fired Units in OTC Modeling Domain with Reduced SCR Operations within the 2013 Top 200 Emitters.
What Happened?

• Collapse of CAIR allowance costs
    • Oversupply of allowances
    • Market uncertainty
  – Less than forecast electric demand
Total US Annual Electrical Generation.
What Happened?

• Collapse of allowance costs
    • Oversupply of allowances
    • Market uncertainty

• Less than forecast electric demand
  – 2008-13 Top 200 NO$_x$ emitters, GLOAD -1.7%

• Increased gas-fired generation
Increased gas-fired generation
Percentage of Total US Annual Electrical Generation by Fuel Type
What Happened?

• Oversupply of allowances
  • $4,600/ton January 2009, $51/ton October 2012
    • Oversupply of allowances
    • Market uncertainty

• Less than forecast electric demand
  – 2008-13 Top 200 NO\textsubscript{x} emitters, GLOAD -1.7%

• Increased gas-fired generation
  – April 2012, Coal = Gas = 32%
Gas Got Cheap

U.S. Natural Gas Electric Power Price

Dollars per Thousand Cubic Feet

Source: U.S. Energy Information Administration
What’s Driving Gas Pricing?

U.S. Shale Production

Source: U.S. Energy Information Administration
What’s Driving Gas Pricing?

U.S. Shale Production

Billion Cubic Feet

Source: U.S. Energy Information Administration
Total Monthly Average Ozone Season Allowance Costs at 3.0 lb NO$_x$ / MWh, Monthly Average Natural Gas Electrical Generation Costs, "53 SCR Boiler" Average Ozone Season Emission Rates.
Gas Got Very Competitive

U.S. Natural Gas Electric Power Price

Dollars per Thousand Cubic Feet

Source: U.S. Energy Information Administration
Total Monthly Average Ozone Season Allowance Costs at 3.0 lb NO\textsubscript{x} / MWh, Monthly Average Natural Gas Electrical Generation Costs, "53 SCR Boiler" Average Ozone Season Emission Rates.
CAIR-region States with Representative Low and High Average NO\textsubscript{X} Emission Rates, (lb/mmBTU), of SCR-Equipped Coal-Fired EGUs in the 2013 Ozone Season.

<table>
<thead>
<tr>
<th>Low</th>
<th>Alabama</th>
<th>Arkansas</th>
<th>Georgia</th>
<th>Maryland</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.077</td>
<td>0.068</td>
<td>0.061</td>
<td>0.074</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>High</th>
<th>Missouri</th>
<th>New Hampshire</th>
<th>New York</th>
<th>Pennsylvania</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.376</td>
<td>0.274</td>
<td>0.323</td>
<td>0.247</td>
</tr>
</tbody>
</table>

Average 2013 Ozone Season NO\textsubscript{X} Emission Rates, (lb/mmBTU), of SCR-Equipped Coal-Fired EGUs in Western States that are not in the CAIR Cap and Trade Program.

<table>
<thead>
<tr>
<th>Arizona</th>
<th>Colorado</th>
<th>Kansas</th>
<th>Montana</th>
<th>Nevada</th>
<th>Texas</th>
<th>Wyoming</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.076</td>
<td>0.067</td>
<td>0.087</td>
<td>0.079</td>
<td>0.064</td>
<td>0.056</td>
<td>0.057</td>
</tr>
</tbody>
</table>
Reduced, “Sub-Optimal” SCR Operation

NO\textsubscript{x} Emission Rates, lb/mmBTU

<table>
<thead>
<tr>
<th>Plant Location</th>
<th>Best Year</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>PA</td>
<td>0.044 (2003)</td>
<td>0.113</td>
<td>0.212</td>
<td>0.316</td>
<td>0.414</td>
<td>0.424</td>
</tr>
<tr>
<td>MO</td>
<td>0.090 (2009)</td>
<td>0.090</td>
<td>0.108</td>
<td>0.230</td>
<td>0.627</td>
<td>0.609</td>
</tr>
<tr>
<td>KY</td>
<td>0.123 (2006)</td>
<td>0.127</td>
<td>0.320</td>
<td>0.307</td>
<td>0.349</td>
<td>0.812</td>
</tr>
<tr>
<td>WV</td>
<td>0.071 (2004)</td>
<td>0.080</td>
<td>0.260</td>
<td>0.206</td>
<td>0.304</td>
<td>0.300</td>
</tr>
<tr>
<td>NC</td>
<td>0.070 (2004)</td>
<td>0.132</td>
<td>0.104</td>
<td>0.116</td>
<td>0.243</td>
<td>0.247</td>
</tr>
<tr>
<td>IL</td>
<td>0.071 (2004)</td>
<td>0.127</td>
<td>0.124</td>
<td>0.137</td>
<td>0.214</td>
<td>0.245</td>
</tr>
</tbody>
</table>
Reduced, “Sub-Optimal” SCR Operation?

Seasonal Emission Rates of Particular Units with Increasing NO\textsubscript{x} Emissions
Numbers of SCR-Equipped EGUs in Top 25, 50, and 100 NO\textsubscript{x} Emitters in CAIR States

<table>
<thead>
<tr>
<th>Ozone Season</th>
<th>Top 25</th>
<th>Top 50</th>
<th>Top 100</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>2009</td>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>2010</td>
<td>5</td>
<td>10</td>
<td>28</td>
</tr>
<tr>
<td>2011</td>
<td>7</td>
<td>14</td>
<td>34</td>
</tr>
<tr>
<td>2012</td>
<td>12</td>
<td>20</td>
<td>44</td>
</tr>
<tr>
<td>2013</td>
<td>11</td>
<td>24</td>
<td>42</td>
</tr>
<tr>
<td>2014</td>
<td>14</td>
<td>28</td>
<td>49</td>
</tr>
</tbody>
</table>
NJ EGU Ozone Season NO$_x$ Emissions
OH EGU Ozone Season NO$_x$ Emissions

- 2008: 55,000 tons
- 2009: 37,000 tons
- 2010: 49,000 tons
- 2011: 45,000 tons
- 2012: 40,000 tons
- 2013: 37,000 tons
MD EGU Ozone Season NO\textsubscript{x} Emissions

NO\textsubscript{x} (tons)
MO EGU Ozone Season NO\textsubscript{x} Emissions

<table>
<thead>
<tr>
<th>Year</th>
<th>NO\textsubscript{x} (tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>35,000</td>
</tr>
<tr>
<td>2009</td>
<td>20,000</td>
</tr>
<tr>
<td>2010</td>
<td>25,000</td>
</tr>
<tr>
<td>2011</td>
<td>27,000</td>
</tr>
<tr>
<td>2012</td>
<td>34,000</td>
</tr>
<tr>
<td>2013</td>
<td>32,000</td>
</tr>
</tbody>
</table>
Ozone Season NO$_x$ Emission Rates of PA Coal-Fired EGUs with SCR

Year


lbs/mmBTU

OTC Program

"NOx SIP Call" Program

CAIR Program

Program
Actual Pennsylvania Statewide Ozone Season EGU NO\textsubscript{x} Emissions as Compared with Emissions at Optimal Rates of SCR-Equipped Coal Plants

![Graph showing NO\textsubscript{x} emissions from 2003 to 2014, comparing actual emissions and emissions at optimal SCR rates.](image-url)
Total Excess NO$_x$ Emissions (tons) from Coal-Fired SCR-Equipped EGUs in 2013 Top 200 Emitters in Eastern US

<table>
<thead>
<tr>
<th></th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>27,600</td>
<td>41,100</td>
<td>59,000</td>
<td>61,500</td>
<td>66,700</td>
</tr>
</tbody>
</table>

Total = 255,900 tons
Increases in $\text{NO}_x$ Emissions in Coal-Fired, SCR-Equipped Electric Generating Units

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