



PM Controls



2016 AQMP WHITE PAPER

SEPTEMBER 2015

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Preface

The purpose of this 2016 Air Quality Management Plan (AQMP) White Paper on Particulate Matter (PM White Paper) is to provide background technical information and present the policy challenges associated with attaining the National Ambient Air Quality Standards (NAAQS) for fine particulate matter (PM_{2.5}), with a focus on the newly adopted federal annual PM_{2.5} standard of 12 micrograms per cubic meter (µg/m³). Annual PM_{2.5} concentrations continue to decrease and the South Coast Air Basin (Basin) is projected to be near attainment of the new annual PM_{2.5} standard once the ozone attainment strategy is fully implemented. Several scientific and policy issues will be described, including the roles of directly emitted PM_{2.5} emissions and PM_{2.5} precursor gases, and the PM_{2.5} co-benefits from the ozone control program. Key to the policy discussion is the potential need for additional measures for PM_{2.5} given that the attainment strategy cannot rely on the “black box” advanced technology emissions reductions that have been used previously to demonstrate attainment of the ozone standard under federal Clean Air Act (CAA) Section 182(e)(5). Even though the NO_x reductions for the ozone strategy will have significant PM_{2.5} benefits, only specific measures adopted at the time of the 2016 AQMP submittal can be credited towards the PM_{2.5} attainment demonstration. This PM White Paper will address these issues as well as the science behind PM_{2.5} formation, followed by potential PM_{2.5} control approaches that could be developed if additional emission reductions are needed for attainment with the PM_{2.5} standards. These concepts include control strategies and seasonal, episodic or geographically-focused controls.

1. INTRODUCTION

The Basin has experienced remarkable improvement in air quality since the 1970's as a direct result of a comprehensive, multi-year strategy of reducing air pollution from all sources. Yet the Basin is still not in attainment of current federal and state air quality standards and, in fact, still has the worst air quality in the nation for ozone. Currently, the Basin is not attaining federal ozone standards or the federal annual and 24-hour PM_{2.5} standards.

While the 2012 AQMP was designed to bring the Basin into attainment with the 24-hour PM_{2.5} standard of 35 mg/m³ by 2015, with additional measures to address the 1997 8-hour ozone standard by 2023, the primary focus of the 2016 AQMP will be to demonstrate attainment of the 2008 ozone standard by 2032 and the annual PM_{2.5} standard by the 2021-2025 timeframe. Attaining the federal ozone standard will have the added benefit of emission reductions that will further improve PM_{2.5} levels.

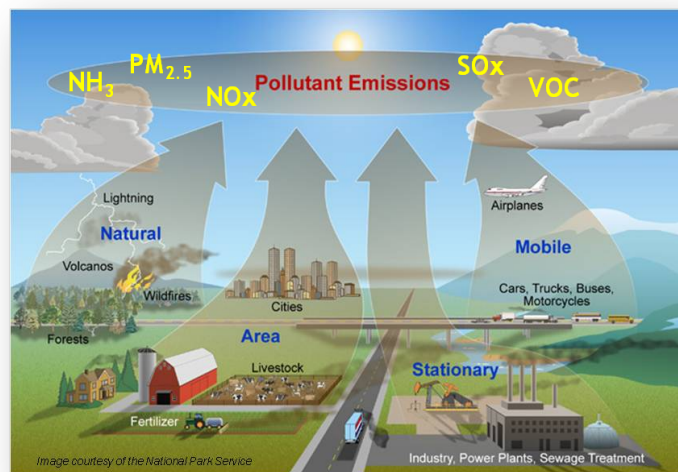
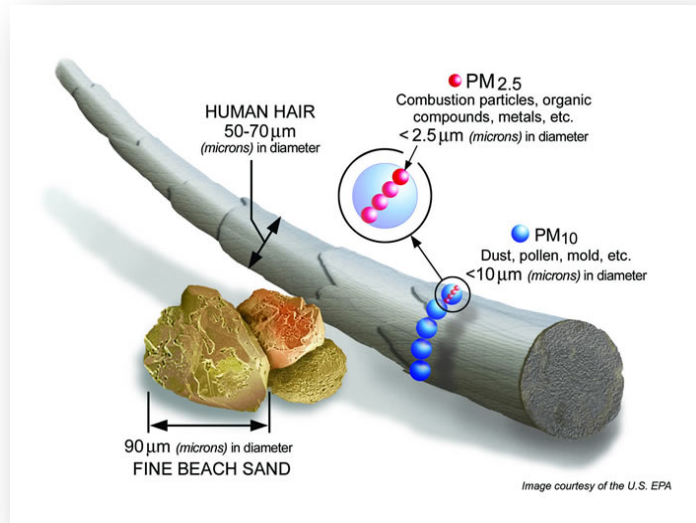
The California State ambient air quality standard is identical to the federal standard for annual PM_{2.5} and there is no State 24-hour PM_{2.5} standard. The State has very stringent PM₁₀ standards (annual PM₁₀ of 20 mg/m³ and 24-hour PM₁₀ of 50 mg/m³). While there is no effective attainment date for the State PM standards, the State standards must be achieved as soon as practicable to protect the public health and welfare of Southern Californians. Progress towards achieving the federal PM_{2.5} standards would be the most expeditious approach for attaining both the federal and State PM standards even though State PM₁₀ standards are more stringent than the federal standard. However, a coarse particle control strategy would be very different and beyond the scope of this white paper. The State PM_{2.5} standard requires Reasonably Available Control Measures (RACM) that will be further evaluated for their feasibility and applicability in the Basin in the 2016 AQMP.

The purpose of this PM White Paper is to provide background technical information and present the policy challenges associated with attaining federal PM air quality standards. The focus will be primarily on the newly adopted federal annual PM_{2.5} standard of 12 mg/m³, but some emission control measures that can be implemented sooner will help to ensure attainment of the 24-hour PM_{2.5} standard of 35 µg/m³. This white paper will describe the scientific basis of PM_{2.5} formation including the major sources of direct PM_{2.5} and PM_{2.5} precursor gases. The PM_{2.5} reduction co-benefits from ozone control programs and climate change strategies will also be described. Finally, potential strategies for further PM_{2.5} control will be considered, should additional controls be needed.

2. BACKGROUND

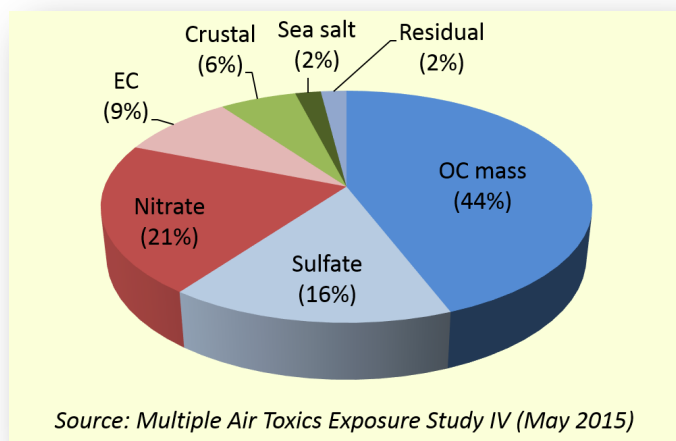
PM_{2.5} and Precursors

Particulate matter (PM), also known as particle pollution, is a complex mixture of microscopic solid and liquid particles suspended in air. Particles of concern are classified into two categories: inhalable coarse particles (PM_{10-2.5}) and fine particles (PM_{2.5}). Inhalable coarse particles are generally created by mechanical or natural processes, such as grinding, sanding, sea spray, windblown dust, and soil. Coarse particles have sizes larger than 2.5 micrometers (μm) and smaller than 10 μm in diameter. Fine particles, such as those found in smoke and haze, are 2.5 μm in diameter or smaller, and are generally formed by combustion processes or by chemical reactions that occur in the atmosphere. PM_{2.5} is of primary concern because, once inhaled, it can travel deeply into the respiratory tract, reaching the lungs. Scientific studies have linked increases in daily PM_{2.5} exposure with increased respiratory and cardiovascular hospital admissions, emergency department visits, and even deaths. Studies also suggest that long-term exposure to PM_{2.5} may be associated with increased rates of chronic bronchitis, reduced lung function and increased mortality from lung cancer and heart disease. People with breathing and heart problems, children, and the elderly may be particularly sensitive to PM_{2.5}. Recently, an additional particle category known as ultrafine particles (often defined as particles less than 0.1 μm) has been studied and found to have distinct chemical and toxicological properties. However, given that there are no ambient standards for ultrafine particles, and that the purpose of this white paper is to address fine particle standards, issues related to ultrafine and coarse particles are beyond the scope of this discussion.



PM in the atmosphere can be categorized as either primary or secondary particles. Primary particles are directly emitted PM from sources such as construction sites, unpaved roads, sea salt, abrasion, fuel combustion, cooking, or fires. Secondary particles are formed in complex chemical reactions that occur in the atmosphere, often aided by sunlight (known as photochemical reactions). In these reactions, precursor gases, such as volatile organic compounds (VOCs), sulfur oxides (SO_x), ammonia (NH₃), and nitrogen oxides (NO_x), are transformed into solid or liquid products that contribute to ambient PM levels. NO_x and SO_x will combine with ammonia to form ammonium sulfate or ammonium nitrate salts, which are generally solids at ambient temperatures and can dissolve into water-containing particles. VOCs react with atmospheric oxidants, producing products with lower volatility that condense and form secondary organic aerosol (SOA), another component of PM. Many combustion processes emit both primary PM and precursor gases that ultimately form PM in the atmosphere. For example, in processes such as motor-vehicle gasoline combustion¹ and wood burning,² SOA produced by oxidation of the emitted VOCs can exceed the amount of emitted primary organic PM_{2.5}.

Secondary particles make up the majority of ambient PM_{2.5} in the Basin. Basin-wide average ambient PM_{2.5} speciation profiles³ measured during the



“A large portion of PM_{2.5} in the Basin is formed from precursor gases of anthropogenic origin.”

recent Multiple Air Toxics Exposure Study (MATES) IV show that the Basin’s PM_{2.5} mass was comprised of four major chemical components: organic carbon (OC), ammonium nitrate, ammonium sulfates, and elemental carbon (EC) with

smaller fractions of crustal particles, sea salt, and other trace elements. Elemental carbon (EC), which is similar to the short-lived climate-forcing species Black Carbon (BC), is an important component of directly emitted PM_{2.5} from internal combustion engines, especially diesel engines. The OC mass portion includes both primary and secondary particle material.

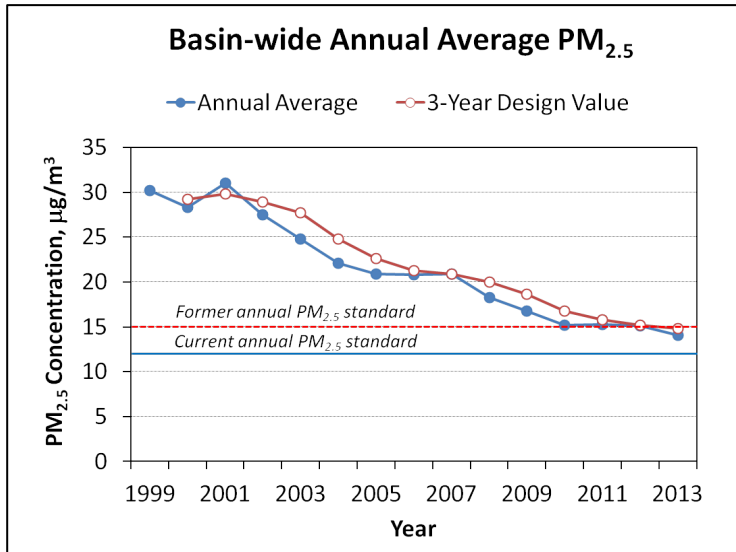
¹ Gordon, T.D., et al. Secondary Organic Aerosol Formation Exceeds Primary Particulate Matter Emissions for Light-Duty Gasoline Vehicles, *Atmos. Chem. Phys.* 2014, 14, 4661-4678.

² Hennigan, C.J., et al. Chemical and physical transformations of organic aerosol from the photo-oxidation of open biomass burning emissions in an environmental chamber, *Atmos. Chem. Phys.* 2011, 11, 7669-7686.

³ SCAQMD, Draft Multiple Air Toxics Exposure Study IV, October 3, 2014.

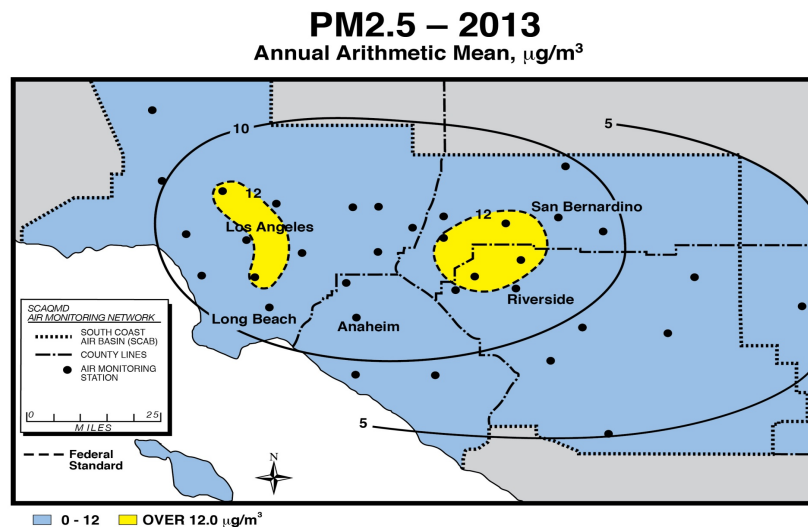
Trends in PM_{2.5} Levels

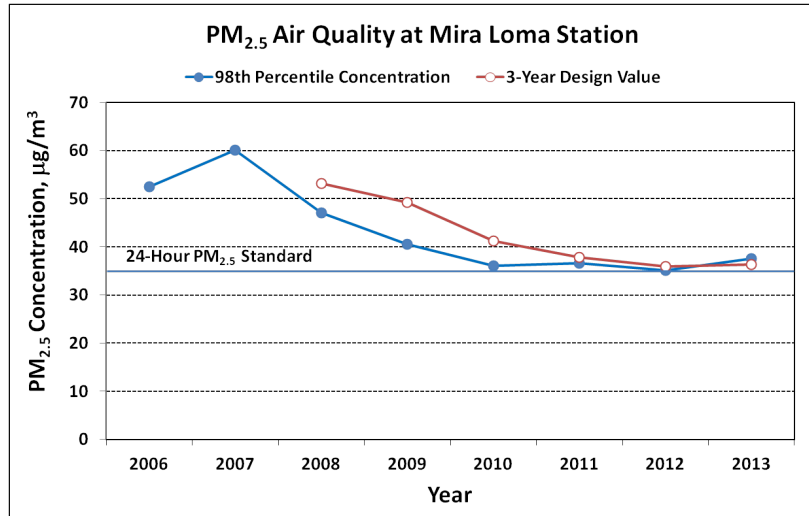
The levels of PM_{2.5} in the Basin have been continually improving since measurements and standards were initiated in the late 1990s. These improvements occurred over a period of significant growth in the Basin's population, vehicle miles traveled (VMT) and economic activity, and are directly attributable to the region's air quality control program.



Based on measurement data through 2013, no air monitoring station in the Basin violated the previous 1997 federal annual PM_{2.5} standard (15 mg/m³ for three years), and in December of 2014, U.S. Environmental Protection Agency (U.S. EPA) proposed a clean data determination finding that the Basin has met the 1997 PM_{2.5} standards. This is based on the form of the federal standard, known as the *design value*, which is the 3-year average of the annual PM_{2.5} average, calculated by station.

However, exceedances still occur above the new 2012 annual PM_{2.5} standard of 12 mg/m³ in the San Bernardino and Riverside County metropolitan areas, with the highest levels in Mira Loma. Los Angeles County also exceeded the new PM_{2.5} standard in the Central Los Angeles and East San Fernando Valley areas in 2013. This new standard requires additional reductions of direct PM_{2.5} and PM_{2.5} precursor gases in order to meet the annual PM_{2.5} standard by the 2021-2025 statutory timeframe.

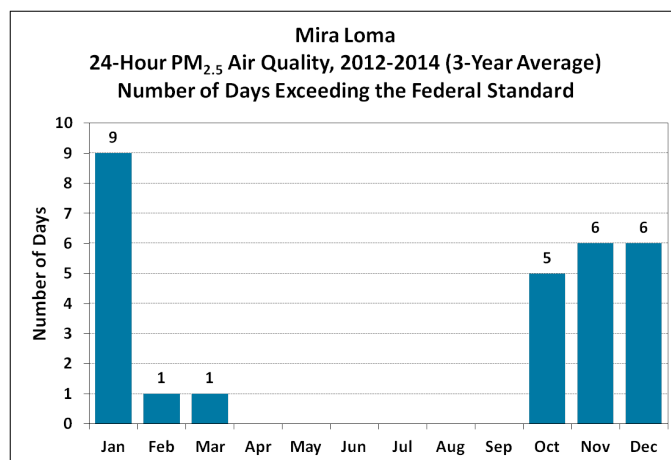




Despite significant progress, the Basin remains in nonattainment for the current 24-hour PM_{2.5} federal standard of 35 mg/m³. As of 2013, the 24-hour PM_{2.5} *design value* (in this case, the 3-year average of annual 98th percentile of the monitored 24-hour concentrations by station), exceeds the federal 24-hour PM_{2.5} standard at only one air monitoring station in Mira Loma in northwestern Riverside County. The 2012 AQMP projected attainment of the 24-hour

PM_{2.5} standard by the end of 2014. However, preliminary monitoring data through June of 2014 indicates that attainment of this standard is not likely to be achieved, largely because of the unanticipated air quality impacts of the severe drought conditions in California. The lack of winter storms and associated rainfall leads to dryer and thus more emissive ground surfaces as well as reduced cleansing and dilution of atmospheric particles. The drought has not only affected PM_{2.5} levels in Southern California; many areas across the state have experienced this reversal in long-term downward trends of PM_{2.5} levels.

In addition, a recent court decision has compelled U.S. EPA to implement PM_{2.5} standards according to the federal CAA, Title 1, Part D, Subpart 4 (hereafter “Subpart 4”) planning requirements specific to PM₁₀, rather than the general pollutant planning requirements (Subpart 1). Subpart 4 provides for attainment by 2015, with potential extensions. In February 2015, the South Coast Air Quality Management District (SCAQMD) Governing Board approved a Supplement to the 2012 AQMP 24-hour PM_{2.5} State Implementation Plan (SIP) for the Basin to comply with Subpart 4 and target attainment in 2015. The Governing Board also directed SCAQMD staff to bring forward early action measures for PM_{2.5} to ensure progress towards attainment under continuing drought conditions. The Supplement was subsequently approved by California Air Resources Board (CARB) and has been submitted to U.S. EPA for consideration. In Summer of 2015, given the most recent ambient PM_{2.5} data showing that 2015 attainment was not feasible, the SCAQMD Governing Board approved a request to U.S. EPA for a reclassification of the Basin to “serious” non-attainment area for 24-hour PM_{2.5} with an attainment date of 2019. The 2016 AQMP will also include a “serious” area plan for PM_{2.5}.



While ozone concentrations peak in the summer months, PM levels can be high at any time of the year, but are typically higher in winter months. These higher winter values are specifically influenced by wintertime temperature inversions and stagnant conditions that reduce atmospheric dilution and trap emissions near ground level. Furthermore, sources such as wood burning have increased emissions during colder weather. Consistent with U.S. EPA guidance, seasonal, episodic, or geographical controls that focus on bringing the Mira Loma station into compliance can continue to be considered as a method to bring the Basin into attainment.

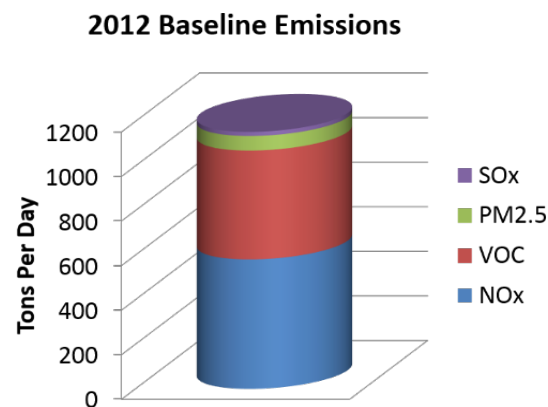
3. ASSESSING FUTURE CONTROL STRATEGIES

Emission Sources of PM_{2.5}

As mentioned above, most PM_{2.5} in the Basin is formed in the atmosphere, and thus a full picture of the sources of PM_{2.5} must also consider precursor gases. Based on the preliminary 2016 AQMP emissions inventory for 2012, there were 581 tons of NO_x emissions per day, 488 tons of VOC emissions, 66 tons of directly emitted PM_{2.5} emissions, and 19 tons of SO_x emissions. The top 10 emission sources of direct PM_{2.5} and its precursor gases are contained in Appendix A.

“Trucks are the No. 1 source of NO_x emissions that form both ground-level ozone and PM_{2.5} in the atmosphere.”

On-road and off-road vehicles emit more than 85% of the total NO_x emissions combined. Consumer products solvent evaporation was the single largest contributor to VOC emissions. Mobile (on- and off-road) sources collectively emit more than half of the total VOC emissions. Transportation source categories, including ships, commercial boats, aircraft trucks, and passenger cars account for more than 40% of the total SO_x emissions. RECLAIM SO_x sources emit more than one-third of the total SO_x emissions. Service and commercial fuel combustion and residential fuel combustion are the next largest contributing SO_x source categories.



Cooking is the largest emission source of directly emitted PM_{2.5}, followed by residential fuel combustion and paved road dust. These top sources are largely uncontrolled sources of directly emitted PM_{2.5}. The content of particles emitted from cooking, the majority of which comes from commercial under-fired charbroiling of meat, are almost all organic carbon,⁴ and studies have shown that commercial meat-cooking contributes more than 20% of the PM_{2.5} organic

⁴ McDonald, J.D., et al. Emissions from charbroiling and grilling of chicken and beef. *JAWMA*, 2003, 53, 185-194.

carbon fraction in Los Angeles air.⁵ Residential fuel combustion is the second largest emission source of directly emitted PM_{2.5}, mostly in the form of wood stove and fireplace wood burning.

Control Effectiveness

In the SCAQMD's 2012 AQMP, a detailed computer air quality model (CMAQ v4.7.1) was used to estimate the regional reductions of ambient PM_{2.5} concentrations that result from reductions in PM precursor emissions. On a ton-per-ton basis, primary PM_{2.5} and SO_x emissions controls were found to be the most effective in reducing PM_{2.5} mass concentrations, compared to NO_x emissions controls. VOC emissions reductions had the lowest effect on reducing annual PM_{2.5} mass concentration. As shown, this comparative effectiveness of emissions reductions is different for the 24-hour PM_{2.5} standard, and may also change with season and location in the Basin.

Comparative Effectiveness of Reductions To Achieve Federal PM_{2.5} Air Quality Standards				
	NO_x	SO_x	VOCs	PM_{2.5}
Annual PM _{2.5} Standard	1	15	0.4	10
24-hour PM _{2.5} Standard	1	8	0.3	15

However, the CMAQ model, while state-of-the-art, has been shown to significantly underestimate SOA formation from VOCs.⁶ Future versions of CMAQ will strive to eliminate this underprediction as additional SOA formation processes are better understood and incorporated in the model.

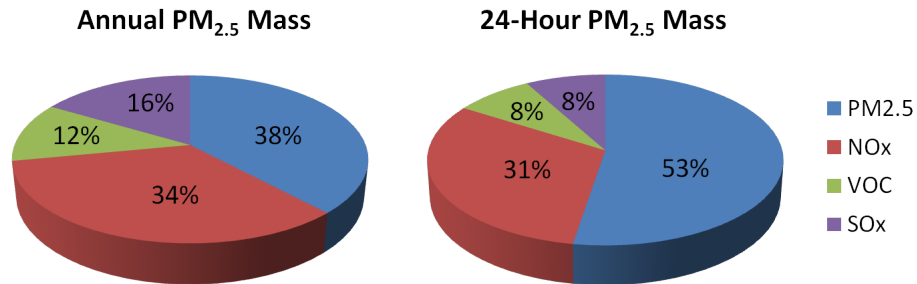
Using 2012 emissions inventories weighted by the relative effectiveness factors, contributions of precursor emissions to achieving both annual and 24-hour PM_{2.5} standards were estimated. For example, while SO_x has a higher relative effectiveness factor than NO_x, total emissions of NO_x are much greater than those of SO_x. Therefore, as shown in the charts below, NO_x and PM_{2.5} contribute more to PM_{2.5} levels than SO_x or VOC. Controls of NO_x emissions will make a significant contribution to reducing annual PM_{2.5} mass concentrations, and thus meeting the federal annual PM_{2.5} standard.

⁵ Norbeck, J. *Standardized Test Kitchen and Screening Tools Evaluation for South Coast Air Quality Management District Proposed Rule 1138*; Prepared under Contract No. S-C95073 for the South Coast Air Quality

Management District, El Monte, CA, by CE-CERT: University of California, Riverside, CA, 1997.

⁶ Carlton, A.G., et al. Model Representation of Secondary Organic Aerosol in CMAQ v4.7, *Environ. Sci. Technol.* 2010, 44, 8553-8560.

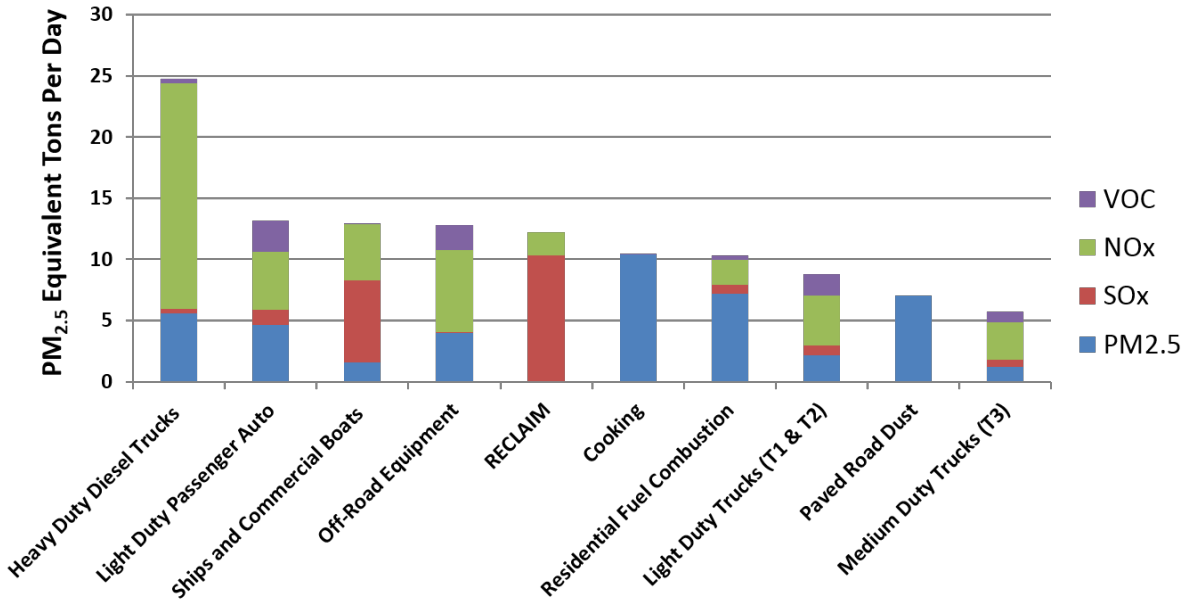
Weighted Contributions of Precursor Emissions (2012)



Attaining the ozone standards requires significant reductions in emissions of NO_x well above and beyond those resulting from current rules, programs, and commercially available technologies. For previous AQMPs, most of these additional reductions relied on the development of new control techniques or improvement of existing control technologies, also known as “black box” measures, as authorized under Section 182(e)(5) of the federal CAA. These “black box” measures, if implemented successfully, will not only allow attainment of the ozone standards, but will also provide significant help in reaching PM_{2.5} standards. In fact, if NO_x emissions reductions designed to meet the former ozone standard in 2023 are achieved, PM_{2.5} levels in the Basin are projected to be very near, if not meeting, the current 2012 federal annual PM_{2.5} standard of 12 mg/m³ by that time. However, attainment of the PM_{2.5} standard may not rely on Section 182(e)(5) measures.

More detailed analysis of the emissions categories contributing to ambient PM_{2.5} mass, using the weighting factors for precursors described above, shows what emission sources could be prioritized for a focused and cost-effective PM control program. Area sources, such as commercial cooking, residential fuel combustion, and paved road dust are major contributors to ambient PM_{2.5}, primarily through direct PM_{2.5} emissions. Mobile sources, both on-road and off-road, are also significant sources of PM_{2.5}, both through direct PM_{2.5} emissions but also precursors such as NO_x.

Emissions Categories Contributing to Annual PM_{2.5} Mass



* Based on 2016 AQMP – Baseline Annual Average Inventory for 2012

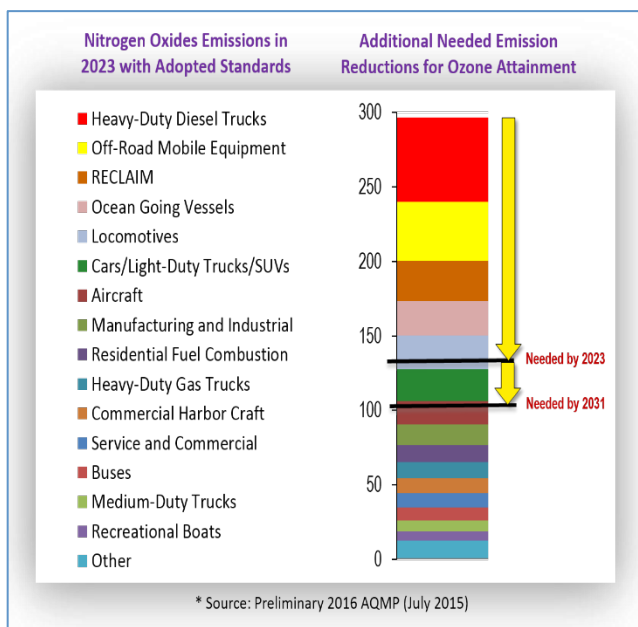
4. RECOMMENDATIONS - PATH TO PM_{2.5} ATTAINMENT IN THE 2016 AQMP

Control Strategy

Through the 2007 and 2012 AQMPs, it was demonstrated that the previous control strategies employed for the PM₁₀ and 1-hour ozone SIPs also benefited PM_{2.5} and 8-hour ozone reductions. Taking the same multi-pollutant approach to assess strategies for the 2016 AQMP suggests that a NO_x-heavy strategy is the most efficient approach for the reduction of fine particulate matter because NO_x reductions are needed for the 1-hour and 1997 8-hour ozone standards within approximately the same timeframe for the federal annual PM_{2.5} attainment demonstration. The PM_{2.5} strategy can be further augmented with targeted and cost-effective directly emitted PM_{2.5} and SO_x controls if needed, should NO_x controls from other control programs be insufficient, not timely, or do not materialize.

Based on the above discussion, several attainment paths can be developed with varying degree of controls among directly emitted PM_{2.5} and PM precursors. Selecting the most efficient path for PM_{2.5} attainment takes into consideration many factors, such as the amount of total reductions needed, technology readiness, attainment deadlines, and the inter-relationship with other NAAQS pollutants such that the control strategy does not need to make drastic mid-term adjustments, thus minimizing potential control costs. The following sections describe the staff recommendations for a prioritized approach in the development of a PM_{2.5} attainment strategy.

1) Co-Benefits from the Ozone NO_x Strategy



Many of the most significant direct PM_{2.5} and PM_{2.5} precursor emission sources are already well controlled, but additional reductions from implementation of adopted control measures from the 2007 and 2012 AQMPs may still not be adequate for attainment of the new federal annual PM_{2.5} standard. PM_{2.5} levels will be further reduced from the additional NO_x emissions reductions needed for the ozone control strategy. Preliminary 2016 AQMP analysis shows that approximately another 150 tons per day of NO_x reductions needed are to meet the 1997 8-hour ozone standard by 2024. This is within the timeframe of the 2012 annual PM_{2.5} standard attainment deadline of 2021-2025. Preliminary projections suggest that without any additional PM controls, but with the ozone NO_x strategy alone, the Basin's annual PM_{2.5} design value would be very near the standard of 12 mg/m³ in 2023.

Given the goal of developing the most efficient and cost-effective path to meeting all clean air standards, and given that these NO_x reductions are needed for ozone attainment anyway, the most desirable path is to control NO_x emissions, not only from stationary and area sources, but primarily from mobile sources that fall under state and federal jurisdiction. Significant reductions are needed from on-road vehicles, off-road engines, ships, and locomotives to achieve the necessary NO_x reductions to meet the federal ozone standards. The 2016 AQMP will capture the anticipated NO_x reductions from the ozone plan, as well as anticipated concurrent reductions of VOCs, SO_x, and directly emitted PM_{2.5} from zero tailpipe emission technologies or efficiency measures that reduce vehicle trips/vehicle miles traveled.

2) Co-Benefits from Climate Change or Air Toxic Control Programs

SCAQMD staff recognizes, to the extent available under the U.S. EPA's PM_{2.5} implementation rule, that there are several near-term measures that are being pursued by CARB under the AB 32 Scoping Plan, including reductions in short-lived climate forcers such as BC. Comprised of microscopic particles emitted from incomplete combustion of biomass, wood, and fossil fuels, BC is a major contributor to global climate change and also a primary component of diesel particulate matter (DPM). Cutting BC emissions would immediately result in reduction of the rate of warming, as well as PM_{2.5} benefits. Identifying the most promising control measures or mitigation options to address BC emissions reductions in the areas of stationary and mobile sources, residential wood combustion, and open biomass burning will provide climate change as well as PM_{2.5} benefits in the near term.

Air toxic control programs reducing DPM or toxic metals would also contribute to PM_{2.5} reductions. Despite significant decreases in air toxics exposure over the past couple of decades, the recent SCAQMD MATES IV results continue to show unacceptably high risk of exposure to DPM, representing two-thirds of the overall air toxic cancer risk. This result emphasizes that continuous efforts towards reducing DPM emissions are needed at local, state, and federal levels and via cooperation with the ports, airports, and other stakeholders. Alternative fueled vehicles with significant zero emission miles traveled, along with coordinated land use and transportation planning with the goal of reducing VMT, will contribute to reduction of DPM, GHG, as well as NO_x emissions. Toxic metals emitted from industrial processes can cause risks to public health and the environment. SCAQMD staff will continue to develop and propose new rules or amend existing rules by strengthening requirements to reduce toxic metal emissions and exposure from various metal industry sources. These measures, although not developed for SIP purposes, will achieve concurrent reductions in directly emitted PM_{2.5} and can be quantified and credited toward needed SIP reductions.

3) Outreach and Incentive Programs

Other programs supporting PM control measure implementation are also important to ensure expected emission reductions are being realized. These programs include outreach and incentive programs. SCAQMD

staff utilizes a variety of tools to raise public awareness and understanding of the significance and health effects of particle pollution and thus, the importance of PM controls to protect public health. Enhanced public outreach should continue to be pursued by various means, including targeted and focused communications campaigns, community workshops, educational brochures and videos, and other digital media formats.

Incentive funding for stationary sources can be pursued and best applied where controls are cost-effective, but not necessarily affordable by the affected sources, especially when controls are considered for smaller businesses. Such incentive funds can be used to subsidize low-emitting equipment purchases either by businesses or the public. Funding for such incentive programs can originate from state and federal grants, penalties/settlements, and other sources.

4) Additional Measures for PM_{2.5} Attainment

Since the federal CAA does not allow for reliance on future technologies (i.e., "black box," Section 182(e)(5) measures) in the PM_{2.5} attainment plan, portions of NO_x controls that are part of the ozone attainment strategy may be not eligible for inclusion as SIP measures for PM_{2.5} purposes. For this reason, additional measures to ensure attainment will need to be evaluated and implemented if needed. Potential control concepts based on the Reasonably Available Control Technology (RACT) or RACM analysis for PM_{2.5} and its precursors as part of the 2016 AQMP will be evaluated for their feasibility and applicability for this air basin. Any additional measures needed to meet the RACT/RACM requirements could be further developed for inclusion in the 2016 AQMP.

Based on the PM_{2.5} formation potentials described above, if additional reductions are still needed for timely PM_{2.5} attainment demonstration, additional SO_x and/or direct PM_{2.5} measures should be a first priority. Examples of such measures can be found in Appendix B.

In developing the PM_{2.5} strategy, geographic, seasonal, and episodic controls should also be considered as they minimize compliance costs while targeting emissions reductions when and where they are needed. Examples of these measures are also contained in Appendix B. Such targeted measures will have even greater benefits for avoiding exceedances of the 24-hour PM_{2.5} standard given that the exceedances are episodic and occur almost exclusively in the colder months. As attainment deadlines for the 24-hour standard are imminent, PM_{2.5} measures arising from the 2016 AQMP development process that can help to ensure timely attainment of the 24-hour PM_{2.5} standard should be developed and adopted as early action measures, parallel to the 2016 AQMP development.

5. CONTINUING RESEARCH AND SCIENTIFIC STUDIES

Continuing research and scientific studies are needed to better quantify organic compounds and their contribution to PM_{2.5} formation. In the Basin, approximately 30-50% of the PM_{2.5} mass is composed of organic

compounds. However, the organic component of PM_{2.5} in the Basin needs further study as certain semi-volatile organic compounds (SVOC) have not been historically inventoried, controlled or incorporated in regional air quality modeling. Continuing research and scientific studies are required to better quantify SVOC emissions and their contribution to PM_{2.5} formation.

The role of ammonia emissions will also be examined further in the 2016 AQMP modeling analysis. Some areas within the Basin may be saturated with ammonia now or in the future relative to SO_x and NO_x, and thus modest ammonia controls may have little effect. Other areas may show that ammonia controls are effective in reducing ambient PM_{2.5}. Even if large ammonia reductions may have benefits, it may not be feasible given the nature of the sources.

SUMMARY

The 2016 AQMP modeling and attainment demonstration analysis will provide refinement to the concepts in this white paper, but it is clear that an integrated approach to multiple air quality challenges will minimize control costs while achieving multiple goals. A NO_x-heavy control strategy will not only provide for attainment of the ozone standards, but also provide significant co-benefits for the reduction of fine particulate matter. Concurrent targeted, strategic, and timely reductions in directly emitted PM_{2.5} and precursors will ensure meeting the federal annual and 24-hour PM_{2.5} standards by the attainment deadlines.

LIST OF ACRONYMS AND ABBREVIATIONS

AB	Assembly Bill
APCD	Air Pollution Control District
AQMP	Air Quality Management Plan
Basin	South Coast Air Basin
BC	Black Carbon
CAA	Clean Air Act
CARB	California Air Resources Board
CHC	Commercial Harbor Craft
CMAQ	Community Multi-scale Air Quality model
DPM	Diesel Particulate Matter
EC	Elemental Carbon
GHG	Greenhouse Gas
MATES	Multiple Air Toxics Exposure Study
NAAQS	National Ambient Air Quality Standards
NH ₃	Ammonia
NO _x	Nitrogen Oxides
OC	Organic Carbon
OGV	Ocean-Going Vessels
PM	Particulate Matter
PM _{2.5}	Particulate Matter with a dynamic diameter less than or equal to 2.5 microns
PM ₁₀	Particulate Matter with a dynamic diameter less than or equal to 10 microns
ppm	Parts Per Million
RACM	Reasonably Available Control Measure
RACT	Reasonably Available Control Technology
RECLAIM	REgional CLean Air Incentives Market
SCAQMD	South Coast Air Quality Management District
SIP	Standard Implementation Plan
SOA	Secondary Organic Aerosol
SO _x	Sulfur Oxides
SVOC	Semi-Volatile Organic Compound
U.S. EPA	United States Environmental Protection Agency
VMT	Vehicle Miles Traveled
VOC	Volatile Organic Compound
mg/m ³	Micrograms per cubic meter
μm	Micrometers

Appendix A: Top Ten Emission Sources by Pollutant¹**1. NO_x**

Emission Sources	2012 Emissions (Tons/Day)
Heavy Duty Diesel Trucks	184.1
Off-Road Equipment	67.0
Light Duty Passenger Auto (LDA)	46.8
Ships and Commercial Boats (OGV & CHC)	45.9
Light Duty Trucks (T1 & T2)	41.2
Medium Duty Trucks (T3)	30.2
Trains	21.3
Heavy Duty Gasoline Trucks	20.9
Residential Fuel Combustion	20.2
Heavy Duty Diesel Urban Buses (UB)	19.6

2. VOC

Emission Sources	2012 Emissions (Tons/Day)
Consumer Products	86.5
Light Duty Passenger Auto (LDA)	64.4
Off-Road Equipment	51.6
Light Duty Trucks (T1 & T2)	42.9
Petroleum Marketing	34.4
Recreational Boats	30.4
Medium Duty Trucks (T3)	21.2
Coatings and Related Process Solvents	18.9
Heavy Duty Gasoline Trucks	14.4
Architectural Coatings and Related Solvents	13.3

¹ Source: Preliminary 2016 AQMP, July 2015.

3. Directly Emitted PM_{2.5}

Emission Sources	2012 Emissions (Tons/Day)
Cooking	10.4
Residential Fuel Combustion	7.2
Paved Roads Dust	7.1
Heavy Duty Diesel Trucks	5.6
Light Duty Passenger Auto (LDA)	4.6
Off-Road Equipment	4.0
Wood and Paper	2.3
Light Duty Trucks (T1 & T2)	2.2
Mineral Processes	2.1
Construction and Demolition	1.7

4. SO_x

Emission Sources	2012 Emissions (Tons/Day)
RECLAIM	6.87
Ships and Commercial Boats (OGV & CHC)	4.46
Aircraft	1.42
Service and Commercial Fuel Combustion	1.15
Light Duty Passenger Auto (LDA)	0.85
Light Duty Trucks (T1 & T2)	0.51
Residential Fuel Combustion	0.49
Manufacturing and Industrial	0.45
Medium Duty Trucks (T3)	0.40
Petroleum Refining	0.36

Appendix B: Opportunities for Emission Reductions to Achieve PM_{2.5} Standards

This appendix describes control concepts toward achieving the federal PM_{2.5} standards if additional emission reductions are needed after implementation of other measures that achieve PM_{2.5} co-benefits and incentive programs as outlined in the PM White Paper. Examples of potential control concepts are discussed by sector. If additional reductions are needed for annual PM_{2.5} standard attainment, some or all of the concepts could be developed as a control measure that can be prioritized for implementation, including time and place controls, such as geographic, seasonal, or episodic controls, as well as incentive programs.

1. Cooking

The SCAQMD has implemented a very successful PM_{2.5} control program for chain-driven charbroilers (used at quick service restaurants), but PM_{2.5} emissions from under-fired charbroilers remain relatively uncontrolled, primarily due to the current high capital costs of equipment, and operation and maintenance (O&M) costs. Based on current emissions inventory, approximately 80% of PM_{2.5} emissions from restaurants are from under-fired charbroilers. SCAQMD is completing a study with University of California Riverside, in partnership with the U.S. EPA and other air agencies in PM_{2.5} nonattainment areas, to identify cost-effective and more affordable under-fired charbroiler controls. Types of devices being evaluated can be generally described as filter-based equipment, electrostatic precipitators (ESPs), catalysts, scrubbers, and other innovative technologies, some of which are nearing commercial availability. Study results are being evaluated and will be used to develop a detailed technical and economic (cost and affordability) feasibility analysis.

If needed for attainment, emission control programs for under-fired charbroilers could potentially be tiered and require high efficiency (and potentially more expensive) controls for larger restaurants and possibly less efficient, less expensive, yet more affordable equipment for smaller sources. Small business incentive programs could also be explored to help offset purchase and installation costs. For example, an incentive program could be explored to help offset the control device costs to restaurants from what could otherwise be less affordable controls for direct PM_{2.5} reductions at small business restaurants. The net result could be an overall reduction of PM_{2.5} pollution at a lower overall cost. SCAQMD continues to work closely with staff from the Bay Area AQMD, San Joaquin Valley APCD, and U.S. EPA Region 9 on research and demonstration projects for these control technologies.

2. Residential and Open Burning

Additional PM_{2.5} reductions from biomass burning were identified by the SB 656 (Sher) report and control measures were developed and implemented in conjunction with the 2007 and 2012 AQMPs. SCAQMD Rule 445 (Wood-Burning Devices) was adopted in 2008 and subsequently amended in 2013. Rule 445 established a mandatory residential wood-burning curtailment program, beginning in 2011, during winter months (November through the end of February) known as the "Check Before You Burn" program. Amendments in

2013 lowered the curtailment threshold from 35 (federal 24-hour PM_{2.5} standard) to 30 µg/m³ to address forecasting uncertainties and assure a level of protection to remain below the standard. Rule 445 specifies the types of devices that can be installed into new and existing developments, includes moisture content requirements for commercial firewood sellers, and establishes a winter wood burning curtailment program. SCAQMD Rule 444 (Open Burning) has been in place since the formation of the SCAQMD and has been amended many times, most recently in 2013. Rule 444 is applicable to agricultural and prescribed (e.g., forest service) open burning sources and includes requirements to minimize smoke emissions. The 2013 amendments to Rule 444 synchronized the wintertime residential wood-burning control program (Rule 445) with the open burning program such that open burning would not occur during a mandatory residential no-burn day.

A new initiative has been implemented to upgrade wood-burning devices in inland, high PM_{2.5} areas. Under this program, households in the greater area surrounding the cities of Riverside and San Bernardino can work with participating retailers to choose from a variety of cleaner hearth products, including gas logs, gas/electric inserts, and more efficient wood stoves (if no gas service) for installation. SCAQMD provides incentives to offset purchase and installation costs. The incentives offered have been increased substantially over past programs and even higher incentives (up to \$1,600) are available for households that qualify under low-income guidelines. This program has been effective, but to achieve maximum emission reductions, higher incentives could be offered or the geographic area eligible to participate could be expanded. Experience has shown that education and outreach to targeted households is a key program component. Since the current eligible project area is relatively small, direct outreach to individual residences has been the most successful.

Potential additional emission reductions via Rule 445 related residential wood burning could involve further restrictions on the types of devices (e.g., U.S. EPA certified wood burning devices) allowed to be installed into existing developments, such as room additions, remodels, etc.

The highest PM_{2.5} levels usually occur during late fall and winter months, with the exception of high values reported near the Fourth of July (attributable to smoke from Independence Day firework displays). However, some high levels occur in early fall. If needed for attainment, further burn restrictions could be established for this fall time period by expanding the wintertime curtailment period to include October. The threshold used to forecast no-burn days under either the residential or the open burning programs could also be lowered. Both options could reduce emissions during peak PM periods or episodes.

As previously mentioned, Rule 445 prohibits wood burning in areas where high PM_{2.5} levels are forecast. If poor PM_{2.5} air quality is, however, forecast for an area that has documented an exceedance of the federal 24-hour PM_{2.5} standard, the no-burn day applies to the entire Basin. This is intended to seek the maximum amount of emission reductions feasible in an attempt to prevent the episodic exceedance. The 2016 AQMP will address the annual PM_{2.5} standard which is less sensitive to these episodes. Currently, the peak PM_{2.5} monitoring site, or "trigger area", to identify a Basin-wide curtailment day is in the Mira Loma area, part of

Source Receptor Area (SRA) 23 (Metropolitan Riverside County). As part of an enhanced control effort, the trigger area could be expanded to include other SRAs with elevated PM_{2.5} levels that have not documented exceedances of the federal 24-hour standard (annual 98th percentile concentration, averaged over 3 years). This would likely result in an increase in Basin-wide no-burn days and help to lower annual PM_{2.5} levels. Alternatively, if air quality modeling supported a truly targeted control program, there could be an increase in the number of no-burn days forecast solely for SRA 23 and immediate upwind areas.

Possible controls for Rule 444 related open burning sources could include mandatory use of chipping/grinding or mulching as alternatives to open burning.

3. Fugitive Dust

PM derived from mechanical disruption (e.g., agriculture, construction, etc.) is primarily in the coarse (PM_{10-2.5}) size fraction; however, entrained road dust is still one of the major direct PM_{2.5} sources due to the region's large number of roadways and high traffic volumes. In response, SCAQMD has adopted regulations to prevent material from being deposited on roadways and a program for efficient street sweeping equipment. For the street sweeping equipment, a testing protocol was developed and minimum pick-up efficiency and entrainment standards are in place (Rule 1186 – PM₁₀ Emissions from Paved and Unpaved Roads, and Livestock Operations). Local jurisdictions must only procure equipment that meets applicable standards and a companion regulation (Rule 1186.1 – Less-Polluting Sweepers) also requires, in most cases, that street sweepers be powered by alternative fuels.

During the development of Rule 1186, SCAQMD staff learned that street sweeping frequencies vary greatly among jurisdictions, from weekly to monthly to, in some cases, not at all. If needed for attainment, minimum street sweeping frequencies could be explored as well as enhanced cleaning on roads with higher silt loadings.

4. Ammonia Control

1) Agricultural Dairies

Livestock waste is the third largest emission source of ammonia in the Basin and is regulated by both SCAQMD Rules 223 (Emission Reduction Permits for Large Confined Animal Facilities) and 1127 (Emission Reductions from Livestock Waste). Recent research found that fresh excreted manure in the animal housing areas is the major source of ammonia emissions and each cow produces approximately 60 kg of manure daily.² Prevailing winds push NO_x and SO_x emissions from industrial and transportation sources in the western Basin to inland areas and these gases mix with ammonia emissions from widespread sources, including approximately 100,000 head of dairy cattle and support stock in western Riverside and San Bernardino counties. Ammonium

² Final 2012 Air Quality Management Plan, Appendix IV-A, Control Measure BCM-04 – Further Ammonia Reductions from Livestock Waste, SCAQMD, February 2013.

nitrate is the most prevalent PM compound measured at the Mira Loma air monitoring station, the only station projected to exceed federal 24-hour standard for PM_{2.5}.

If needed for attainment, seasonal or episodic approaches to control ammonia from dairy manure may be beneficial in reducing the secondarily formed air contaminants in the area. One possible approach would be to reduce ammonia emissions from fresh manure using an ammonia-reducing agent. Sodium bisulfate, when dissociated, reduces the pH and protonates ammonia, converting it to ammonium. The ammonium is then bound by sulfate to form ammonium sulfate, which is retained in the manure in its solid form. In California, sodium bisulfate has been used by dairies in northern and southern counties, including San Bernardino and Riverside counties, mainly to prevent cow lameness and nuisance flies. Theoretically, 100 pounds (lbs) of sodium bisulfate would bind 14 lbs of ammonia. This method of control was initially proposed in the 2012 AQMP for an assessment to evaluate the technical and economic feasibility of application, including episodic application.

If deemed feasible and necessary, seasonal or episodic ammonia controls may be considered, for example by applying sodium bisulfate to fresh manure during high PM_{2.5} months or for days only when higher concentrations occurred or are anticipated to occur based on the past analyses. However, costs associated with sodium bisulfate use can be high and the need to offset the costs through an incentive program would need to be considered.

2) Anaerobic Digestion

The SCAQMD Rule 1133 series establishes requirements for composting of organic waste such as animal manure, biosolids, greenwaste, and foodwaste. As ongoing efforts at the state level for organics diversion to meet AB 32 and landfill diversion goals, AB 341 (Chesbro) has created challenges relative to controlling VOC and ammonia emissions from increased composting of greenwaste, and increasingly from foodwaste. AB 341 was approved by the legislature in 2011 to further reduce GHG emissions by diversion of organic materials away from landfills. This legislation established a goal that 75% of solid waste be reduced, recycled, or composted by 2020. This has created a statewide challenge to develop mechanisms to accommodate the state mandate while not adversely affecting air quality. Inclusive of these challenges are local air quality rules and regulations associated with composting operations/methods, permitting, and off-road vehicle use. Local air districts are working with CARB and California Department of Resources Recycling and Recovery (CalRecycle) to address these issues.

According to the composting industry³, the majority of the yard trimmings and tree prunings processed (i.e., chipped and ground) in the Basin are not composted but go through a much shorter pathogen reduction process. These organic materials are used as an alternative daily cover (ADC) or for other beneficial uses at landfills or as a ground cover on commercial or public lands. The majority of mobile, point, and area source

³ Paul Ryan, Inland Empire Disposal Association, E-mail communication, November 13, 2014.

emissions from compostable materials handling through chipping and grinding are not sufficiently controlled to minimize potential emissions in the Basin. Conversely, composting is relatively well regulated through current air quality planning and rulemaking. Two legislative mandates, AB 1594 (Williams) and AB 1826 (Chesbro) approved in 2014 will help the state achieve diversion goals by 2020 through recycling of compostable organic waste materials. AB 1594 closes diversion credit for yard trimmings and prunings, including greenwaste, which is used as an ADC or for other beneficial uses at landfills. AB 1826 will drive the recycling of yard trimmings and food scraps by requiring commercial generators to sign up for composting or anaerobic digestion service for their organic waste. More organic materials are expected to be diverted in the future and consideration must be given to expansion of the organics processing industry and the emissions impact from those processes and associated equipment compared to the overall benefits of diversion.

Anaerobic digestion (AD) has been identified as a technically viable method of organic waste treatment in which organic waste is transformed to renewable biogas, mainly composed of methane (CH₄) and carbon dioxide (CO₂), in an oxygen-free environment. Digesters can minimize emissions of ammonia, VOC, and other odorous pollutants in well-managed operating conditions, which can contribute to reductions of PM_{2.5} formation. However, air quality permitting, off-road vehicle use, as well as high capital investment and O&M costs, may be a disincentive. CalRecycle is in the process of amending and creating new requirements for California Code of Regulations, Titles 14 and 27 to address these and other implementation issues. As part of this process in particular, a stand-alone set of in-vessel digestion regulations has been proposed to divert compostable organic materials from landfills to reduce GHG generation, while producing biofuels or bioenergy. Use of digesters may bring about air quality benefits (e.g., decreasing GHG, ammonia, and VOC emissions) and co-benefits of PM_{2.5} reduction in the Basin.



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