# Strategic Workplan for Particulate Matter Research: 2000 to 2004

U.S. Department of Transportation
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16. Abstract

The *Strategic Workplan for Particulate Matter: 2000 to 2004* summarizes the state of knowledge of highway related research into Particulate Matter (PM) pollution as determined from previous research efforts and identifies initiatives to fill gaps in knowledge of PM. In an effort to coordinate future research efforts to answer many of the unknown questions about PM emissions, FHWA undertook a project to define the transportation community's needs for future research with the goal of establishing a plan for future research studies that would define the relationship and contribution of PM emissions from highway vehicles. The work was undertaken because of the increasing concern that PM has on human health and the environment and the need to reduce emissions of PM from vehicles. It examines several areas that are considered essential in understanding the transportation community's contribution to particulate matter (PM) emissions.

The report examines future research needs by investigating four uncertainties in the current knowledge of PM including likely nonattainment areas for $PM_{10}$ and $PM_{2.5}$ pollution, whether PM is a regionally or locally produced pollutant, what the transportation contribution is to the total emissions from all sources, and then the most effective control strategies for reducing PM emissions. These four uncertainties are then used to define five focus areas which the research projects can be grouped, including monitoring, chemical characterization of PM, sources, analysis and modeling, and control strategies. The focus areas are then further refined into fourteen individual projects which are outlined as the projects that should be initiated to understand the transportation contribution to PM pollution.

This report was developed to determine projects that would define the highway vehicles contribution to PM pollution and determine appropriate control strategies for reducing emissions. Although some of the projects outlined in this report are likely to be initiated by FHWA, it is hoped that other transportation and environmental organizations will use this information to assist in the planning of their research efforts.

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# Executive Summary

## Introduction

This Strategic Workplan for Particulate Matter Research is designed to provide direction for the research on particulate matter (PM) being undertaken by and on behalf of the transportation community. It identifies a set of five research focus areas and describes the priority research projects necessary to most effectively develop needed information and tools and to target resources.

PM is the term used to describe a complex mix of solid particles and liquid droplets found in the air. The United States Environmental Protection Agency (EPA) established major changes to the National Ambient Air Quality Standard (NAAQS) for PM in July 1997. The revised NAAQS are expected to have wide-ranging impacts on the transportation community, including:

- *An expected increase in the number of PM nonattainment areas*, particularly in the eastern United States, thus greatly expanding the number of state departments of transportation (DOTs), metropolitan planning organizations (MPOs), and local transportation agencies that are affected by PM regulations;

- *A focus on combustion processes (including vehicle engines)*, as a major source of PM, particularly in urban areas where combustion-related emissions are likely to compose a greater share of total emissions, thus increasing the likelihood of more widespread transportation-related control programs for PM; and

- An emerging *recognition of PM as a regional problem*, caused in part by secondary PM, that is formed and transported over great distances, thus redefining PM, in part, from a local to a regional-level issue and expanding the need for broader emission control programs.

There are, however, major weaknesses in the basic analytic tools and data that are needed to develop appropriate policy responses. In particular, policymakers charged with responding to the new standards are challenged by a limited understanding of spatial and chemical trends in ambient PM emissions, inaccurate and incomplete emissions inventories, and inadequate emissions models. The large gaps in information necessitate targeted research focused specifically on the needs of the transportation community that:

- Identifies gaps in the PM science knowledge base that are hindering policy development;

- Supplies an objective information foundation suitable for developing the next generation of transportation-related policy tools and techniques; and

- Coordinates the PM research program for transportation sources with existing and future research initiatives.

The Workplan was developed with input from transportation and air quality experts throughout the country. It draws extensively on information gathered in a detailed literature review of PM research, and on the results of a one-day symposium with transportation and air quality experts held in January 2000.

## Linking Transportation Policy Questions and Research Focus Areas

The final output of this Workplan is a set of priority research projects. The projects are intended to fill PM research gaps that are most critical to the transportation community. Within the Workplan, the priority projects are categorized according to five broad research focus areas (monitoring, characterization, transportation sources, modeling, and control strategies) and how they address four key transportation policy questions. By linking research focus areas to resolution of key transportation policy questions, implementation of the Workplan will facilitate development of information, tools, and approaches that transportation agencies can use to handle emerging issues related to the new PM standards.

## Transportation Policy Questions

In the coming years, two critical policy issues for transportation agencies in $PM_{2.5}$ and $PM_{10}$ nonattainment areas will be developing appropriate transportation control strategies and demonstrating "conformity" of transportation plans. Their ability to carry out these activities, however, is constrained by gaps in knowledge and a lack of tools. Addressing these and other issues will require resolution of four policy questions:

- What areas will be in nonattainment?
- What kind of problem is PM: local, regional or both?
- What is the transportation contribution to PM?
- What are the most cost-effective control strategies for transportation sources?

These four questions provide a framework for undertaking the priority projects in the Workplan, first by determining where PM is a problem and where the problem is coming from, and then by developing effective transportation control strategies.

## Research Focus Areas

***Focus Area One: Monitoring.*** The research goal of "focus area one" is to ensure that enhancements to the Nation's PM monitoring system improve understanding of the contribution of transportation to PM. The EPA's ambient air quality monitoring program provides the data needed to track air quality throughout the United States. The data gathered by the PM monitoring system provide a major source of information for the designation of future nonattainment areas, as well as for tracking compliance with NAAQS, and developing emissions modeling tools, emissions inventories, and control programs. EPA, in coordination with state air quality agencies, is presently expanding the PM monitoring system to support future NAAQS. These networks will substantially improve the capability of the PM monitoring system to address the new $PM_{2.5}$ NAAQS. The monitoring systems, however, may not be adequate to provide data needed for accurate determination of transportation sector-related PM emissions. Project P1 will analyze preliminary data from the $PM_{2.5}$ monitoring network to identify potential $PM_{2.5}$ nonattainment areas. Project P2 will integrate critical transportation sector PM research concerns into EPA's supersite PM research program. Project P3 will examine state-of-the-art techniques for measuring the semi-volatile component of PM.

***Focus Area Two: Characterization.*** The research goal of "focus area two" is to advance understanding of the spatial occurrence of PM and its sources, with an emphasis on $PM_{2.5}$ and secondary PM formation. Characterization of PM draws on spatial and chemical analysis of monitoring data to improve understanding of where PM problems occur and how they are caused. Accurate characterization of PM can help to ensure that equitable and effective control strategies are developed. At present, however, understanding of the spatial and chemical characteristics of $PM_{2.5}$ is based on a small number of region-specific studies. This research does not fully address key PM characterization concerns that are relevant to transportation agencies, such as the likely extent of areas that will be affected by $PM_{2.5}$ regulations, the magnitude of secondary PM formation and transport, and the relative contribution of transportation sources to $PM_{2.5}$. Targeted analysis of the data collected by improvements in the $PM_{2.5}$ monitoring network will be vital to answering these questions. Project P4 will review and update transportation-related source profile information used in PM speciation analysis. Project P5 will utilize speciation monitoring data to provide an improved understanding of the relative contribution of transportation to PM.

***Focus Area Three: Transportation Sources.*** The research goal of "focus area three" is to improve understanding of motor vehicle-related sources of PM and PM precursor emissions. Despite several decades of regulation on PM emissions, relatively little is known about the operating variability of PM emissions from motor vehicles as a result of changes in speed, engine deterioration, fuel and driving behavior. Recent studies for light-duty vehicles have begun to expand this knowledge. However, additional research is needed. Project P6 will conduct dynamometer studies of diesel-fueled vehicles/engines that are representative of the current fleet mix to generate better data on the contribution of diesel vehicles to PM and PM precursor emissions. Project P7 will conduct dynamometer studies of sample vehicles to determine the impact of gross emitter gasoline powered vehicles on PM emissions. Project P8 will examine re-entrained road dust contributions to $PM_{2.5}$ in urban areas in the eastern United States.

***Focus Area Four: Modeling.*** The research goal of "focus area four" is to improve PM emission modeling for transportation sources. The PART5 model is EPA's accepted motor vehicle PM emissions model, and is required in the development of $PM_{10}$ inventories and analyses. The accuracy of emission factor models is important because these models are used to develop emission inventories and to evaluate the emission effects of transportation projects and control strategies. The quality and accuracy of user inputs to the models, such as vehicle travel data, are also important for accurate inventory development and analysis. It is widely recognized that the PART5 model contains a number of weaknesses that limit the precision of the model. The following priority research projects are designed to fill gaps in modeling techniques and improve the accuracy of emissions' estimates. Project P9 will develop a coordinated model improvement program for incorporating new research on motor vehicle-related emissions into EPA's PM model on a timely basis or will develop new models as necessary. Project P10 will identify improvements needed in travel data to improve the use of the PM emission model for inventory development and analysis. Project P11 will develop an approach to the ammonia emissions component for possible inclusion in one of EPA's motor vehicle emission factor models.

***Focus Area Five: Control Strategies.*** The research goal of "focus area five" is to improve understanding of the costs and effectiveness of PM control strategies for transportation sources. With the potential for a significant number of new $PM_{2.5}$ non-attainment areas under the new NAAQS, there is an increased need to improve understanding of potential control measures for transportation. Project P12 will analyze the costs and effectiveness of existing transportation source PM control strategies at reducing PM and PM-precursor emissions. Project P13 will develop a menu of transportation-source $PM_{2.5}$ control strategies for regions to consider in air quality planning, including an evaluation of costs and effectiveness in different geographic settings. Project P14 will evaluate the interactions between transportation-related PM and ozone control strategies, and other air pollutants.

## Next Steps

The research focus areas and priority projects outlined in this Workplan provide a map for conducting future transportation-related PM research. However, additional steps will be required to implement the Workplan, including development of detailed project scopes, identification of project leadership roles, and selection of funding opportunities. Important implementation issues include:

- **Multiagency implementation approach.** FHWA acknowledges that the technical complexity and broad scope of the projects contained in the Workplan will require a multiagency implementation approach. Extensive coordination between FHWA, state DOTs, and MPOs will be critical; however, the multidisciplinary range of projects outlined in the Workplan will also necessitate extensive involvement by academic and applied research organizations, as well as state and federal air quality agencies, and industry groups. An open dialogue among all these groups is encouraged to facilitate speedy resolution of issues critical to implementing this Workplan — particularly, equitable distribution of research leadership, development of detailed project scope information, and funding responsibilities for individual projects.

- **Project implementation time frame.** An aggressive four-year time frame is envisioned for conducting the research described in the Workplan. Adherence to this schedule will ensure that completion of the research generally coincides with EPA's planned designation of new nonattainment areas and improves the ability of state DOTs to develop timely and appropriate transportation policy responses.

- **Project scheduling.** This Workplan does not include a specific time line for the initiation of individual projects. This plan, however, recognizes that certain projects must be initiated before others because they answer questions that need to be addressed early on by transportation agencies and because their findings and outcomes will help lay the foundation for other projects.

In terms of DOT's key policy concerns, research focus areas 3, 4, and 5 (transportation sources, modeling, and control strategies) are of most direct relevance. However, research focus areas 1 and 2 (monitoring and characterization) are acknowledged to provide critical background information on PM, without which sound policy decisions cannot be made.

Communication of research results to transportation stakeholders is an important aspect of the implementation of this research Workplan. The products of all the research projects need to be accessible to transportation professionals, and in some cases, special outreach methods and training will be required. Possible methods for distributing information about the research results might include development of a PM Web site, or newsletter, as well as conferences and seminars.

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# INTRODUCTION

This Strategic Workplan for Particulate Matter Research is designed to provide direction for the research on particulate matter (PM) being undertaken by and on behalf of the transportation community. It identifies a set of five research focus areas and describes the research projects necessary to most effectively develop needed information and tools and to target resources. Sponsored by the Federal Highway Administration (FHWA), this plan was developed by FHWA in cooperation with atmospheric scientists, air quality experts, environmental and transportation planners from state departments of transportation (DOTs), metropolitan planning organizations (MPOs), air quality agencies, industry, and academia.

## Purpose and Need for Transportation-Focused PM Research

PM is the term used to describe a complex mix of solid particles and liquid droplets found in the air. PM varies widely in terms of its physical and chemical properties and there are many sources that contribute to atmospheric concentrations. A primer on PM is provided in Appendix A.

Concern about the adverse health impacts of particulates first led to regulation of PM under the Clean Air Act (CAA) in 1971 when the United States Environmental Protection Agency (EPA) established a National Ambient Air Quality Standard (NAAQS) for PM. Since the early 1970s, a number of transportation agencies, primarily in Western States, have been involved in the development of air quality plans to reduce PM emissions and to reach attainment of the national standards.

More recently, numerous scientific studies have linked exposure to fine PM with significant human health problems across the United States. In response to these findings, the EPA established major changes to the NAAQS for PM in July 1997.[1] The revised NAAQS are expected to have wide-ranging impacts on the transportation community.[2] These impacts include:

- An expected *increase in the number of PM nonattainment areas*, particularly in the Eastern United States, thus greatly expanding the number of state DOTs, MPOs, and local transportation agencies that are affected by PM regulations;

- A *focus on combustion processes (including vehicle engines)*, as a major source of PM, particularly in urban areas where combustion-related emissions are likely to compose a greater share of total emissions, thus increasing the likelihood of more widespread transportation-related control programs for PM;

- An *emerging recognition of PM as a regional problem*, caused in part by secondary PM, that is formed and transported over great distances, thus redefining PM, in part, from a local to a regional-level issue and expanding the need for broader emission control programs.

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[1] On May 14, 1999, the U.S. Court of Appeals for the District of Columbia Circuit issued an opinion on the national ambient air quality standards for ozone and PM that EPA issued in July 1997. On June 28, 1999, the federal government filed a petition for rehearing key aspects of the case in the U.S. Court of Appeals for the D.C. Circuit. The U.S. Supreme Court ruled on February 27, 2001, in favor of EPA's revised standards although implementation of the requirements is pending.

[2] In the context of this Workplan, the terms "transportation," "transportation sector," and "transportation community" are considered to include on-road mobile sources, including passenger and commercial vehicles and bus transit service, as well as sources like road dust associated with mobile sources. Rail and non-surface transportation modes are not considered as part of the Workplan, although they may contribute to total transportation sector PM emissions.

Given an increase in the number of PM nonattainment areas, transportation agencies in many parts of the country will be required to participate in the development of transportation-related emission inventories and control strategies for inclusion in State Implementation Plans (SIPs) for PM. They will also potentially be faced with undertaking conformity analyses for PM.

In addition to these new requirements, transportation agencies also have an interest in PM because of the relationships between PM and other current and emerging atmospheric concerns. The interrelationship between PM and other air pollutants is summarized in Figure 1. Interactions between PM and ozone are an important concern since ozone's precursors, oxides of nitrogen ($NO_X$) and volatile organic compounds (VOCs), also contribute to secondary formation of PM and for many locations meteorological conditions conducive to high ozone formation often lead to high levels of PM. High concentrations of PM also contribute to regional haze, which is a concern for visibility in urban and rural areas. In addition, PM indirectly affects global climate change by increasing light scattering and the number of particles available for cloud droplet formation. Some particulates are also toxic, such as diesel particulate exhaust and semi-volatile polycyclic aromatic hydrocarbons (PAH), therefore reductions in the mass of these particulates may also reduce toxic air contaminants.

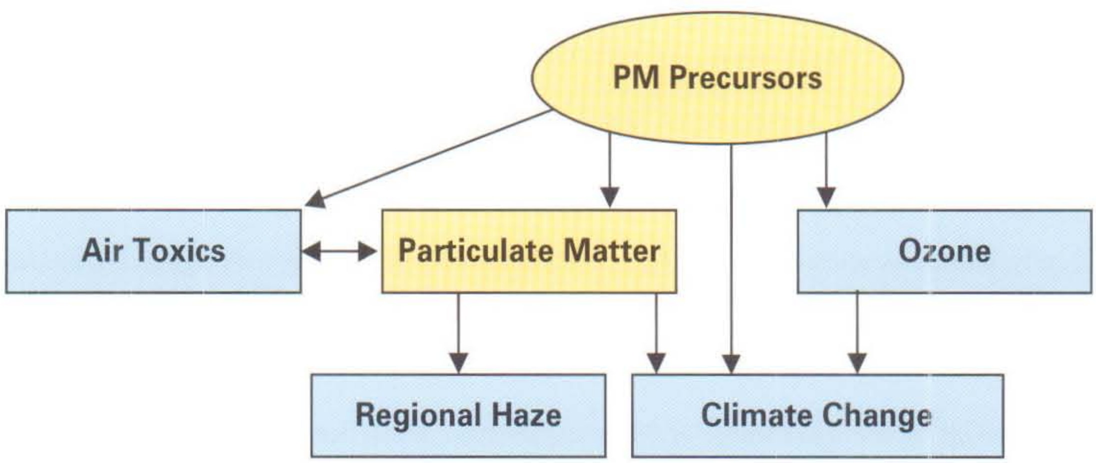


*Figure 1. Relationship of PM to Other Atmospheric Concerns*

Despite continued challenges to meet existing PM standards, as well as the potential repercussions of the new PM NAAQS on the transportation community, and the relationship between PM and other air quality concerns, there are acknowledged major weaknesses in the basic analytic tools and data that are needed to develop appropriate policy responses. In particular, policymakers charged with responding to the new PM standards are challenged by factors such as a limited understanding of spatial and chemical trends in ambient PM emissions, inaccurate and incomplete emissions inventories, and inadequate emissions models. The large gaps in information necessitate targeted research focused specifically on the needs of the transportation community.

## FHWA's Role in PM Research

The FHWA's 1998 National Strategic Plan establishes the Agency's mission *"to continually improve the quality of our Nation's highway system and its intermodal connections."* It identifies five strategic goals for achieving this mission, one of which is to protect and enhance the natural environment and communities affected by highway transportation.

Building on the National Strategic Plan, FHWA established an environmental research program as a core component of the Agency's environmental stewardship responsibilities. The Agency's broad environmental research goals are identified in FHWA's 1998 Strategic Plan for Environmental Research. Air quality research, including investigation of PM-related issues, is one of eight program goals established in the Strategic Plan for Environmental Research.

This Strategic Workplan for PM Research draws on FHWA's previous strategic planning initiatives to provide direction and focus for the Agency's role in PM research. It establishes a two-fold vision for conducting research that establishes a transportation focus in PM research and ensures that research results are relevant to the needs of transportation policymakers.

- **Bringing a Transportation Focus to Study of PM Issues.** Despite significant concern about the health impacts of PM and increasing evidence that the transportation sector may be a significant contributor to ambient PM concentrations, substantial research gaps remain in terms of understanding the formation, characteristics, source apportionment, and modeling of PM, particularly in relation to transportation sources.

  Critical uncertainties in the research include a lack of knowledge about the chemical composition of PM and relative source contributions, as well as the extent of secondary PM formation in the atmosphere. Developing better information about the characteristics and source apportionment of PM is a critical step for the development of emissions models and inventories that can be used for policy development and planning. As a result, a program of transportation-focused research is needed both to develop the information and tools needed to shape future policies and programs.

- **Developing Applied Research Products that Respond to Needs of Transportation and Air Quality Planning Practitioners.** Transportation-focused PM research must be targeted to the policy and program needs of the transportation community, and integrating these needs with ongoing and future research initiatives in a timely and cost-effective manner. In this regard, the Workplan is designed to:

  - Identify gaps in the PM science knowledge base that are hindering policy development;
  - Supply an objective information foundation suitable for developing the next generation of transportation-related policy tools and techniques; and,
  - Coordinate the PM research program for transportation sources with existing and future research initiatives.

## Developing a Strategic Research Workplan for PM

This Strategic Workplan for PM Research was developed with input from transportation and air quality experts throughout the country, as shown in Figure 2. It draws extensively on information gathered in a detailed literature review of PM research, and on the results of a one-day symposium with transportation and air quality experts held in January 2000.

**PM Literature Review.** A comprehensive review of recent literature was conducted to gather information about current PM research in five broad topic areas:

- Spatial, temporal and chemical variations of PM;
- Sources of PM emitted by the road transportation sector;

- PM measurement techniques;
- Emission factor development models; and,
- Strategies for controlling transportation source PM emissions.

**One-day PM Symposium.** To more fully incorporate the perspectives of the transportation community, a one-day symposium was held in Charleston, South Carolina, during January 2000. A range of academic and applied researchers, as well as air quality and transportation planners from federal, state, and local agencies were invited to the symposium. Attendees participated in a series of breakout sessions designed to gather expert input on key research topics. The breakout sessions matched the topics used for the literature review. Together, the results of the literature review and the symposium were used to provide insights during development of this Workplan. The results of the symposium are summarized in Appendix B.

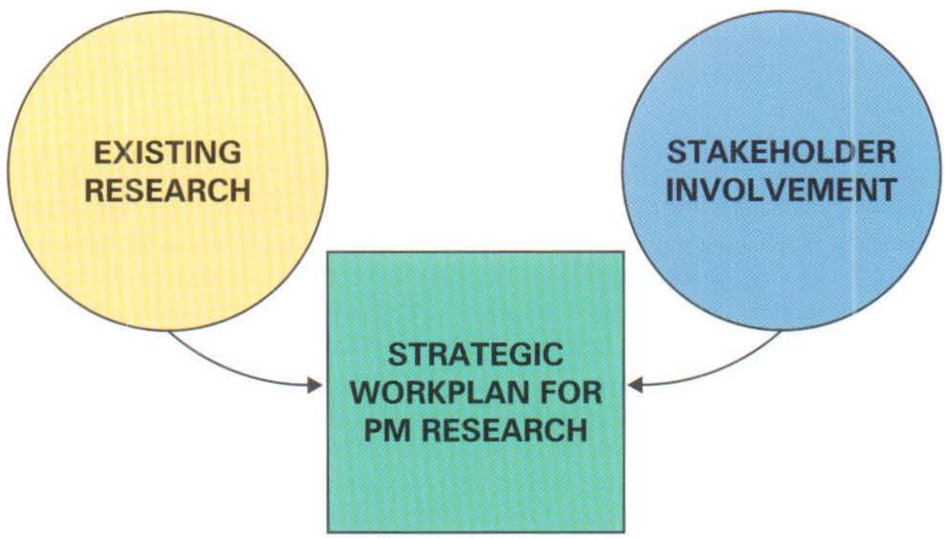


*Figure 2. Workplan Development Process*

## Linking PM Research Focus Areas to Transportation Policy Questions

### Research Focus Areas and Goals

The final output of this Workplan is a set of priority research projects. The projects are intended to fill PM research gaps that are most critical to the transportation community. Within the Workplan, the priority projects are categorized according to five broad research focus areas and according to how they address four key transportation policy questions. By linking research focus areas to resolution of key transportation policy questions, implementation of the Workplan will facilitate development of information, tools, and approaches that transportation agencies can use to handle emerging issues related to the new PM standards.

### PM Research Focus Areas

The research community and transportation professionals who participated in the FHWA PM Research Symposium identified five key research focus areas for inclusion in the Workplan:

- **Monitoring** – Research to incorporate transportation source concerns into PM monitoring approaches;

- **Characterization** – Research that addresses the spatial, temporal, and chemical variations in ambient PM;

- **Transportation Sources** – Research that addresses sources of PM from transportation;

- **Modeling** – Research concerned with improving transportation source PM emission factor models and travel data inputs; and,

- **Control Strategies** – Research to identify and evaluate transportation source PM control strategies.

Each of these topics represents a distinct area of research that is also linked to resolution of a key transportation policy question.

## Transportation Policy Questions

Transportation agencies will face a number of important policy challenges in regard to PM over the coming years. Transportation agencies in $PM_{2.5}$ and $PM_{10}$ non-attainment areas may be required to assist air quality agencies in developing transportation control strategies for State Implementation Plans (SIPs). Transportation agencies will also need to demonstrate conformity of their transportation plans in PM nonattainment and maintenance areas. Gaps in knowledge and lack of tools, however, currently constrain the ability to effectively carry out these activities. Addressing these and other issues will require resolution of four important policy questions.

- **What areas are expected to be in nonattainment?**

  EPA will designate $PM_{2.5}$ nonattainment areas over the period 2002–05, and transportation agencies need to know early on whether they may be faced with a nonattainment designation. Early knowledge will allow transportation agencies to develop the capacity to address PM nonattainment issues and participate with air quality agencies in the development of nonattainment area designations and SIPs, and in the completion of the conformity process.

- **What kind of problem is PM: local, regional, or both?**

  This question addresses two issues: 1) To what extent are $PM_{2.5}$ problems associated with local sources versus transported from other regions? and 2) To what extent are atmospheric concentrations of PM affected by direct PM emissions versus secondary formation? Transportation and air quality agencies need to be able to answer these questions in order to identify the appropriate level and target for control strategies.

- **What is the transportation contribution to PM?**

  The contribution of transportation sources determines the extent to which the SIP may focus on these sources. Transportation agencies need to understand the contributions of different transportation sources and how roadway characteristics and transportation system performance affect transportation emissions.

- **What are the most cost-effective control strategies for transportation sources?**

  Transportation agencies need to understand the costs and effectiveness of potential strategies, and the other implications of these strategies, to select and implement the most appropriate control strategies.

These four questions provide a logical sequence to undertake the priority projects in the Workplan. Answers to the first two questions need development to provide state and local transportation agencies with an understanding of whether PM is a problem in their regions and where the problem is originating. The last two questions are most critical to transportation agencies and relate directly to transportation sources and the effectiveness of transportation control strategies.

### Integrating Research Focus Areas and Policy Questions

Figure 3 summarizes how the five research focus areas and the key transportation policy questions are interrelated. This diagram is the "blueprint" for the Workplan and it identifies how each priority project helps to answer one or more of the transportation community's critical policy questions.

As this figure shows, a number of research projects help answer more than one of the research questions. Most emphasis, however, has been placed on research to help understand the contribution of transportation sources to PM, because this is a critical research gap of primary importance to the transportation community. The blueprint shows how the research priorities in this plan form a research path that integrates findings across focus areas to answer the transportation community's critical research questions.

## Other PM Research Initiatives Relevant to the Research Focus Areas and Projects

Currently, many research initiatives are being conducted on PM. Most projects focus on health effects of PM. However, agencies within EPA, other Federal and State agencies and industry also are sponsoring studies examining the relationships between PM and source contribution, as well as the local and regional nature of PM. In identifying the key transportation related projects for this workplan as shown in Figure 3, extensive literature was reviewed that included published peer reviewed papers, conference proceedings and reports prepared for commercial and government agencies.

Two important Web sites currently contain a broad array of information on studies related to PM research. These sites are maintained and updated frequently and provide the latest information on current and planned PM research efforts. The first is an EPA site (*http://www.epa.gov/ttn/amticpm.html*). This site maintains: 1) current and ongoing information on the EPA sponsored PM Supersites; 2) the latest from the Clean Air Scientific Advisory Committee (CASAC) on PM; and 3) EPA guidance on PM network design, data management, speciation, and policy. The second site is the Particulate Matter Research Activities (PMRA) Web site (*http:/www.pmra.org/*). That site keeps and sorts current, ongoing and future PM research. The site is operated and maintained by the Health Effects Institute in collaboration with EPA. The PMRA Web site broadly covers all aspects of PM research; and identifies a project's title, principal investigator, sponsor, schedule (time period), funding level, and an overview of the study.

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| **Key Questions:** | What areas will be in nonattainment? | What kind of problem is PM: local, regional or both? | What is the transportation contribution to PM? | | What are the most cost-effective control strategies for transportation sources? |
| **Proposed Projects:** | P1: Conduct an analysis of preliminary data from $PM_{2.5}$ monitoring network to identify potential nonattainment areas. *— Provides advance warning of potential nonattainment areas.* | P4: Review and update transportation-related source profile information used in PM speciation analysis. *— Ensures collection of basic data needed to determine if mobile source PM emissions are a significant contributor to PM problem.* | P6: Conduct dynamometer studies of diesel fueled vehicles/engines that are representative of current fleet mix to generate better data on the contribution of diesel vehicles to PM and PM precursor emissions. *— Provides primary and precursor data for building models needed to estimate transportation emissions.* | P9: Develop a coordinated model improvement program for incorporating new research on motor vehicle-related emissions into EPA's particulate matter model on a timely basis. *— Enhances credibility of models to assess transportation contribution and for control strategy evaluation.* | P12: Analyze the costs and effectiveness of existing transportation source PM control strategies at reducing PM and PM-precursor emissions. |
| | P2: Integrate critical transportation sector PM research concerns into EPA's "supersite" PM research program. *— Ensures that key transportation elements are incorporated into EPA program to accurately assess transportation contributions.* | P5: Utilize speciation monitoring data to provide an improved understanding of the relative contribution of transportation to PM. *— Provides preliminary indication of extent of mobile source PM emissions that cause PM problem & therefore should be modeled/controlled.* | P7: Conduct dynamometer studies of sample vehicles to determine the impact of gross emitter gasoline powered vehicles on PM emissions. *— Provides primary and precursor data for building models needed to estimate transportation emissions.* | P10: Identify improvements needed in travel data to improve the use of the PM emission model for inventory development and analysis. *— Enhances credibility of emission inventory for transportation sources, which are used to formulate control strategies.* | P13: Develop a menu of transportation-source $PM_{2.5}$ control strategies for regions to consider in air quality planning, including an evaluation of costs and effectiveness in different geographic settings. |
| | P3: Examine state-of-the-art techniques for measuring the semi-volatile component of PM. *— Critical component of mobile source PM that is presently not well measured.* | | P8: Conduct a re-entrained road dust study that identifies the extent to which re-entrained roadway dust contributes to $PM_{2.5}$ in urban areas in the Eastern United States *— Provides a better basis for building models needed to estimate transportation share.* | P11: Develop an ammonia emission component for inclusion in one of EPA's motor vehicle emission factor models. *— Important precursor transportation emissions that are not currently modeled.* | P14: Evaluate the interactions between transportation-related particulate matter and ozone control strategies. |
| **Focus Areas:** | MONITORING | CHARACTERIZATION | SOURCES | MODELING | CONTROL STRATEGIES |

*Figure 3. Connection Between Transportation Issues and Research Agenda*

Based on a review of these Web sites, at least one relevant project was found within each of the five research focus areas discussed in the "Research Focus Areas, Goals, and Priority Projects" section of this Workplan. Below, current ongoing research projects, relevant to projects identified in Figure 3 are identified. Note that recommended project numbers are used in the discussion (e.g., Project P3) to facilitate the cross-referencing of Figure 3 with the details of the topic areas and projects outlined below.

## PM Monitoring

Recommended Project P3 identifies the need for examining state-of-the-art techniques for measuring semi-volatiles. Three current research projects are ongoing, or have been recently completed, in this area. First, Gundel and Stockburger, sponsored by EPA's National Exposure Research Laboratory (NERL), are investigating the development of a $PM_{2.5}$ semi-volatile organic compounds (SVOC) sampler — since in areas of the country where organics are a main component of the fine particle mass, this will result in a significant negative bias in the mass measurement. The earliest sampling of ambient organic aerosol consisted of collecting particles on quartz filters and analyzing them for compounds of interest. With the recognition that positive and negative artifacts were possible, a sorbent bed of an acrylic polymer (PUF or XAD) was added following the filter to collect SVOCs that were vaporized from the filter or were present in the gas phase of the incoming air stream. To account for compounds that are in both gaseous and particulate phases (and thus increase accuracy), current thinking is that SVOCs require a denuder to be placed upstream of the filter.

Second, Koutrakis et al., sponsored by Electric Power Research Institute (EPRI), are investigating fine particulate mass measurements in field studies with the specific intent of 1) measuring the particle mass artifacts due to losses or gains of semi-volatile compounds, and 2) comparing measurements obtained from a variety of integrated and continuous particle mass measurement techniques.

The third study, sponsored by Tennessee Valley Authority (TVA) is using a sampler which incorporates the state-of-the-art collection techniques for semi-volatile aerosol particles. The sampler is operated in the field along with one of the FRM monitors in the TVA network. Data collected will help in determining the contribution of semi-volatile aerosols to fine particulate matter loadings.

## PM Characterization

Project P4 identifies the need for updated source profile information for PM speciation analysis. Three current research projects are ongoing, or have been recently completed, in this area.

First, under sponsorship by the Health Effects Institute (HEI), Gertler is investigating ambient sampling of diesel PM. The study is obtaining chemically speciated diesel profiles that will be used to source apportion diesel versus other ambient constituents in the air. The particle number and the chemically speciated, size-segregated, particle distributions are being measured. These results will be compared to measurements from 25 years ago to determine the change in diesel exhaust particle mass in ambient air. Particulate emissions from light-duty gasoline vehicles are also being measured to compare their contribution to those from diesel vehicles.

Second, under sponsorship of EPA's National Risk Management Research Laboratory (NRMRL), Smith and Wasson are developing PM source signatures. The project will provide updated and augmented data on the chemical composition and size distribution of fine particulate matter (PM), smaller than 2.5 microns, from a variety of source types. Particular emphasis will be placed on acquiring detailed PM organic speciation data in order to allow greater differentiation of sources in source apportionment than is possible when source profiles are limited to PM elemental compositions. The extended profiles will be made available for inclusion in the Office of Air Quality Planning and Standards (OAQPS) SPECIATE database for use by EPA Regional Offices and State environmental agencies in apportioning ambient fine PM to emission sources.

The TVA project is a study on mobile source contribution to fine particulate mass. The study uses two continuous PM mass monitors; one collocated with a routine fine PM monitor and one located in the same community adjacent to a major interstate highway. The contribution of mobile sources will be inferred from the difference in PM mass and chemistry at the two monitors that capture the same community sources. This will provide information on mobile source contribution that is currently lacking in the Tennessee Valley. A chemical mass balance (CMB) modeling technique will be applied to historical and recently-collected chemically-speciated samples of $PM_{2.5}$ to determine source attribution for $PM_{2.5}$ in the Tennessee Valley.

## Sources of PM

Project P6 recommends that engine testing be conducted on a representative fleet of diesel fueled engines to generate better data on the contribution of diesel fueled vehicles to PM pollution. An ongoing project, under sponsorship of EPA/NRMRL, has developed an integrated on-road sampling system to test gaseous emissions from heavy-duty diesel tractors as they operate on highways. This system has demonstrated the transient nature of exhaust emission levels even for "steady state" operations and is being modified to include particle size and mass measurements. The measurement systems available to define the particle size distribution of these emissions are laboratory grade units with relatively long sample processing times. The development of a suitable sampling system that provides a sample which is cooled and diluted as the actual exhaust pipe discharges, and preserves the sample for a sufficient period to allow the analytical instruments to complete their cycles, is the focus of this effort.

## Modeling of PM

Project P11 recommends the development of a modeling procedure for assessing ammonia emissions from transportation sources. A current research project being sponsored by the Coordinating Research Council (CRC) involves the determination of ammonia emission rates from in-use light and heavy-duty vehicles. The objective of this study is to sample the rate of ammonia and ammonium ion emission levels from on-highway vehicles while traveling in a tunnel. Samples are to be taken during an existing tunnel study in the Tuscarora Mountain Tunnel. The contribution of ammonia from mobile sources represented by this on-highway fleet will be estimated and compared to other estimates.

## PM Control Strategies

Project P12 seeks to determine the cost and effectiveness of existing transportation source PM control strategies. As part of EPA's Supersite program, the New York State DOT is assessing the effectiveness of new emission control technologies, for example, Compressed Natural Gas (CNG) bus deployment and Continuously Regenerating Technology (CRT) introduced in New York City and their impact on ambient air quality, using remote open path roadside, mobile platform, and fixed site measurements of carbon dioxide, carbon monoxide, nitric oxide, nitrous acid, and formaldehyde and aerosol chemical composition. At the conclusion of this study, sufficient information will be available to assess both the cost and effectiveness of these new engine control technologies on PM and PM precursors.

Likewise, Project P14 seeks to expand the understanding between ozone and PM control strategies. An ongoing research study is being conducted by Cass et al., under the sponsorship of EPA's National Center for Environmental Research and Quality Assurance (NCERQA), to investigate the effects of emissions controls on ozone and fine particle air quality in both California and the Northeast region of the United States. By simultaneously accounting for ozone and fine particle formation and transport, improved methods will be developed to greatly increase the computational speed of PM air quality models. The models developed will be applied both in Southern California and in the Northeastern United States, and formal evaluations of model performance will be conducted. The completed models will be used to evaluate the effects of emissions controls on ozone and fine particle air quality in both California and the Northeast.

# RESEARCH FOCUS AREAS, GOALS AND PRIORITY PROJECTS

This section identifies and describes the research project priorities for the transportation community. This Workplan recommends the implementation of the fourteen projects (referenced in Figure 3) falling under the five research focus areas discussed in Section 1— monitoring, characterization, sources, modeling, and control strategies.

The recommended research projects are diverse in scope, ranging from fairly specific research initiatives to broad programmatic initiatives involving multiagency or multistakeholder coordination. This range in scope reflects the complexity of the PM issue and the significant research gaps that currently exist. Figure 4 provides a lexicon for the recommended projects based on project scope.

| Recommended Project | Issue Specific Project | Multi-Faceted Project | Programmatic Initiative |
|---|---|---|---|
| P1: Conduct analysis of preliminary data from $PM_{2.5}$ monitoring network to identify potential $PM_{2.5}$ non-attainment areas | ✓ | | |
| P2: Integrate critical transportation sector PM research concerns into EPA's "super site" PM research program | | | ✓ |
| P3: Examine state-of-the-art techniques from measuring semi-volatiles | ✓ | | |
| P4: Review and update transportation-related source profile information used in PM speciation analysis | ✓ | | |
| P5: Utilize speciation monitoring data to provide an improved understanding of the relative contribution of transportation to PM | | ✓ | |
| P6: Conduct dynamometer studies of diesel fueled vehicles/ engines that are representative of current fleet mix | | ✓ | |
| P7: Conduct dynamometer studies of sample vehicles to determine the impact of gross emitter gasoline powered vehicles | | ✓ | |
| P8: Conduct a re-entrained road dust study that identifies the extent to which re-entrained roadway dust contributes to $PM_{2.5}$ in urban areas in the Eastern United States. | ✓ | | |
| P9: Develop a coordinated model improvement program for incorporating new research on motor vehicle-related emissions into EPA's PM model on a timely basis. | | | ✓ |
| P10: Identify improvements needed in travel data to improve the use of the PM emission model for inventory development and analysis | | ✓ | |
| P11: Develop ammonia emissions component for inclusion in one of EPA's models. | ✓ | | |
| P12: Analyze the costs and effectiveness of existing transportation source PM control strategies | | ✓ | |
| P13: Develop a menu of transportation-source $PM_{2.5}$ control strategies for regions to consider in air quality planning | | ✓ | |
| P14: Develop assessment of interactions between transportation source control strategies for PM and other air pollutants | | ✓ | |

***Figure 4. Classification of Projects in Terms of Scope***

Research initiatives that involve specific activities, such as analyses of currently available monitoring data, have specific (often singular) objectives, can be conducted by a relatively small research team, and can fall under the auspices of a single sponsoring agency. In most cases, the results of focused initiatives will feed multifaceted projects or even broader programmatic initiatives.

Multi-faceted projects attempt to fill multiple research gaps and are designed to address various, although related, objectives. For instance, projects that strive to improve modeling methodologies likely will require multi-disciplinary research teams with expertise in air quality and transportation modeling. Such projects may be best conducted under the auspices of multi-agency collaborative efforts, and most likely address multiple objectives (such as enhanced data collection practices, model development, and model application for impact assessment). Similarly, recommended projects that in effect are programmatic initiatives involve multiple objectives and may *require* multi-agency collaboration.

The following sub-sections describe the recommended projects under each of the five research areas. First, existing research gaps are identified to set the context for the recommendations. This is followed by project descriptions that discuss how the selected projects will address research gaps.

## Monitoring

**Research Goal. Ensure that enhancements to the Nation's PM monitoring system improve understanding of the contribution of transportation to PM.**

### Overview

The EPA's ambient air quality monitoring program provides the data needed to track air quality throughout the United States. The data gathered by the PM monitoring system provide a major source of information for the designation of future nonattainment areas, as well as for tracking compliance with NAAQS, and developing emissions modeling tools, emissions inventories, and control programs.

EPA, in coordination with state air quality agencies, is presently expanding the PM monitoring system to support future NAAQS by establishing:

- A network of $PM_{2.5}$ mass monitors, and;
- A network of $PM_{2.5}$ chemical speciation monitors.

These networks will substantially improve the capability of the PM monitoring system to address the new $PM_{2.5}$ NAAQS. In addition, EPA has established seven PM Supersites with the primary objective of improving the understanding of PM characterization. The monitoring systems, however, may not be adequate to provide data needed for accurate determination of transportation sector-related PM emissions. To improve the understanding, a monitoring system is needed for the counting and classification of vehicles contemporaneously with a PM monitoring network. The gaps or uncertainties that should be addressed by the correlated monitoring efforts are associated with the areas noted below.

Understanding the temporal variation of PM is important to the transportation sector since a portion of ambient PM concentration is reactive in which time plays a role in the PM formation, transport and deposition. Generally, short term time intervals (1-hour or less) are important to developing a sound understanding because chemical reactivity, transport, deposition and traffic volumes will change significantly over the course of a day. The short sampling periods should provide sufficient fidelity to correlate vehicle emissions and traffic volumes. Further, an improved understanding in temporal variations may identify episodic PM violations that are the result of unusual conditions.

Improved understanding in the spatial variation of PM refers to the variability of the pollutant composition from one geographical area to another. The spatial variation may be the result of "transport" from other regions or due to differences in locally generated PM emissions. Developing an improved understanding from a study which can determine the "transport" component associated with PM generated in one geographic region but carried by atmospheric processes to another location is essential since control strategy effectiveness will be highly dependent upon this determination. In general, the spatial variability in PM appears to be a strong function of the geographic location with the inter-mountain States in the Western United States typically having problems with fugitive dust, California with nitrates, the Midwest and northeast with sulfates and the South with secondary organic compounds. An understanding of these differences and the role transportation sources play must be improved.

Chemical transformation of the volatile emissions that may be present in PM is an important area for improved understanding as research has shown that PM from transportation sources has significant component of semi-volatile compounds (e.g., ammonium nitrate). In addition, current methods do not accurately reflect what may be actually inhaled due to limitation in current monitoring methods.

To accurately discern the transportation related ambient PM, networks should include measurements of traffic volume and vehicle classification. For example, "gross emitters" typically represent less than 10 percent of the regional fleets, but account for 50 percent of gasoline-fueled tailpipe vehicle emissions. Therefore, a transportation apportionment study will need to characterize the "gross emitters" in addition to counting their numbers. Failure to accurately account for these vehicles will harm efforts to curb tailpipe gasoline-fueled vehicle emissions by incorrectly targeting all gasoline-fueled vehicles in control strategies when only a fractional percentage are responsible for the PM tailpipe emissions.

A transportation related source apportionment study must consider both the regional traffic contribution as well as the local traffic contribution. Counting and vehicle classification are important components of correlating vehicle emissions with sampled PM concentrations. Studies have been conducted which include traffic monitoring methods, but these studies often are not correlated well with the sampling times of the PM samplers or the counts have not been conducted over a regional area with the purpose of relating the regional disperse individual site measurements to the region as a whole. This is important since PM is a pollutant that can be chemically-transformed, transported and deposited over significant distances and times and, therefore, regional traffic information must be incorporated into the local counting to provide a complete picture of vehicle PM emissions.

Finally, a transportation source apportionment study must include both local and regional-scale measures of meteorology. Areas having frequent winds (e.g., mountain valleys, river valleys, ridge tops) are the least likely to have pollution problems. This is because emissions are continually dispersed and transported and do not remain in the area where they were generated. However, the emissions may be channeled to other areas leading to possible PM problems. Because of this, it is important for sites to have meteorological instruments that can account for the local meteorology. Relying on weather data measured many miles away from a local site will only provide general information about the site of interest. This phenomenon has been widely seen for CO in which ambient CO monitor data often shows low concentrations at times when traffic volume is relatively high. However, as a result of transport, the peak carbon monoxide concentrations are often found to occur in the late night hours and not near the location of peak emissions.

The following priority research projects are designed to ensure that transportation issues are addressed within PM monitoring activities.

## Priority Projects

### Project P1: Conduct an analysis of preliminary data from the $PM_{2.5}$ monitoring network to identify potential $PM_{2.5}$ nonattainment areas.

No accurate estimates of the scale and geographic extent of ambient $PM_{2.5}$ concentrations exist (USEPA, 1996). Data from the new $PM_{2.5}$ monitoring network will provide the foundation for EPA's $PM_{2.5}$ nonattainment designations across the United States and many areas that are presently unaffected by $PM_{10}$ are anticipated to become $PM_{2.5}$ nonattainment areas. $PM_{2.5}$ nonattainment status will have significant regional transportation policy implications because transportation has been shown to be a significant contributor to $PM_{2.5}$ (Wongphatarakul et al., 1998; Lawson and Smith, 1998; Schauer et al., 1996). This project will analyze preliminary data from the national $PM_{2.5}$ monitoring network to identify potential $PM_{2.5}$ problem areas around the Nation and to examine the extent of secondary PM formation in these regions.

***Relevance to Transportation Community.*** *Designation of $PM_{2.5}$ nonattainment areas will have a profound impact on the transportation programs and policies of affected regions, particularly if secondary PM is found to make up a significant portion of total ambient $PM_{2.5}$. This project will provide transportation agencies with advance identification of potential $PM_{2.5}$ problem areas, and an understanding of the extent to which ambient $PM_{2.5}$ results from secondary formation from precursor pollutants and from pollutants that are transported from other regions. This will provide an opportunity to shape future policy development, such as designation of nonattainment boundaries and implementation of conformity in PM nonattainment areas more effectively.*

### Project P2: Integrate critical transportation sector PM research concerns into EPA's Supersite PM research program.

The EPA's supersite PM research program consists of a set of special studies that extend beyond the national regulatory monitoring networks for PM to support development of SIPs. Key components of the program include:

- Accelerating the testing of advanced sampling methods to replace current technologies;
- Providing advanced measurements that simultaneously support PM and ozone SIPs;
- Fostering collaborative partnerships across the research and regulatory monitoring communities; and,
- Providing additional information useful in upcoming health risk assessments of PM and its components.

In late January of 2000, EPA announced the final selection of a set of seven region-specific supersite PM study locations, each of which will feature research programs conducted by academic institutions. The studies are located in Fresno, CA; Los Angeles, CA; Houston, TX; St Louis, MO; Baltimore, MD; Pittsburgh, PA; and New York, NY (a pilot supersite in Atlanta, GA is close to completion). The studies, with the exception of the Fresno site that is already underway, were deployed in mid-2000 and are scheduled to conclude prior to 2005 when the earliest PM SIPs are due.

The supersite studies are a critical PM research opportunity that will yield an unparalleled array of data about PM characteristics, yet only the New York supersite presently includes a transportation-specific objective. At the New York Supersite, an evaluation of the emissions impacts of alternative fuel buses and after-engine bus emission control technology will be included as part of the research program. Inclusion of similar transportation-related components at other supersites will require greater involvement by the transportation community, but will help to expand consideration and awareness of transportation-related research concerns.

***Relevance to Transportation Community.*** *The EPA's supersites analysis will provide a primary focus for PM research in the United States over the next five years. This project will involve a coordinated effort to incorporate transportation issues into the development of Supersite monitoring programs. At a minimum, the transportation community should continuously track the Supersite research findings to assess their significance in the context of transportation concerns, and to communicate findings to transportation agencies. Consideration should also be given to developing a program of transportation research initiatives with specific Supersite teams. Topics for consideration might include relative source apportionment, highway related "hot-spot" analyses, and effectiveness of transportation-sector control strategies.*

**Project P3: Examine state-of-the-art techniques for measuring the semi-volatile component of PM.**

Transportation sources in some major urban areas are an important contributor of semi-volatile compounds such as ammonium nitrate. However, according to recent research by Kim et al. (1999, 2000), and Pang et al. (2000), current PM mass monitoring techniques may not accurately measure the semi-volatile fraction of PM. Semi-volatiles may be underestimated by monitors as a result of evaporation caused by pressure change during sampling or as a result of decomposition and chemical reactions that occur during filter storage. Kim et al. and Pang et al. find that loss of nitrates may be significant, accounting for upwards of 20 percent of the total $PM_{2.5}$ mass on some days and up to 10 percent of the annual average. Alternatively, overestimation of semi-volatiles may result from gaseous adsorption onto filters or from chemical reactions that occur during filter storage. Gains may also be significant, according to Kim et al., and Pang et al., with a 6 to 20 percent gain on an annual basis.

Monitoring of semi-volatiles is an emerging issue of concern both to academic researchers and to the regulated community. Development of practical semi-volatile monitoring methods that can be incorporated into the "federal reference method" for monitoring techniques will require discussion between EPA, industry experts, regulated agencies, and academic researchers. This project will include development of a research forum to facilitate such a dialogue.

***Relevance to Transportation Community.*** *The contribution of semi-volatiles to total PM represents a basic knowledge gap in the PM monitoring science. Since the transportation sector is a major source of semi-volatiles, improved monitoring techniques that facilitate assessment of the relative contribution of semi-volatiles to total PM will ensure that the transportation sector's contribution to PM is estimated accurately, that emission control programs are designed accordingly, and that appropriate credit is granted for integrating strategies related to semi-volatiles.*

## Characterization

**Research Goal – Advance understanding of the spatial occurrence of PM and its sources, with an emphasis on $PM_{2.5}$ and secondary PM formation.**

### Overview

Characterization of PM draws on spatial and chemical analysis of monitoring data to improve understanding of where PM problems occur and how they are caused. Accurate characterization of PM can help to ensure that equitable and effective control strategies are developed. At present, however, understanding of the spatial and chemical characteristics of $PM_{2.5}$ is based on a small number of region-specific studies, such as work by Eldred and Cahill (1994) on remote sites; work by Lipfert (1998) on clusters of urban fine particles; and work by EPA (1996, 1999) on data collected from the rural-focused visibility monitoring network. This research does not fully address key PM characterization concerns that are relevant to transportation agencies, such as the likely extent of areas that will be affected by $PM_{2.5}$ regulations, the magnitude of secondary PM formation and transport, and the relative contribution of transportation sources to $PM_{2.5}$. The transport of PM from one region to another is not well understood and it will be more important for $PM_{2.5}$ than $PM_{10}$. Targeted analysis of the data collected by improvements in the $PM_{2.5}$ monitoring network will be vital to answering these questions.

Several critical research gaps exist in the understanding of the characterization of PM and its sources, and in particular for $PM_{2.5}$ and secondary PM.

- **Emission Source Profiles.** Using the Chemical Mass Balance (CMB) method to determine source contribution of PM monitored data requires the use of up-to-date and accurate sets of chemical signature profiles. For example, in the latest state-of-the-science CMB analysis for PM completed for the Northern Front Range Air Quality Study (NFRAQS), conclusions were reached that gasoline coldstarts and "gross" emitters were responsible for the majority of PM emissions. This is in sharp contrast with results from PART5 which finds that less than two percent of the PM emissions are from these two categories. The NFRAQS conclusion hinges on the diesel and gasoline-fueled emission source profiles used in the analysis.

- **Geographic variation in transportation contribution to PM.** The contribution of transportation sources to PM will vary widely across the Nation. To date, studies have focused efforts on local or small regional studies with a focus on characterizing PM. With the availability of a nationwide speciation monitoring network, opportunities exist to begin to determine potential source contribution from transportation sources. For example, sulfates can be considered non-transportation related PM (only those emissions associated with the refinery of crude oil to gasoline and diesel). Through an analysis of the data conclusions the effects of transportation related emissions on PM concentration can be determined.

The following priority research projects are designed to advance the understanding of the spatial occurrence of PM and its sources.

## Priority Projects

### Project P4: Review and update transportation-related source profile information used in PM speciation analysis.

EPA and others have devoted considerable effort to the design and implementation of a nationwide network of PM speciation monitors that identify the chemical constituents present in PM. The chemical speciation data generated by the new network of speciation monitors will be combined with source profile information to determine the relative apportionment of PM emissions. Outdated source profile information, however, may hamper the accuracy of source apportionment estimates derived from new speciation monitor data.

As fuels, technologies, and use patterns have changed from 1970 to the present, so have the chemical profiles for many transportation-sector emissions sources. For example, catalytic converters on spark-ignition vehicles and improved diesel engine technologies have substantially reduced carbon emissions from these sources. Source profiles must be updated to reflect changing technology and to ensure that the value of the speciation network is maximized.

The first phase of this research project will review the adequacy of source profile information to determine the extent to which transportation-sector source profiles are out-of-date. In the second phase of the project, updated source profile information will be developed for use in conjunction with speciation monitor data.

***Relevance to Transportation Community.*** *Variations in the chemical composition of PM reflect the relative contribution of source categories. Accurate information about the chemical speciation characteristics of PM is therefore critical to determining future emission control strategies. The data generated through the speciation-monitoring network will greatly improve understanding of the relative contribution of different emissions source categories, such as diesel engines versus industrial sources and will help to focus future control strategy development.*

### Project P5: Utilize speciation monitoring data to provide an improved understanding of the relative contribution of transportation to PM.

Current estimates of the contribution of transportation to PM are based on a small number of region-specific studies that do not provide insight on variations in the relative share of transportation's contribution to PM from region to region, or the significance of secondary PM. The chemical speciation-monitoring network that is currently under development will provide a substantial amount of additional data on the relative source apportionment of PM in different regions of the country. This project will analyze data from the monitoring network to determine issues such as how the contribution of transportation to PM varies across the country, as well as the culpability of key transportation sources such as diesel trucks, and the potential for regional transport of PM.

***Relevance to Transportation Community.*** *As analysis of spatial, chemical and temporal variations in the characteristics of PM advances, this information will form a critical foundation for developing appropriate State and regional mitigation approaches. Nonattainment area designations must reflect the extent of contributing sources to PM NAAQS violations, while control strategy development must reflect the types of PM that are prevalent. For example, in regions where coarse mode ($PM_{2.5}$ to $PM_{10}$) size particles dominate, control strategies that focus on reducing resuspended agricultural or street dust may be most appropriate. In areas where $PM_{2.5}$ particles are dominant, however, a focus on control of combustion sources may be more relevant.*

## Transportation Sources

**Research Goal – Improve understanding of motor vehicle-related sources of PM and PM precursor emissions.**

### Overview

Despite several decades of regulation of PM emissions, relatively little is known about the operating variability of PM emissions from motor vehicles caused by factors such as changes in speed, engine deterioration, fuel characteristics and driving behavior. Recent studies on light-duty vehicles, such as those conducted by the Coordinating Research Council (CRC) and National Renewable Energy Laboratory (NREL), have begun to expand this knowledge (Cadle et al., 1998; Norbeck et al., 1998 and Whitney et al., 1998). Likewise, independent heavy-duty engine testing facilities in the US include West Virginia University and the California Center for Environmental Research and Technology (C-CERT).

Three broad categories of motor vehicle-related emissions are major contributors to ambient PM concentrations:

- **Vehicle Tailpipe Emissions.** Motor vehicles emit PM as a component of tailpipe exhaust emissions and nearly all tailpipe PM emissions are classified as $PM_{2.5}$. The principle factors that influence tailpipe emission rates are fuel type, emission control technology, engine maintenance, fuel economy, and driving conditions, such as vehicle speed. Average tailpipe emission rates for diesel-fueled vehicles are approximately one to two orders of magnitude higher than gasoline vehicles. However, gasoline-fueled vehicles account for approximately 95 percent of the on-road vehicles.

- **Brake and Tire Wear Emissions.** Vehicles generate PM emissions as a result of brake and tire wear during travel. These particles are initially suspended in the air, and may become part of reentrained road material. The relative complexity involved in measuring brake and tire wear emissions has resulted in relatively few comprehensive studies on this issue. Existing research, however, suggests that brake and tire wear-related PM emissions are a relatively small share of total transportation source PM emissions (Cooper et al., 1995; Cowherd, 1997).

- **Re-Entrained Road Dust Emissions.** Re-entrained road dust is usually an important source of $PM_{10}$ emissions. Vehicle travel on paved and unpaved travel surfaces, including roads, parking lots and staging areas, results in PM emissions caused by entrainment of solid particles into the atmosphere by forces of wind or vehicles acting on exposed materials. Roadway particles may originate from a variety of sources including roadway surface materials, road construction activities, tire and brake wear, or application of deicing and anti-skid material.

From these three broad categories the most relevant research gaps to improving the understanding of mobile source contribution to PM emissions are the following.

- **Vehicle Tailpipe Emissions.** Current evidence strongly suggests that vehicle tailpipe emissions will likely be the dominant source of $PM_{2.5}$ from transportation sources. Regional-scale emission inventories using emission factor models such as PART5 indicate that diesel combustion typically contributes more than 50 percent of an air basins transportation contribution to $PM_{2.5}$. Yet little research has examined the in-use characteristics of the current diesel fleets nationwide and considerable uncertainty surrounds their in-use deterioration. Thus, a priority for improved understanding of source contribution from motor vehicles is developing an improved understanding of in-use deterioration from on-road diesel engines, especially those built since 1994 that use catalytic oxidation devices for which no information is available on long-term effectiveness and maintenance practices.

- **Gross Emitters.** Recent studies on high emitting gasoline fueled vehicles have found emission rates 5 to 10 times PM rates of normal emitters. Since gasoline fueled vehicles compose approximately 95 perecnt of the operating fleet, it is important that the causes for the gross emitters be identified so that effective control measures can be targeted at gross PM emitters. A research study directed at determining the impact and causes of gross emitting PM vehicles would advance this current research gap.

- **Re-entrained road dust in the Eastern United States.** Source contribution of fugitive dust emissions still remain in question as to their origin (pavement, shoulders, windblown); to what degree the number of vehicles plays and the degree to which quantities are entrained from vehicle motion and their size distribution. Current research efforts, such as NCHRP 25-18, are directed at improving this understanding, but are not directed at improving the understanding of urban and Eastern United States re-entrained road dust that will likely be an important component to the $PM_{2.5}$ source contribution in the Eastern United States. To date, almost all studies on re-entrained road dust have been in the Western United States; by directing a research study at urban eastern cities, an important research gap will be closed and will help eastern agencies in preparation of their PM SIPs.

The following priority research projects have been designed to improve the understanding of motor vehicle-related sources of PM and PM precursor emissions.

## Priority Projects

### Project P6: Conduct dynamometer studies of diesel fueled vehicles/engines that are representative of current fleet mix to generate better data on the contribution of diesel vehicles to PM and PM precursor emissions.

Studies of in-use heavy-duty diesel emissions indicate that actual PM emissions may be considerably higher than current "*PART5*" and "EMFAC7G" emission factor models predict because factors such as engine deterioration, tampering and vehicle operating characteristics are poorly understood (Weaver et al., 1998). Although diesel vehicles manufactured since 1994 can have considerably lower emission rates because they incorporate advances in emission control technology, slow fleet turnover rates for diesel trucks reduce the impact of cleaner truck engines (Norbeck, et al., 1998).

This project will study diesel vehicle tailpipe emissions to determine the in-use characteristics of current diesel fleets nationwide. Such studies are typically conducted for a small sample of vehicles selected to be representative of fleet characteristics of interest, such as fuel type, vehicle age, and emissions control technology. Current monitoring techniques for measuring tailpipe PM emissions include direct measurements (light-duty vehicles on dynamometers); indirect measurements (heavy-duty engines on chassis-dynamometers combined with vehicle loads); tunnel measurements, and models that combine experimental measurement and physical approximations.

***Relevance to Transportation Community.*** *Until recently, PM regulations have focused on controlling $PM_{10}$ problems that are localized, and that occur in a small number of locations in Western States. Control of $PM_{2.5}$, in contrast, is likely to affect major urban areas in the Eastern United States as well as larger regions in the Western United States. In addition, combustion sources, particularly diesel-powered vehicles, are likely to be shown to be a significant contributor to $PM_{2.5}$ emissions. Dynamometer studies of diesel vehicles will provide a better understanding of transportation's contribution to $PM_{2.5}$.*

**Project P7: Conduct dynamometer studies of sample vehicles to determine the impact of gross emitter gasoline powered vehicles on PM emissions.**

In-use PM emission rates of less than 3 mg/mile are typical for newer (post-1991) model light duty gasoline autos and trucks (Cadle et al., 1998; Norbeck et al., 1998; and Whitney et al., 1998). As vehicles age and accumulate mileage, however, deterioration of engine operating characteristics and emission control components can result in higher emission rates. In a recent CRC and NREL series of studies, high gaseous emitter gasoline vehicles were found to have approximately 5 to 10 times the particulate emission rates of normal emitter vehicles (Cadle et al., 1998; Norbeck et al., 1998; and Whitney et al., 1998). This project will study gasoline vehicles to determine the impact of gross emitters.

***Relevance to Transportation Community.*** *As diesel vehicle emissions improve with fleet turnover and use of cleaner fuels, the relative significance of gross-emitter gasoline vehicle-related PM emissions will increase. Studies to determine the impact of gasoline vehicles on PM are needed.*

**Project P8: Conduct a re-entrained road dust study that identifies the extent to which re-entrained roadway dust contributes to $PM_{2.5}$ in urban areas in the Eastern United States.**

There have been extensive studies of the impact of re-entrained dust in the Western United States, (Cowherd, 1997; Cowherd et al., 1998; Kinsey, 1995; Light et al., 1998; Moen et al., 1996) however, very little is known about the extent of re-entrained dust in the Eastern United States. Research on re-entrained dust from roadways has primarily been confined to analysis of sites in the Western United States where arid climatic conditions prevail. Some researchers suggest that current models that rely on existing research, overestimate re-entrained dust from roadways by as much as a factor of 10. (Larson and Silva, 1997, Light et al., 1998, Moen, et al., 1996, and Venkatram and Fitz, 1999). Research should focus on developing a better understanding of the contribution of re-entrained PM in eastern, urban areas, and determining the sources of re-entrained dust (i.e., sand, tire wear, crustal material, etc). There are large fluctuations in the level of re-entrained particulate emissions because of the sporadic nature of materials handling and the effects of precipitation and wind.

***Relevance to Transportation Community.*** *Lack of understanding about the significance of re-entrained roadway dust in major urban areas of the eastern United States, and in-use diesel engine emissions make existing emissions models inadequate for air quality planning. Future research must focus on developing information about transportation sources that enhances emissions factor models.*

## Modeling

**Research Goal – Improve PM emission modeling for transportation sources.**

### Overview

The PART5 model is EPA's accepted motor vehicle PM emissions model, and is required in the development of $PM_{10}$ inventories and analyses. The model is used to calculate emission factors (in grams per mile) for gasoline and diesel-powered motor vehicles for particle sizes up to 10 microns ($PM_{10}$ and $PM_{2.5}$). The model is capable of estimating emission rates for PM from vehicle exhaust, exhaust components, brakewear, tirewear, and re-entrained road dust. The State of California uses its own emissions model, EMFAC, to estimate PM emissions because of the unique regulations on vehicles in that State.

The accuracy of emission factor models is important because these models are used to develop emission inventories and to evaluate the emission effects of transportation projects and control strategies. The quality and accuracy of user inputs to the models, such as vehicle travel data, are also important for accurate inventory development and analysis.

It is widely recognized that the PART5 model contains a number of weaknesses that limit its accuracy (Graboski, 1997; Turner, 1995, 1998; Weaver et al.,1999). These weaknesses then limit the usefulness to which the modeling results can be used to establish accurate emission inventories and set emission budgets for PM, and in particular for $PM_{2.5}$ and secondary PM.

Although various projects relevant to the transportation community can be identified, the following priority research project areas are designed to fill the most important research gaps in modeling techniques to the transportation community.

- **Model improvement program for incorporating new research on motor vehicle-related emissions.** Most of the information used for estimating exhaust PM emissions from light-duty and heavy-duty vehicles are based either on certification data or from studies dating back to the early 1980s. This problem also extends to the other PM emission factors, including brake, tire wear and re-entrained road dust. These outdated emission factors make the model results suspect and the accuracy questionable. The broad number of emission factor improvement studies, all of which affect the reliability of the model for source contribution assessment, makes incorporation and updating of these factors critical to the transportation community. The development of a model improvement program to incorporate the completed and most current research will help to facilitate the incorporation of these results into the newest version of a particulate emission factor model.

- **Identify improvements needed in travel data for emission factor models.** Travel data are currently used in conjunction with emission factors to estimate regional emissions. However, travel data collected by transportation or planning agencies do not match the needs for developing an accurate emission inventory. For example, fuel type is frequently not included in the travel surveys. In order to develop a more accurate emission inventory for a region, the level of specificity in the emission factor model should match the level of detail in the travel data information. Improving the detail in the travel data to match the specificity in the emission factor model will lead to more accurate emission inventories and in particular lead to an improved assessment. By improving the travel data detail available, a more accurate PM inventory will be available leading to better estimates of the transportation communities' source contribution.

- **Develop an approach to incorporate ammonia emissions.** Neither the MOBILE or PART5 model currently incorporate ammonia emissions. For some locations ammonia nitrate is a major component of the total $PM_{2.5}$ (e.g., San Joaquin Valley, South Coast Air Basin). Thus ammonia emissions from mobile sources may play an important role in fine PM formation since $NO_X$ is emitted concurrently with ammonia. In order to accurately assess the significance, an approach is needed to accurately incorporate ammonia emissions into an emission factor model for mobile sources.

Specific priority research projects under the three areas listed above follow.

## Priority Projects

### Project P9: Develop a coordinated model improvement program for incorporating new research on motor vehicle-related emissions into EPA's PM model on a timely basis or developing new models as necessary.

The PART5 model was developed in the early 1990s and released in August 1994; the model was re-released in February 1995 with updates to correct a few problems identified with the initial release. Since that time, there has been a great deal of research that has advanced understanding of PM emissions from motor vehicles, yet this improved understanding of PM has not been incorporated into the PART5 model. As a result, the PART5 model does not adequately account for many factors that affect $PM_{10}$ emission rates. In particular, recent research findings regarding factors that affect tailpipe emission rates such as in-use engine deterioration (Cadle et al., 1998, Norbeck et al., 1998, Weaver et al., 1998, Whitney et al., 1998), and factors that affect brake and tire wear such as weight and vehicle class (Cooper et al., 1995); and research on re-entrained road dust (Cowherd, 1998; Cowherd et al., 1998b; NCHRP 25-18, 1999) have not been incorporated into PART5.

The development of a coordinated model improvement program will ensure that existing research understanding is incorporated into the PART5 model and that future research findings are incorporated into new versions of the model in a timely manner. The model improvement program will be used to identify whether there is enough evidence and consensus in the research community to warrant incorporating research findings into the model.

***Relevance to Transportation Community.*** *The transportation community needs to have a PM model that includes state-of-the-art information to improve the accuracy of inventories and to improve the analysis of control strategies. Flawed or oversimplified modeling procedures limit the ability to estimate emissions accurately and could lead to improper or unnecessary efforts to reduce motor vehicle emissions.*

### Project P10: Identify improvements needed in travel data to improve the use of the PM emission model for inventory development and analysis.

Travel data inputs are an important input to the PART5 model, particularly information on the portion of vehicle travel by various classes of heavy-duty diesel vehicles and their age. Recent changes in new diesel engine control technologies are resulting in rapid changes in emissions. In addition, the newest heavy-duty diesel vehicles have much longer engine life cycles. These factors will vary widely both by facility types and within regions and will not be accurately reflected on the gross national average fleet mix. The model allows users to provide customized inputs of the percent of VMT for 12 vehicle categories and by vehicle age or registration. Travel data collected by State and local planning agencies, however, typically do not match the data needed for emissions models. For example, traffic count data typically do not identify the fuel used by vehicles (e.g., gasoline or diesel). While this issue is a problem common for modeling all criteria pollutants, there are certain travel data issues specific to modeling PM. For example, heavy-duty diesel vehicles are important contributors to PM, and the PART5 model accounts for three different classes of heavy-duty diesel vehicles (e.g., light heavy-duty diesels, medium heavy-duty diesels, and heavy heavy-duty diesels). Most traffic count data, however, do not distinguish among different categories of heavy-duty vehicles, limiting the accuracy of emission estimates that can be developed. This project will identify the travel data needs and develop a set of recommendations for improving travel data collection to improve the accuracy of PM emissions modeling.

***Relevance to Transportation Community.*** *Transportation agencies are responsible for collecting travel data for use in transportation emission models and need accurate local-level data in order to accurately establish emission inventories and to analyze transportation projects and controls.*

**Project P11: Develop an approach to ammonia emissions component for possible inclusion in one of EPA's motor vehicle emission factor models (PART or MOBILE).**

PART5 calculates exhaust emission factors for primary emitted particulates, brake and tire wear emissions, and re-entrained road dust emissions. However, the PART5 model does not provide emission estimates for gas phase emissions that form as a result of chemical reactions in the atmosphere. These PM precursor emissions are at times a significant contributor to ambient PM in some regions (Turner, 1998). While EPA's "MOBILE" model does estimate some PM precursor emissions (such as VOC and $NO_X$), the MOBILE model does not estimate emissions of ammonia that is an important PM precursor.

This project will involve developing modeling procedures to estimate ammonia emissions and to incorporate these procedures into the MOBILE or PART5 models. Although work is still being undertaken on developing an air quality model that can accurately estimate the effects of precursor emissions on ambient PM, this project will help to provide the foundation for estimating the transportation contribution to all major PM precursors.

***Relevance to Transportation Community.*** *Ammonia is an important PM precursor emitted by transportation sources that is not currently included in emission models. If secondary formation is a major contributor to PM, planners need to estimate the impacts of transportation projects on PM precursor emissions and air quality.*

## Control Strategies

**Research Goal – Improve understanding of the costs and effectiveness of PM control strategies for transportation sources.**

### Overview

Transportation and air quality agencies in states with $PM_{10}$ nonattainment areas have examined and implemented a number of transportation-related strategies to reduce PM air quality problems. Several recent reports provide an overview of potential PM control strategies for transportation sources. (MECA, 1999, EPA, 1990, STAPPA, 1996). These control strategies can be grouped into three categories:

- **Fuel and vehicle technology controls.** Fuel and technology-based PM control strategies tend to focus on diesel vehicles since diesels emit a disproportionate share of PM from motor vehicles. Vehicle technology and fuel approaches identified include: engine design modifications, use of oxidation catalysts and catalytic trap oxidizers (particulate filters), conversion to alternative fueled vehicles, heavy-duty vehicle retirement/scrappage programs, heavy-duty diesel inspection and maintenance (I&M) programs, use of low-sulfur diesel fuel, and high-cetane fuel.

- **Roadway re-entrained dust controls.** Dust control measures include paving, road surface improvements, and use of road surface treatments to stabilize unpaved roadway surfaces or road shoulders, use of street sweepers and vacuum systems; and reductions in sand application practices (as a road deicer).

- **Vehicle travel reduction.** Strategies to reduce vehicle miles of travel (VMT) include the traditional inventory of transportation demand management (TDM) strategies that have been implemented to reduce other criteria pollutants that are also PM precursors. However, there has not been significant analysis of the effects of VMT reduction strategies on direct PM emissions and ways to target PM emission sources.

With the potential for a significant number of new $PM_{2.5}$ nonattainment areas under the new NAAQS, there is an increased need to improve understanding of potential control measures for transportation. States will be required to develop SIPs that identify how they will move toward attainment of the NAAQS. Many of these areas will have had limited experience with PM and will differ markedly in terms of climate, geography, and other conditions from parts of the country that have been the focus of earlier efforts. In areas where transportation sources contribute a significant share of PM, transportation control strategies will need to be examined for potential inclusion in the SIP.

A number of critical research gaps exist in the understanding of PM-related control strategies for transportation sources:

- **Control Strategy Cost Effectiveness.** The cost effectiveness of existing and potential PM control strategies for mobile sources is poorly understood. Research on the cost effectiveness of transportation-related control strategies is frequently non-existent or narrowly based on one or two location-specific studies that do not necessarily provide an accurate portrayal of cost effectiveness at a national level. Additional research is needed to provide basic data on the cost effectiveness of an array of control strategy options that can assist State DOTs in determining appropriate control strategies.

- **Geographic Variation in Control Strategy Effectiveness.** Research on PM-related transportation control strategies has focused on a small number of States located in the Western half of the United States, such as Arizona, California, Colorado, and Washington. The characteristics of PM problems in these areas, however, are likely to differ from those found in other regions such as the Midwest, the East Coast, or the Southeast. For example, re-entrained dust problems are likely to be very different in an urban East Coast setting with a wetter and more humid climate as compared to a rural western setting. Additional research is needed to better understand the effectiveness of different control strategies outside the Western United States.

- **Fuel and Technology-related Controls for Gasoline Vehicles.** Fuel and vehicle technology-related control strategy research is heavily focused on diesel engine technologies, in part because diesels are a focus of existing PM regulation. As diesel engines become cleaner, the relative share of PM emissions generated by gasoline-powered vehicles is likely to increase. More research is needed to determine the effectiveness of control strategies for gasoline-powered vehicles; however, the level of additional research should be correlated to the relative share of total PM emissions that are emitted by gasoline-powered vehicles. In addition, research is needed to assess the effectiveness of inspection and maintenance programs in preserving the effectiveness of vehicle technology-based controls for both diesel and gasoline engines.

- **Compatibility with other Air Quality Goals.** The interactions between PM control strategies and control strategies for other pollutants such as ozone and air toxics is unclear. As the overlap particularly between PM and ozone nonattainment areas increases, this issue is likely to become a key concern. For example, some ozone-related TDM control strategies that promote use of diesel-powered transit may generate increased PM emissions, while some PM-related engine technology controls may increase $NO_X$ emissions that adversely affect ozone. Understanding the complexity of these interactions will require additional research.

Priority research projects designed to improve the understanding of the costs and effectiveness of PM control strategies for transportation sources are described below.

## Priority Projects

### Project P12: Analyze the costs and effectiveness of existing transportation source PM control strategies at reducing PM and PM-precursor emissions.

$PM_{10}$ nonattainment areas around the country have implemented local-level transportation-related control strategies for PM, such as, use of roadway surface treatments and road construction dust controls. Only a limited understanding exists, however, of the costs and effectiveness of these PM control strategies particularly in terms of how these measures contribute toward meeting the $PM_{2.5}$ NAAQS since areas have not had to address this smaller size fraction.

This project would involve a set of case studies of existing transportation PM control strategies to identify the full costs of implementing these measures and to measure effects at reducing $PM_{10}$ emissions, $PM_{2.5}$ emissions, and PM-precursor emissions. The estimated reductions would be compared with the reductions required within the SIPs. Emission reductions would also be compared with estimates of the effects of improvements in diesel fuels and vehicle technologies to assess the relative contribution of these strategies.

***Relevance to Transportation Community.*** *This project would provide transportation decisionmakers with a better understanding of the extent to which existing, locally implemented control strategies contribute to attainment of the PM NAAQS. Transportation officials need to come to the table with an understanding of the costs and effectiveness of potential strategies when working with air quality officials to develop SIP measures.*

**Project P13: Develop a menu of transportation-source $PM_{2.5}$ control strategies for regions to consider in air quality planning, including an evaluation of costs and effectiveness in different geographic settings.**

State and local transportation and air quality agencies have limited knowledge of the full range of options to reduce $PM_{2.5}$ from transportation sources. Existing control strategies in use in $PM_{10}$ non-attainment are targeted towards the coarse mode fraction and are unlikely to be sufficient or appropriate for control of $PM_{2.5}$ in many parts of the country designated as nonattainment under the new $PM_{2.5}$ standard.

This project involves developing a menu of control strategies to help inform decisionmakers about the full range of options available for PM control. The emissions effects of each option will be assessed quantitatively using emission models in a range of different geographic settings (e.g., areas with different temperatures, road types, vehicle fleet mixes). Issues of concern to transportation decisionmakers will also be identified, including estimated costs, implementation issues, effects on other transportation goals (e.g., safety, mobility), and locational factors.

***Relevance to Transportation Community.*** *Transportation decisionmakers need to have information to help them select the most appropriate control measures for transportation sources if required. This project goes beyond the first project by examining the potential of measures in regions where PM controls have not yet been implemented or considered.*

**Project P14: Evaluate the interactions between transportation-related PM, ozone, air toxics, climate change, and other air pollutant control strategies.**

The effect of control strategies on both PM and ozone is important because many areas of the country expected to be designated as nonattainment for $PM_{2.5}$ are ozone nonattainment or maintenance areas. The effect of control strategies on both PM and ozone is important because many areas of the country expected to be designated as nonattainment for the 24-hour $PM_{2.5}$ are ozone nonattainment or maintenance areas. This is because in many locations (particularly in the Eastern half of the United States) similar meteorological conditions conducive to high ozone formation also lead to high levels of $PM_{2.5}$. As a result, State and local decisionmakers need to understand the implications of control strategies on both $PM_{2.5}$ and ozone as well as the implications on air toxics and greenhouse gases.

Some control strategies may be beneficial in reducing both PM and ozone pollution. Since the ozone precursors, VOC and $NO_X$, are also precursors for secondary PM, ozone controls may already be working to reduce secondary PM formation. On the other hand, some ozone control strategies may result in increased PM as well as other effects on air toxics and greenhouse gases. For example, an increase in transit bus service provision could increase PM emissions since diesel buses have high PM emission rates compared to other classes of vehicles. This would in addition increase air toxic emissions since diesel is considered a significant air toxic. Conversely, carbon dioxide would decrease as the transit bus service produces significantly less carbon dioxide than gasoline fueled vehicles.

This project involves modeling the impacts of transportation control strategies on both PM and ozone as well as their impact on air toxics and greenhouse gases using emission factor models and urban air shed models.

***Relevance to Transportation Community.*** *Transportation decisionmakers need to understand the implications of proposed controls on both PM and ozone to address conformity issues for these pollutants.*

## NEXT STEPS – IMPLEMENTING THE WORKPLAN

The research focus areas and priority projects outlined in this Workplan provide a base-map for conducting future transportation-related PM research. Additional steps will be required to implement the Workplan, including development of detailed project scopes, identification of project leadership roles, and selection of funding opportunities. This section of the Workplan identifies important implementation issues, including the research approach and timeframe for initiating the projects described in this Workplan.

- **Multiagency Implementation Approach.** FHWA acknowledges that the technical complexity and broad scope of the projects contained in the Workplan will require a multiagency implementation approach. Extensive coordination between FHWA, State DOTs, and MPOs will be critical. However, the multidisciplinary range of projects outlined in the Workplan will also necessitate extensive involvement by academic and applied research organizations as well as State and Federal air quality agencies, and industry groups. An open dialogue among all these groups is encouraged to facilitate speedy resolution of issues critical to implementing this Workplan, particularly, equitable distribution of research leadership, development of detailed project scope information, and funding responsibilities for individual projects.

- **Project Implementation Timeframe.** An aggressive four-year timeframe is envisioned for initiating the research described in the Workplan. Adherence to this schedule will ensure that completion of the initial research coincides with EPA's planned designation of new nonattainment areas. Hence, this improves the ability of State DOTs to develop timely and appropriate transportation policy responses.

- **Project Scheduling.** This Workplan does not include a specific timeline for the initiation of individual projects. However, this plan recognizes that certain projects must be initiated before others because they answer questions that need to be addressed early on by transportation agencies and their findings and outcomes will help lay the foundation for other projects.

In terms of the transportation community's key policy concerns, research focus areas 3, 4, and 5 (transportation sources, modeling, and control strategies) are of most direct relevance. However, research focus areas 1 and 2 (monitoring and characterization) are acknowledged to provide critical background information on PM, without which sound policy decisions cannot be made. Given the need to schedule these projects, this Workplan divides projects into three sets, as shown in Figure 5.

| *Implementation Phase* | | |
|---|---|---|
| ***EARLY*** | ***INTERMEDIATE*** | ***LATE*** |
| Project P1: Conduct an analysis of preliminary data from the $PM_{2.5}$ monitoring network to identify potential $PM_{2.5}$ nonattainment areas. | Project P4: Review and update transportation-related source profile information used in PM speciation analysis. | Project P3: Examine state-of-the-art techniques for measuring semi-volatiles. |
| Project P2: Integrate critical transportation sector PM research concerns into EPA's Supersite PM research program. | Project P5: Utilize speciation monitoring data to provide an improved understanding of the relative contribution of transportation to PM. | Project P11: Develop ammonia emissions component for inclusion in one of EPA's models. |
| Project P9: Develop a coordinated model improvement program for incorporating new research on motor vehicle-related emissions into EPA's PM model on a timely basis. | Project P6: Conduct dynamometer studies of diesel fueled vehicles/engines that are representative of current fleet mix to generate better data on the contribution of diesel vehicles to PM and PM precursor emissions. | Project P12: Analyze the costs and effectiveness of existing transportation source PM control strategies at reducing PM and PM-precursor emissions. |
| | Project P7: Conduct dynamometer studies of sample vehicles to determine the impact of gross emitter gasoline powered vehicles on PM emissions. | Project P13: Develop a menu of transportation-source $PM_{2.5}$ control strategies for regions to consider in air quality planning, including an evaluation of costs and effectiveness in different geographic settings. |
| | Project P8: Conduct a re-entrained road dust study that identifies the extent to which re-entrained roadway dust contributes to $PM_{2.5}$ in urban areas in the Eastern United States. | Project P14: Develop assessment of interactions between transportation source control strategies for PM and ozone. |
| | Project P10: Identify improvements needed in travel data to improve the use of the PM emission model for inventory development and analysis. | |

*Figure 5. Project Implementation Schedule*

## Early Implementation Projects

A subset of the projects are recommended for initial implementation:

Project P1: Conduct an analysis of preliminary data from the $PM_{2.5}$ monitoring network to identify potential $PM_{2.5}$ nonattainment areas.

This project will provide valuable baseline information for State DOTs and MPOs about potential non-attainment status that will help to generate interest in and support for implementing other projects in the Workplan.

Project P2: Integrate critical transportation sector PM research concerns into EPA's Supersite PM research program.

This project should be considered a top priority because the super site program is already under development. A window of opportunity to include transportation research components may be missed if there is inaction on the part of the transportation community now.

Project P9: Develop a coordinated model improvement program for incorporating new research on motor vehicle-related emissions into EPA's PM model on a timely basis.

This project will support early resolution of critical transportation policy questions such as control strategy effectiveness and source apportionment, and is therefore of particular interest to the transportation community.

## Intermediate Projects

These projects should be initiated second because they fill important research gaps that help to support later research projects but follow from the initial set of projects.

Project P4: Review and update transportation-related source profile information used in PM speciation analysis.

Project P5: Utilize speciation monitoring data to provide an improved understanding of the relative contribution of transportation to PM.

Project P6: Conduct dynamometer studies of diesel fueled vehicles/engines that are representative of current fleet mix to generate better data on the contribution of diesel vehicles to PM and PM precursor emissions.

Project P7: Conduct dynamometer studies of sample vehicles to determine the impact of gross emitter gasoline powered vehicles on PM emissions.

Project P8: Conduct a re-entrained road dust study that identifies the extent to which re-entrained roadway dust contributes to $PM_{2.5}$ in urban areas in the Eastern United States.

Project P10: Identify improvements needed in travel data to improve the use of the PM emission model for inventory development and analysis.

## Late Implementation Projects

These projects should be initiated third because they require information for earlier research projects or address issues that are secondary to some of the issues addressed in the first two sets of projects.

Project P3: Examine state-of-the-art techniques for measuring semi-volatiles.

Project P11: Develop ammonia emissions component for inclusion in one of EPA's models.

Project P12: Analyze the costs and effectiveness of existing transportation source PM control strategies at reducing PM and PM-precursor emissions.

Project P13: Develop a menu of transportation-source $PM_{2.5}$ control strategies for regions to consider in air quality planning, including an evaluation of costs and effectiveness in different geographic settings.

Project P14: Develop assessment of interactions between transportation source control strategies for PM and ozone.

### Dissemination of Research Results

Communication of research results to transportation stakeholders is an important aspect of the implementation of this research Workplan. The products of all the research projects need to be accessible to transportation professionals. In some cases, special outreach methods and training will be required. Possible methods for distributing information about the research results might include development of a PM Web site, or newsletter, as well as conferences and seminars.

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# APPENDIX A

## PM — A Primer

**Particle Size.** PM is characterized by size, expressed as a particle's aerodynamic equivalent diameter in micrometers (or microns). Fine particles are typically defined as those less than 2.5 microns in diameter ($PM_{2.5}$) and coarse mode particles are those greater than 2.5 microns, but less than 10 microns in diameter ($PM_{10}$). Particle size is closely linked to relative health impacts, as well as source origination, and chemical composition.

**Health Effects of PM.** The adverse effects of PM on human health have been recognized for many decades. The major risks to human health include not only premature mortality from acute pollution episodes, but also aggravation of existing respiratory and cardiovascular disease, damage to lung tissue, impaired breathing and respiratory symptoms, and alterations to the body's physical and immune system defenses against inhaled particles. Populations at general risk include children, people of all ages with asthma, and elderly persons with illnesses such as bronchitis, emphysema, and pneumonia. PM causes adverse health effects by depositing in the lungs where it interferes with the respiratory process. The health risk from an inhaled dose of PM appears to depend on the size, composition, and concentration of the particulate.

**PM in the Atmosphere.** PM can result from direct emissions from various sources (primary PM) or it can be formed in the atmosphere by a combination of gaseous emissions (secondary PM).

- **Primary Particles.** There are two major types of direct PM emissions:

  *Fugitive and Re-entrained Dust Particles.* Fugitive dust includes wind blown particles and dust arising primarily from construction, agriculture, and natural landscapes. Material resuspended by vehicles traveling on unpaved and paved roads is called re-entrained dust and considerable quantities of re-entrained dust on road and pavement surfaces arise from vehicle tires tracking soil from unpaved roads, the erosion of the road surface itself, and the degradation of parts of the vehicle, especially the tires. The amount of re-entrained and fugitive dust is extremely difficult to predict or measure as it depends on factors such as the dust loading of the surface, the preceding dry period, wind speed and the volume of traffic.

  *Combustion-related Particles.* Major sources of combustion-related particles include diesel motor vehicles, residential wood combustion, utility and commercial boilers. Metallurgical processes and many other industrial operations also lead to the emission of particles into the atmosphere. The mode of formation and chemical composition of the particles varies greatly from one source to another.

- **Secondary Particles.** Secondary particles are formed within the atmosphere by the oxidation of gaseous sulfur dioxide ($SO_2$) and $NO_X$, to form sulfate and nitrate aerosols. Hydrocarbons also act as a catalyst to formation of secondary PM. The principal types of secondary particles are ammonium sulfate and nitrate. The sources that emit $SO_X$ and $NO_X$ are generally located in urban areas, with the exception of power plant utilities. However, secondary sulfate and nitrate particles typically form over several days, which can result in long transport distances. These transported secondary particles can comprise a significant portion of the ambient PM.

**Chemical Characteristics of PM.** $PM_{10}$ and $PM_{2.5}$ are composed of varying proportions of six broad chemical constituents:

- **Re-entrained and Fugitive Dust.** Fugitive dust consists mainly of oxides of aluminum, silicon, calcium, titanium, iron, and other metal oxides. The precise combination of these minerals depends on the geology of the area and the presence of industrial processes such as steel making, smelting, mining, and cement production. Re-entrained dust includes material from vehicles and roads such as brake wear, tire wear, and pavement material. Re-entrained and fugitive dust is mostly in the coarse particle fraction.

- **Sulfates.** Ammonium sulfate, ammonium bisulfate, and sulfuric acid are the most common forms of sulfate found in atmospheric particles, resulting from conversion of $SO_X$ gases to particles. These compounds are water-soluble and reside almost exclusively in the $PM_{2.5}$ size fraction.

- **Nitrates.** Ammonium nitrate is the most abundant nitrate compound, resulting from a reversible gas/particle equilibrium between ammonia gas ($NH_3$), nitric acid gas, and particulate ammonium nitrate. Because this equilibrium is reversible, ammonium nitrate particles can easily evaporate in the atmosphere, or after they have been collected on a filter, owing to changes in temperature and relative humidity.

- **Sodium Chloride.** Salt is found in suspended particles near seacoasts and after deicing materials are applied. In its raw form (e.g., deicing sand), salt is usually in the coarse particle fraction and classified as a geological material. After evaporating from a suspended water droplet (as in sea salt or when re-suspended from melting snow), it is abundant in the $PM_{2.5}$ fraction. Sodium chloride is often neutralized by nitric or sulfuric acid and is classified as a sulfate or nitrate.

- **Organic and Elemental Carbon.** Particulate organic carbon consists of hundreds, possibly thousands of separate compounds that contain carbon atoms. Because of this lack of molecular specificity, and owing to the semi-volatile nature of many carbon compounds, particulate "organic carbon" is operationally defined by the sampling and analysis method. Elemental carbon, often called "soot,"or carbon black, contains pure, graphitic carbon, and dark-colored, non-volatile organic materials such as tar, biogenics, and coke.

**PM Regulatory Background.** Regulation of PM in the United States has occurred in three broad phases, beginning in 1971:

- **Total Suspended Particulate Standard, 1971.** The first NAAQS for PM was promulgated in 1971. The standard was expressed in terms of Total Suspended Particulate (TSP), and based on a reference method for measuring attainment that used a "high-volume" sampler, which collects PM up to a nominal size of 25-45 microns. The standard for TSP was 260 $\mu g/m^3$, 24-hour average, not to be exceeded more than once per year, and a 75 $\mu g/m^3$ annual geometric mean.

- **$PM_{10}$ Standard, 1987.** In 1987 EPA revised the PM NAAQS following nearly a decade of debate over evidence that smaller particulates pose a greater hazard to health. The new standard replaced TSP as the reference method with a new indicator that includes only particles with an aerodynamic equivalent of less than or equal to 10 microns ($PM_{10}$). As with the TSP standard, a 24-hour average, and an annual mean were established.

- **$PM_{2.5}$ Standard, 1997.** In response to evidence that morbidity and mortality effects occur at levels well below the $PM_{10}$ standard, in 1997, EPA added new $PM_{2.5}$ standards, set at 15 micrograms per cubic meter ($\mu g/m^3$) and 65 $\mu g/m^3$, respectively, for the annual and 24-hour standards. In addition, the form of the 24-hour standard for $PM_{10}$ was changed. EPA is beginning to collect data on $PM_{2.5}$ concentrations. Beginning in 2002, based on three years of monitoring data, EPA will designate areas as nonattainment that do not meet the new $PM_{2.5}$ standards.

The planned time frame for review and implementation of the $PM_{2.5}$ NAAQS is shown in Figure A-1.

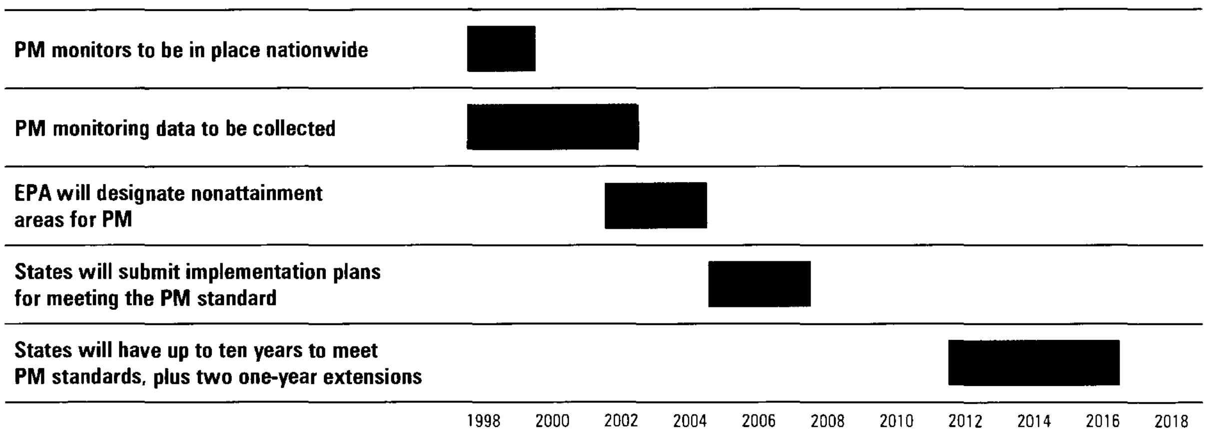


*Figure A-1. Time Frame for Implementation of $PM_{2.5}$ Standard*

# APPENDIX B

## Symposium Summary
## Spatial, Temporal, and Chemical Variations of PM

The session focused on 1) assessing the current understanding of the variation (spatial, temporal, and chemical) of ambient PM concentration across the United States and 2) the causes and processes that lead to elevated PM periods. The review and assessment spans spatial scales from national to state to local level.

Participants highlighted the need for research to focus on collecting more data from the limited number of sites that have a comprehensive data collection and analysis effort in order to better understand the variation in PM concentrations. The identified research needs applicable to the transportation community included:

- Gain better understanding of spatial, temporal and chemical variation of PM emissions within and across classes of vehicles,
- Develop strategies to identify and measure high PM emitting vehicles,
- Update motor vehicle PM source chemistry profiles to account for changes in fuels, brake pads, new engine technologies, etc., for both on-road and off-road vehicles, and
- Gain a better understanding of the relationship between air toxics and PM emissions for transportation sources.

Researchers also noted that broad interagency coordination is needed across all of the affected community, as no single source type (mobile, utility, industrial, and fugitive) is likely to dominate the source contribution for any location.

### Critical Research Concerns

**Contribution of Off-Road Emissions and Other Combustion Sources:** Although both groups saw on-road mobile sources as significant contributors to the PM problem, off-road mobile sources were seen as a contributor that could easily rival mobile source contribution and have a significant impact on the chemical variation of PM. Identifying the contribution of off-road mobile sources was therefore identified as an important priority.

**Need linkages to EPA's New Supersites:** Researchers believed that an opportunity exists to improve understanding of local transportation measures by collecting information such as vehicle counts, fleet mix, age distribution, and facility types during planned and ongoing studies, for at least some of the new EPA's PM Supersites. Collection and analysis of PM and transportation data at the PM Supersites should be undertaken with an awareness of transportation networks to further the understanding of the temporal and spatial distribution of PM.

**Examination of the Speciation Network:** The PM speciation network (just now in the early stage of data collection) should be examined or supplemented for a better understanding of transportation source contribution. Improvements might include a higher sampling frequency and an expanded list of compounds for analysis.

**Research Topic #1: Undertake a Critical Analysis of New $PM_{2.5}$ and $PM_{10}$ monitoring network.** Both sessions identified examination of the monitoring network as a very useful way to better understand the spatial, temporal and chemical variation of PM across the nation and also locally. Currently, only a few areas across the country have an adequate database to describe temporal, chemical and spatial variations. Examination of the national network would include exploring both the mass and speciated-monitoring network in combination with key transportation data (VMT, facility type, fleet mix and age distribution) to determine the transportation related source contribution to the PM problem.

**Research Topic # 2: Gain a Better Understanding of Variations Among Emissions Within Classes as Well as Across Classes and Strategies to Tackle the High Emitters:** Current research strongly suggests that 80 percent of the exhaust PM is emitted by 20 percent of the vehicles, either because of age or improperly functioning emission controls. Further research is needed on how to identify these high PM emitters. In addition, diesel-fueled vehicles are seen as significant contributors to exhaust PM; they typically account for only 5 percent of the VMT, but more than half of the exhaust PM. However, the use of cleaner diesel-fueled vehicles introduced since 1994 has increased the PM exhaust contribution share from gasoline-fueled engines. Further research is needed to study PM emissions across vehicle classes.

**Research Topic # 3: Develop Better Estimates of all Vehicle Miles Traveled.** Current estimates of total VMT contain a degree of uncertainty, particularly for arterials and even more so for local roadways. An incomplete assessment of VMT adversely affects the certainty in the PM emissions estimate. This uncertainty will have broad implications on any type of conformity analysis based on PM emission inventories. Furthermore, a lack of understanding of VMT by facility type affects the estimated spatial and temporal distribution of PM emissions, and as a result, may hamper the implementation of effective control strategies.

**Research Topic # 4: Update Motor Vehicle PM Source Chemistry Profiles for Changes in Fuels, Brake Pads, New Engine Technologies, etc.** Much of the underlying basis for source contribution is based on PM source chemical profiles. However, much of the motor vehicle PM source profiles are significantly dated and in need of updating. Updating the PM source profiles is needed in particular for motor vehicles with new engine technologies as well as for brakes and tires.

## Understanding of Sources of PM

The overall discussion focused on answering questions about the level of uncertainty associated with the contribution of transportation sources to primary and secondary PM. This included discussion of the characterization of PM by location and the spatial extent to which the PM monitoring sites can be considered representative.

Attendees noted the important gap between research efforts that have been conducted to date on PM emission factors and the emission factor models that are used for regulatory purposes, that have not been updated to reflect the results of this research. Thus, an important practical gap in improving the current emission factor models requires updating the current regulatory models with the latest information and also expanding their functionality. Conducting validation studies and improving the packaging for end users are other important needs to improve the use of these models.

An overarching theme was the need to integrate the air quality planning with the transportation planning process. The two processes require frequent feedback both in the regulatory setting, and in expanding the understanding of local PM source contribution.

## Critical Research Concerns

**Incorporating the Research into Modeling Tools:** Both groups identified a number of studies that have been undertaken but whose results have not yet been incorporated into current emission models (PART5, EMFAC7G). This lack of integration hinders some of the current planning efforts because the current tools are based on dated information, apply to limited situations and are not comprehensive. Further, the models need to be validated for a broad range of settings (e.g., pavement types, silt loading, levels of VMT, humidity).

**Continue to Improve the Understanding of Transportation Source Contribution:** It is important to the transportation community to better understand its contribution to the PM problem because of the implication for infrastructure development (e.g., new freeway construction or increases in VMT may lead to regional PM exceedance problems). To that end, methods and models need further development to improve the reliability of the source apportionment.

**Research Topic #1: Undertake Source Fingerprinting of Mobile Sources.** Special studies are needed to develop more up-to-date source fingerprinting profiles for gasoline and diesel-fueled vehicles. This will increase the robustness of conclusions drawn about source contribution of transportation versus stationary sources. Also, as part of the special studies, detailed data collection should be conducted to collect traffic information such as fleet mix, volume, age, fuel-type and speed. These data can be used in combination with mobile source modeling to corroborate source apportionment studies based on PM monitoring.

**Research Topic #2: Collect Transportation Data in Connection with EPA's Supersites Monitoring Program.** EPA's PM Supersites will soon be collecting a comprehensive suite of data including PM size distribution, mass, number and composition. Supplemental transportation data (VMT, fleet mix, age, fuel-type, activity and speeds) should also be collected so that analyses can be performed to determine transportation related source contribution at these intensively monitored sites. Analysis of these supplemental data will help in identifying the contribution from mobile sources and likely reduce the uncertainty in the source contribution.

**Research Topic #3: Develop Better Understanding of Secondary Aerosols:** Mobile source $NO_X$ and VOC emissions may at times contribute significantly to nitrate and secondary organic aerosol formation. Photochemical models are used to simulate the complex nitrate and secondary organic aerosol formation process. Based on these simulations the most effective control strategy can be developed. Currently, some locations have knowledge about local sulfate and nitrate formation, but very little about secondary organic aerosols, which at times may be a significant contributor to $PM_{2.5}$. Research should be undertaken to better understand secondary organic aerosol distribution in both time and space. The research should also include further study to improve the understanding of the process leading to secondary organic aerosol formation from gas phase precursors.

**Research Topic #4: Improve the Understanding of the PM Gas/Diesel Split:** Much of the focus of primary PM emissions studies IS on diesel-fueled vehicles. However, recent model year diesel-fueled vehicles have drastically reduced their base PM emission rate and contribute only about 5 percent of the total VMT. Thus the fraction of gasoline to diesel contribution to PM is changing, and, with impending Tier II controls will continue to change. Research should focus both on the current gas/diesel PM split, and on the implications of future mandated changes and control technologies.

## Improved PM Measurement Methods

This session focused on identifying the current state of technology with respect to PM measurement methods and identifying those areas, that need further research and development. The areas identified included: the missing semi-volatile mass in routine measurements, the temporal and chemical resolution in the acquisition of PM data, and procedures needed to assure a consistent approach to the measurement of ultrafine particles.

Participants noted that transportation related parameters are frequently missing in PM study efforts. Both sessions identified the following overall gaps/weaknesses in current work:

- Routine PM measurements are generally not helpful in understanding transportation related source contribution because the complex changes in source contribution mix over a 24-hour period,
- Semi-volatile aerosols are probably significant and are generally underestimated with current measurement practices,
- PM Supersites need additional traffic-related measurements, and
- Improved measurements methods and calibration for PM ultrafine particles are needed.

### Critical Research Concerns

**Limited Understanding from Routine PM Measurements:** Although analysis of the current $PM_{10}$ (and future fine $PM_{2.5}$ study) network does provide information on overall trends, it does not provide information about the source contribution or chemical characterization of the PM. Thus better understanding of the composition of PM will come as a result of studies directed at the PM speciation network, the Supersites and through special studies. Currently, only the New York Supersite is focusing efforts in order to study the relationship between transportation and PM.

**Underestimation of Semi-Volatile Aerosols:** Particles which are not measured as a result of deposition onto filters because of their volatile composition are probably significant at certain times and locations. Research methods need to be developed that can both quantify the underestimation and clarify when and where their contribution is significant.

**Portable Sampling Devices:** Current methods for assessing site representativeness as well as for identifying maximum concentration use saturation monitoring techniques. These techniques only provide 24-hour integrated concentrations. Research efforts are needed to develop methods that will give higher resolution (e.g., half-hourly or real-time) PM concentrations so that more definitive conclusions can be drawn about source contribution. These devices will need to be cost effective because of widespread deployment.

**Ultrafine Measurement Techniques:** Some studies have identified the fact that traffic contributes to a significant increase of ultrafine PM in urban environments and that ultrafine particles are more effective at reducing pulmonary volume exchange than larger particles. As a result, ultrafine particles are of significant interest. However, for ultrafine particles less than 40 nm, calibration is a serious problem. Calibration is the critical next step. In addition, the necessity for standardization in measurement approach is needed so that studies performed by different researchers may be compared.

**Research Topic #1: Improve Measurement Method to Apportion PM Contribution from Mobile Sources.** There is a need for measurement methods to better apportion the PM contribution from mobile sources, particularly for diesel-fueled vehicles. Special studies are needed to develop more up-to-date source profiles for gasoline and diesel-fueled vehicles. This will increase the robustness of conclusions drawn about source contribution of transportation. Also, as part of the special studies, detailed data collection should be conducted to collect traffic information such as fleet mix, volume, age and speed. These data can be used in combination with mobile source modeling to corroborate source apportionment studies based on PM monitoring.

**Research Topic #2: Develop Techniques for Assessing Semi-Volatile PM:** Currently, significant loss from semi-volatile material (e.g., ammonium nitrate, organic compounds) may occur due to filter artifacts (gas adsorption and chemical reactions). This loss of semi-volatiles may be significant, accounting for upwards of 20 percent of the total $PM_{2.5}$ mass. A significant portion of the precursor semi-volatiles ($NO_X$ and VOC's) originate from combustion of gasoline and diesel fueled vehicles. Research is needed to develop practical methods, which can measure the loss of semi-volatile material during and after sampling. In addition, further work is needed to assess the positive artifact that may result from adsorption of gaseous organic compounds on the filter medium.

**Research Topic #3: Supplement Targeted PM Supersites for Traffic Related Measurements:** Currently, PM Supersites are focused on PM measurements by identifying source characterization (or characterizing sources) based on chemical mass balance. Additional measures should be made to corroborate findings based on direct measurements of high resolution CO, NO and $NO_2$, and traffic information such as fleet mix, volume, age and speed. Analysis of these supplemental data will help in identifying the contribution from mobile sources and likely reduce the uncertainty in the source contribution.

**Research Topic #4: Standardization and Calibration Techniques for Ultrafine Particles.** It is likely that most of the exposure to ultrafine particles are from transportation related fuel combustion. Current techniques for ultrafine measurements are not consistent in their approach (e.g., some techniques use dilution and some do not use dilution). The need for a standard approach is a necessity so that concentrations may be compared. In addition, to be able to compare different measurement techniques a calibration or reference is needed. Current efforts in this area of research are currently in the formative stages.

## Emission Factors and PM Models

The session focused on development of emission factors and emission inventories for PM emitted directly from motor vehicles and gas-phase pollutants that form particles in the atmosphere. Emphasis was also placed on the development of methods to better quantify secondary particulate formation and improvements to chemical mass balance models.

Participants in the session noted that the current weaknesses in developing emission inventories will hamper emission inventory-based control strategies (e.g., conformity) because the emission budgets will change as improvements to the inventory occur. The key weaknesses and data gaps identified by the group include:

- High degree of uncertainty associated with exhaust emissions factors and emission inventories for all transportation sources.
- Poor estimates of re-entrained road dust.

- Poor estimate of emissions for brake and tire wear.
- Limited tools and testing of models for secondary particulate formation.

## Critical Research Concerns

**Weakness in Emission Inventories:** An accurate emission inventory is needed to assess control strategies and emission budgets for conformity. Unfortunately, the current emission inventories have a very high degree of uncertainty. Historically, primary emphasis has been placed on receptor modeling to determine source contribution, that relies on accurate and comprehensive emission source profiles, which change with new technologies and new fuels. In addition, receptor models cannot be used to project future source contribution. In order to assess future-year control strategies and emission budgets for conformity, accurate emission inventories are needed. Areas of important research to the transportation community include: improvements to emissions factors for both the on-road and off-road emission sources across all engine technologies, engine size, fuel, real-time driving cycles, altitude, and ambient temperature. PM emissions should be identified by particle size, as well as chemical and gaseous composition, especially for diesel-fueled engines.

**Re-entrained Road Dust:** Current modeling methods used to estimate re-entrained road dust emissions both for $PM_{10}$ and $PM_{2.5}$ are limited as to their range of functionality. They are based on a fairly limited data set of re-entrained road dust measurements and do not cover all conditions. Improvements are needed for the range over which the models are truly applicable.

**Brake and Tire Wear Emissions:** Emissions from brake and tire wear may be significant contributors to PM concentrations at roadway intersections or at freeway off-ramps. In addition, recent improvements in brakes and tire technology have led to smaller size PM and to changes in PM composition. A better understanding of the size and composition of today's tires and brakes is needed so that this information can be properly incorporated into emission inventories and modeling studies.

**Secondary Particulate Modeling:** Mobile source $NO_X$ emissions may at times contribute significantly to nitrate aerosol formation. Photochemical models are used to simulate the complex nitrate formation process. Based on these simulations, the most effective control strategy can be developed. Currently, a better understanding of the chemical and physical formation process is needed to improve reliability of existing models. In addition, the process leading to secondary organic aerosol formation from gas phase precursors is not well understood.

**Research Topic #1: Develop Improved Estimates of Direct PM Emission Rates from Transportation Sources.** The session identified that direct PM emission factors are the most important research area associated with emissions inventories. The primary purpose for the research will be to improve all the factors that affect PM emission rates for mobile sources. Current factors used in EPA's PART5 model are out of date. Thus the first step in improving the inventory will be to improve the base emission factors for diesel and gasoline fired engines for a variety of conditions, including:

- Engine technology
- Engine condition (age)
- Driving cycle

- Altitude
- Temperature

In addition information for the PM emission rate should include the particle size distribution and chemical composition. The PM emission rates should be based on "real-time" monitoring of mobile source PM. Besides PM emission rates, emissions efforts should also be directed at developing refined estimates of mobile source ammonia emissions because of ammonia's importance to secondary PM formation.

**Research Topic #2: Develop an Improved Model for Re-entrained Road Dust.** Current approaches to the modeling of re-entrained road dust are limited as to their range of applicability. A wider-range of "correction factors" are needed that characterize paved road surface conditions, including soil type, meteorology (wind speed, humidity, rainfall), traffic volume, road surface, road treatment, and maintenance. Ideally, these corrections will be based on first principles, but a statistical approach may also be feasible. Further research is needed to develop a full range of "correction factors" applicable to all conditions observed nationwide for both $PM_{2.5}$ and $PM_{10}$.

**Research Topic #3: Improve Understanding of Today's Emissions from Brake and Tires.** EPA's current emission factor model (PART5) for tire and brake wear is based on light-duty vehicles only and is also quite dated, not reflecting today's brake and tire wear compositional changes. The areas of further research for emission factor development include:

- Expanded light-duty vehicle testing as well as heavy-, medium-duty vehicle testing,
- Temperature effects on brake and tire wear,
- Equipment variations (e.g., disc brakes, studded tires), and
- Chemical composition and size distribution characterization.

**Research Topic #4: Develop Improved Secondary PM Models.** Currently, the relative contribution from transportation sources to secondary PM is poorly known. In many instances it is likely that gases from mobile sources are major contributors to secondary PM, which in turn may be a significant portion of the total PM inventory. Research is needed to reduce the level of uncertainty in determining source contribution and hence provide useful control strategy information. Along with continued improvement in the emission inventory, the areas that need further research for PM modeling include:

- Improved understanding of the growth in particle formation, starting with smallest size particles (nanometers) to accumulation mode size particles and their incorporation into a PM model,
- A highly detailed accounting of the physical and chemical processes leading to fine PM formation,
- High time resolution information on particle size and chemically speciated sampling, and
- Improved modeling and computational software — Modeling is constrained by typically available computational resources. Future modeling systems should be evaluated against future high resolution data, and be built flexibly enough to allow for use now, but also for easy scaling to higher resolution or sophistication as computational resources improve.

## Control Strategies for Transportation-Related PM

These sessions focused on 1) developing a better understanding of impacts of existing control strategies, 2) undertaking a critical evaluation of the accuracy of emission estimates, and 3) examining those future control strategies most likely to be needed at the federal, state, and local levels.

Participants highlighted the relative lack of knowledge about other PM-related issues as a challenge to conducting research on control strategies. Weaknesses highlighted by participants included:

- Lack of understanding about secondary versus primary PM,
- Inaccuracies in the mobile source PM inventory,
- Geographic diversity of PM problems, and
- Weaknesses in travel and emissions models and data inputs used to evaluate controls.

These concerns led participants in both sessions to place a priority on conducting research in other research areas that may provide relevant information on control strategies.

### Critical Research Concerns

**Coordination Among Partners:** The morning group participants, in particular, suggested that while FHWA has a different set of concerns from the traditional research community, FHWA must look for partners in research. Members of both groups expressed surprise about the existence of the NCHRP project presented at the introduction session, and concern that this research initiative was not more widely known. Clearly, coordination must be strengthened across the research community.

**Weaknesses in Travel Models/Travel Data:** The afternoon group discussed interactions between travel models and emission models, and concluded that there are weaknesses in the ability to gather necessary travel data (e.g. truck classes, VMT by category, etc.) for purposes of modeling PM emissions from transportation sector. MPO representatives talked about the limited applicability of travel models to analyzing PM issues. The group indicated that research into better data collection, improved travel models, and stronger interfaces with emissions models are all needed.

**Weaknesses in Emissions Models:** Basic weaknesses in models and data inputs make accurate estimates of control strategy effectiveness difficult. Particularly, failure to account for factors such as ammonia from catalyst-equipped vehicles.

**Control Strategy Categorization:** The a.m. group suggested that there are a number of alternative ways to categorize transportation related control strategies: 1) by implementation level, i.e. federal, state, or local; 2) by behavioral changes — e.g., car pooling, spare the air days; or 3) by type, e.g. engine technology and inspection programs, fuels. There was a divergence of opinion about which types of control strategies should be pursued.

**Research Topic #1: Review of Existing Control Strategy Impacts.** Both session participants agreed that a valuable starting point for future research is a comprehensive review of PM control strategy reductions that are achievable with existing PM regulations.

The purpose of such a review should be to determine, to the extent possible, whether existing control strategies can achieve reductions likely to be required under current and future standards, and if not, to provide an assessment of the extent of the "gap" that must be filled. Control strategies suggested for inclusion in this review included:

- Low sulfur diesel,
- Recent (1994 on) transit bus regulations,
- Heavy duty vehicle $NO_X$/PM standards,
- Tier II standards for light duty vehicles (diesel and gasoline), and
- Off-road engine controls — locomotives, marine, and others.

**Research Topic #2: Critical Assessment of Accuracy in Control Strategy Estimates.** Both the a.m. and p.m. groups raised concerns about the accuracy of existing control strategy reduction estimates and agreed that a critical assessment of the validity of control strategy reduction estimates is needed. The p.m. group discussed some of the reasons for weakness in the current estimates. The focus of this discussion was on:

- Inaccurate data on travel, particularly for trucks, that limits accuracy of modeling,
- Lack of knowledge about secondary PM, and
- A poor understanding of in-use deterioration rates.

**Research Topic #3: Identify and Examine Key Control Strategies Most Likely to be Required (e.g., Inspection & Maintenance & On-Board Diagnostics, After Engine Treatment Technologies, and Fuels).** The morning group suggested that given current uncertainties in our understanding of PM, control strategy research should be directed to those control strategies that are most likely to be required. General consensus among both morning and afternoon groups was that I/M & OBD are both strong candidates for such research. As members of the afternoon group observed, emission control equipment may experience significant deterioration in actual vehicle use, and I/M or OBD would help address that concern. Other potential research topics include after treatment technologies, and fuels, reformulated gas, pricing & market strategies, conformity, and freight related "TDM" style measures.

**Research Topic #4: Improve Travel and Emissions Models.** The afternoon group discussed at length the inadequacies in existing models used to evaluate control strategies and develop inventories. The data underlying these models are often of poor quality — with inadequate or inaccurate information about vehicle mix, etc. In addition, the design of the models is not sophisticated enough to address issues such as secondary PM formation.

**Research Topic #5: Interactions Across Pollutant Control Strategies.** The afternoon group indicated that controls on $NO_X$ and VOC might have antagonistic effects. For example ammonia from catalyst equipped vehicles may increase PM problems, but relatively little scrutiny of this issue has occurred to date.