Shenandoah Group
Contribution Assessment

Draft May 29, 2007
Mountain Class I Areas

Area of Influence
Groupings
1. GRSM (5)
2. MACA
3. SHEN (4)
4. SIPS
5. SWAN
6. BRIG
7. MING (4)
Objectives

- Pollutant Contributions: 2000-2004 20% Best and Worst Days
- New IMPROVE equation
  - Natural Background Calculations
- Glidepath and Progress in 2018
- Emissions Sensitivities
- Areas of Influence
  - Back Trajectory, Residence Time
  - Source Sector Emissions
  - List of Contributing Sources (states to supply)
Average Extinction for 20% Worst Days
New IMPROVE Algorithm (nia)
2000-2004
Average Extinction for 20% Best Days
New IMPROVE Algorithm (nia)

2000-2004

Extinction (Mm⁻¹)

Sea Salt
CM
Soil
EC
POM
Amm NO₃
Amm SO₄
Rayleigh

VISTAS coastal
VISTAS inland
non-VISTAS
2000-2004 Reconstructed Extinction
New IMPROVE Algorithm
20% Worst Days
Shenandoah, VA

Sea Salt
CM
Soil
LAC
POM
Amm NO3
Amm SO4
Rayleigh
2000-2004 Reconstructed Extinction
New IMPROVE Algorithm
20% Best Days
Shenandoah, VA
2000-2004 Reconstructed Extinction
New IMPROVE Algorithm
20% Worst Days
James River Face, VA
2000-2004 Reconstructed Extinction
New IMPROVE Algorithm
20% Best Days
James River Face, VA
Dolly Sods and Otter Creek Wilderness Areas share an IMPROVE monitor.
2000-2004 Reconstructed Extinction
New IMPROVE Algorithm
20% Worst Days
Dolly Sods, WV

[Graph depicting the reconstructed extinction levels from 2000 to 2004 for various sources including Sea Salt, CM, Soil, LAC, POM, Amm NO3, Amm SO4, and Rayleigh, showing the worst days highlighted in blue.]

Extinction (Mm⁻¹)
Conclusions: Contributions

- On 20% Worst Days
  - SO4 dominates light extinction
  - Organic carbon generally second largest contribution; fire indicated on few days
  - NO3 contribution comparatively small
- SO4 also dominates 20% Best Days
- Conclude: Focus on reducing SO2 emissions
New IMPROVE Equation

- Endorsed by IMPROVE Steering Committee as accounting for latest science
  - Defines two terms each for SO4, NO3, and OC with higher extinction efficiencies ($b_{\text{ext}}$) associated with high mass and lower $b_{\text{ext}}$ associated with low mass
  - Increases mass multiplier for organic carbon from 1.4 to 1.8
  - Adds term for fine mass sea salt
  - Adds term for absorption due to NO2 (only if NO2 measurements available)
  - Calculates site specific Rayleigh scattering
New IMPROVE Equation

- Light scattering measured by nephelometer and calculated using new IMPROVE equation show good correlation.
  - Original equation under estimated scattering on highest days and over estimated scattering on lowest days.
- New equation generally indicates higher extinction on 20% worst days and lower extinction on 20% best days.
Aerosol Scattering vs. Nephelometer Scattering
Using New or Old IMPROVE Algorithm and Daily f(RH)
Shenandoah, VA 1996 - 2004

New IMPROVE

\[ y = 1.04x + 6.27 \]
\[ R^2 = 0.79 \]

Old IMPROVE

\[ y = 0.80x + 13.76 \]
\[ R^2 = 0.81 \]
Aerosol Scattering vs. Nephelometer Scattering Using New or Old IMPROVE Algorithm and Daily f(RH) James River Face, VA 2000 - 2004

**New IMPROVE**

\[ y = 1.09x + 10.32 \]

\[ R^2 = 0.85 \]

**Old IMPROVE**

\[ y = 0.83x + 16.60 \]

\[ R^2 = 0.86 \]
Tombach reviewed for VISTAS the original assumptions by Trojonis et al. 1990 used to define natural background levels of visibility impairing pollutants and recent scientific developments. He also made recommendations for changes in assumptions. (Tombach and Brewer, 2005)

Hand and Malm (2005) reviewed assumptions for calculating light extinction in the original IMPROVE equation and made recommendations for revisions.

The IMPROVE Steering Committee reviewed and approved new equation for calculating light extinction (2005).

Ames (2006) reviewed methods to project natural background levels for 20% worst visibility days using the new IMPROVE equation and IMPROVE approved revised methods

Revised glide paths calculated for reaching natural background conditions at Class I areas by 2064.
Natural Conditions

Left = Default Natural Conditions; Center = New IMPROVE Algorithm; Right = W20 with New IMPROVE Algorithm
Shenandoah Glide Path to Natural Conditions (2004-2064)
(5-yr Rolling Average for 20% Haziest Days - New IMPROVE equation and NB II)

Deciviews (dv)

- Default Glide Path SHEN
- New Glide Path SHEN
- Default 5-yr Rolling Avg SHEN
- New 5-yr Rolling Avg SHEN
- Annual g90 - Old
- Annual g90 - New

Base old | Base new | Default NB | NB2
Shenandoah NP | 27.9 | 29.3 | 11.38 dv | 11.4 dv
Dolly Sods Glide Path to Natural Conditions (2004-2064)
(5-yr Rolling Average for 20% Haziest Days - New IMPROVE equation and NB II)

Deciviews (dv)

Default Glide Path DOSO
New Glide Path DOSO
Default 5-yr Rolling Avg DOSO
New 5-yr Rolling Avg DOSO
Annual g90 - Old
Annual g90 - New

<table>
<thead>
<tr>
<th>Base old</th>
<th>Base new</th>
<th>Default NB</th>
<th>NB2</th>
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<tr>
<td>Dolly Sods WA</td>
<td>27.6</td>
<td>29.0</td>
<td>11.38 dv</td>
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</table>
CMAQ Air Quality Model 2018 Run
- Accounts for Clean Air Interstate Rule (utility controls)
- Does not include controls for BART (Best Available Retrofit Technology)
- VISTAS states inventories as of Feb 2007
- Inventories for neighboring states effective Aug 2006
Model Performance 20% Haziest Days in 2002
Observations (left) vs Modeled Base G2a (right)
Shenandoah, VA

Julian Day in Worst 20% group

bEXT (1/Mm)

bCM
bSOIL
bEC
bOC
bNO3
bSO4
Modeled Responses to 2018 Base G2a Emissions on 20% Haziest Days
Shenandoah, VA

![Chart showing modeled responses to 2018 base G2a emissions on 20% haziest days. The chart displays the difference in BeXt (1/MM) for various pollutants over Julian days.](image-url)
Uniform Rate of Progress Glide Path (Base G2a projections)

Shenandoah - 20% Worst Days

New IMPROVE equation

Uniform rate of progress = 4.2 dv by 2018
Visibility at Shenandoah on 20% Haziest Days
Visibility at Shenandoah – Natural Conditions
Model Performance 20% Haziest Days in 2002
Observations (left) vs Modeled Base G2a (right)
James River Face, VA
Modeled Responses to 2018 Base G2a Emissions on 20% Haziest Days

James River Face, VA
Uniform Rate of Progress Glide Path (Base G2a projections)
James River Face - 20% Worst Days

New IMPROVE equation

Uniform rate of progress = 4.2 dv by 2018
Modeled Responses to 2018 Base G2a Emissions on 20% Haziest Days
Dolly Sods, WV
Uniform Rate of Progress Glide Path (Base G2a projections)

Dolly Sods - 20% Data Days

New IMPROVE equation

Rate of progress for Otter Creek is same as rate of progress for Dolly Sods
VI STAS Source Sector Emissions Sensitivities (Delivered Jan 2006)

- Evaluated responses to emissions reductions for specific pollutants and source sectors
- Greatest visibility improvement from further reducing SO2 emissions from utilities and industries
Shenandoah, VA (20% Worst Days)

\[ \Delta B_{\text{ext}} \text{ (Mm}^{-1}) \]

-16.00
-14.00
-12.00
-10.00
-8.00
-6.00
-4.00
-2.00
0.00
2.00

SO\textsubscript{2} EGU
SO\textsubscript{2} nonEGU
NO\textsubscript{x} Ground
NO\textsubscript{x} Point
NH\textsubscript{3}
VOCs
PC Ground
PC Point
PC Fires

- Bio.
- Antro.
- BCs
- MRPO
- M-VU
- CEN
- VISTAS
- WV
- VA
- TN
- NC
- MS
- KY
- GA
- FL
- AL
James River Face, VA (20% Worst Days)

ΔB_{ext} (Mm^{-1})

-18.00
-16.00
-14.00
-12.00
-10.00
-8.00
-6.00
-4.00
-2.00
0.00
2.00

SO2_EGU
SO2_nonEGU
NOx_Ground
NOx_Point
NH3
VOCs
PC_Ground
PC_Point
PC_Fires

Bio.
Antro.
BCs
MRPO
M-VU
CEN
VISTAS
WV
VA
TN
SC
NC
MS
KY
GA
FL
AL
Emissions sensitivities for Otter Creek are the same as for Dolly Sods.
Conclusion: Source Sector Emissions Sensitivities

- Reductions in SO2 emissions from EGU and non-EGU show largest improvements in visibility
  - WV largest contributor
  - SO2 from KY, VA, MRPO, MANE-VU, and Boundary Conditions (outside VISTAS 12 km domain) also contribute

- Small benefits from reducing NOx, anthropogenic VOC or primary carbon
VI STAS Geographic Areas of Influence

- Hysplit model used to generate back trajectories for Class I areas (Air Resource Specialists)
  - Back trajectories for individual 20% worst days in 2002
    - Helpful for evaluating model performance in 2002
  - Residence time plots for 20% worst days in 2000-2004 indicate probable contribution
    - Helpful to understand geographic area most likely to influence Class I areas
- SO2 Area of Influence defined from residence weighted by SO4 extinction and considering SO2 emissions
Residence Time for 20% Worst Days in 2000-2004

Shenandoah, VA
SO2 Area of Influence for Shenandoah, VA

Green circles indicate 100-km and 200-km radii from Class I area. Red line perimeter indicate Area of Influence with Residence Time > 10%. Orange line perimeter indicate Area of Influence with Residence Time ≥ 5%.
Green circles indicate 100-km and 200-km radii from Class I area. Red line perimeter indicate Area of Influence with Residence Time ≥ 10%. Orange line perimeter indicate Area of Influence with Residence Time ≥ 5%.
Residence Time for 20% Worst Days in 2000-2004

James River Face, VA
SO2 Area of Influence for James River Face, VA

Green circles indicate 100-km and 200-km radii from Class I area.
Red line perimeter indicate Area of Influence with Residence Time $> 10\%$
Orange line perimeter indicate Area of Influence with Residence Time $> 5\%$.
2018 SO2 Emissions weighted by Residence Time
James River Face, VA

Green circles indicate 100-km and 200-km radii from Class I area. Red line perimeter indicate Area of Influence with Residence Time ≥ 10%. Orange line perimeter indicate Area of Influence with Residence Time ≥ 5%.
Residence Time for 20% Worst Days in 2000-2004

Dolly Sods, WV
SO2 Area of Influence for Dolly Sods, WV

Green circles indicate 100-km and 200-km radii from Class I area.
Red line perimeter indicate Area of Influence with Residence Time \(>10\%\)
Orange line perimeter indicate Area of Influence with Residence Time \(\geq 5\%\).
2018 SO2 Emissions weighted by Residence Time
Dolly Sods, WV

Green circles indicate 100-km and 200-km radii from Class I area.
Red line perimeter indicate Area of Influence with Residence Time ≥ 10%.
Orange line perimeter indicate Area of Influence with Residence Time ≥ 5%.
Reasonable Progress Analysis

- States consider 4 Statutory Factors to determine what controls are reasonable:
  - Costs of Compliance
  - Time to Comply
  - Remaining Useful Life
  - Energy and Other Environmental and Impacts
## Annual 2018 BaseG2 Emissions (%) Within Area of Influence
### Shenandoah, VA

<table>
<thead>
<tr>
<th>Tier</th>
<th>VOC</th>
<th>NOX</th>
<th>CO</th>
<th>SO2</th>
<th>PM-10</th>
<th>PM-2.5</th>
<th>NH3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Comb. Elec. Util.</td>
<td>1%</td>
<td>26%</td>
<td>1%</td>
<td>53%</td>
<td>14%</td>
<td>25%</td>
<td>1%</td>
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<tr>
<td>Fuel Comb. Industrial</td>
<td>1%</td>
<td>17%</td>
<td>2%</td>
<td>28%</td>
<td>5%</td>
<td>6%</td>
<td>0%</td>
</tr>
<tr>
<td>Fuel Comb. Other</td>
<td>7%</td>
<td>9%</td>
<td>4%</td>
<td>6%</td>
<td>7%</td>
<td>14%</td>
<td>1%</td>
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<tr>
<td>Chemical &amp; Allied Product Mfg</td>
<td>2%</td>
<td>1%</td>
<td>1%</td>
<td>2%</td>
<td>1%</td>
<td>1%</td>
<td>1%</td>
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<tr>
<td>Metals Processing</td>
<td>1%</td>
<td>2%</td>
<td>4%</td>
<td>4%</td>
<td>3%</td>
<td>6%</td>
<td>0%</td>
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<tr>
<td>Petroleum &amp; Related Industries</td>
<td>1%</td>
<td>0%</td>
<td>0%</td>
<td>2%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Other Industrial Processes</td>
<td>3%</td>
<td>6%</td>
<td>0%</td>
<td>5%</td>
<td>9%</td>
<td>10%</td>
<td>1%</td>
</tr>
<tr>
<td>Solvent Utilization</td>
<td>39%</td>
<td>1%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>1%</td>
<td>0%</td>
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<tr>
<td>Storage &amp; Transport</td>
<td>6%</td>
<td>0%</td>
<td>1%</td>
<td>0%</td>
<td>1%</td>
<td>1%</td>
<td>0%</td>
</tr>
<tr>
<td>Waste Disposal &amp; Recycling</td>
<td>4%</td>
<td>2%</td>
<td>3%</td>
<td>0%</td>
<td>4%</td>
<td>9%</td>
<td>0%</td>
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<tr>
<td>Highway Vehicles</td>
<td>19%</td>
<td>20%</td>
<td>45%</td>
<td>0%</td>
<td>2%</td>
<td>2%</td>
<td>10%</td>
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<tr>
<td>Off-highway</td>
<td>16%</td>
<td>18%</td>
<td>37%</td>
<td>1%</td>
<td>3%</td>
<td>7%</td>
<td>0%</td>
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<td>Miscellaneous</td>
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<td>0%</td>
<td>1%</td>
<td>0%</td>
<td>50%</td>
<td>18%</td>
<td>85%</td>
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</tbody>
</table>

**VISTAS Total**

<table>
<thead>
<tr>
<th></th>
<th>100%</th>
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## Annual 2018 BaseG2 Emissions (%) Within Area of Influence
Shenandoah, VA

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<td>51%</td>
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<tr>
<td>Fuel Comb. Elec. Util.-Oil</td>
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<td>0%</td>
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<tr>
<td>Fuel Comb. Elec. Util.-Other</td>
<td>0%</td>
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<tr>
<td>Fuel Comb. Elec. Util.-Internal Combustion</td>
<td>1%</td>
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<tr>
<td>Fuel Comb. Industrial-Coal</td>
<td>22%</td>
</tr>
<tr>
<td>Fuel Comb. Industrial-Oil</td>
<td>3%</td>
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<tr>
<td>Fuel Comb. Other-Commercial/Institutional Coal</td>
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<tr>
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<td>0%</td>
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<td>Fuel Comb. Other-Misc. Fuel Comb. (Except Residential)</td>
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<td>Fuel Comb. Other-Residential Wood</td>
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James River Face, VA

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<tr>
<td><strong>VISTAS Total</strong></td>
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<td>Fuel Comb. Elec. Util.</td>
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<td>25%</td>
<td>1%</td>
<td>53%</td>
<td>15%</td>
<td>26%</td>
<td>1%</td>
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<td>5%</td>
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<tr>
<td>Fuel Comb. Other</td>
<td>6%</td>
<td>8%</td>
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<td>6%</td>
<td>7%</td>
<td>14%</td>
<td>1%</td>
</tr>
<tr>
<td>Chemical &amp; Allied Product Mfg</td>
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<tr>
<td>Metals Processing</td>
<td>1%</td>
<td>2%</td>
<td>5%</td>
<td>4%</td>
<td>3%</td>
<td>6%</td>
<td>0%</td>
</tr>
<tr>
<td>Petroleum &amp; Related Industries</td>
<td>0%</td>
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<td>0%</td>
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<td>0%</td>
<td>0%</td>
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</tr>
<tr>
<td>Other Industrial Processes</td>
<td>4%</td>
<td>6%</td>
<td>0%</td>
<td>5%</td>
<td>9%</td>
<td>11%</td>
<td>1%</td>
</tr>
<tr>
<td>Solvent Utilization</td>
<td>41%</td>
<td>1%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>1%</td>
<td>0%</td>
</tr>
<tr>
<td>Storage &amp; Transport</td>
<td>6%</td>
<td>0%</td>
<td>1%</td>
<td>0%</td>
<td>1%</td>
<td>1%</td>
<td>0%</td>
</tr>
<tr>
<td>Waste Disposal &amp; Recycling</td>
<td>4%</td>
<td>2%</td>
<td>3%</td>
<td>0%</td>
<td>4%</td>
<td>9%</td>
<td>0%</td>
</tr>
<tr>
<td>Highway Vehicles</td>
<td>19%</td>
<td>21%</td>
<td>47%</td>
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<td>2%</td>
<td>13%</td>
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<tr>
<td>Off-highway</td>
<td>14%</td>
<td>17%</td>
<td>36%</td>
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<td>5%</td>
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<tr>
<td>Miscellaneous</td>
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<td>0%</td>
<td>2%</td>
<td>0%</td>
<td>52%</td>
<td>20%</td>
<td>81%</td>
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<tr>
<td><strong>VISTAS Total</strong></td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
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<td>100%</td>
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</tbody>
</table>
Annual 2018 BaseG2 Emissions (%) Within Area of Influence
Dolly Sods, WV

<table>
<thead>
<tr>
<th>Tier</th>
<th>SO2</th>
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<tbody>
<tr>
<td>Fuel Comb. Elec. Util.-Coal</td>
<td>52%</td>
</tr>
<tr>
<td>Fuel Comb. Elec. Util.-Oil</td>
<td>1%</td>
</tr>
<tr>
<td>Fuel Comb. Elec. Util.-Gas</td>
<td>0%</td>
</tr>
<tr>
<td>Fuel Comb. Elec. Util.-Other</td>
<td>0%</td>
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<tr>
<td>Fuel Comb. Elec. Util.-Internal Combustion</td>
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<tr>
<td>Fuel Comb. Industrial-Coal</td>
<td>23%</td>
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<tr>
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<tr>
<td>Fuel Comb. Industrial-Gas</td>
<td>1%</td>
</tr>
<tr>
<td>Fuel Comb. Industrial-Other</td>
<td>0%</td>
</tr>
<tr>
<td>Fuel Comb. Industrial-Internal Combustion</td>
<td>0%</td>
</tr>
<tr>
<td>Fuel Comb. Other-Commercial/Institutional Coal</td>
<td>3%</td>
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<tr>
<td>Fuel Comb. Other-Commercial/Institutional Oil</td>
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<tr>
<td>Fuel Comb. Other-Commercial/Institutional Gas</td>
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<tr>
<td>Fuel Comb. Other-Misc. Fuel Comb. (Except Residential)</td>
<td>0%</td>
</tr>
<tr>
<td>Fuel Comb. Other-Residential Wood</td>
<td>0%</td>
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<tr>
<td>Fuel Comb. Other-Residential Other</td>
<td>2%</td>
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</table>
4 Statutory Factors

- For Utilities and Industrial Boilers
  - Switch to fuel with lower sulfur content
    - Coal or Oil
  - Post-combustion controls
    - Flue Gas Desulfurization
- Modification trigger PSD review?
4 Statutory Factors (continued)

Costs of Compliance

- Fuel switch for coal or oil
  - May have to blend low S fuel to maintain boiler performance
  - Price difference for lower S fuel
  - Cost of boiler modifications for lower S fuel
  - <$1000/ton
4 Statutory Factors (continued)

- Costs of Compliance
  - Flue Gas Desulfurization
    - Construction costs: absorber tower, sorbent, waste handling facility
    - Operational and maintenance costs
    - Costs per ton vary with boiler size, type, facility
    - Utility costs range $1,000 - $5,000/ton
    - Industrial costs range $3,000 - $20,000+/ton
4 Statutory Factors (continued)

- Time for Compliance
  - 2+ years for fuel switching (fuel contracts)
  - 3+ years for post-combustion control
    (dependent on market and availability of labor and materials)
- Remaining Useful Life
  - Facility specific
4 Statutory Factors (continued)

- Energy and Non-Air Environmental Impacts
  - Lower sulfur fuel may affect boiler operations
  - FGD slightly reduces energy production
    - Burn more coal per unit energy produced
    - Increase disposal of sludge, wastewater
    - Increase carbon emissions
      - CO2 is released as byproduct from CaSO4 formation