Technical Basis of the 2012 SJV PM$_{2.5}$ Plan Modeling

Please e-mail questions to webcast@valleyair.org any time during this presentation

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Introduction

- ARB conducted a science symposium in April to present:
  - Current understanding of PM$_{2.5}$ in the Valley
  - Modeling approach
- The Modeling Protocol was reviewed by ARB, District, U.S. EPA, and academia
- Presentations and Modeling Protocol are posted on District’s website
Presentation Outline

- Modeling Requirements and Process
- Current Scientific Knowledge of PM$_{2.5}$ Formation in the San Joaquin Valley
- Modeling Results and Precursor Sensitivities
- Acknowledgements
Modeling Requirements and Process
Consistency with U.S. EPA Guidance

- Appropriate model(s) and other analyses
- Need for modeling protocol document
- Application and evaluation of model(s)
- Model attainment test
- Supplemental analyses
- Use of the best possible science
Weight of Evidence Approach for Attainment

- Use all available technical information in a corroborative manner to determine best attainment strategy:
  - Grid-based photochemical modeling
  - Supplemental analyses:
    - Air quality trends
    - Emission trends
    - Source – receptor modeling
Use and application of Photochemical Models

- Identifying the most effective mix of pollutants to control
- Establishing attainment targets
- Models are best used in a relative (rather than absolute) sense
  - Relative Response Factors (RRFs)
- Attainment test combines measures data and modeling to project air quality into the future
  - Speciated Model Attainment Test (SMAT)
\[ RRF = \frac{\text{Simulated Future Year Concentration}}{\text{Simulated Base Year Concentration}} \]

- RRFs are specie and location specific
“Speciating” the FRM Filter

- Speciated Model Attainment Test (SMAT), which uses RRFs, requires speciated PM\(_{2.5}\)
- Federal Reference Method (FRM) filters are not speciated
- Four FRM sites have co-located speciation monitors
- Use \texttt{Sulfate, Adjusted Nitrate, Derived Water, Inferred Carbonaceous material balance approach} (SANDWICH) to estimate FRM speciation
Air-Quality Modeling

- US EPA’s CMAQ model
- SAPRC-99 chemistry
- Solves coupled sets of differential equations for advection, diffusion, and chemistry
- MOZART global model provides initial and boundary conditions
- 15 vertical layers up to 100 mb

CMAQ – Community Multi-scale Air Quality
SAPRC – Statewide Air Pollution Research Center
MOZART – Model of Ozone and Related Trace Species
Quality Assurance

- Does the model replicate the observed nature of the PM$_{2.5}$ problem?

- Requires:
  - Iterative model runs
  - Re-generating meteorology and emissions inputs
  - Evaluating predictions for each specie
  - Focus evaluation on seasons / months contributing to high PM$_{2.5}$
Model Performance Evaluation

- Operational (quantitative) – Ability to reproduce observed temporal and spatial patterns for meteorological parameters and pollutants
- Phenomenological (qualitative) – General comparisons of observed features
- Diagnostic (semi-quantitative) – How accurate is the model in characterizing the sensitivity of PM$_{2.5}$ (and species) to changes in emissions?
- Corroborative (qualitative) – Model consistent with other analyses?
Current Scientific Knowledge of PM$_{2.5}$ Formation in the San Joaquin Valley
Role of Science Studies

- Provide ambient measurements to expand our understanding of the nature of PM$_{2.5}$
- Improve the algorithms in models and their ability to simulate air quality conditions
- Support model applications to predict future air quality and the response to controls
California Regional Particulate Matter Air Quality Study (CRPAQS)

- Major field study conducted in 2000
- Funded by a public / private partnership
- Provided the fundamental science behind annual plan and current 24-hour plan
- Most comprehensive data and science in the country on the origin and fate of PM$_{2.5}$
- Continues to be a cornerstone of PM$_{2.5}$ research
CRPAQS Findings

- Winter PM$_{2.5}$ episodes are driven by multi-day periods of stagnation, cool temperatures, and high humidity
- Transport is limited during these winter episodes
- Key PM$_{2.5}$ constituents are ammonium nitrate and carbon compounds
PM$_{2.5}$ Chemical Composition

2008-2010 Peak Day Composition
Bakersfield

- Elemental Carbon: 5%
- Organic Carbon: 16%
- Ammonium Sulfate: 9%
- Ammonium Nitrate: 67%
- Elements: 1%
- Geological: 2%

2008-2010 Peak Day Composition
Fresno

- Elemental Carbon: 7%
- Organic Carbon: 33%
- Ammonium Sulfate: 6%
- Ammonium Nitrate: 51%
- Elements: 2%
- Geological: 1%
Carbon compounds are highest in urban areas due to contributions from wood burning, cooking, and mobile sources.
Sources of Organic Carbon

- Residential burning a significant contributor in the winter
- New markers for wood combustion helped identify impacts

Wood Smoke Contribution to \(\text{PM}_{2.5}\) at Fresno

Gorin et. al. 2005
Elevated ammonium nitrate concentrations occur in both urban and rural areas.
Precursors to Ammonium Nitrate

- Nitric acid ($\text{HNO}_3$) and ammonia ($\text{NH}_3$) are precursors to ammonium nitrate.
- Measured $\text{HNO}_3$ concentrations are much lower than concentrations of $\text{NH}_3$.
Annual Average PM$_{2.5}$ Trends

Change in Annual PM$_{2.5}$ Design Values

- Bakersfield-California
- Fresno-1st
- Modesto

Design Value (µg/m$^3$)

Trend in PM$_{2.5}$ Seasonal Pattern

Changes in PM$_{2.5}$ Seasonal Pattern
Bakersfield-California

Concentrations (ug/m$^3$)

Month

0 10 20 30 40 50 60

1 2 3 4 5 6 7 8 9 10 11 12

1999-2001

2009-2011
Effectiveness of Wood Burning Controls

The "zero-line" represents no change from the expected concentration.
Effectiveness of NO\textsubscript{x} Controls

Winter average PM2.5 nitrate at Bakersfield and Fresno compared to basin-wide NO\textsubscript{x} emissions
Ongoing Efforts to Improve Science

- Annual science meetings:
  - International Conference on Atmospheric Chemical Mechanisms
  - International Aerosol Modeling Algorithms Conference

- Field studies to improve modeling databases:
  - U.S. EPA / ARB Advanced Monitoring Initiative (Feb. 2007)
  - ARCTAS (June 2008)
  - CalNex (May-July 2008)
  - DiscoverAQ (Jan-Feb 2013)
Attainment Demonstration Modeling Results
Attainment Demonstration Modeling

- Attainment predicted in all counties except Kern and Kings based on implementation of ongoing control program
- Most sites in northern and central Valley expected to attain prior to 2019
- Scenario with enhanced wood burning curtailment program predicts attainment in all counties except Kern
Ongoing Emission Reductions

- New emission reductions each year from implementation of ongoing ARB and District control programs
- As a result between 2007 and 2019:
  - NO$_x$ emissions will decrease by over 50%
  - PM$_{2.5}$ emissions will decrease by over 25%
  - SO$_x$ emissions will decrease by 30%
# Base/Future Design Values

<table>
<thead>
<tr>
<th>Monitoring Station</th>
<th>2007 DV</th>
<th>2019 DV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bakersfield – California</td>
<td>65.6</td>
<td>35.7</td>
</tr>
<tr>
<td>Bakersfield – Planz</td>
<td>67.8</td>
<td>32.9</td>
</tr>
<tr>
<td>Fresno – First Street</td>
<td>63.0</td>
<td>30.5</td>
</tr>
<tr>
<td>Fresno – Hamilton</td>
<td>61.2</td>
<td>28.6</td>
</tr>
<tr>
<td>Clovis</td>
<td>58.4</td>
<td>28.6</td>
</tr>
<tr>
<td>Modesto – 14th Street</td>
<td>54.8</td>
<td>24.7</td>
</tr>
<tr>
<td>Merced – M Street</td>
<td>48.3</td>
<td>22.6</td>
</tr>
<tr>
<td>Stockton – Hazelton St.</td>
<td>44.7</td>
<td>21.4</td>
</tr>
<tr>
<td>Visalia – N Church St.</td>
<td>58.2</td>
<td>29.4</td>
</tr>
<tr>
<td>Corcoran – Patterson</td>
<td>60.8</td>
<td>32.1</td>
</tr>
</tbody>
</table>
Base/Future DV Composition

2007

- NH4NO3: 15.2
- (NH4)2SO4: 2.2
- OC: 0.3
- EC: 0.5
- Salt: 41.1
- Geologic: 4.7
- Blank: 65.6 µg/m³

2019

- NH4NO3: 6.5
- (NH4)2SO4: 4.4
- OC: 0.5
- EC: 0.2
- Salt: 22.5
- Geologic: 0.5
- Blank: 35.7 µg/m³
Attainment Demonstration at Bakersfield - California Site

<table>
<thead>
<tr>
<th>2007 Design Value (ug/m3)</th>
<th>2019 Design Value with Wood Burning Program Enhancement (ug/m3)</th>
<th>2019 Final Design Value (ug/m3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>65.6</td>
<td>35.7</td>
<td>35.4</td>
</tr>
</tbody>
</table>

- Attainment predicted based on implementation of ongoing control program plus enhanced wood burning curtailment and commercial cooking measures
Precursor Sensitivity Analysis
Air quality models provide the best tool to evaluate the potential effectiveness of controlling different PM$_{2.5}$ precursors.

This analysis has been done as part of previous modeling efforts for CRPAQS as well as the current PM$_{2.5}$ plan.

The current plan integrates the results of all these studies in determining the most effective control approach.
ARB conducted multiple modeling sensitivity runs to compare the effectiveness of:

- Directly emitted PM$_{2.5}$
- NO$_x$
- SO$_x$
- VOCs
- Ammonia

Results are expressed in terms of reduction in the 2019 Design Value.
Modeled Effect of 25% Precursor Reductions at Bakersfield – California

<table>
<thead>
<tr>
<th>Precursor</th>
<th>PM$_{2.5}$ Reduction (µg/m$^3$)</th>
<th>Tons of Emissions</th>
<th>µg/m$^3$ Reduction/ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary PM$_{2.5}$</td>
<td>4.44</td>
<td>15</td>
<td>0.29</td>
</tr>
<tr>
<td>NO$_x$</td>
<td>3.75</td>
<td>42</td>
<td>0.09</td>
</tr>
<tr>
<td>NH$_3$</td>
<td>0.55</td>
<td>72</td>
<td>0.008</td>
</tr>
<tr>
<td>SO$_x$</td>
<td>0.18</td>
<td>4</td>
<td>0.04</td>
</tr>
<tr>
<td>VOC</td>
<td>-0.09</td>
<td>87</td>
<td>-0.001</td>
</tr>
</tbody>
</table>
Benefits of Direct PM$_{2.5}$ Controls

- Direct PM$_{2.5}$ has substantial amounts of organic carbon (OC)
- OC is a major component of future PM$_{2.5}$
- Reduction of direct PM$_{2.5}$ leads to less OC
- This leads to a significant reduction in the design value

25% Reduction in PM$_{2.5}$ reduces design value by 12%
Benefits of $\text{NO}_x$ vs. Ammonia Control – Previous Studies

- Previous modeling studies indicated:
  - Large reductions in $\text{NO}_x$ led to generally commensurate reductions in ammonium nitrate
  - Large reductions in ammonia were much less effective, particularly in urban areas
  - Observed reductions in ammonium nitrate and ambient $\text{NO}_x$ track reductions in $\text{NO}_x$ emissions
CRPAQS NO\textsubscript{x} and Ammonia Sensitivity

![Graph showing percent nitrate reduced over time with bars for 50% NO\textsubscript{x} and Ammonia Reduction.]
Benefits of NOx versus Ammonia Controls – Current Modeling

- Ammonia is in excess compared to nitric acid, so atmosphere is more response to $\text{NO}_x$ than ammonia reductions
- Isopleths nearly parallel to ammonia axis means small benefits (relative to $\text{NO}_x$ reduction)

25% reduction in NOx reduces design value by 10%
25% reduction in NH3 reduces design value by 1.5%
Benefits of NO\textsubscript{x} Versus VOC Control – Previous Studies

- Previous modeling studies indicated:
  - At current NO\textsubscript{x} and VOC concentrations, further VOC controls produce little benefit, and may actually increase ammonium nitrate slightly
  - Secondary organic aerosol formation from VOCs is negligible in winter
CRPAQS VOC Sensitivity

Source: Kleeman, M.J., personal communication, May 2008
Benefits of NO$_x$ versus VOC controls – Current Modeling

- For ozone, VOC controls may have varying amounts of benefits.
- For PM$_{2.5}$, VOC controls lead to minor disbenefits by making more NO$_x$ available for nitric acid (HNO$_3$) formation.
- HNO$_3$ + ammonia (NH$_3$) = Ammonium Nitrate

25% reduction in VOCs increases design value by 0.2%
Benefits of SO$_x$ Control

- SO$_x$ controls lead to less sulfuric acid (H$_2$SO$_4$)
- Less H$_2$SO$_4$ leads to less ammonium sulfate
- Sulfate is a small component of PM$_{2.5}$ resulting in minor impacts in reducing the design value

25% reduction in SO$_x$ reduces design value by 0.5%
Benefits of Localized Reductions

- ARB also conducted sensitivity runs examining benefits of further NO\textsubscript{x} and PM\textsubscript{2.5} control in Kern County only.

- Reductions in the Bakersfield design value were somewhat smaller than seen from Valleywide reductions, but the benefit per ton was greater:
  - PM\textsubscript{2.5}: 1.0 µg/m\textsuperscript{3} per ton benefit
  - NO\textsubscript{x}: 0.12 µg/m\textsuperscript{3} per ton benefit
Summary of Precursor Findings

- Reductions in direct $\text{PM}_{2.5}$ are the most beneficial
- $\text{NO}_x$ controls also provide large benefits
- $\text{NH}_3$ and $\text{SO}_x$ controls offer very small benefits
- VOC controls produce very small disbenefits
Summary
Current Multi-Pollutant Control Approach

- Current efforts have focused on implementing commitments for meeting annual PM$_{2.5}$ and 8-hour ozone standard
- NO$_x$ reductions are key for both ozone and PM$_{2.5}$ progress
- Diesel risk reduction program also provides important PM and health benefits
Progress Towards Annual Standard

- Current $\text{NO}_x$ control strategy, coupled with focus on wood burning has been effective
- Annual design values have decreased 30% to 40% over the last decade
- When variations in meteorology are considered, even greater progress is seen
- Most sites in northern and central Valley now attain the standard
Progress Towards 24-Hour Standard

- 24-hour design values have decreased 30% to 40% over the last decade
- After accounting for variations in meteorology, the number of exceedance days has decreased over 60%
- Concentrations during severe episodes are 40% lower than they were ten years ago
- Despite progress, addressing the 24-hour standard remains a challenge
Current Science on 24-Hour PM$_{2.5}$

- PM$_{2.5}$ concentrations build up over long periods with stagnant weather
- Key components are ammonium nitrate and carbon
- Ammonium nitrate is distributed more regionally, while carbon is more localized in urban areas
Reducing Carbon

- The most important sources of organic carbon are mobile sources, wood burning, and commercial cooking.

- Control strategy focuses on:
  - Ongoing mobile source control program
  - Enhancement of wood burning curtailment program
  - Control of commercial cooking operations

- As a result, organic carbon concentrations are predicted to decrease by 65% and elemental carbon by 80%.
Reducing Ammonium Nitrate

- Reducing NO$_x$ is most effective in reducing ammonium nitrate concentrations
- Control strategy focuses on:
  - Ongoing mobile source control program
  - District control program for stationary sources
- As a result, ammonium nitrate concentrations are predicted to decrease by more than 45%
Weight of Evidence

- 24-Hour design values have decreased 30-40% over the last decade
- Air quality trends demonstrate past effectiveness of NO\textsubscript{x} and PM\textsubscript{2.5} emission reductions
- Emissions of NO\textsubscript{x} and PM\textsubscript{2.5} are expected to drop over 50% and 25% respectively by 2019
- Modeling predicts ammonium nitrate will decrease by over 45% and organic carbon by 65%
- This results in attainment throughout the Valley by 2019
Acknowledgements
We greatly benefited from the collaboration with the staff of the San Joaquin Valley Air Pollution Control District during the modeling process.

Please e-mail your questions to webcast@valleyair.org

Thank you very much for your attention!
“Bare-Knuckle” Supercomputing

- Partly funded by the San Joaquin Valley-wide Air Pollution Study Agency