APPENDIX 1

Allegheny County Health Department’s
November 7, 2012, Review Memo

(a.) Source-Specific BART Modeling Report with VISTAS Met Data: Cheswick Power Station – Unit 1

(b.) Application of Wet Electrostatic Precipitation Technology in the Utility Industry for Multiple Pollutant Control Including Mercury

Bureau of Air Quality
Department of Environmental Protection
[This page intentionally left blank.]
Subject: Revision of Review Memo for BART Application
GenOn Power Midwest LP
Cheswick Plant

To: Jim Thompson
Air Quality Program Manager
Allegheny County Health Department

From: David D. Good, Air Pollution Control Engineer

Through: Jayme Graham
Supervisor Planning Section
Air Quality Program
Allegheny County Health Department

Sandra Etzel
Chief Engineer
Air Quality Program
Allegheny County Health Department

1. Background:

The Regional Haze regulation in 40 CFR 51.308(e) requires state implementation plans (SIPs) to contain emission limits representing Best Available Retrofit Technology (BART) for certain facilities that may reasonably be anticipated to cause or contribute to visibility impairment at a Class I area. The BART requirements apply to units that were in existence on August 7, 1977 but were not in operation before August 7, 1962 that collectively, at a facility, have the potential to emit more than 250 tons per year of a visibility impairing pollutant. Visibility impairing pollutants include: NOx, SO2, PM10, and PM2.5. VOC and NH3 may be visibility-impairing pollutants; however the PA Department of Environmental Protection (DEP) has determined that modeling tools to assess the visibility impacts from VOC and NH3 are not available at this time. The BART requirements only apply to facilities in 26 specific categories listed in the Clean Air Act.

States and local agencies are required to determine BART for each unit subject to BART based on an analysis of the best system of continuous emission control technology available and associated emission reductions achievable. The analysis must take into consideration the technology available, the costs of compliance, the energy and non-air quality environmental impacts, any pollution control equipment in use at the units, the remaining useful life of the units, and the degree of improvement in visibility which may reasonably be anticipated to result from use of the technology.

The Allegheny County Health Department (ACHD) requested that Allegheny County facilities subject to BART conduct the BART analysis required by the Regional Haze rule and submit a BART proposal. The PA DEP and ACHD have determined that an engineering analysis of VOC control options is not needed, as visibility impairment contributions of VOCs from BART-eligible sources have been found to
have a combined negligible impact of less than 0.05 dv on Class I areas in other studies (see VISTAS 2007). EPA has determined that BART requirements for EGUs (Electric Generating Units) covered by CAIR are satisfied by the CAIR requirements for NOx and SO2, so an engineering analysis is not required for these pollutants. For Allegheny County EGUs the only pollutant requiring an engineering analysis is PM10.

A BART review memo was previously submitted on May 4, 2009. Since that time, the facility was issued an Installation Permit (IP No. 0054-I004a) and a Title V Operating Permit (TVOP No. 0054). During the permitting process, the PM10 emission limits in the previous BART review memo of 361.0 tons/year were found to be incorrect. The current BART review memo requirements reflect the current control devices, emission limits and regulations that the facility is bound to by their Installation and Title V Operating Permits.

2. Process Description:

GenOn Cheswick is a fossil fuel fired steam electric generating plant of more than 250 million BTU’s per hour heat input. The plant is composed of one main boiler (Boiler #1) exhausting to one stack, which fires coal or synfuel as an alternate fuel. Natural gas is combusted as an auxiliary fuel for startup, shutdown, and at the operator’s discretion. Pollution control equipment for the main boiler includes low NOx burners, electrostatic precipitation with flue gas conditioning, selective catalytic reduction and flue gas desulfurization (FGD). The boiler is rated at 5,500 MMBtu/hr when combusting coal or synfuel.

Boiler #1 was originally constructed between 1962 and 1977, and the total emissions of three of the eligible pollutants (SO2, NOx and PM10) are over 250 tons, making it subject to the Best Available Retrofit Technology (BART) requirements that are a part of the Regional Haze rules specified in 40 CFR Part 51, Subpart P Protection of Visibility.

The following information relates to Boiler #1, the lone BART affected unit:

<table>
<thead>
<tr>
<th>Point Emission Source</th>
<th>Install Date</th>
<th>SO2 Potential To Emit (TPY)(2)</th>
<th>NOx Potential to Emit (TPY)(1)</th>
<th>PM10 Potential To Emit (TPY)(3)</th>
<th>VOC Potential To Emit (TPY)(1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S-001a Coal/ Gas Boiler 1</td>
<td>1970</td>
<td>33726.0</td>
<td>10840.0</td>
<td>788.0</td>
<td>82.0</td>
</tr>
</tbody>
</table>

(1) Potential-to-Emit Emissions per Title V Operating Permit No. 0054 (issued 12-30-2010)
(2) Potential-to-Emit Emissions per Installation Permit No. 0054-I004a (issued 4-20-2010)
(3) PM10 Potential-to-Emit Emissions per Installation Permit No. 0054-B004a (issued 4-20-2010) and excludes H2SO4 (sulfuric acid mist).

For comparison, the baseline year (2002), 2009 and 2010 emissions (tpy) for Boiler #1 are as follows:

<table>
<thead>
<tr>
<th>Year</th>
<th>SO2</th>
<th>NOx</th>
<th>PM10</th>
<th>VOC</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>42,017.9</td>
<td>5,761.2</td>
<td>205.7</td>
<td>10.7</td>
</tr>
<tr>
<td>2009</td>
<td>32,746.4</td>
<td>2,999.1</td>
<td>649.8(4)</td>
<td>10.2</td>
</tr>
<tr>
<td>2010</td>
<td>11,806.3</td>
<td>2,521.9</td>
<td>439.5(4)</td>
<td>6.8</td>
</tr>
</tbody>
</table>

(4) Includes condensable PM and H2SO4

Calendar year 2009 is the last complete calendar year in which Boiler #1 was operated without the FGD system in service.
3. **NESCAUM CALPUFF Modeling:**

Based upon the NESCAUM modeling (results shown in table below) the maximum impact of this source on a Class 1 area due to PM10 was 0.0336 deciviews (dv). This impact is on the Otter Creek Wilderness Area. The impacts from SO2 and NOx are not considered in this memo, since the source will be participating in CAIR.

<table>
<thead>
<tr>
<th>Nat_bgr</th>
<th>Maxclsi</th>
<th>Total</th>
<th>SO4</th>
<th>NO3</th>
<th>PM10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Best</td>
<td>otcn</td>
<td>3.4898</td>
<td>3.1606</td>
<td>0.8134</td>
<td>0.0336</td>
</tr>
<tr>
<td>Average</td>
<td>otcr</td>
<td>2.5034</td>
<td>2.2569</td>
<td>0.5611</td>
<td>0.0229</td>
</tr>
<tr>
<td>Worst</td>
<td>otcn</td>
<td>1.7710</td>
<td>1.5910</td>
<td>0.3856</td>
<td>0.0156</td>
</tr>
</tbody>
</table>

The NESCAUM modeling effort was conducted in accordance with 40 CFR 51, Appendix Y – Guidelines for BART Determinations Under the Regional Haze Rule. Section III of Appendix Y provides guidance for determining if a particular BART-eligible source (or group of sources) causes or contributes to visibility impairment in nearby Class I areas. The EPA guidance notes that the threshold “for determining whether a source “contributes” to visibility impairment should not be higher than 0.5 deciviews.”

4. **BART Analysis**

GenOn performed its own BART modeling in January 2007, and provided the ACHD with a report containing the results. The modeling report was also performed prior to the facility installing a FGD pollution control device and constructing a new stack for the main boiler emissions. The input to the model of 176.1 lb/hr non-sulfate PM10 emissions produced a highest 98th percentile (8th highest) impact of 0.03 delta deciviews, which is consistent with the NESCAUM modeling results. This visibility impact (filterable and organic condensable PM10)\(^1\) is well below the EPA guidance threshold of 0.5 delta-deciviews. The recommended PM10 (excluding H2SO4) limit of 180.0 lb/hr (788.0 tons/yr) below is consistent with the emissions input that was modeled by the facility (see Appendix).

The NESCAUM modeling was performed prior to the facility installing a FGD pollution control device and constructing a new stack for the main boiler emissions. Additionally, the pre-FGD BART modeling that was performed by GenOn speciated the PM10 into component parts and used a new post-processing algorithm for estimating light extinction from particulate matter component concentrations. This algorithm was developed and approved by the IMPROVE Steering Committee. The GenOn BART model followed the VISTAS BART Protocol and produced results similar to those of the NESCAUM model. The new stack height is 552.5 ft, which is 198.5 feet shorter than the NESCAUM & GenOn modeled stack height of 751 ft (see Appendix). The FGD unit reduces sulfur oxides & PM10 emissions so it is assumed that those reductions, along with a significantly shorter stack, will create even less of a change in visibility at the maximum impacted Class I area (Otter Creek Wilderness Area) when compared to the GenOn BART modeling results. Since the GenOn BART modeling results demonstrated a slightly lower change in visibility than the NESCAUM model results, it can be concluded that the current PM10 emission limits will yield a change in visibility that is comparable to the results of the NESCAUM model.

Although the aforementioned modeling analyses showed that the PM10 emissions from GenOn

---

\(^1\) The NPS spreadsheet specifies that, since only the filterable PM10 emissions were available at the time, the H2SO4 and organic condensable PM10 emissions were assumed to be 208% and 51% of the filterable PM10 emissions, respectively. The "organic portion" was modeled as secondary organic aerosols. See Appendix.
Cheswick are not “reasonably anticipated to cause or contribute to any visibility impairment in a Class I area,” the ACHD performed a BART analysis in accordance with the Guidelines for BART Determinations Under the Regional Haze Rule issued by the EPA and available at [http://www.epa.gov/air/visibility/actions.html#bart](http://www.epa.gov/air/visibility/actions.html#bart) (40 CFR 51 Appendix Y). The guidelines provide a process for making BART determinations that States and local agencies can use in implementing the regional haze BART requirements on a source-by-source basis, as provided in 40 CFR 51.308(e)(1).

ACHD decided not to exempt a BART-eligible source based on a “cause or contribute” deciview threshold, and made BART determinations for all BART-eligible sources. This approach was consistent with that performed by the PA DEP for other BART-eligible EGUs located in the Commonwealth.

The ACHD’s BART analysis took into account each of the five statutory factors required by the Clean Air Act (CAA). These factors are: the costs of compliance; the energy and non-air quality environmental impacts of compliance; any existing pollution control technology in use at the source; the remaining useful life of the source; and the degree of improvement in visibility which may reasonably be anticipated to result from the use of such technology. These statutory factors for BART were codified at 40 CFR 51.308(e)(1)(ii).

In addition, for the source subject to BART identified in this review memo, ACHD used the BART determination process under the guidelines to do the following: conduct an analysis of emissions control alternatives, which includes the identification of available, technically feasible retrofit technologies (which, in turn, is based on the existing emissions control equipment in use at the source), and for each technology identified, an analysis of the cost of compliance, the energy and non-air quality environmental impacts, and the degree of visibility improvement in affected Class I areas resulting from the use of the control technology. As part of the BART analysis, ACHD took into account the remaining useful life of the source and any existing control technology present at the source. For this source, ACHD determined a “best system of continuous emission reduction” based upon its evaluation of these factors. Below is the five-factor analysis, in detail, for the BART-eligible emissions unit at this facility that had the greatest impact.

**BART Five-Factor Analysis:**

**STEP – 1: Identify All Available Retrofit Control Technologies**

<table>
<thead>
<tr>
<th>Boiler #1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Existing controls:</strong></td>
</tr>
<tr>
<td><strong>Retrofit controls:</strong></td>
</tr>
</tbody>
</table>

A baghouse or a wet ESP installed downstream of the existing FGD are the available retrofit control options with the practical potential for application to Boiler #1 for the control of PM10. Installation of a baghouse (i) between the existing dry ESP and FGD or (ii) as a replacement for the existing dry ESP is of questionable value because the plant currently utilizes an SO3 emissions control system (hydrated lime injection) in series with a wet FGD scrubber. Consequently, PM10 emission levels following these controls would be primarily dependent on the operation of the wet scrubber regardless of any reductions provided by a fabric filter baghouse. Importantly, although the aforementioned retrofit controls are potentially available for the purposes of completing a BART analysis, U.S. EPA does not consider these among the list of feasible retrofit emission control technologies for coal-fired EGUs subject to the Clean
Air Interstate Rule (CAIR) and the Mercury and Air Toxics Rule (MATS). EPA has recognized that the feasible retrofit emission control technologies for coal-fired EGUs subject to CAIR and MATS, as listed in the support documents for EPA’s Integrated Planning Model (IPM), provide co-beneficial PM10 control – details are available on the EPA website per the following link: http://www.epa.gov/airmarkets/progsregs/epa-ipm/BaseCasev410.html#documentation.

STEP – 2: Eliminate Technically Infeasible Options Identified under Step 1

A baghouse is a technically infeasible option for an emissions source operated with an FGD system. A wet ESP is a technically feasible option for additional PM10 control for an emissions source operated with an FGD system. Information concerning the application of a wet ESP technology is attached to this memo – information pertinent to this BART analysis is presented below:

“Wet ESPs can be configured either as tubular precipitators with vertical gas flow or as plate precipitators with horizontal gas flow. For a utility application, tubular wet ESPs would be appropriate as a mist eliminator above a FGD scrubber, while the plate type could be employed at the back end of a dry ESP train for final polishing of the gas in a hybrid ESP. In general, tubular precipitators are more efficient than the plate type and take up less space due to simple geometry.”

STEP – 3: Evaluate Control Effectiveness of Remaining Control Technologies

For the purposes of this BART analysis, the ACHD has assumed that a wet tubular ESP can reduce PM10 emissions by 95%².

STEP – 4: Evaluate Impacts and Document the Results

Cost of Compliance:
According to the EPA-CICA Fact Sheet (http://www.epa.gov/ttn/ciac1/cica/atech_e.html#111), a typical wet tubular ESP could have annualized cost of $12 to $46 per scfm (West Electrostatic Precipitator (ESP), Wire-Pipe Type). Here, the depicted minimum annualized cost is $12 per scfm in 1998 dollars. Based on the installation of a new wet tubular ESP for Boiler #1, sized for similar operating parameters listed in the operating permit (1.56E+06 SCFM @ 68°F), and not correcting for inflation, the annualized cost is $18,720,000. The potential PM10 (excluding H₂SO₄) emissions for Boiler #1 are 180 lb/hr (788.0 tons per year), resulting in a cost of $25,000 per ton PM10 removed (=18,720,000 / (788 tons * 0.95)), and a minimum cost of $557,000,000 per deciview change (=18,720,000 / 0.0336 dv). Importantly, because the modeled impact to the nearby Class I areas attributable to Cheswick’s PM10 emissions did not consider the additional emissions control provided by the existing wet FGD, the calculated cost per deciview change would be significantly higher because the modeled impacts for the existing emissions control configuration would be lower (i.e., < 0.0336 dv).

STEP – 5: Evaluate Visibility Impacts

Using the CALPUFF NWS platform computer modeling the visibility impact of this facility due to PM10 on the Otter Creek Wilderness Area was found to be 0.0336 dv and is well below the 0.5 delta-

² EPRI tests for wet tubular ESP showed a 95% reduction of particulate matter. See Appendix.
deciview regional haze perceptibility threshold. The costs of possible new controls in terms of dollars per deciview for this facility were calculated to be at least $557,000,000 /dv for a wet tubular ESP for Boiler #1. In the event that BART was required due to source-specific impacts, this analysis indicates that it would not be cost effective to require this control option.

The results from this analysis are consistent with the aforementioned 40 CFR 51, Appendix Y – Guidelines for BART Determinations Under the Regional Haze Rule. Section IV.D.9 to Appendix Y lists the following with respect to Step 1:

If you find that a BART source has controls already in place which are the most stringent controls available (note that this means that all possible improvements to any control devices have been made ), then it is not necessary to comprehensively complete each following step of the BART analysis in this section. As long these most stringent controls available are made federally enforceable for the purpose of implementing BART for that source, you may skip the remaining analyses in this section, including the visibility analysis in step 5. Likewise, if a source commits to a BART determination that consists of the most stringent controls available, then there is no need to complete the remaining analyses in this section.

With respect to PM10 emissions, because the Boiler #1 flue gas stream cannot bypass the ESP and FGD systems, which are the most stringent controls available for a coal-fired boiler, and because the PM10 emission limits and other FGD operating conditions (e.g., operate with a minimum of 3 spray levels when firing coal) established in the aforementioned Installation Permit are federally-enforceable, and because the results from two independent modeling studies showed that the visibility impacts from PM10 emissions (without consideration of the FGD system in-service) to nearby Class I areas are imperceptible, no additional analyses are required for this facility.

5. Conclusion:

Per EPA guidance, the impact of this facility does not warrant additional control due to the small contribution (0.0336 dv) to regional haze and the high cost per deciview improvement for additional controls. Consequently, the ACHD recommends that the BART requirements for the GenOn Cheswick facility are satisfied by the following:

1. The control equipment described in this analysis is required by Title V Operating Permit No. 0054 (issued 12-30-2010) and Installation Permit No. 0054-I004a (issued 4-20-2010);

2. The conditions of Title V Permit No. 0054 (issued 12-30-2010) and Installation Permit No. 0054-I004a (issued 4-20-2010) along with the implementation of EGU CAIR requirements satisfy BART requirements for this facility; and

3. PM10 emissions shall be limited by Installation Permit No. 0054-I004a (issued 4-20-2010) emission limitations in the table below.

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Emission Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM10*</td>
<td>180.0 lbs/hr</td>
</tr>
</tbody>
</table>

* Includes condensable PM and excludes sulfuric acid mist (H2SO4). Emissions to be calculated from EPA test method 5B/202, as per EGU MACT.
References:

Source-Specific BART Modeling Report with VISTAS Met Data: Cheswick Power Station - Unit 1
Source-Specific BART Modeling Report with VISTAS Met Data: Cheswick Power Station - Unit 1

Prepared By: Olga Kostrova

Reviewed By: Robert J. Paine

ENSR Corporation
January 2007
Document No.: 10267-047-115
Contents

1.0 Executive Summary................................................................. 1-1
  1.1 Location of Source vs. Relevant Class I Areas .................. 1-2
  1.2 Organization of Report Document .................................. 1-2

2.0 Source Description and Emissions Data............................. 2-2

3.0 Input Data to CALPUFF Model ........................................... 3-2
  3.1 General Modeling Procedures ...................................... 3-2
  3.2 Model Selection and Features ........................................ 3-2
  3.3 Technical Options Used in the Modeling ......................... 3-2
  3.4 CALPUFF Modeling Domain and Receptors .................. 3-2

4.0 Air Quality Modeling Procedures ........................................ 4-2
  4.1 Air Quality Database.................................................... 4-2
  4.2 Light Extinction and Haze Impact Calculations ............... 4-2
  4.3 Natural Conditions and Monthly f(RH) at Class I Areas .... 4-2
  4.4 Quality Assurance Procedures ..................................... 4-2

5.0 Modeling Results ................................................................. 5-2

6.0 References........................................................................... 6-2

List of Appendices

Appendix A  Modeling Protocol and Correspondence

Appendix B  CALPOST List Files for Shenandoah National Park

Appendix C  Re-Calculating CALPOST Visibility Outputs with the New IMPROVE Algorithm
List of Tables

Table 2-1: Cheswick Power Station Modeling Emissions Parameters .................................................. 2-2
Table 4-1 Sea Salt Concentrations and Raleigh Scattering Coefficients .................................................. 4-2
Table 4-2 Background concentrations used as input to CALPUFF ........................................................ 4-2
Table 5-1 Summary of Results – Cheswick BART Modeling ............................................................. 5-2

List of Figures

Figure 1-1: Location of Cheswick Power Station in Relation to Nearby Class I Areas ......................... 1-2
Figure 3-1 Cheswick CALPUFF Computational Grid in Relation to the VISTAS Subdomain #5 ....... 3-2
1.0 Executive Summary

Orion Power MidWest, L.P., a subsidiary of Reliant Energy, owns and operates the Cheswick Power Station ("Cheswick"), a coal-fired electric generating station located on an 82-acre site in the borough of Springdale, approximately 18 miles northeast of Pittsburgh. Cheswick has been identified by the Allegheny County (PA) Health Department (ACHD) and Pennsylvania Department of Environmental Protection (PADEP) as being a source that is eligible for consideration of BART controls for PM₉₀ (CAIR serves as BART for SO₂ and NOₓ). The purpose of this document is to summarize dispersion modeling analysis conducted for the BART-eligible Cheswick Unit 1.

The Regional Haze Rule regulations require the determination of BART for any BART-eligible source that "emits any air pollutant which may reasonably be anticipated to cause or contribute to any impairment of visibility" in any mandatory Class I federal area. Pursuant to federal regulations, states have the option of exempting a BART-eligible source from the BART requirements based on dispersion modeling demonstrating that the source cannot reasonably be anticipated to cause or contribute to visibility impairment in any Class I area. In states subject to the Clean Air Interstate Rule (CAIR) and that will be imposing regional limits for overall SO₂ and NOₓ emissions from electric generating units (EGUs), the U.S. Environmental Protection Agency (EPA) has determined that CAIR satisfies the BART requirements for SO₂ and NOₓ. Therefore, each CAIR state can limit BART analyses to only consider potential visibility impairment due to emissions of primary PM₁₀, where primary particulate matter (PM) emissions are defined as the sum of filterable PM plus condensable PM emissions. By letter of November 17, 2006, the PADEP confirmed that participation in the CAIR trading program satisfies the SO₂ and NOₓ BART requirements for Pennsylvania EGUs. Accordingly, this modeling report focuses solely on performing BART modeling analyses for primary particulate matter (PM₁₀) emissions from Cheswick Unit 1.

The Regional Haze Rule regulations require the determination of BART for any BART-eligible source that "emits any air pollutant which may reasonably be anticipated to cause or contribute to any impairment of visibility" in any mandatory Class I federal area. Pursuant to federal regulations, states have the option of exempting a BART-eligible source from the BART requirements based on dispersion modeling demonstrating that the source cannot reasonably be anticipated to cause or contribute to visibility impairment in any Class I area. In states subject to the Clean Air Interstate Rule (CAIR) and that will be imposing regional limits for overall SO₂ and NOₓ emissions from electric generating units (EGUs), the U.S. Environmental Protection Agency (EPA) has determined that CAIR satisfies the BART requirements for SO₂ and NOₓ. Therefore, each CAIR state can limit BART analyses to only consider potential visibility impairment due to emissions of primary PM₁₀, where primary particulate matter (PM) emissions are defined as the sum of filterable PM plus condensable PM emissions. By letter of November 17, 2006, the PADEP confirmed that participation in the CAIR trading program satisfies the SO₂ and NOₓ BART requirements for Pennsylvania EGUs. Accordingly, this modeling report focuses solely on performing BART modeling analyses for primary particulate matter (PM₁₀) emissions from Cheswick Unit 1.

The document entitled “Source-Specific BART Modeling Protocol: Cheswick Power Station – Unit 1” was submitted to the ACHD and PADEP in November 2006. A copy of the modeling protocol along with subsequent correspondence among the ACHD, PADEP, ENSR and Reliant Energy pertinent to the modeling protocol are presented in Appendix A of this report. The modeling exercise was conducted in general accordance with the protocol with the exception that the VISTAS 3-year meteorological data set and VISTAS modeling procedure were used in lieu of the 1-year MANE-VU meteorological data set and MANE-VU modeling procedure as proposed in the protocol (please see the January 4, 2007 email transmittal between the PADEP and ENSR presented in Appendix A). The modeling procedures are consistent with those outlined in the final VISTAS common BART modeling report (Dated August 31, 2006), available at http://www.vistas-sesarm.org/documents/BARTModelingReport_rev3.2_31Aug06.pdf. This report references relevant portions of the common VISTAS report.

The results of the modeling study demonstrate that visibility impacts due to primary PM₁₀ emissions from Cheswick Unit 1 are imperceptible, below 0.5 delta dv (8th highest or 98th percentile day in each of the three modeled years 2001, 2002 and 2003) at all Class I areas. It should be noted that nearly all of the visibility impacts can be attributed to inorganic condensable PM emissions, which are modeled as sulfuric acid (H₂SO₄) emissions that result from the conversion of a small fraction (typically 1 percent or less) of the SO₂ in the coal-fired boiler flue gas stream into SO₃ and H₂SO₄. Reliant and ENSR submit that the implementation of CAIR will also reduce emissions of sulfates / inorganic condensable PM emissions since these emissions are directly proportional to SO₂ emissions. The modeling shows that the visibility impacts from non-sulfate PM₁₀ are so low (maximum 0.03 delta dv, 8th highest or 98th percentile day in each of the three modeled years 2001, 2002 and 2003) that additional BART analyses for primary particulate would likely yield no meaningful visibility improvements.
1.1 Location of Source vs. Relevant Class I Areas

Figure 1-1 shows a plot of the Cheswick Power Station relative to nearby Class I areas located within the VISTAS Regional Planning Organization states. There are three Class I areas within 300 km of the plant: (1) Shenandoah National Park, (2) Otter Creek Wilderness, and (3) Dolly Sods Wilderness. The BART evaluation modeling was conducted for each of these Class I areas in accordance with the referenced VISTAS common BART modeling protocol.

1.2 Organization of Report Document

Section 2 of this report describes the source emissions that were used as input to the baseline emissions BART modeling. Section 3 describes the input data that was used for the modeling including the modeling domain, terrain and land use, and meteorological data. Section 4 describes CALPUFF modeling and the air quality modeling procedures. Section 5 discusses CALPUFF modeling results. References are provided in Section 6.
Figure 1-1: Location of Cheswick Power Station in Relation to Nearby Class I Areas
2.0 Source Description and Emissions Data

The emissions data used to assess the visibility impacts at the selected Class I areas are discussed in this section. As noted earlier, the ACHD and PADEP will consider CAIR to suffice for EGU BART for SO\textsubscript{2} and NO\textsubscript{x} (reference the August 24, 2006 letter from Ms. Sandra L. Etzel of the ACHD to Mr. J. Derek Furstenwerth of Reliant Energy and the aforementioned letter dated November 17, 2006 from the PADEP to Reliant Energy). Further, the DC District Court reaffirmed EPA’s decision that CAIR satisfies BART requirements for electrical generating units for SO\textsubscript{2} and NO\textsubscript{x} controls in a decision rendered on December 12, 2006. Therefore, this report will focus only on PM\textsubscript{10}. Since various components of PM\textsubscript{10} emissions have different visibility extinction efficiencies, the PM\textsubscript{10} emissions are divided or "speciated" into several components. Cheswick is using, where available, source-specific emissions and speciation factors. Otherwise, default values from EPA’s AP-42 reference document are used.

Unit 1 at the Cheswick Power Station is a coal-fired unit. Electrostatic precipitator controls are currently installed on the Cheswick unit. Total PM\textsubscript{10} is comprised of filterable and condensable emissions. Total PM\textsubscript{10} is comprised of filterable and condensable emissions.

- Baseline filterable PM\textsubscript{10} emissions (units of lb/hr) were conservatively based on the source-specific emission factors (units of lb/MMBtu) included in the 2005 air emissions inventory and the maximum daily heat input recorded during a three-year period from July 2003 through June 2006. The maximum daily heat input data were extracted from the unit’s certified continuous emission monitoring data acquisition system.

- Filterable PM can be subdivided by size category consistent with the default approach from a speciation spreadsheet provided by the National Park Service, based upon AP-42 Tables 1.1-5 and 1.1-6 for a dry-bottom boiler firing pulverized coal with an ESP for PM control. The applicable NPS spreadsheet parameterizes various components of the filterable PM\textsubscript{10} emissions as coarse inorganic PM\textsubscript{10}, fine inorganic PM\textsubscript{10} and elemental carbon. The percentage breakdown of filterable PM\textsubscript{10} emissions for these three components is 55.6%, 42.8%, and 1.6%, respectively.

- Condensable PM\textsubscript{10} consists of inorganic and organic compounds. The inorganic portion is assumed to consist of H\textsubscript{2}SO\textsubscript{4}. The organic portion is modeled as secondary organic aerosols. According to the NPS spreadsheet, if only the filterable PM\textsubscript{10} emissions are available, then the H\textsubscript{2}SO\textsubscript{4} and organic condensable PM\textsubscript{10} emissions are assumed to be 208% and 51.8% of the filterable PM\textsubscript{10} emissions, respectively.

Table 2-1 provides a summary of the modeling emission parameters that were used in the BART CALPUFF modeling, consistent with the source emissions data mentioned above.

Sulfuric acid mist (H\textsubscript{2}SO\textsubscript{4}) is emitted from coal-fired boilers proportionally due to trace conversion of SO\textsubscript{2}. The same reductions in regional SO\textsubscript{2} that will be implemented under CAIR will cause similar and proportional reductions in regional H\textsubscript{2}SO\textsubscript{4}. Since CAIR reductions have been determined to satisfy BART for SO\textsubscript{2} (and also NO\textsubscript{x}), the same mechanisms under CAIR will also address BART for H\textsubscript{2}SO\textsubscript{4}. The modeling analyses performed, therefore, address the visibility impacts due to primary PM\textsubscript{10} (filterable and organic condensable) emissions from Cheswick unit, with and without sulfates (i.e., inorganic condensables, assumed to be sulfuric acid mist).
## Table 2-1: Cheswick Power Station Modeling Emissions Parameters

<table>
<thead>
<tr>
<th>Stack Parameters</th>
<th>Units</th>
<th>Unit 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>X Location UTM 17, NAD83</td>
<td>km</td>
<td>602.397</td>
</tr>
<tr>
<td>Y Location UTM 17, NAD83</td>
<td>km</td>
<td>4488.209</td>
</tr>
<tr>
<td>Stack Height</td>
<td>m</td>
<td>228.6</td>
</tr>
<tr>
<td>Base Elevation</td>
<td>m</td>
<td>230.7</td>
</tr>
<tr>
<td>Diameter</td>
<td>m</td>
<td>6.4</td>
</tr>
<tr>
<td>Gas Exit Velocity</td>
<td>m/s</td>
<td>31.0</td>
</tr>
<tr>
<td>Stack Gas Exit Temperature</td>
<td>deg K</td>
<td>441</td>
</tr>
<tr>
<td>SO$_2$ (1)</td>
<td>lb/hr</td>
<td>n/a</td>
</tr>
<tr>
<td>NO$_x$ (1)</td>
<td>lb/hr</td>
<td>n/a</td>
</tr>
<tr>
<td>PM$_{10}$ Filterable</td>
<td>lb/hr</td>
<td>116</td>
</tr>
<tr>
<td>PM$_{10}$ Condensable</td>
<td>lb/hr</td>
<td>301</td>
</tr>
<tr>
<td>Total PM$_{10}$ (2)</td>
<td>lb/hr</td>
<td>417</td>
</tr>
</tbody>
</table>

### PM$_{10}$ Filterable

<table>
<thead>
<tr>
<th></th>
<th>lb/hr</th>
<th>Unit 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse Matter</td>
<td></td>
<td>64.5</td>
</tr>
<tr>
<td>Fine Soil</td>
<td></td>
<td>49.6</td>
</tr>
<tr>
<td>Fine Elemental Carbon</td>
<td></td>
<td>1.9</td>
</tr>
</tbody>
</table>

### PM$_{10}$ Condensable

<table>
<thead>
<tr>
<th></th>
<th>lb/hr</th>
<th>Unit 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inorganic (H$_2$SO$_4$)</td>
<td></td>
<td>241</td>
</tr>
<tr>
<td>Organic</td>
<td></td>
<td>60.1</td>
</tr>
</tbody>
</table>

1) SO$_2$ and NO$_x$ are not BART-applicable for EGU sources in CAIR states. Inorganic PM$_{10}$ (H$_2$SO$_4$) results from trace conversion of SO$_2$ which will be addressed under CAIR.

2) Total PM$_{10}$ is the sum of filterable PM$_{10}$ plus condensable PM$_{10}$. 
3.0 Input Data to CALPUFF Model

3.1 General Modeling Procedures

Although MANE-VU has processed a single year of data for use in BART assessments, a better (3-year) database is available for parts of Pennsylvania (including the Cheswick Power Station) that lie within the VISTAS modeling domain. VISTAS has developed five sub-regional 4-km CALMET meteorological databases for three years (2001-2003). The sub-regional modeling domains are strategically designed to cover all potential BART eligible sources within VISTAS states and all PSD Class I areas within 300 km of those sources. The extents of the 4 km sub-regional domains are shown in Figure 4-4 of the VISTAS common BART modeling report. The BART modeling for the Cheswick station was done using the 4-km subdomain #5.

USGS 90-meter Digital Elevation Model (DEM) files were used by VISTAS to generate the terrain data at 4-km resolution for input to the 4-km sub-regional CALMET run. Likewise, USGS 90-meter Composite Theme Grid (CTG) files were used by VISTAS to generate the land use data at 4-km resolution for input to the 4-km sub-regional CALMET run.

Three years of MM5 data (2001-2003) were used by VISTAS to generate the 4-km sub-regional meteorological datasets. See Sections 4.3.2 and 4.4.2 in the VISTAS common BART modeling report for more detail on these issues.

All of the modeling for the Cheswick plant used the 4-km subdomain #5. A smaller computational grid within the VISTAS subdomain #5 was designed to minimize computation time and output file size. The Cheswick computational grid domain covers distances of 432 km W-E and 352 km N-S and is shown in Figure 3-1. This domain includes three Class I areas with 50 km buffer N-S and 100 km buffer W-E, plus a nearly 50-km buffer around the source (up to the limit of the VISTAS sub-domain northern boundary).

3.2 Model Selection and Features

As noted in the VISTAS report, this modeling uses the BART-specific versions of CALMET and CALPUFF that have been posted at http://www.src.com. These versions contain enhancements funded by the Minerals Management Service (MMS) and VISTAS. They are maintained on TRC’s Atmospheric Studies Group CALPUFF website for public access. This release includes CALMET, CALPUFF, CALPOST, CALSUM, and POSTUTIL as well as CALVIEW.

The major features of the CALPUFF modeling system, including those of CALMET and the post processors (CALPOST and POSTUTIL) are referenced in Section 3 of the VISTAS report.

3.3 Technical Options Used in the Modeling

CALMET modeling for the VISTAS-provided 4-km subdomains was pre-determined by the VISTAS contractor, and, therefore, we assume that VISTAS approves of the manner in which CALMET has been run for the subdomain data that they provide.

For CALPUFF model options, the Cheswick plant followed the VISTAS common BART modeling report, which states that the IWAQM (EPA, 1998) guidance should be used. The VISTAS report also notes that building downwash effects are not required to be included unless the state directs the source to include these effects.
3.4 CALPUFF Modeling Domain and Receptors

The initial baseline emissions modeling runs used the 4-km subdomain #5 CALMET data run in observation mode with surface stations, upper air stations and precipitation data stations, supplied by VISTAS, as discussed above. This domain includes all Class I areas within 300 km of the source, plus buffers.

The receptors used for each of the Class I areas are based on the National Park Service database of Class I receptors, as recommended by VISTAS.
Figure 3-1  Cheswick CALPUFF Computational Grid in Relation to the VISTAS Subdomain #5
4.0 Air Quality Modeling Procedures

This section provides a summary of the modeling procedures outlined in the VISTAS report that was used for the refined CALPUFF analysis conducted for the Cheswick Power Station.

4.1 Air Quality Database

Hourly measurements of ozone from all non-urban monitors, as generated by VISTAS and available on the VISTAS CALPUFF page on the TRC web site http://www.src.com/verio/download/sample_files.htm, were used as input to CALPUFF. Currently, VISTAS advises sources to use a background ammonia concentration of 0.5 ppb, and not to use the ammonia limiting method. However, since there are no NOx emissions being considered in this application, the results are not sensitive to the ammonia concentration used.

4.2 Light Extinction and Haze Impact Calculations

The CALPOST postprocessor was used for the calculation of the impact from the modeled source's primary and secondary particulate matter concentrations on light extinction. The formula that is used is the existing IMPROVE/EPA formula, which is applied to determine a change in light extinction due to increases in the particulate matter component concentrations. Using the notation of CALPOST, the formula is the following:

\[ \text{b}_{\text{ext}} = 3f(\text{RH}) \left[ (\text{NH}_4\text{SO}_4) + 3f(\text{RH}) \left[ \text{NH}_4\text{NO}_3 \right] + 4[\text{OC}] + 1[\text{Soil}] + 0.6[\text{Coarse Mass}] + 10[\text{EC}] + b_{\text{Ray}} \right] \]

The concentrations, in square brackets, are in µg/m³ and \( b_{\text{ext}} \) is in units of Mm⁻¹. The Rayleigh scattering term \( (b_{\text{Ray}}) \) has a default value of 10 Mm⁻¹, as recommended in EPA guidance for tracking reasonable progress (EPA, 2003a).

Dr. Ivar Tombach, consultant to VISTAS, has provided a spreadsheet calculation system (see Appendix C) that incorporates the revised IMPROVE equation for determining light extinction from particulate concentration estimates. Reliant Energy elected to use this approach instead of the old/current IMPROVE equation in the presentation of the BART evaluation modeling results due to the better performance of the new IMPROVE equation.

The old/current IMPROVE algorithm does not incorporate the effects of naturally occurring sea salt on background visibility, but the new algorithm does account for this effect. Therefore, the modeling effort incorporated this effect into the present CALPUFF framework by using the guidance provided by Dr. Ivar Tombach. Tables 4-1 lists sea salt concentrations and Raleigh coefficients that were used in Dr. Ivar Tombach’s new IMPROVE equation.

Table 4-1 Sea Salt Concentrations and Raleigh Scattering Coefficients

<table>
<thead>
<tr>
<th>Sea Salt Concentration (µg/m³)</th>
<th>Shenandoah NP</th>
<th>Dolly Sods W</th>
<th>Otter Creek W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raleigh Scattering Coefficient (Mm⁻¹)</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>
The assessment of visibility impacts at the Class I areas used CALPOST Method 6. Each hour’s source-caused extinction is calculated by first using the hygroscopic components of the source-caused concentrations due to ammonium sulfate and nitrate (not relevant for EGUs in CAIR states except for H2SO4 emissions) and monthly Class I area-specific f(RH) values. The contribution to the total source-caused extinction from ammonium sulfate and nitrate is then added to the other, non-hygroscopic components of the particulate concentration (from coarse and fine soil, secondary organic aerosols, and from elemental carbon) to yield the total hourly source-caused extinction.

The EPA BART rule significance threshold for the contribution to visibility impairment is 0.5 deciviews, corresponding to the limit of perceptibility for haze effects. The VISTAS model approach indicates that with the use of the 4-km sub-regional CALMET database, a source does not cause or contribute to visibility impairment if the 98th percentile (or 8th highest) day’s change in extinction from natural conditions does not exceed 0.5 deciviews for any of the modeled years. As an added check, the 22nd highest prediction over the three years modeled should also not exceed 0.5 deciviews for a source to be considered not to have a perceptible regional haze impact.

Figure 4-1 of the VISTAS common BART modeling report presents a flow chart showing the components of that modeling report for the analysis to determine whether a source is subject to BART. Again, it should be noted that the modeling for the Cheswick Power Station focused on sub-regional fine-scale modeling as depicted in the upper half of the figure.

### 4.3 Natural Conditions and Monthly f(RH) at Class I Areas

Three Class I areas (Shenandoah NP, Otter Creek W, and Dolly Sods W) were modeled for the Cheswick Power Station. For these Class I areas, natural background conditions were established in order to determine a change in natural conditions related to a source’s emissions. For the BART evaluation modeling, natural background light extinctions shown in Table 4-2 were used, modified as noted below with site-specific considerations, and corresponding to the annual average (EPA 2003, Appendix B), consistent with the July 19, 2006 EPA guidance to Region 4 on this issue (“Regional Haze Regulations and Guidelines for Best Available Retrofit Technology (BART) Determinations”, Joseph W. Paise/ EPA OAQPS to Kay Prince/Branch Chief).

<table>
<thead>
<tr>
<th>Component Represented</th>
<th>Components of Natural Background Concentrations (µg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shenandoah NP</td>
<td>Dolly Sods W</td>
</tr>
<tr>
<td>Soil (PM fine)</td>
<td>10.98</td>
</tr>
</tbody>
</table>

To determine the input to CALPOST, it is first necessary to convert the deciviews to extinction using the equation:

\[
\text{Extinction (Mm}^{-1}\text{)} = 10 \exp(\text{deciviews/10})
\]

For example, for Shenandoah, 7.41 deciviews is equivalent to a visibility extinction of 20.98 inverse megameters (Mm⁻¹); this extinction excludes the default 10 Mm⁻¹ for Rayleigh scattering. This remaining extinction is due to naturally occurring particles, and is held constant for the entire year’s simulation. Therefore, the data provided to CALPOST for Shenandoah would be the total natural background extinction minus 10 (expressed in Mm⁻¹), or 10.98. This is most easily input as a fine soil concentration of 10.98 µg/m³ in CALPOST, since the extinction efficiency of soil (PM-fine) is 1.0 and there is no f(RH) component. The concentration entries for all other particle constituents would be set to zero, and the fine soil concentration would be kept the same for each month of the year. The monthly values for f(RH) for input to CALPOST were...

### 4.4 Quality Assurance Procedures

Section 6 of the VISTAS BART Protocol (Revision 3.2 – 8/31/06) establishes QA procedures for ensuring that BART modeling applications satisfy the regulatory objectives of the BART program. In order to document that proper QA/QC procedures were applied in the execution of the BART evaluation modeling for Cheswick, ENSR provides the following question and answer format to demonstrate that proper QA procedures were in place for this particular application:

1) Did we use the test met file to "benchmark" our use of the CALMET files on our computers? (see p. 59, sec 6.2, first paragraph, last two sentences)

*Response:* ENSR has conducted this test successfully. The equivalency demonstration can be found in the modeling archive, in the zip file “ExampleBARTSimulation.zip”. The zip file contains a readme file that describes the contents of the zip file.

2) The VISTAS BART protocol mentions on page 60, second full paragraph, a list of QA checks to perform on model inputs.

*Response:* ENSR has conducted numerous CALPUFF analyses, and uses CALDESK animation software as well as Lakes Environmental CALVIEW software with base maps to visualize the sources, receptors, and meteorology. ENSR also uses the CALPUFF QA output files in conjunction with ArcMap GIS software to plot the locations of the sources and receptors as CALPUFF interprets them from the input data. The output files from CALPUFF and CALPOST were reviewed independently by ENSR staff to assure accuracy and compliance with approved regulatory procedures.

3) Common practice requires that a model project CD be created that contains all the data and program files needed to reproduce the model results presented in the report (see VISTAS BART protocol, page 60, third full paragraph).

*Response:* All files generated from the CALPUFF runs are carefully documented in a separate modelers data archive. This is a complete package that any reviewer can use to recreate the modeling results.

4) For source-specific domain, the grid parameters should be specified as part of the source-specific protocol (see VISTAS BART protocol, page 60, last sentence).

*Response:* Meteorological and computations grid parameters are routinely specified in BART modeling protocols. We have provided a source-specific protocol for the meteorological data used in this analysis.

5) CALMET switch settings in the control file should be reviewed. (see VISTAS BART modeling protocol, page 61, first paragraph)

*Response:* ENSR is using CALMET switches consistent with those used in the subdomain data provided directly from VISTAS, and so we are inherently accepting the approved control file settings used by the VISTAS contractor.

6) Quality assurance of the source and emissions data is a major component of the CALPUFF modeling (see VISTAS BART protocol page 61, Section 6.2.3)

*Response:* ENSR has worked closely with the Reliant Energy environmental staff to review the stack exhaust parameters and the peak daily emission rates for the pollutants being modeled in CALPUFF.
7) Quality control of application of CALPOST and POSTUTIL is also important (see VISTAS BART protocol, page 62, Section 6.2.4)

Response: ENSR has considerable experience with CALPUFF system modeling, including the POSTUTIL and CALPOST portions of the modeling. The procedures used by ENSR are consistent with the guidance in the VISTAS protocol and with approved approaches used by ENSR in other BART applications and in recent PSD permit applications.
5.0 Modeling Results

The BART modeling results for Unit 1 at Cheswick are provided in Table 5-1. The table lists regional haze impacts with sulfates and without sulfates modeled (sulfates result from conversion of SO₂, a pollutant for which BART is already satisfied due to regulation under CAIR). The table indicates that the 8th highest day’s impacts for each year and each Class I area, even including measured sulfates, are below 0.5 delta dv, with the maximum impact equal to 0.26 delta dv. These results demonstrate that even when sulfates are included, Cheswick PM₁₀ emissions do not cause or contribute to regional haze in any Class I area within 300 km of the source according to the perceptibility threshold in EPA’s BART rule.

It is also useful to list the non-sulfate portion of the visibility impact from the Cheswick Station, since regional CAIR controls on SO₂ will also effectively control regional emissions of sulfates (H₂SO₄). The highest 98th percentile (8th highest) impact for the non-sulfate particulate emissions from Cheswick Unit 1 is about 0.03 delta deciviews.

In conclusion, Reliant Energy believes that no further BART analysis is warranted because:

1) SO₂ and NOₓ controls are covered under the CAIR rule. Resulting reductions in regional SO₂ will likewise reduce the formation of sulfates (H₂SO₄) that result from inorganic condensable PM emissions.

2) Total PM₁₀ impacts (even including sulfates) are below the EPA-specified 0.5 delta-deciview regional haze perceptibility threshold, with the maximum impact equal to 0.26 delta dv.

3) Most of these impacts are due to sulfuric acid mist emissions, which the regional implementation of CAIR will effectively address.

4) The remaining visibility impact (filterable and organic condensable PM₁₀) is well below the 0.10 delta-deciview threshold, a threshold that MANE-VU considers to be so low that additional BART analysis is not required.

Appendix B lists delta-deciview results (with and without sulfates) for the top 22 days for each year modeled at the highest impacted Class I area - Shenandoah National Park.
Table 5-1  Summary of Results – Cheswick BART Modeling

<table>
<thead>
<tr>
<th>Class I Area</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td># of days</td>
<td>Max 24-hr</td>
<td># of days</td>
</tr>
<tr>
<td></td>
<td>with impact</td>
<td>impact (dv)</td>
<td>with impact</td>
</tr>
<tr>
<td></td>
<td>&gt; 0.5 dv</td>
<td></td>
<td>&gt; 0.5 dv</td>
</tr>
<tr>
<td><strong>Impacts with Sulfates using New IMPROVE equation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dolly Sods W</td>
<td>0</td>
<td>0.42</td>
<td>0</td>
</tr>
<tr>
<td>Otter Creek W</td>
<td>0</td>
<td>0.47</td>
<td>0</td>
</tr>
<tr>
<td>Shenandoah NP</td>
<td>0</td>
<td>0.40</td>
<td>1</td>
</tr>
<tr>
<td><strong>Impacts without Sulfates using New IMPROVE equation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dolly Sods W</td>
<td>0</td>
<td>0.05</td>
<td>0</td>
</tr>
<tr>
<td>Otter Creek W</td>
<td>0</td>
<td>0.05</td>
<td>0</td>
</tr>
<tr>
<td>Shenandoah NP</td>
<td>0</td>
<td>0.05</td>
<td>0</td>
</tr>
</tbody>
</table>
6.0 References


Environmental Protection Agency (EPA), Guidance for Tracking Progress Under the Regional Haze Rule, EPA-454/B-03-003, Appendix A, Table A-3, September, 2003

Environmental Protection Agency (EPA), Guidance for Estimating Natural Visibility Conditions Under the Regional Haze Program, EPA 454/B-03-005, September 2003


Visibility Improvement State and Tribal Association of the Southeast (VISTAS), Revision 3, Report for the Application of the CALPUFF Model for Analyses of Best Available Retrofit Technology (BART), updated August 31, 2006.
Appendix A

Modeling Protocol and Correspondence
RE BART Modeling Protocol Comments 18 December 2006

From: Paine, Bob [BPaine@ensr.aecom.com]
Sent: Monday, December 18, 2006 5:16 PM
To: Leon-Guerrero, Timothy
Cc: Herb, Nancy; Shimshock, John
Subject: RE: BART Modeling Protocol Comments

Tim,

We are available at 2 PM EST on Wednesday. We'll provide a call-in number tomorrow.

Bob

-----Original Message-----
From: Leon-Guerrero, Timothy [mailto:tleonguerr@state.pa.us]
Sent: Monday, December 18, 2006 3:08 PM
To: Paine, Bob
Cc: Herb, Nancy; Shimshock, John
Subject: RE: BART Modeling Protocol Comments

Bob,

Nancy and I are available Wednesday afternoon and all day Thursday. Let us know a time, data and call-in number. We can discuss any outstanding issues at that time.

Timothy A. Leon Guerrero
Chief, Air Quality Modeling Section
Harrisburg, PA
717 783-9243
tleonguerr@state.pa.us

-----Original Message-----
From: Paine, Bob [mailto:BPaine@ensr.aecom.com]
Sent: Monday, December 18, 2006 1:53 PM
To: Leon-Guerrero, Timothy
Cc: Herb, Nancy; Shimshock, John
Subject: RE: BART Modeling Protocol Comments

Tim,

I have conferred with John Shimshock of Reliant Energy on these preliminary comments (John's e-mail address had a typo, so I forwarded the comments to him separately). Our initial responses to your comments are provided below, provided after each comment in brackets. So as not to delay this procedure any further with the holidays approaching, I wonder if we could have a conference call on Wednesday or Thursday this week to finalize our BART modeling procedures. The completion date of January 10, 2007 looks somewhat doubtful at this point, but we expect quite low impacts from well-controlled PM10 emissions, and Reliant Energy believes that the impacts of the PM10 emissions are either so low that even zero emissions would achieve very little visibility improvement, and also that the ESP controls are already highly efficient, so that no further BART controls are practical.

Bob

-------------
Consultant: ENSR/AECOM (ENSR)
Companies: Reliant Energy, Conemaugh Plant, Indiana County
Reliant Energy, New Castle Power Plant, Lawrence County
Reliant Energy, Keystone Power Plant, Armstrong County
Reliant Energy, Portland Generating Station, Northampton County
Reliant Energy, Cheswick Power Station, Allegheny County

General Comments:

All modeling activities should be fully documented. Please include all reference documents and ensure copies are sent to the appropriate regional offices.

Please include an electronic version of the modeling protocol (with any changes regarding my comments) with the modeling analysis.

[BPaine: Reliant Energy should have no problem complying with these requests.]

CALMET Comments:
ENSR plans to use the same MM5 used in the MANE-VU modeling analysis. The applicant will have to provide proper documentation if the 12-km data set indicates a more refined grid will be needed.

[Paine: yes, we are agreeing to use the highest day's prediction for the exemption test as a screening procedure due to the limitations of the MANE-VU database. We have a follow-up question regarding exemption below.]

CALPUFF Comments:

The modeling domains appear to maintain the 50-km buffer between the source/receptors and the model boundaries. Does ENSR believe its lateral boundaries are chosen well enough to prevent individual puffs from leaving the modeling domain that could have had an effect on the Class I receptors (reentered the domain)?

[Paine: a buffer of 50 km is typically approved by the Federal Land Managers. For the plants in western PA, due to the large north-south distance to be covered, we would agree to expand the east-west buffer zone to 100 km.]

Please document the reasoning behind the 1.0 ppb ammonia background concentration used in the CALPUFF modeling.

[Paine: that is what is used in the MANE-VU modeling. Since NOx emissions are not being modeled, the selection of the ammonia background will not affect the results.]

Please indicate which version of CALPUFF is used in the modeling analysis.

[Paine: the MANE-VU CALMET system was run with an older version of the model. For consistency, we need to use the following model versions:

CALPUFF: Version 5.711a, Level 040716
CALPOST: Version 5.51, Level 030709]

Emission rates were included for all BART eligible units. Could ENSR provide a reason why there are some significant differences in the PM10 emission rates between the two units at Keystone and Conemaugh? Also, the Keystone stack parameters do not appear to reflect the installation of scrubber and the construction of a new stack. Does Reliant intend to model its new scrubbed stacks at Keystone?

[Paine: the PM10 emissions are derived from the available stack tests. Due to boiler differences, the stack tests had different results. We are using the results of the stack tests directly.]

We are modeling regional haze rule baseline conditions that existed during the defined period of 2000-2004. Future stack changes as a result of the Clean Air Interstate Rule or other factors are not accounted for in the BART exemption modeling. In any case, though, the long-range travel involved for the Class I areas to be evaluated would likely make the stack height and plume rise differences immaterial in the results.]

CALPOST/Presentation of Results:

Please follow the VISTAS reporting outlined in section 4.5 of the VISTAS modeling protocol. Please note that Pennsylvania and other MANE-VU states are not using a visibility threshold limit in their analysis. Therefore all model output should be included.

[Paine: all modeling results will be presented. We have proposed, however, that a modeling result below the EPA BART rule specified threshold of 0.5 delta deciviews will lead to a finding of no required BART determination analysis for PM10 for each plant involved in the BART analysis. If this is not what PA DEP will agree to, please specify an alternative analysis or threshold for this determination. Basically, we are modeling only PM10 for these plants, which are already well controlled for PM10 with electrostatic precipitators. Therefore, no further BART controls for PM10 emissions would be proposed.]

From: Leon-Guerrero, Timothy [mailto:tleonguerr@state.pa.us]
Sent: Thursday, December 14, 2006 2:06 PM
To: Paine, Bob
Cc: Herb, Nancy; jshimsock@reliant.com
Subject: BART Modeling Protocol Comments

Bob,

I attached some comments regarding the BART Modeling protocols you sent me. These are informal and general in nature. I need to figure out how I'm going to get them out to the region and the companies themselves at a later date. Let me know if you have any questions (I will be out until Monday after today).

Timothy A. Leon Guerrero
Chief, Air Quality Modeling Section
Harrisburg, PA
717 783-9243
tleonguerr@state.pa.us
BART modeling protocol - Cheswick Power Station 21 December 2006

From: Shimshock, John
Sent: Thursday, December 21, 2006 11:50 AM
To: 'tleonguerr@state.pa.us'
Cc: 'Paine, Bob'; 'jmaranche@achd.net'
Subject: BART modeling protocol - Cheswick Power Station

Attachments: BART Modeling Protocol - Cheswick - 02Nov.pdf

Good day Tim,

I’m following-up on my recent conversations with Jason Maranche of the Allegheny County Health Department (ACHD). Jason mentioned that you and others from the ACHD discussed the BART modeling protocol for Reliant’s Cheswick facility. Per Jason’s request, please find attached the subject protocol. The proposed modeling procedures for Cheswick are the same as described in our protocols for the Conemaugh, Keystone, New Castle and Portland facilities. ENSR will conduct the modeling in accordance with the protocol and your comments as discussed during our recent correspondence. Reliant Energy expects to submit the BART analysis reports for all 5 of our facilities to the PA DEP by January 31, 2007. A copy of the BART analysis report for Cheswick will be submitted to the ACHD. Please contact me if you have any questions or comments. Thanks again for you assistance with this project. Happy Holidays!

John Shimshock
Reliant Energy, Inc.
(724) 597-8405

RE BART Modeling Protocol Comments 04 January 2007

From: Leon-Guerrero, Timothy [tleonguerr@state.pa.us]
Sent: Thursday, January 04, 2007 9:34 AM
To: Paine, Bob
Cc: Herb, Nancy; Shimshock, John
Subject: RE: BART Modeling Protocol Comments

In my mind this would be the most preferred option. Just make sure you follow the VISTA's protocol and in particular the sections regarding what model results to present.

Timothy A. Leon Guerrero
Chief, Air Quality Modeling Section
Harrisburg, PA

717 783-9243
tleonguerr@state.pa.us

-----Original Message-----
From: Paine, Bob [mailto:BPaine@ensr.aecom.com]
Sent: Thursday, January 04, 2007 9:27 AM
To: Leon-Guerrero, Timothy
Cc: Herb, Nancy; Shimshock, John
Subject: RE: BART Modeling Protocol Comments

Tim,

As I recall during our conference call with you and Nancy before Christmas on the Reliant BART protocols, the PA DEP would accept the use of the VISTAS 3-year met data set (subdomain 5) for sources in SW Pennsylvania. It is our recent experience that this data set is more robust than the MANE-VU data because it has a finer grid spacing (4 km vs. 12 km) and encompasses 3 years rather than just 1 year for the MANE-VU data. If we were to use the VISTAS three years, we would report the 98th percentile statistics.

So, can we use the VISTAS data for Reliant BART assessments for Keystone, Conemaugh, Cheswick, and New Castle as an option? We do not see this as a major schedule impediment, and would still be able to complete the BART assessments this month.

Regards,

Bob Paine, CCM, QEP
Technical Director
Direct line 978.589.3164
Bob,

Nancy and I are available Wednesday afternoon and all day Thursday. Let us know a time, data and call-in number. We can discuss any outstanding issues at that time.

Timothy A. Leon Guerrero
Chief, Air Quality Modeling Section
Harrisburg, PA
717 783-9243
tleonguerr@state.pa.us

Tim,

I have conferred with John Shimshock of Reliant Energy on these preliminary comments (John's e-mail address had a typo, so I forwarded the comments to him separately). Our initial responses to your comments are provided below, provided after each comment in brackets. So as not to delay this procedure any further with the holidays approaching, I wonder if we could have a conference call on Wednesday or Thursday this week to finalize our BART modeling procedures. The completion date of January 10, 2007 looks somewhat doubtful at this point, but we expect quite low impacts from well-controlled PM10 emissions, and Reliant Energy believes that the impacts of the PM10 emissions are either so low that even zero emissions would achieve very little visibility improvement, and also that the ESP controls are already highly efficient, so that no further BART controls are practical.

Bob

Consultant: ENSR/AECOM (ENSR)
Companies: Reliant Energy, Conemaugh Plant, Indiana County
Reliant Energy, New Castle Power Plant, Lawrence County
Reliant Energy, Keystone Power Plant, Armstrong County
Reliant Energy, Portland Generating Station, Northampton County
Reliant Energy, Cheswick Power Station, Allegheny County

General Comments:

All modeling activities should be fully documented. Please include all reference documents and ensure copies are sent to the appropriate regional offices.

Please include an electronic version of the modeling protocol (with any changes regarding my comments) with the modeling analysis.

[Tim: Reliant Energy should have no problem complying with these requests.]

CALMET Comments:

ENSR plans to use the same MM5 used in the MANE-VU modeling analysis. The applicant will have to provide proper documentation if the 12-km data set indicates a more refined grid will be needed.
[Paine: yes, we are agreeing to use the highest day's prediction for the exemption test as a screening procedure due to the limitations of the MANE-VU database. We have a follow-up question regarding exemption below.]

CALPUFF Comments:

The modeling domains appear to maintain the 50-km buffer between the source/receptors and the model boundaries. Does ENSR believe its lateral boundaries are chosen well enough to prevent individual puffs from leaving the modeling domain that could have had an effect on the Class I receptors (reentered the domain)?

[Paine: a buffer of 50 km is typically approved by the Federal Land Managers. For the plants in western PA, due to the large north-south distance to be covered, we would agree to expand the east-west buffer zone to 100 km.]

Please document the reasoning behind the 1.0 ppb ammonia background concentration used in the CALPUFF modeling.

[Paine: that is what is used in the MANE-VU modeling. Since NOx emissions are not being modeled, the selection of the ammonia background will not affect the results.]

Please indicate which version of CALPUFF is used in the modeling analysis.

[Paine: the MANE-VU CALMET system was run with an older version of the model. For consistency, we need to use the following model versions:

CALPUFF: Version 5.711a, Level 040716
CALPOST: Version 5.51, Level 030709]

Emission rates were included for all BART eligible units. Could ENSR provide a reason why there are some significant differences in the PM10 emission rates between the two units at Keystone and Conemaugh? Also, the Keystone stack parameters do not appear to reflect the installation of scrubber and the construction of a new stack. Does Reliant intend to model its new scrubbed stacks at Keystone?

[Paine: the PM10 emissions are derived from the available stack tests. Due to boiler differences, the stack tests had different results. We are using the results of the stack tests directly.]

We are modeling regional haze rule baseline conditions that existed during the defined period of 2000-2004. Future stack changes as a result of the Clean Air Interstate Rule or other factors are not accounted for in the BART exemption modeling. In any case, though, the long-range travel involved for the Class I areas to be evaluated would likely make the stack height and plume rise differences immaterial in the results.

CALPOST/Presentation of Results:

Please follow the VISTAS reporting outlined in section 4.5 of the VISTAS modeling protocol. Please note that Pennsylvania and other MANE-VU states are not using a visibility threshold limit in their analysis. Therefore all model output should be included.

[Paine: all modeling results will be presented. We have proposed, however, that a modeling result below the EPA BART rule specified threshold of 0.5 delta deciviews will lead to a finding of no required BART determination analysis for PM10 for each plant involved in the BART analysis. If this is not what PA DEP will agree to, please specify an alternative analysis or threshold for this determination. Basically, we are modeling only PM10 for these plants, which are already well controlled for PM10 with electrostatic precipitators. Therefore, no further BART controls for PM10 emissions would be proposed.]-----Original Message-----
From: Leon-Guerrero, Timothy [mailto:tleonguerr@state.pa.us]
Sent: Thursday, December 14, 2006 2:06 PM
To: Paine, Bob
Cc: Herb, Nancy; jshimsock@reliant.com
Subject: BART Modeling Protocol Comments

Bob,

I attached some comments regarding the BART Modeling protocols you sent me. These are informal and general in nature. I need to figure out how I'm going to get them out to the region and the companies themselves at a later date. Let me know if you have any questions (I will be out until Monday after today).

<<ENSR.doc>>

Timothy A. Leon Guerrero
Chief, Air Quality Modeling Section
Harrisburg, PA

717 783-9243
tleonguerr@state.pa.us
Appendix B

CALPOST List Files for Shenandoah National Park
CALPOST Output Without Sulfates

<table>
<thead>
<tr>
<th>YEAR DAY</th>
<th>HR</th>
<th>RECEPTOR (COORDINATES) (km)</th>
<th>E2XT (Source Ext. E2X/BG Ext. Total)</th>
<th>%CH%E2X/CH%BG Ext. (%)</th>
<th>CH%BG Ext. (%)</th>
<th>bsOC</th>
<th>bsBC</th>
<th>bsPM2.5</th>
<th>bsPM10</th>
<th>Rand</th>
<th>df(tot) (dr/brick)</th>
<th>dAv</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>1</td>
<td>497</td>
<td>1603.249</td>
<td>26.329</td>
<td>0.128</td>
<td>29.39</td>
<td>20.97</td>
<td>0.109</td>
<td>0.00</td>
<td>0.087</td>
<td>0.009</td>
<td>0.009</td>
</tr>
<tr>
<td>2006</td>
<td>2</td>
<td>488</td>
<td>1603.01</td>
<td>31.084</td>
<td>0.106</td>
<td>21.06</td>
<td>20.25</td>
<td>0.131</td>
<td>0.00</td>
<td>0.083</td>
<td>0.005</td>
<td>0.006</td>
</tr>
<tr>
<td>2006</td>
<td>3</td>
<td>485</td>
<td>1602.06</td>
<td>41.975</td>
<td>0.105</td>
<td>21.54</td>
<td>20.92</td>
<td>0.126</td>
<td>0.00</td>
<td>0.082</td>
<td>0.004</td>
<td>0.005</td>
</tr>
<tr>
<td>2006</td>
<td>4</td>
<td>483</td>
<td>1600.388</td>
<td>22.111</td>
<td>0.151</td>
<td>28.10</td>
<td>20.14</td>
<td>0.27</td>
<td>0.00</td>
<td>0.063</td>
<td>0.003</td>
<td>0.006</td>
</tr>
<tr>
<td>2006</td>
<td>5</td>
<td>482</td>
<td>1600.517</td>
<td>4.581</td>
<td>0.148</td>
<td>29.57</td>
<td>20.62</td>
<td>0.25</td>
<td>0.00</td>
<td>0.062</td>
<td>0.003</td>
<td>0.006</td>
</tr>
<tr>
<td>2006</td>
<td>6</td>
<td>481</td>
<td>1600.288</td>
<td>22.111</td>
<td>0.146</td>
<td>28.10</td>
<td>20.14</td>
<td>0.26</td>
<td>0.00</td>
<td>0.062</td>
<td>0.003</td>
<td>0.006</td>
</tr>
<tr>
<td>2006</td>
<td>7</td>
<td>478</td>
<td>1599.518</td>
<td>38.110</td>
<td>0.140</td>
<td>29.10</td>
<td>20.14</td>
<td>0.21</td>
<td>0.00</td>
<td>0.062</td>
<td>0.003</td>
<td>0.006</td>
</tr>
<tr>
<td>2006</td>
<td>8</td>
<td>476</td>
<td>1599.389</td>
<td>41.975</td>
<td>0.136</td>
<td>29.57</td>
<td>20.62</td>
<td>0.25</td>
<td>0.00</td>
<td>0.062</td>
<td>0.003</td>
<td>0.006</td>
</tr>
<tr>
<td>2006</td>
<td>9</td>
<td>474</td>
<td>1598.517</td>
<td>4.581</td>
<td>0.134</td>
<td>29.57</td>
<td>20.62</td>
<td>0.25</td>
<td>0.00</td>
<td>0.062</td>
<td>0.003</td>
<td>0.006</td>
</tr>
<tr>
<td>2006</td>
<td>10</td>
<td>472</td>
<td>1597.756</td>
<td>29.111</td>
<td>0.131</td>
<td>29.57</td>
<td>20.62</td>
<td>0.24</td>
<td>0.00</td>
<td>0.061</td>
<td>0.003</td>
<td>0.006</td>
</tr>
<tr>
<td>2006</td>
<td>11</td>
<td>470</td>
<td>1597.257</td>
<td>29.111</td>
<td>0.127</td>
<td>29.57</td>
<td>20.62</td>
<td>0.24</td>
<td>0.00</td>
<td>0.061</td>
<td>0.003</td>
<td>0.006</td>
</tr>
<tr>
<td>2006</td>
<td>12</td>
<td>468</td>
<td>1596.465</td>
<td>29.111</td>
<td>0.123</td>
<td>29.57</td>
<td>20.62</td>
<td>0.24</td>
<td>0.00</td>
<td>0.061</td>
<td>0.003</td>
<td>0.006</td>
</tr>
<tr>
<td>2006</td>
<td>13</td>
<td>466</td>
<td>1595.664</td>
<td>29.111</td>
<td>0.119</td>
<td>29.57</td>
<td>20.62</td>
<td>0.24</td>
<td>0.00</td>
<td>0.061</td>
<td>0.003</td>
<td>0.006</td>
</tr>
</tbody>
</table>

Source-Specific BART Modeling Report: Cheswick Power
Station Unit 1 – 10267-047-115

January 2007
Appendix C

Re-Calculating CALPOST Visibility Outputs with the New IMPROVE Algorithm
Instructions:
A Postprocessor for Recalculating CALPOST Visibility Outputs
with the New IMPROVE Algorithm

Version 2
14 October 2006

Introduction

CALPOST can be used to processes outputs from CALPUFF modeling of a source’s emissions to calculate the 24-hr average visibility impairments caused by primary and secondary particulate matter attributable to emissions from the modeled source. Those increments are presented in two tables, both labeled “Ranked Daily Visibility Change”, in the CALPOST output (LST) file. The table of interest to us has the subtitle “Modeled Extinction by Species” and lists the dates and locations of such incremental impacts in light extinction (b_...) in ranked order, starting with the one that represents the largest percentage change in light extinction.¹

In addition, with a different setup of the control file CALPOST.INP, the CALPOST postprocessor can be used to calculate 24-hr averages of NO₂ concentrations. As described below, the outputs from that additional CALPOST run can be used to assess the visibility impact of the NO₂ gas in the source plume.

Visibility effects due to particulate matter are calculated in CALPOST from CALPUFF-modeled particulate matter component concentrations using effectively the “traditional” IMPROVE algorithm. CALPOST allows for choice of the humidity scattering enhancement function (f(RH)) to be used with the IMPROVE algorithm; for modeling in connection with the US EPA’s Regional Haze Regulations (RHR), the appropriate form of f(RH) is the one described and tabulated in the EPA’s 2003 guidance for tracking progress under the RHR. Visibility effects due to NO₂ are not considered in the CALPOST visibility calculation.

Recently, the IMPROVE Steering Committee developed a new algorithm for estimating light extinction from particulate matter component concentrations. This algorithm (the “new IMPROVE algorithm”) provides a better correspondence between the measured visibility and

¹ The other table in the CALPOST visibility output file, with the subtitle “% of Modeled Extinction by Species”, provides equivalent results in terms of changes in the haze index, in deciviews. The two tables represent the same results, with identical ranking of events, while just using different (but mathematically related) metrics.
that calculated from particulate matter component concentrations. The new algorithm differs in several substantive ways from the traditional one:

- The extinction efficiencies of sulfates, nitrates, and organics have been changed and are now functions of their concentrations. The extinction efficiencies of sulfate and nitrate are no longer identical, although the new hygroscopic scattering enhancement factors applied to them are the same.

- The concentration of particulate organic matter (POM; variously also labeled OCM or OMC, and sometimes just called “organics”) is now taken to be 1.8 times that of the measured organic carbon (OC) concentration. (Confusingly, CALPOST labels the organics concentration as OC.)

- The contribution of fine sea salt to light extinction has been added, and is accompanied by its own hygroscopic scattering enhancement factor, \( f_{s}(RH) \).

- The light scattering by air itself (Rayleigh scattering) now varies with site elevation and mean temperature. It is to be rounded off to the nearest one \( \text{Mm}^{-1} \) when used with the new algorithm.

- The light absorption by \( \text{NO}_2 \) gas has been added.

The new IMPROVE algorithm is represented by the following formula:\(^2\)

\[
\begin{align*}
\beta_{ext} &= 2.2 f_s(RH) \cdot \text{[small sulfate]} + 4.8 f_s(RH) \cdot \text{[large sulfate]} + 2.4 f_s(RH) \cdot \text{[small nitrate]} + 5.1 f_s(RH) \cdot \text{[large nitrate]} + 2.8 \text{[small organics]} + 6.1 \text{[large organics]} + 10 \text{[elemental carbon]} + 1 \text{[fine soil]} + 1.7 f_{ss}(RH) \cdot \text{[sea salt]} + 0.6 \text{[coarse matter]} + 0.3 \text{[Rayleigh scattering (site specific)]} + 0.33 \text{[NO}_2\text{(ppb)]} \\
\end{align*}
\]

(Eq. 1)

The concentrations of “large” and “small” sulfate particles are calculated as follows:

\[
\begin{align*}
\text{[large sulfate]} &= \frac{[\text{total sulfate}]}{20} \cdot [\text{total sulfate}] \quad \text{if } [\text{total sulfate}] < 20 \, \mu g/m^3 \\
\text{[large sulfate]} &= [\text{total sulfate}] \quad \text{if } [\text{total sulfate}] \geq 20 \, \mu g/m^3 \\
\text{[small sulfate]} &= [\text{total sulfate}] - [\text{large sulfate}] \\
\end{align*}
\]

(Eqs. 2)

Identical formulas, with changes in component names, are used for nitrate and organics. In effect, these formulas conclude that low concentrations of these components are mainly in the form of “small” particles with their own extinction efficiency and \( f_s(RH) \), while high

\(^2\) Square brackets denote concentrations.
concentrations (approaching 20 µg/m³) are mainly in the form of “large” particles with a different extinction efficiency and f_{i}(RH). The scaling factor [total sulfate]/20 sets the fraction of total sulfate that is small.

The sea salt concentration is taken to be 1.8*[{Cl}⁻] or, if chloride ion measurements are not available, the chlorine concentration can be used in its place. Site specific Rayleigh scattering values have been calculated for all IMPROVE sites. Nitrogen dioxide concentrations are not measured at IMPROVE sites, but the ambient NO₂ concentrations under natural conditions can be expected to be negligibly small. The higher NO₂ concentration in a source plume may be great enough to cause a change in visibility, however.

In order to enable CALPOST to calculate CALPUFF-modeled source impacts on visibility using the new IMPROVE algorithm, it would have to be extensively reprogrammed. As an alternative, such a calculation could be done “off line” by adding another layer of post processing after CALPOST. To this end, I have developed a processor, in the form of an Excel workbook, that takes the CALPOST “Ranked Daily Visibility Change: Modeled Extinction by Species” output table, referenced against default annual average natural conditions concentrations, and creates an equivalent table of results based on the new algorithm. It can also incorporate the visibility impact due to light absorption by NO₂ in the plume.

The following describes the science behind the processor (which we’ll call the CALPOST-IMPROVE Processor) and provides instructions for using it.

**Concepts**

In addition to the mechanical changes imposed by all the new terms in the new IMPROVE formula, applying the new algorithm also requires some conceptual changes. The biggest of these is that the extinction efficiencies of sulfates, nitrates, and organics now depend on the concentrations of those species. The practical implication of this is that extinction is no longer linearly additive. To calculate total extinction, you cannot take a background level of extinction and add to it CALPOST’s calculation of extinction caused by the particulate matter coming from a source, because when the two aerosols mix in the atmosphere their combined mass concentration results in increases in the extinction efficiencies of both the background and the source contribution. This means that combining background particulate matter with the particulate matter from a source gives an extinction result that is greater than the sum of the two separate extinctions.

With the nonlinear behavior resulting from applying the new IMPROVE algorithm, the extinction impact of the source (i.e., the increase in extinction resulting from introducing source emissions into the atmosphere) is the sum of three parts:

1. The source impact calculated by the new IMPROVE algorithm using the CALPOST outputs for a plume in isolation;

---

2. An increase in that source impact because the extinction efficiency increases when the source’s aerosol combines with the background aerosol; and correspondingly,

3. An increase in the extinction of the background aerosol because of that same mixing.

The total new extinction is the sum of the above three components plus the original background extinction. The original background extinction is just that calculated by the new IMPROVE algorithm from background concentrations of the various components, without any consideration of the effects of the plume. For this application, the background is taken to be that described by EPA’s default natural conditions. The difference between the total extinction and the background is the impact of the source.

More details about the calculation are given in the appendix.

**Description of Processor**

The CALPOST-IMPROVE Processor is a Microsoft Excel workbook that consists of four worksheets. In Version 2 the worksheets are the following.

1. **Input & Output** – The output table from CALPOST is imported here and user entries are made for the Rayleigh scattering coefficient and, if desired, for a sea salt concentration at the Class I area of interest. The NO₃ concentration on each day attributable to the emissions from the source can also be entered together with an assumption of what fraction of the NO₃ is in the form of NO₂. A revised table, with extinction based on the new IMPROVE algorithm is then presented on the same page. This is the only page on which user input takes place, and the results of the calculations appear on this page.

2. **Calculations** – The calculations themselves are all done on this worksheet. There is no user input to this page. The variables are explained on the worksheet itself, so the user can find intermediate values if so inclined.

3. **F(RH)** – This worksheet tabulates the traditional IMPROVE f(RH) against RH, and then also lists values for the three new humidity growth functions, fₐ(RH), fₛ(RH), and fₛₐ(RH). It serves as a lookup table for the “Calculations” worksheet.

4. **Rayleigh & Sea Salt** – This page tabulates the IMPROVE-recommended Rayleigh scattering coefficients for all VISTAS Class I areas and for Class I areas in adjacent states. It also lists the average sea salt concentrations for the same locations, as tabulated on the VIEWS web site, based on chloride or chlorine measurements by IMPROVE monitors between 2000 and 2004. This sheet just provides information for the user; it is not linked to the rest of the workbook. The user can obtain Rayleigh and sea salt numbers for the Class I area of interest from this table and then manually enter them in the designated spaces in worksheet 1.
Instructions for Using the CALPOST-IMPROVE Processor

These instructions apply to Version 2 of the processor. Version 2 includes the ability to calculate the light extinction effects of NO₂ resulting from the source's emissions.

Step 1. Begin by opening the output (.LST) file from a CALPOST visibility calculation run in a text editor or word processing program. In the second half of the file, locate the table “Ranked Daily Visibility Change” with the subheading “Modeled Extinction by Species”.

Step 2. Copy this table and paste it onto a new page. Save it as a text (.txt) file, not as a formatted (e.g., MS Word .doc or .rtf) file. The final table should contain only the column headings and the data. Delete all other captions, any additional data summaries at the end, and blank lines before or after the table. The processor can handle a maximum of 22 lines of data (i.e., the highest rank in the last, unlabeled, column should be 22) plus a row of column captions. Delete any data that exceed this limit. (Fewer than 22 lines of data are OK.) The result should look like the example in Figure 1, although the line wrapping may differ.

Step 3. Open the CALPOST-IMPROVE Processor in Microsoft Excel. Save the open file under a new name so that the original empty processor will remain available for future use. The front worksheet, labeled “Input & Output” looks like Figure 2. There is a large empty box, surrounded by double lines, into which the table created above will be imported, as described below. On the right is a box into which NOₓ concentrations may be entered manually, and a small box below this box is provided for entry of the user’s assumption of what fraction of that NOₓ is in the form of NO₂. Two smaller boxes provide for user input of the Rayleigh scattering coefficient and, optionally, sea salt concentration for the Class I area, as described below. Results of the new IMPROVE algorithm calculations appear in blue in the lower half of the worksheet and some additional results, that are also useful for quality control, appear in green to the right of the large box. At the moment, many results cells will display nonsensical numbers and error messages, such as shown in Figure 2.

Step 4. Select the upper left cell (A1) in the large box. On the Excel menu bar, go to Data>Get External Data and click on Import Text File. (If the large box is not empty, click on Edit Text Import instead.) Select the file that contains the table created in Step 2 and click on the Get Data button. Go through the Text Import Wizard steps, checking that all values appear correctly in separate columns. (The label "COORDINATES (km)" will be split over two columns; this is OK.) When everything appears in order, click Finish.

---

4 The background concentrations that were entered into CALPOST must be the EPA-prescribed default annual average natural conditions concentrations for the East. The processor will not give correct answers if other concentrations were used in CALPOST.

5 For future reference in Step 7, this may also be a good time to locate the table with the same title but with the subtitle “% of Modeled Extinction by Species”, which appears later in the output file.

6 If the workbook has already been used, the boxes may not be empty. This does not matter.

7 The exact wording may vary slightly between different versions of Microsoft Excel. The terminology used here is from Excel 2004 for Macintosh.
### Figure 1. Example of CALPOST Output Table, in Proper Format for Importing into the CALPOST-IMPROVE Processor.

Step 5. The “Import Data” window will appear, with cell A7 indicated as the location at which data will be entered. Click on the Properties button. In the window that appears, select “Overwrite existing cells with new data, clear unused cells” and uncheck “Adjust column width”, then click on OK. Now click on the OK button in the “Import Data” window.

Step 6. Assuming that your Excel application is set up to automatically recalculate whenever any entries are changed, you should now have filled the cells in the large box on the first worksheet.

---

If the processor already had data in it and Edti Text Import was clicked in Step 4, then the “Import Data” window will not appear and Step 5 can be skipped.

---

<table>
<thead>
<tr>
<th>YEAR</th>
<th>DAY</th>
<th>HR</th>
<th>RECEPTOR</th>
<th>COORDINATES (km)</th>
<th>TYPE</th>
<th>NEXT(Original)</th>
<th>NEXT(Prop)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>175</td>
<td>0</td>
<td>1027</td>
<td>1479.069</td>
<td>24.483</td>
<td>5.495</td>
<td>21.650</td>
</tr>
<tr>
<td>25.28</td>
<td>1.009</td>
<td>5.401</td>
<td>0.045</td>
<td>0.442</td>
<td>0.002</td>
<td>0.001</td>
<td>0.084</td>
</tr>
<tr>
<td>2002</td>
<td>177</td>
<td>0</td>
<td>1021</td>
<td>1479.444</td>
<td>24.778</td>
<td>5.493</td>
<td>21.650</td>
</tr>
<tr>
<td>22.74</td>
<td>1.506</td>
<td>4.475</td>
<td>0.040</td>
<td>0.538</td>
<td>0.001</td>
<td>0.001</td>
<td>0.054</td>
</tr>
<tr>
<td>14.67</td>
<td>3.200</td>
<td>2.640</td>
<td>0.428</td>
<td>0.832</td>
<td>0.001</td>
<td>0.001</td>
<td>0.022</td>
</tr>
<tr>
<td>2002</td>
<td>533</td>
<td>0</td>
<td>1026</td>
<td>1802.762</td>
<td>24.457</td>
<td>2.594</td>
<td>21.290</td>
</tr>
<tr>
<td>12.18</td>
<td>3.109</td>
<td>2.917</td>
<td>0.527</td>
<td>0.328</td>
<td>0.001</td>
<td>0.000</td>
<td>0.002</td>
</tr>
<tr>
<td>2002</td>
<td>283</td>
<td>0</td>
<td>1026</td>
<td>1802.762</td>
<td>24.457</td>
<td>2.594</td>
<td>21.290</td>
</tr>
<tr>
<td>11.45</td>
<td>3.200</td>
<td>3.269</td>
<td>0.201</td>
<td>0.428</td>
<td>0.001</td>
<td>0.001</td>
<td>0.003</td>
</tr>
<tr>
<td>2002</td>
<td>195</td>
<td>0</td>
<td>1045</td>
<td>1848.348</td>
<td>27.580</td>
<td>2.011</td>
<td>21.830</td>
</tr>
<tr>
<td>6.21</td>
<td>3.700</td>
<td>1.943</td>
<td>0.633</td>
<td>0.815</td>
<td>0.001</td>
<td>0.000</td>
<td>0.001</td>
</tr>
<tr>
<td>6.63</td>
<td>3.000</td>
<td>1.542</td>
<td>0.320</td>
<td>0.699</td>
<td>0.060</td>
<td>0.000</td>
<td>0.003</td>
</tr>
<tr>
<td>2003</td>
<td>173</td>
<td>0</td>
<td>1139</td>
<td>1579.259</td>
<td>25.042</td>
<td>1.649</td>
<td>21.650</td>
</tr>
<tr>
<td>7.62</td>
<td>3.000</td>
<td>1.625</td>
<td>0.612</td>
<td>0.010</td>
<td>0.000</td>
<td>0.000</td>
<td>0.008</td>
</tr>
<tr>
<td>2002</td>
<td>234</td>
<td>0</td>
<td>1021</td>
<td>1479.244</td>
<td>25.778</td>
<td>5.124</td>
<td>22.199</td>
</tr>
<tr>
<td>6.47</td>
<td>4.500</td>
<td>1.462</td>
<td>0.625</td>
<td>0.610</td>
<td>0.060</td>
<td>0.000</td>
<td>0.003</td>
</tr>
<tr>
<td>2002</td>
<td>236</td>
<td>0</td>
<td>1021</td>
<td>1479.244</td>
<td>25.778</td>
<td>5.124</td>
<td>22.199</td>
</tr>
<tr>
<td>6.49</td>
<td>3.900</td>
<td>1.384</td>
<td>0.180</td>
<td>0.514</td>
<td>0.001</td>
<td>0.000</td>
<td>0.003</td>
</tr>
<tr>
<td>2002</td>
<td>229</td>
<td>0</td>
<td>1021</td>
<td>1479.244</td>
<td>25.778</td>
<td>5.124</td>
<td>22.199</td>
</tr>
<tr>
<td>6.59</td>
<td>3.300</td>
<td>1.281</td>
<td>0.140</td>
<td>0.013</td>
<td>0.060</td>
<td>0.000</td>
<td>0.003</td>
</tr>
<tr>
<td>2002</td>
<td>275</td>
<td>0</td>
<td>1026</td>
<td>1802.762</td>
<td>24.457</td>
<td>1.270</td>
<td>21.470</td>
</tr>
<tr>
<td>5.92</td>
<td>3.100</td>
<td>1.292</td>
<td>0.635</td>
<td>0.028</td>
<td>0.060</td>
<td>0.000</td>
<td>0.003</td>
</tr>
<tr>
<td>2002</td>
<td>263</td>
<td>0</td>
<td>1045</td>
<td>1848.348</td>
<td>27.580</td>
<td>1.237</td>
<td>22.100</td>
</tr>
<tr>
<td>5.69</td>
<td>4.600</td>
<td>1.222</td>
<td>0.608</td>
<td>0.095</td>
<td>0.060</td>
<td>0.000</td>
<td>0.003</td>
</tr>
<tr>
<td>2002</td>
<td>252</td>
<td>0</td>
<td>1026</td>
<td>1802.762</td>
<td>24.457</td>
<td>1.189</td>
<td>22.100</td>
</tr>
<tr>
<td>5.18</td>
<td>4.000</td>
<td>1.116</td>
<td>0.613</td>
<td>0.095</td>
<td>0.060</td>
<td>0.000</td>
<td>0.003</td>
</tr>
<tr>
<td>2002</td>
<td>243</td>
<td>0</td>
<td>1021</td>
<td>1479.244</td>
<td>25.778</td>
<td>0.992</td>
<td>21.470</td>
</tr>
<tr>
<td>4.62</td>
<td>3.200</td>
<td>0.813</td>
<td>0.179</td>
<td>0.091</td>
<td>0.000</td>
<td>0.000</td>
<td>0.005</td>
</tr>
<tr>
<td>2002</td>
<td>538</td>
<td>0</td>
<td>1026</td>
<td>1802.762</td>
<td>24.457</td>
<td>0.870</td>
<td>21.389</td>
</tr>
<tr>
<td>4.93</td>
<td>3.500</td>
<td>0.842</td>
<td>0.620</td>
<td>0.099</td>
<td>0.060</td>
<td>0.000</td>
<td>0.003</td>
</tr>
<tr>
<td>2002</td>
<td>238</td>
<td>0</td>
<td>1021</td>
<td>1479.244</td>
<td>25.778</td>
<td>0.870</td>
<td>21.389</td>
</tr>
<tr>
<td>4.91</td>
<td>3.200</td>
<td>0.822</td>
<td>0.626</td>
<td>0.099</td>
<td>0.060</td>
<td>0.000</td>
<td>0.003</td>
</tr>
<tr>
<td>2002</td>
<td>249</td>
<td>0</td>
<td>1045</td>
<td>1848.348</td>
<td>27.580</td>
<td>0.817</td>
<td>21.299</td>
</tr>
<tr>
<td>4.84</td>
<td>3.100</td>
<td>0.632</td>
<td>0.153</td>
<td>0.693</td>
<td>0.060</td>
<td>0.000</td>
<td>0.003</td>
</tr>
<tr>
<td>2002</td>
<td>151</td>
<td>0</td>
<td>1117</td>
<td>1808.636</td>
<td>24.092</td>
<td>0.745</td>
<td>21.389</td>
</tr>
<tr>
<td>3.49</td>
<td>3.200</td>
<td>0.794</td>
<td>0.633</td>
<td>0.087</td>
<td>0.060</td>
<td>0.000</td>
<td>0.003</td>
</tr>
<tr>
<td>2002</td>
<td>160</td>
<td>0</td>
<td>1021</td>
<td>1479.244</td>
<td>25.778</td>
<td>0.735</td>
<td>21.650</td>
</tr>
<tr>
<td>3.49</td>
<td>3.500</td>
<td>0.710</td>
<td>0.614</td>
<td>0.010</td>
<td>0.060</td>
<td>0.000</td>
<td>0.003</td>
</tr>
<tr>
<td>2002</td>
<td>234</td>
<td>0</td>
<td>1021</td>
<td>1479.244</td>
<td>25.778</td>
<td>0.703</td>
<td>21.299</td>
</tr>
<tr>
<td>3.30</td>
<td>3.100</td>
<td>0.620</td>
<td>0.680</td>
<td>0.092</td>
<td>0.060</td>
<td>0.000</td>
<td>0.003</td>
</tr>
<tr>
<td>2002</td>
<td>247</td>
<td>0</td>
<td>1021</td>
<td>1479.244</td>
<td>25.778</td>
<td>0.661</td>
<td>22.100</td>
</tr>
<tr>
<td>2.99</td>
<td>4.000</td>
<td>0.654</td>
<td>0.604</td>
<td>0.092</td>
<td>0.060</td>
<td>0.000</td>
<td>0.002</td>
</tr>
</tbody>
</table>

---

Source-Specific BART Modeling Report: Cheswick Power Station Unit 1 – 10267-047-115

January 2007
Figure 2. Example of Appearance of Input & Output Worksheet before Data Entry.
numbers should have appeared in the green columns to the right, and some numbers will have appeared in the output table in blue on the lower half of the worksheet. If the data import worked properly, none of the imported data should have spilled out of the large box. Check that all the column captions in bold outside the large box are now duplicated on the first line in the box. (There won’t be a caption for Rank.)

Step 7. As a further check on whether everything is correct so far, the dv information in the three columns to the right of the large box should be the same as that in the second CALPOST table “Ranked Daily Visibility Change: % of Modeled Extinction by Species”, which was mentioned in Footnote 1.

Step 8. Beneath the large box that was just filled with imported data, enter the Rayleigh scattering coefficient for the Class 1 area of interest into the top small box after red instruction 3. Also, if you wish, fill in the other small box, the one after red instruction 4, with the annual average sea salt concentration. (The sea salt box may be left blank, but the Rayleigh scattering coefficient box must be filled in.) To help with filling in these two boxes, the fourth worksheet, “Rayleigh & Sea Salt”, provides IMPROVE-calculated values of the Rayleigh coefficients for Class 1 areas in the VISTAS region and in adjacent states. Also, average sea salt concentrations for 2000-2004, calculated in accordance with the new IMPROVE procedures, can be found there.

Step 9. If the impact due to NO2 is to be considered, a second CALPOST run will be needed to provide the 24-hr average NOX concentrations estimated by CALPUFF. For this purpose, run CALPOST using the ASPEC – NOX option in Input Group 1 of the CALPOST.INP control file. The NOX values to insert in the NOX input box on the Input & Output page of the processor have to be extracted manually from the CALPOST output file for each date and receptor listed in the file that was imported in Steps 1 through 5 above and are displayed in the left hand columns in the large box.

Step 10. Select a value between 0 and 1 to represent what fraction of NOX is in the form of NO2. Enter this value into the small box at red instruction 6 below the column where the NOX concentrations were entered.10

Step 11. The blue data table at the bottom of the page represents the new IMPROVE algorithm outputs. An example is shown in Figure 3. This table can be compared with the original CALPOST table at the top of the page. All of the columns in both tables show exactly the same variables, except that the F(RH) column in the top table is replaced by just the RH in the lower table (since the new procedure has three different F(RH) functions) and a new baNO2 column has been added to the bottom table to show the light absorption due to NO2 (in Mm$^{-2}$). Although the events are listed in the same order in both tables, note that their rankings may have changed, as is the case for many of the lines in the blue output table in Figure 3.

---

8 Steps 8 and 9 are optional. If the impact due to NO2 is of no interest, just leave the entry fields mentioned in these steps blank.
10 An easy way to see the effect of the NO2 on the source’s impact in the output table in the lower half of the page is to toggle this NO2/NOX value between the selected value and zero.
For those who are interested in more detail concerning the calculations that take place, values of the three f(RH) functions appear in columns M through O on the second, “Calculations” spreadsheet. The extinction impact of the source, including enhancement of the extinction efficiencies for sulfates, nitrates, and organics because of greater total mass concentrations, appears in columns V through AC. Extinction due to the annual average natural background appears in Columns AJ through AN; natural background extinctions for those components that are enhanced by greater total mass concentrations appear in columns AU through AX.
Figure 3. Example of Appearance of Finished Input & Output Worksheet.
Appendix
Details of Calculation Approach

As an example of the calculation steps, assume that the sulfate concentration resulting from emissions from a source is \([S_E]\) and the sulfate in the undisturbed natural background is \([S_N]\), for a total ambient sulfate concentration of \([S_T]\). According to Equations 1 and 2 in the main body of this document, the total extinction due to sulfate for this combination is

\[
\text{[sul fate]} = 2.2\cdot f_{(RH)}\cdot [\text{small sulfate}] + 4.8\cdot f_{(RH)}\cdot [\text{large sulfate}], \tag{Eq. A-1}
\]

where

\[
[\text{large sulfate}^T] = \begin{cases} \{[S_T]/20\} \cdot [S_T] & \text{if } [S_T] < 20 \, \mu g/m^3 \\ [S_T] & \text{if } [S_T] \geq 20 \, \mu g/m^3 \end{cases}
\]

(Eq. A-2)

\[
[\text{small sulfate}^T] = [S_T] - [\text{large sulfate}^T],
\]

and the subscript \(T\) denotes total sulfate.

For the original background, where there is no source impact, the corresponding formulas for the terms in Equations A-2 are

\[
[\text{large sulfate}^N] = \begin{cases} \{[S_N]/20\} \cdot [S_N] & \text{if } [S_N] < 20 \, \mu g/m^3 \\ [S_N] & \text{if } [S_N] \geq 20 \, \mu g/m^3 \end{cases}
\]

(Eq. A-3)

\[
[\text{small sulfate}^N] = [S_N] - [\text{large sulfate}^N],
\]

where the subscript \(N\) denotes natural sulfate.

Similar calculations need to be carried out for nitrates. Contributions of the other particulate components are linear and can just be calculated according to Equation 1.

If the impact due to \(NO_2\) is also to be considered, then the source impact due to this component is, according to Equation 1,

\[
\text{[ext(NO}_2]} = 0.33 \cdot [NO_2], \tag{Eq. A-4}
\]

where \([NO_2]\) is in ppb. It is reasonable to assume that the ambient \(NO_2\) concentrations under natural conditions would be so small as to cause negligible light absorption, so the corresponding term is not needed in the natural conditions calculation.

The contributions due to the various components are summed together as in Equation 1 to obtain the total extinction \([\text{ext}]\) and the natural background extinction \([\text{ext}]_N\). The
fractional change in extinction is then calculated as the difference, normalized by the natural background extinction

\[
\frac{(b_{\text{ext}T} - b_{\text{ext}N})}{b_{\text{ext}N}} \quad \text{(Eq. A-5)}
\]

a result that can also be expressed in deciviews.

These formulas are used in the CALPOST-IMPROVE Processor. Similar formulas apply for nitrates and organics. There is no nonlinearity in the remaining terms in Equation 1.
U.S. Locations

AK, Anchorage  
(907) 561-5700

AL, Birmingham  
(205) 980-0054

AL, Florence  
(256) 767-1210

CA, Alameda  
(510) 748-6700

CA, Camarillo  
(805) 388-3775

CA, Orange  
(714) 973-9740

CA, Sacramento  
(916) 362-7100

CO, Ft. Collins  
(970) 493-8878

CO, Ft. Collins Tox Lab.  
(970) 416-0916

CT, Stamford  
(203) 323-6620

CT, Willington  
(860) 429-5323

FL, St. Petersburg  
(727) 577-5430

FL, Tallahassee  
(850) 385-5006

GA, Norcross  
(770) 381-1836

IL, Chicago  
(630) 836-1700

IL, Collinsville  
(618) 344-1545

LA, Baton Rouge  
(225) 751-3012

MA, Harvard Air Lab.  
(978) 772-2345

MA, Sagamore Beach  
(508) 888-3900

MA, Westford  
(978) 589-3000

MD, Columbia  
(410) 844-9280

ME, Cheswick  
(207) 773-9501

MI, Detroit  
(269) 385-4245

MN, Minneapolis  
(952) 924-0117

NC, Charlotte  
(704) 529-1755

NC, Raleigh  
(919) 872-6600

NH, Belmont  
(603) 524-8866

NJ, Piscataway  
(732) 981-0200

NY, Albany  
(518) 453-6444

NY, Rochester  
(585) 381-2210

NY, Syracuse  
(315) 432-0506

NY, Syracuse Air Lab.  
(315) 432-0506

OH, Cincinnati  
(513) 772-7800

PA, Langhome  
(215) 757-4900

PA, Pittsburgh  
(412) 261-2910

RI, Providence  
(401) 274-5685

SC, Columbia  
(803) 216-0003

TX, Dallas  
(972) 509-2250

TX, Houston  
(713) 520-9900

TX, San Antonio  
(210) 296-2125

VA, Chesapeake  
(757) 312-0063

VA, Glen Allen  
(804) 290-7920

WA, Redmond  
(425) 881-7700

WI, Milwaukee  
(262) 523-2040

Headquarters  
MA, Westford  
(978) 589-3000

Worldwide Locations

Azerbaijan
Belgium
Bolivia
Brazil
China
England
France
Germany
Ireland
Italy
Japan
Malaysia
Netherlands
Philippines
Scotland
Singapore
Thailand
Turkey
Venezuela

www.ensr.aecom.com

A Trusted Global Environmental, Health and Safety Partner
APPLICATION OF WET ELECTROSTATIC PRECIPITATION TECHNOLOGY IN THE UTILITY INDUSTRY FOR MULTIPLE POLLUTANT CONTROL INCLUDING MERCURY

Presented By: Wayne Buckley
Authors:
Ralph Altman, EPRI
&
Wayne Buckley
Dr. Isaac Ray
Croll-Reynolds Clean Air Technologies

Abstract
Wet electrostatic precipitation technology can be used to control acid mists, sub-micron particulate, mercury, metals and dioxins/furans as the final polishing device within a multi-pollutant air pollution control system. Test results from coal -fired installations demonstrate >90% removal efficiencies on PM2.5, SO3, and near zero opacity. Additionally, wet ESP technology can be used for mercury removal. How wet ESPs work, what configurations they come in and some of the design considerations are described. New developments to wet ESP technology to reduce cost, (membrane WESP), make higher performing in less space (single pass dual field) and enhance mercury control (plasma-enhanced ESP) will also be discussed.

Introduction
Power utilities are coming under increased scrutiny from regulators, the public and environmental groups. The ready availability of information about power plant emissions, along with recognition of the effects of acid gases, fine particulate and toxic chemicals on the environment and human respiratory systems, are forcing utilities to control their emissions to a much greater degree than ever before. The U.S. Environmental Protection Agency (EPA) has issued regulations to control PM10, NOx and SO2. New regulations to control mercury, PM2.5 and other hazardous air pollutants are being proposed. The trend is clear: EPA is seeking to control a multitude of pollutants that are comprised of smaller and harder-to-capture sub-micron particles, mists and metals.

The first ESP developed was actually a wet ESP to remove a sulfuric acid mist plume from a copper smelter designed by Dr. Cottrell in 1907. The technology has become a standard piece of process equipment for the sulfuric acid industry for over 50 years to abate SO3 mist, a sub-micron aerosol. In the past twenty years, wet ESP technology has been employed in numerous industrial applications for plume reduction associated with PM2.5 and SO3 mist, as well as for removal of toxic metals. Unfortunately, wet electrostatic precipitation is a relatively unknown technology to most industries and utilities because air regulations up to recently have not required high levels of control of sub-micron particulate.

Most utility facilities already have some sort of dry technology installed to control particulate emissions, such as a cyclone, fabric filter or dry ESP. Where acid gases or condensable particulate may be present
in a gas stream, a scrubber or gas absorber is typically in place. However, as regulations emerge requiring stringent control of sub-micron particulate—which includes acid mists, low and semi-volatile metals, mercury, and dioxins/furans—wet ESP technology is increasingly attractive due to its low pressure drop, low maintenance requirements, high removal performance and reliability as a final polishing device.

**ESP Operation**
Electrostatic precipitation consists of three steps: (1) charging the particles to be collected via a high-voltage electric discharge, (2) collecting the particles on the surface of an oppositely charged collection electrode surface, and (3) cleaning the surface of the collecting electrode.

As particles become smaller, gravitational and centrifugal forces become less powerful, while electrical and, to a lesser degree, Brownian forces become greater, especially for 0.1 to 0.5-micron particles. Consequently, electrical collection is an effective method for separating those sub-micron particles from the gas stream.

**TABLE 3**

<p>| PARTICLE DISPLACEMENTS IN STANDARD AIR DUE TO VARIOUS FORCE FIELDS |
|----------------------|-----------------|-----------------|----------------|-----------------|-----------------|
| <strong>PARTICLE DIAMETER</strong> | <strong>Displacements in 1 sec. for force field listed</strong> |</p>
<table>
<thead>
<tr>
<th><strong>Size in Microns</strong></th>
<th><strong>Feet</strong></th>
<th><strong>Cc</strong></th>
<th><strong>Grav.</strong></th>
<th><strong>Cent</strong></th>
<th><strong>Elect.</strong></th>
<th><strong>Brown.</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>10.0</td>
<td>3.28 x 10 (-5)</td>
<td>01.016</td>
<td>.024</td>
<td>20.5</td>
<td>0.98</td>
<td>.0000057</td>
</tr>
<tr>
<td>1.0</td>
<td>3.28 x 10 (-6)</td>
<td>01.165</td>
<td>.00027</td>
<td>00.235</td>
<td>0.11</td>
<td>.0000194</td>
</tr>
<tr>
<td>0.1</td>
<td>3.28 x 10 (-7)</td>
<td>02.93</td>
<td>.0000069</td>
<td>00.0059</td>
<td>0.27</td>
<td>.0000972</td>
</tr>
<tr>
<td>0.01</td>
<td>3.28 x 10 (-8)</td>
<td>22.6</td>
<td>.00000053</td>
<td>00.00046</td>
<td>2.12</td>
<td>.0008540</td>
</tr>
</tbody>
</table>

* Stokes Cunningham slip-correction factor-dimensionless
** Gravitational force field-downward linear displacements based on 32.2 ft./s² acceleration
*** Centrifugal force field-outward radial displacements based on 862 g’s acceleration
**** Electrostatic force field-normal linear displacements based on 7500 volts/in. Field strength and a saturation charge on the particles.
***** Brownian movement-random linear displacements based on average values

Most importantly, whereas mechanical collectors exert their force upon the entire gas, ESPs exert their force only upon the particles to be collected. ESPs typically operate at around 0.5-1.0 inch pressure drop, regardless of air volume or particle size. Alternatively, a mechanical collector such as a venturi scrubber would have to operate at around 60 inches of water column to achieve 95 percent collection efficiency on 0.5-micron particles. This is a major reason why dry ESPs are predominantly used in the utility industry. Every inch of pressure drop translates into dramatically higher energy requirements for operating the ID fan. To achieve 95 percent removal efficiency on 0.5-micron particles in a 1,000,000 cfm air flow, 12,000 kW of energy is required using a venturi scrubber, while an ESP needs only 100-
200 kW of energy for I.D. fan operation.

Dry ESPs
Dry ESPs consist of a series of parallel vertical plates, which act as the collecting electrodes, with a series of discharge electrodes in between the plates spaced some distance apart. As the contaminated flue gas passes through the ESP, negatively charged ions form near the tips of the sharp points of the ionizing electrode (corona discharge). These negatively charged ions move toward the positively charged collecting electrode surface and charge the contaminated particles passing through the ESP. These charged particles become attracted to the positively charged collection plate, where they accumulate on the surface. The collected particulate builds up on the dry collection surface and forms a layer of particles or “cake” that has insulating properties.

Dry ESPs perform best when particle deposits on the collecting plates have a resistivity greater than approximately $10^7$ ohm-cm, but less than $2 \times 10^{10}$ ohm-cm. If resistivity is less than $10^7$, the electrostatic force holding the dust particles on to the dust layer is too low and re-entrainment of particles in the flue gas can become a serious problem, reducing efficiency. If resistivity exceeds $2 \times 10^{10}$ ohm-cm, the voltage drop through the particle layer to the grounded electrode becomes significant, lowering field strength in the space between the ionizing electrode and the top of the dust layer. This can cause a breakdown in the electrical field and “back corona” can take place, again lowering efficiency. Resistivity becomes a limiting factor to the amount of electrical power that can be achieved within a dry ESP.

To dislodge the dust from the collecting electrode surface and into the bottom hopper, mechanical rappers or sonic horns are employed. However, portions of the particles remain suspended in air and get re-entrained in the gas stream. This secondary re-entrainment requires the use of another dry ESP field to collect the re-entrained particulate plus those particles not captured in the first field.

Dry ESPs have been used successfully for many years in industrial and utility applications for coarse particulate removal. Dry ESPs can achieve 99+ percent efficiency for particles 1 micron to 10 micron in size. However, they have several limitations that prevent their use in all applications:

- Dry ESPs are not capable of removing toxic gases and vapors that are in a vapor state at 400°F.
- Due to their low corona power levels because of resistivity of the particulate cake, dry ESPs cannot efficiently collect the very small fly ash particles.
- Dry ESPs cannot handle moist or sticky particulate that would stick to the collection surface.
- Dry ESPs cannot remove oxidized or elemental mercury
- Dry ESPs require a lot of real estate for multiple fields due to re-entrainment of particulate.
- Dry ESPs rely on mechanical collection methods to clean the plates, which require maintenance and periodic shutdowns.

Therefore, dry ESPs may not be the best practicable control device to meet the proposed PM2.5 standard, or as a final mist eliminator for acid gas mist on FGD systems in order to reduce opacity levels to near zero.
Wet ESPs
Wet ESPs operate in the same three-step process as dry ESPs—charging, collecting and finally cleaning of the particles. However, cleaning of the collecting electrode is performed by washing the collection surface with liquid, rather than mechanically rapping the collection plates (Figure 1).

While the cleaning mechanism would not be thought to have any impact upon performance, it significantly affects the nature of the particles that can be captured, the performance efficiencies that can be achieved and the design parameters and operating maintenance of the equipment. Simply stated, wet ESP technology is significantly different than dry ESP technology.

Because wet ESPs operate in a wet environment in order to wash the collection surface, they can handle a wider variety of pollutants and gas conditions than dry ESPs. Wet ESPs find their greatest use in applications where gas streams fall into one or more of the following categories:

- The gas in question has a high moisture content;
- The gas stream includes sticky particulate;
- The collection of sub-micron particulate is required;
- The gas stream has acid droplets or H2SO4
- The temperature of the gas stream is below the dew point.

Because wet ESPs continually wet the collection surface area and create a slurry that flows down the collecting wall to a recycle tank, the collecting walls never build up a layer of particulate cake.
Consequently, there is no deterioration of the electrical field due to resistivity, and power levels within a wet ESP can be dramatically higher than in a dry ESP. The ability to inject much greater electrical power within the wet ESP and elimination of secondary reentrainment are the main reasons a wet ESP can collect sub-micron particulate more efficiently.

Wet operation also prevents re-entrainment. The captured particulate flows down the collection wall in suspension to a recycle tank for treatment and never gets re-entrained into the flue gas. This reduces the need for multiple fields, as in a dry ESP where additional fields must be added to capture re-entrained particles from the previous field.

Wet ESPs are most effective for submicron particulate control. Smoke plume from a stack is the clearest sign of the presence of sub-micron particles in a gas stream. Due to refraction of sunlight, 0.5-micron particles are the most visible. Additionally, the surface area of the smallest particles in a flue gas is greater than the surface area of larger particles. One gram of 0.1-micron particles has 10 times the surface area as a gram of 1.0-micron particles (60 m$^2$ vs. 6.0 m$^2$). Toxic vapors however, condense uniformly on the surface area of all particles. That is why the capture of a gram of 0.1-micron ash particles is 10 times more effective at removing toxic pollutants than the capture of a gram of 1.0-micron ash particles.

In wet ESPs, the delivery mechanism for the irrigating liquid is critical to maintain thorough wetting of the collecting electrode surface to avoid corrosion issues without degrading the electrical system.

**Collection Efficiency**

For a given particulate or droplet size and concentration, ESP efficiency can be calculated by using the exponential Deutsch-Anderson equation. Field experience has shown that, with some modification, the same equation can also be applied to wet ESPs. The Deutsche-Anderson equation is:

$$\text{Eff} = 1 - \exp (-Aw/V)$$

Where the collecting electrode surface area, $A$, and volumetric flow rate, $V$, are calculated from the known geometry of the ESP and the process design data. The drift, or migration velocity, $w$, is determined by the operating power and particle size distribution.

There are two types of charging processes at work in an ESP. For particles greater than 1 micron, “field-charging” is primary and refers to particles being charged through the collision of negative ions as they follow the electric field lines to the surface of the particles. The peak operating voltage is the most important factor in field charging. For particles smaller than 0.5 micron, “diffusion-charging” is primary and occurs because of the random motion of the sub-micron particles and their collision with negative ions. The current density injected into the ESP is the most important factor in diffusion charging.

Wet ESPs are capable of removing sub-micron particles, droplets, and mists as small as 0.01 micron in size up to 99.9+ percent efficiency depending upon the number of fields employed and can achieve near zero opacity levels.
Tubular vs. Plate
Wet ESPs can be configured either as tubular precipitators with vertical gas flow or as plate precipitators with horizontal gas flow (Figure 1). For a utility application, tubular wet ESPs would be appropriate as a mist eliminator above a FGD scrubber, while the plate type could be employed at the back end of a dry ESP train for final polishing of the gas in a hybrid ESP. In general, tubular precipitators are more efficient than the plate type and take up less space due to simple geometry. A tubular wet ESP is just a horizontal ESP turned vertical with all four sides enclosed to act as collection surface. Other differences between the two types are:

- For a given efficiency, a tubular precipitator may be operated at twice the gas velocity of a plate precipitator of equal electrode length
- For a given efficiency, a tubular precipitator has a smaller footprint than a plate type precipitator.

Tubular precipitators can be designed as either up-flow or down-flow. In up-flow tubular ESPs, flue gas enters at the bottom of the ESP and flows upwards. The wash nozzles are located at the bottom spraying up into the ESP, co-current with the gas. In some cases, nozzles that spray down into the field are added above the field. In down-flow designs, the flue gas enters the top of the wet ESP and flows downwards. Similarly, the sprays are mounted on top, spraying down co-current with the gas.

![Diagram](image)

Figure 1: The comparison of a tubular WESP vs. a plate type WESP shows that, for a given efficiency, a tubular WESP can operate at twice the velocity of a plate type WESP, resulting in a smaller footprint (Applicable mostly for new construction).

While in some installations a down-flow design may minimize inter-connecting ductwork, it will require a mechanical mist eliminator to capture the water mist that has been carried along with the flue gas before entering the stack. Conversely, an up-flow, tubular wet ESP is an excellent mist eliminator due to its ability to capture sub-micron droplets and requires no mechanical mist eliminator.

Air Distribution
Distribution of the flue gas throughout the wet ESP is a critical design function. Overloading a section of
the wet ESP will negatively impact collection efficiency. While perforated plates below the electrical section will aid in proper air flow distribution, an alternative is using some sort of scrubber in front of the wet ESP. This accomplishes multiple purposes:

- Removal of any acid gas present, which reduces corrosion in the wet ESP and allows for less expensive materials of construction to be used (i.e., FGD application)
- Removal of particulate larger than 2 microns, which reduces the particulate loading on the wet ESP and allows for smaller size of the wet ESP
- Cooling of the gas, which reduces the gas volume and cuts down on the size of the wet ESP
- Saturation of the gas, which enhances condensation within the wet ESP
- Enhanced airflow distribution throughout the wet ESP due to limited pressure drop.

**Sparking**

Since wet ESP efficiency is directly proportional to the electrical power conveyed to the moving gas, each time a spark occurs, the voltage, and consequently the particulate collection efficiency, is reduced. Sparking rate for a given inter-electrode spacing is a function of the inlet loading (mist, droplet, or particulate) and alignment of the discharge electrodes. Additionally, the power level and efficiency of a wet ESP can be dramatically increased by properly designing the automatic voltage control system. While the industry average seldom goes beyond 50 percent conduction (i.e., the ability to deliver 50 percent of the available power to the gas), the proper selection of the transformer-rectifier (T/R), automatic voltage controller (AVC) and current limiting reactor (CLR) can deliver much greater conduction.

**Corona Current Suppression**

If there is a high loading of charged particles, corona current is diminished due to the low mobility of charged particles in the inter-electrode space. This phenomenon is called current suppression or space charge effect. A high concentration of fine particles, a typical scenario for space charge effect, can reduce the corona current by a factor of 50 or more.

Certain criteria should be met in order to prevent the deterioration of removal efficiency in the presence of a space charge effect. The level of current suppression that will be experienced in a particular application is related to the total surface area of the suspended particles and the designed corona current density within the given volume of the wet ESP collection section. For example, particles of 0.6-micron diameter have 100,000 cm$^2$/gram of surface, whereas particles of 0.3-micron diameter have more than 10 times the surface area per unit weight (1,100,000 cm$^2$/gram). For a given grain loading, the finer the particle, the more potential there is for current suppression to occur.

In the case of multiple fields in a wet ESP, collection efficiency can be maintained even in the presence of current suppression. The first pass will operate in “suppressed” conditions at a somewhat reduced efficiency level, but will condition the gas for the second pass, which will operate at its full design potential.

**Materials of Construction**
A wet ESP’s collection section can be made out of any conductive material. However, the material chosen must be corrosion resistant to any acid mist contained in the flue gas. Wet ESPs have been made out of conductive fiberglass, carbon steel, various stainless steels and various high-end alloys depending upon the duty intended. Most multi-pollutant applications for wet ESPs typically employ some sort of scrubber in front of the wet ESP to remove corrosive acid gases. Material selection should be based upon a “worst-case” scenario analysis in order to protect the equipment against upset conditions. Alternatively, the water sprayed into the ESP can be treated to neutralize acids collected within the ESP. Proper pH control is essential to maintain integrity of the equipment.

Modular
Like dry ESPs, wet ESPs can be modular. Each field is limited in size to the power of the available transformer. The largest transformers available today are 70,000 V @ 2500 mA of installed electrical power. Depending on the specific application (large air flow or heavy inlet loading), multiple sections can be arranged together, either in series or in parallel, to achieve the required efficiencies.

Utility Application
Coal fired plants are starting to recognize the need for wet ESP technology to reduce opacity related to PM2.5 and SO3 concentrations in the flue gas as States start to mandate more stringent opacity limits.

Northern State Power’s Shirco Station with two 750 MW boilers installed the first full-scale wet ESP in the country to reduce opacity. Eleven modules/unit of tubular, upflow wet ESP technology were installed after a FGD system and opacity was reduced to less than 10% with 22 Wet ESP modules in service.

In several instances where plants have installed SCR technology with ammonia injection on high sulfur coal and FGD systems are installed, increased plume resulted from higher levels of SO3 and fine ammonia salt concentration in the flue gas. These plants are considering installing a wet ESP after the FGD system to capture the additional SO3 and ammonia salts, which cannot be captured in the FGD
system due to their sub-micron nature. Therefore, for the 25% of coal fired plants that burn high sulfur bituminous coal that have FGD systems installed, installing a wet ESP is the next logical step to meet opacity, PM2.5 SO$_3$ and mercury standards.

**Tubular Pilot Wet ESP at First Energy’s Bruce Mansfield Station**
Croll-Reynolds installed a pilot wet ESP at a major coal-fired plant in 2001. This plant burns 3% bituminous coal and has a FGD system installed for PM10 and SO$_2$ control. A 5,000 acfm slipstream, tubular pilot wet ESP was installed for PM2.5 and SO$_3$ control, the two primary contributors to stack plume. Speciated mercury testing was also performed to measure collateral benefits of installing wet ESP technology.

| Summary of Pilot Wet ESP Test Results - Bruce Mansfield Plant –2001-2002 |
|-------------------------------------------------|---------------|---------------|---------------|---------------|---------------|
| | PM2.5 | SO$_3$ Mist Tests | Particulate | Oxidized | Elemental |
| Average of all Tests | | | | | |
| Test Series | Sep-01 | Nov-01 | Sep-01 | Nov-01 | Sept-01 | Sept-01 | Sept-01 |
| Airflow-acfm | 8394 | 8235 | 8394 | 8235 | 8000 | 8000 | 8000 |
| Velocity – ft./sec. | 10 | 10 | 10 | 10 | |
| # of fields | 1 | 2 | 1 | 2 | 1 | 1 | 1 |
| Power Levels | 100% | 100% | 100% | 100% | 100% | 100% |
| Inlet | 0.0292 | 0.0506 | 11.475 | 10.01 | 0.011 | 0.689 | 6.245 |
| Outlet | 0.0063 | 0.002 | 2.7 | 0.85 | 0.004 | 0.158 | 3.474 |
| Removal % | 79% | 96% | 76% | 92% | 64% | 77% | 44% |

An initial series of tests completed during Sept. of 2001 were performed in a single electrical field at approximately 8,000-cfm. Removal achieved at this higher than designed for airflow was 79% for PM2.5 and 76% for SO$_3$. Mercury testing during this time period showed 64% for particulate, 77% for oxidized and 44% for elemental. Removal levels for particulate and oxidized mercury were similar to that for PM2.5 and SO$_3$. Most importantly, 44% removal of elemental mercury was measured at the highest inlet concentration. Mercury levels were extremely low because most of the particulate and water soluble HgCl was already removed in the upstream FGD system. It is estimated that at higher inlet levels, higher removal efficiencies would be expected.

In order to improve removal efficiency within the wet ESP pilot, the electrical system was subsequently retrofitted from a single to a two-field configuration. New test results on PM2.5 and SO$_3$ improved to 96% and 91% respectively.

**Observation Tube**
In order to estimate opacity on this slipstream application, Croll-Reynolds supplied a 19’ long observation tube to that is the same diameter as the top of the stack. A light source provided at one end
with an observation port at the other allows for direct visual observation. The pictures below show the results at varying power levels.

Observation tube – 19’ long to simulate diameter of top of stack.

10,000 cfm wet ESP unit at Bruce Mansfield plant

Pictures looking down the observation tube

Looking down observation tube with minimal power.

Looking down observation tube with some power on in the WESP.

Looking down observation tube with maximum power on in the WESP.

Hybrid ESP Design

However, the majority of coal-fired plants do not have a wet FGD system installed. Many are considering installation of fabric filters with injection of activated carbon for mercury control to meet new proposed mercury standards as well as removal of PM2.5. A viable, cost-effective alternative that offers multi-pollutant control is needed. Retrofit of a dry ESP last field with a wet field offers the potential to remove PM2.5, SO3 mist, SO2 and mercury without the drawbacks of activated carbon injection/fabric filter technology.
For those plants with undersized dry ESPs, retrofit of a dry ESP with a wet field offers the ability to meet opacity requirements with minimal cost and impact. The Electric Power Research Institute tested the concept of adding a wet ESP after a dry ESP in an unsaturated condition during 1994-1995 at pilot scale level on coal-fired flue gas, primarily for opacity abatement. Those results indicated that a single wet field could achieve very high collection efficiency, greater than 90 percent.

In terms of outlet emissions, the tests indicated that a dry ESP emitting more than 0.1 lb/MMBtu before conversion would emit less than 0.03 lb/MMBtu after conversion to a wet field. This high efficiency results from the high power levels possible when fly ash electrical resistivity is no longer a controlling factor. Furthermore, the water wash system in the wet field eliminates the need for traditional mechanical rapping and thus virtually eliminates all re-entrainment losses. The EPRI tests also established that a wet ESP could be successfully operated with the flue gas temperature well above the moisture dew point. This method of operation means that equipment downstream of the converted ESP will not have to be operated under saturation conditions.

Finally, the EPRI tests demonstrated that the conversion to wet operation partially reduced SO$_2$, HCL and HF along with some oxidized mercury. Measured results from the pilot showed the following removal levels across the wet ESP.

- Particulate matter: 95%
- Sulfur dioxide: 20%
- Hydrogen chloride: 35%
- Hydrogen fluoride: 45%
- Oxidized Mercury: 50%
- Total mercury 30%*

(*Outlet elemental mercury was measured at higher levels than inlet Hg$^\circ$. It is estimated that some of the oxidized mercury degassed back to elemental mercury in the water solution due to improper pH control/water chemistry.)

In 2000-2001, EPRI participated in a full-scale demonstration of this concept at Mirant’s Dickerson Station for opacity reduction. While performance testing reported high collection efficiency on PM2.5 and SO$_3$ with opacity as low as 10%, mechanical issues associated with the wet ESP design, which could have been corrected if non-technical issues had not limited the length of the project, prevented continued implementation of this approach. No mercury testing was performed at this site.

Croll-Reynolds has since designed and installed a horizontal, plate wet ESP at slipstream pilot scale that overcomes the mechanical issues experienced at Dickerson. A patented water header system prevents splashing, a unique plate design assures thorough water coverage to avoid dry spots and a drainage system eliminates arcing and mist carryover downstream.
**Benefits**
Adding a wet ESP field behind an existing dry ESP or retrofitting the last field offers several benefits to traditional methods for removing PM2.5, SO$_3$ mist and some fraction of SO$_2$ and mercury:

- Less pressure drop than a fabric filter or FGD system. Typically $\frac{1}{2}$" w.c. pressure drop across a wet ESP, similar to that of a dry ESP field.

- There are no moving parts since a wet ESP is self-cleaning, reducing maintenance.

- Less real estate is required. A wet ESP field can be retrofitted to an existing dry ESP, thereby avoiding the problem of trying to find space for new equipment within the confines of a plant.

- The wet ESP field can operate above the saturation point, thereby avoiding costly upgrading of downstream duct and stack materials of construction. The wet ESP section would be constructed of a high-grade stainless steel.

- Capital costs are significantly less than a fabric filter or full FGD system, typically in range in the $25$-$35$/kw depending upon difficulty of the installation.

- Operating costs are minimal with less than 3 watts/CFM-power usage within the wet ESP.

- There is no impact on existing upstream air pollution control equipment or process.

- Multiple pollutant control is possible. While primarily a particulate control device, similar to a fabric filter, a wet ESP retrofit offers the collateral benefit of being able to abate acid mists (SO$_3$), oxidized mercury, some acid gas (SO$_2$, HCL) as well as some elemental mercury.

- Opacity can be reduced to 10% or less due to removal of PM2.5 and SO3 mist.

- There is no contamination of fly ash. The wet ESP section is located downstream of the dry ESP.

- Fuel blending/switching can be accommodated to minimize fuel costs while meeting emission standards.

- There is no sorbent injection system. Installation, handling, injection of sorbent plus disposal issues of mercury–laden carbon are eliminated.

- Any mercury collected in the wet ESP slurry can be treated in a wastewater treatment system to remove the mercury from the water, concentrating the waste and reducing handling and disposition of a hazardous waste.
- Wastewater from the wet ESP can be recycled, minimizing water-related issues.

**New Hybrid Pilot Demonstration**
Because this approach offers so many potential benefits and there has not been sufficient testing of the concept and resolution of mechanical issues associated with the approach, the Electric Power Research Institute and Croll-Reynolds intend to construct a mobile 10,000 cfm slip-stream pilot wet ESP for installation after a dry ESP. One plant using PRB coal with high elemental mercury emissions has already committed to being a host. The plant is installing SCR technology for further NOx abatement. Testing for PM2.5, SO3, SO2 and mercury removal will be performed.

The pilot wet ESP consists of stainless steel plates with a patented water feed system that promotes uniform and thorough water coverage while minimizing the potential for plugging, splashing and mist carryover. Custom designed ionizing electrodes are configured to suit the electrical profile required for various flue gas concentrations.

**Mercury Control – Plasma Enhanced ESP Technology**
Mercury adsorbed onto particulate and oxidized forms of mercury are readily removed from the flue gas using a wet scrubber or flue gas desulfurization system. However, the remaining elemental mercury vapor passes through the air pollution control devices unabated. Most mercury research has focused on sorbent injection followed by a baghouse for those plants without an FGD system, typically where low sulfur coal is used.

Tests of wet ESP technology at the Bruce Mansfield pilot plant indicate that a wet ESP can remove both oxidized and particulate forms of mercury at similar levels to that for PM2.5 and SO3. Mercury testing showed 64% for particulate, 77% for oxidized in the single electrical field configuration. Most importantly, 44% removal of elemental mercury was measured at the highest inlet concentration. Mercury levels were extremely low because most of the particulate and water soluble HgCl was already removed in the upstream FGD system. It is estimated that at higher inlet levels and/or a dual electrical field configuration, higher removal efficiencies would be expected.

To increase elemental mercury removal efficiencies using wet ESP technology, MSE Technology Applications, Inc. and Croll-Reynolds Clean Air Technologies, Inc. developed a technology that uses the central electrode of a standard wet electrostatic precipitator to inject a mercury oxidizing reagent gas directly into a flue gas stream. As the reagent gas passes through this corona discharge, reactive species are formed that subsequently oxidize elemental mercury into fine particulate. The mercury particulate acquire a negative charge in the electrical field and are attracted to positive electrodes where they are adsorbed into the liquid layer and are removed from the process in the washdown cycle. Under test conditions where the flue gas temperature was maintained well above the saturation temperature, the mercury oxidation efficiency of the technology increased to 79%.

**Membrane Based Wet ESP technology**
Ohio University, Southern Environmental and Croll-Reynolds have patented and developed a new membrane based Wet ESP with dramatically reduced cost and weight compared to metallic wet ESPs.
Cleaning of the corrosion resistant fabric membranes is facilitated by capillary action between the fibers, providing even water distribution, & continuous flushing which removes collected material without spraying, so the entire precipitator remains on line.

DOE’s National Energy Technology Laboratory has awarded SEI/CRAT and Ohio University a grant to compare metallic and membrane based wet ESP technology in a pilot unit at First Energy’s Bruce Mansfield Plant in Shippingport, Pa. Testing will begin this summer on the membrane wet ESP.

**Conclusion**

Wet ESP technology is a proven, well-known technology that can achieve very high removal of mists, particles and aerosols with low pressure drop and minimum maintenance, if properly designed and built. Whereas it has traditionally been installed after a FGD system in a saturated flue gas as a final wet electrostatic mist eliminator, it can also be retrofitted to an existing dry ESP last field to increase collection of PM2.5, SO3 and mercury and reduce opacity.

New improvements to the technology include enhancing its removal capability adding electrical fields within the same physical envelop, oxidizing elemental mercury using plasma and reducing cost by using membrane collection material.

Successful demonstration of these various developments will offer coal-fired plants using either bituminous, sub-bituminous or lignite coal a reliable control technology that has multi-pollutant capability for reducing PM2.5, SO3 mist, mercury with the co-benefits for some SO₂ and HCL trim control.

**Key Words**

Wet electrostatic precipitation
Wet ESP
Hybrid ESP