STRATEGIC WORKPLAN FOR AIR TOXICS RESEARCH

Final Report

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ACRONYMS AND ABBREVIATIONS

ARB	Air Resources Board
CI	compression ignition
CNG	compressed natural gas
CO	carbon monoxide
CO_2	carbon dioxide
CRC	Coordinating Research Council
DEOG	diesel exhaust organic gas
DOE	Department of Energy
DPM	diesel particulate matter
EC	elemental carbon
EPA	U.S. Environmental Protection Agency
FHWA	Federal Highway Administration
FTP	Federal Test Procedure
GIS	geographic information system
HAPs	hazardous air pollutants
HC	hydrocarbon
HDDVs	heavy-duty diesel vehicles
HEI	Health Effects Institute
I/M	inspection and maintenance
IRIS	Integrated Risk Information System
LA92	Los Angeles 1992 unified driving cycle
LDGV	light-duty gasoline vehicle
LPG	liquefied petroleum gas
MOVES	Motor Vehicle Emission Simulator
MSATs	mobile source air toxics
MTBE	methyl tertiary butyl ether
NAAQS	National Ambient Air Quality Standards
NATTS	National Air Toxics Trends Stations
NFRAQS	Northern Front Range Air Quality Study
NO_x	oxides of nitrogen
NREL	National Renewable Energy Laboratory
PAH	polynuclear aromatic hydrocarbons
PAMS	Photochemical Assessment Monitoring Stations
PEMS	portable emission measurement systems
PM	particulate matter
POM	polycyclic organic matter
ppm	parts per million
REMSAD	Regulatory Modeling System for Aerosols and Deposition
RFG	reformulated gasoline
SCAQMD	South Coast Air Quality Management District
SI	spark ignition
SIP	State Implementation Plan

ACRONYMS AND ABBREVIATIONS (continued)

STAPPA/ALAPCO	State and Territorial Air Pollution Program Administrators/Association of Local Air Pollution Control Officials
UV	ultraviolet
VMT	vehicle miles traveled
VOCs	volatile organic compounds
VSP	vehicle specific power

INTRODUCTION

This strategic workplan for air toxics research is designed to provide direction for the research on air toxics being undertaken by and on behalf of the transportation community. It identifies a set of four research focus areas and describes program areas where research is needed 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, metropolitan planning organizations, air quality agencies, industry, and academia.

In some instances, the research objectives noted in this workplan overlap with other Federal agency objectives, most notably the U.S. Environmental Protection Agency (EPA). Thus, the report recommendations are expected to be used as a tool to communicate with these agencies, and identify leveraging opportunities. For the purposes of the workshop, and this report, the transportation community was broadly defined to include the federal, state, and local agencies and related organizations that are involved in transportation-air quality analyses and evaluations. The air toxics-related research that FHWA ultimately decides to sponsor may differ from that described in this research plan. In addition, there may be instances where FHWA decides to contribute to the accomplishment of studies which are being directed by other agencies and organizations. There are also expected to be instances where FHWA is the primary research sponsor, and the project is performed collaboratively with the contributions of other agencies and organizations. The research priorities in this report are presented without regard to who the primary research sponsor might be.

The research ideas in this workplan are based on suggestions made by the participants at a one-day workshop that was held on May 12, 2003 in Rosemont, Illinois. There were 55 workshop participants, including the facilitators. Workshop participants represented a broad spectrum of research areas, interests, and organizations. Names and contact information for the workshop participants are included in Appendix A.

Workshop sessions were organized into four primary research or focus areas. These focus areas were: (1) vehicle emissions characterization, (2) ambient monitoring, (3) analysis, and (4) control strategies/measures. Each workshop participant attended three sessions lasting one hour apiece and provided their recommendations to the session facilitators about which research efforts the transportation community should undertake in the near future. For the purposes of this workshop and this associated report, the transportation community is defined to be those responsible for on-road vehicles, associated roadways, and roadway construction equipment. Those recommendations are the focus of this report. The session organization is summarized in Appendix B.

This report is organized with the first four chapters describing the priority research areas discussed at the corresponding workshop sessions. Each chapter contains a brief introduction, a summary of the current information base by topic area from the companion literature review

(FHWA, 2003), a summary of the discussion that occurred during the workshop sessions, and concludes with 3 or 4 proposed program areas for research. Chapter 5 of this report summarizes the priority research areas for all sessions/topics combined.

One of the difficult issues for air toxics is to decide which individual air toxic compounds to focus on. The 1990 Clean Air Act Amendments listed 188 hazardous air pollutants (HAPs) for EPA to regulate. However, not all of these compounds are emitted by motor vehicles. Because EPA is charged with determining whether mobile source air toxics controls are technologically feasible and setting vehicle-based air toxics controls, the evaluations that EPA had performed as of 2001 are summarized in EPA's *Technical Support Document for Control of Emissions of Hazardous Air Pollutants from Motor Vehicles and Motor Vehicle Fuels.* In this technical support document, EPA identifies 21 of the 188 compounds that should be considered mobile source air toxics (MSATs), and examines the mobile source contributions to national inventories of these compounds, and the impacts of existing and newly promulgated mobile source control programs.

The term mobile source air toxics, or MSATs, was developed by EPA to signify those air toxics emitted by nonroad engines and on-highway motor vehicles. Section 202(l) of the Clean Air Act, which addresses controls for HAPs from motor vehicles and motor vehicle fuels, does not specify which pollutants are to be evaluated as air toxics, other than benzene, formaldehyde, and 1,3-butadiene. EPA developed a list of 21 MSATs by comparing the lists of compounds identified in motor vehicle emission data bases and studies with the toxic compounds listed in the Integrated Risk Information System (IRIS). This list is shown in Table 1. The purpose of the list is to provide a screening tool that identifies those compounds emitted from motor vehicles or their fuels for which further evaluation is appropriate. Six mobile source air toxics are of primary concern according to EPA: benzene, 1,3-butadiene, formaldehyde, acetaldehyde, acrolein, and diesel particulate matter plus diesel exhaust organic gases. These compounds are shaded in Table 1. EPA's National-Scale Air Toxics Assessment identified these pollutants as posing the greatest health risks.

Table 1. List of Mobile Source Air Toxics

Acetaldehyde	Diesel Particulate Matter + Diesel Exhaust Organic Gases	Methyl Tertiary Butyl Ether (MTBE)
Acrolein	Ethylbenzene	Naphthalene
Arsenic Compounds	Formaldehyde	Nickel Compounds
Benzene	n-Hexane	Polycyclic organic matter (POM)
1,3-Butadiene	Lead Compounds	Styrene
Chromium Compounds	Manganese Compounds	Toluene
Dioxin/Furans	Mercury Compounds	Xylene

The IRIS listing and the summary of cancer and noncancer health effects described in the final Health Assessment Document for Diesel Exhaust are based on studies linking serious adverse health effects to whole diesel exhaust exposure, using diesel particulate matter (DPM) as the measure of dose. Available science, while suggesting an important role in toxicity for the particle phase component of diesel exhaust, cannot rule out a role for the gas phase components such as semi-volatile organics that are partly in both the gas and particle phases.

EPA defines diesel particulate matter (DPM) plus diesel exhaust organic gas (DEOG) as a primary mobile source air toxic. This definition was adopted because it was believed to focus on the components of diesel exhaust expected to contribute to observed cancer and noncancer health effects. Research studies do not separate the health effects of the particulate and gaseous components of diesel exhaust. DPM+DEOG is a particular type of emission which is composed of many listed HAPs, including chemicals that fall into the group of polycyclic organic matter (POM) chemicals, as well as some HAP metals and volatile organic compounds (VOCs). POM includes organic compounds with more than one benzene ring, and which has a boiling point greater than or equal to 100°C.

A group of seven polynuclear aromatic hydrocarbons (7-PAH), which have been identified by EPA as probable human carcinogens [benz(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, chrysene, dibenz(a,h)anthracene, and indeno(1,2,3-cd)pyrene] are sometimes used as surrogates for the larger group of POM compounds. Another common PAH grouping is referred to as 16-PAH. This grouping includes the following compounds in addition to the 7-PAH group: acenaphthene, acenaphylene, anthracene, benzo(g,h,i)perylene, fluoranthene, fluorene, naphthalene, phenanthrene, and pyrene.

MSATs come from many sources. First, some air toxics are present in fuel and are emitted to the air when the fuel evaporates or passes through the engine unburned. Benzene, for example, is a component of gasoline. Cars emit small quantities of benzene in unburned fuel, or as vapor when gasoline evaporates. Second, MSATs are formed through engine combustion processes. For instance, a significant amount of gasoline-vehicle benzene comes from the incomplete combustion of compounds in gasoline such as toluene and xylene that are chemically very similar to benzene (EPA, 2000). Like benzene, these compounds occur naturally in petroleum and become more concentrated when petroleum is refined to produce high-octane gasoline. DPM + DEOG emissions, as well as formaldehyde, acetaldehyde, and 1,3-butadiene, are also by-products of incomplete combustion. Third, some compounds, like formaldehyde and acetaldehyde, are also formed through a secondary process when other mobile source pollutants react in the atmosphere. Fourth, metal air toxics result from engine wear or from impurities in oil or gasoline. They can also be present in fuel and lubricant additives. Metals also appear in emissions that are related to vehicle operation-brake and tire wear, mechanical deterioration of catalysts and other exhaust system components, and resuspension of road dust. Finally, burned and unburned oil emitted via the tailpipe are sources of HAPs.

Other comprehensive studies besides EPA's MSAT study that have examined the importance of mobile sources to measured air toxic concentrations have included EPA's National Air Toxics Assessment and the South Coast Air Quality Management District (SCAQMD) Multiple Air Toxic Exposure Study-II. EPA's National Air Toxics Assessment collects and evaluates monitoring data from around the United States and estimates the contributions of various source types to measured concentrations (EPA, 2002a). EPA compiled 1996 ambient monitoring data for 33 toxic air pollutants and estimated source contributions. On-road mobile sources contributed 30 to 65 percent of the total measured concentrations for the six priority

MSATs. Mobile sources (primarily non-road engines/vehicles) were also responsible for 16 percent of nickel concentrations, 8 percent of chromium, and 5 to 6 percent of arsenic and manganese levels.

The SCAQMD conducted the Multiple Air Toxic Exposure Study-II during 1998 and 1999, which involved monitoring and modeling over 30 different pollutants across the South Coast Air Basin, including most of the 21 MSATs identified by EPA. Using monitored concentrations, the SCAQMD estimated that MSAT (DPM, 1,3-butadiene, benzene, formaldehyde, and acetaldehyde) contributed a large portion of the total excess cancer risk from the more than 30 pollutants measured. Whether the results of this study are borne out by future research is still in question – nevertheless, it is important research.

Transportation agencies have an interest in air toxics because of the potential health risks of exposures to individual HAPs from mobile sources and because of the relationships between air toxics and other current atmospheric concerns. The interrelationship among air toxics and other pollutants is summarized in Figure 1. Interactions between air toxics and ozone are an important concern since one of ozone's precursors, VOCs, include many of the EPA MSATs. Some particulates are also toxic, such as diesel particulate matter plus diesel exhaust organic gases, therefore reductions in the mass of these particulates may also reduce toxic air contaminants. In addition, particulate matter (PM) indirectly affects global climate change by increasing light scattering and the number of particles available for cloud droplet formation.

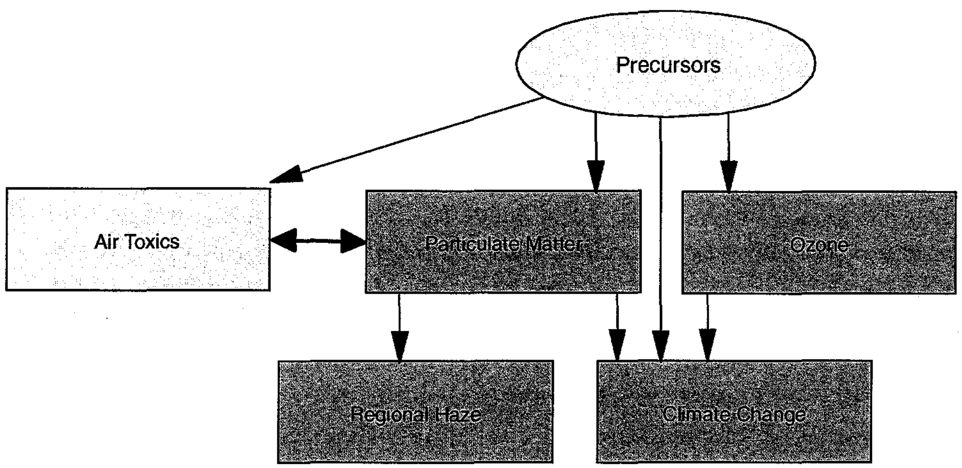

Figure 1. Relationship of Air Toxic to Other Atmospheric Concerns

Air toxics can be divided into those that are primarily organics and those that are particulates. The organic HAPs react in the atmosphere (each at different rates) to form ozone – so they are ozone precursors. Similarly, particulate HAPs are $PM_{2.5}$ and PM_{10} precursors. Some areas are also finding organic compounds, including secondary organic aerosols, to be an important contributor to measured $PM_{2.5}$ ambient concentrations. Particulates contribute to regional haze, as well. Therefore, the importance of mobile source air toxics in ozone and $PM_{10}/PM_{2.5}$ formation, or to regional haze, is a factor to consider if and when air toxic control strategies are formulated.

Table 2 provides additional detail about which of the 21 MSATs are primarily organic versus inorganic (i.e., metals). Note that DPM plus DEOG as well as POM are both organic and inorganic. Of the inorganic air toxics, arsenic, chromium, lead, manganese, mercury, and nickel are metals. Among the organic air toxics, benzene is stable in the atmosphere, but formaldehyde, acetaldehyde, acrolein, and 1,3-butadiene are reactive. Formaldehyde, acetaldehyde, and acrolein are emitted directly by motor vehicles and also formed secondarily in the atmosphere.

Table 2. Mobile Source Air Toxics that are Primarily Organic Versus Inorganic

Specific Organic Compounds	Compounds Containing Inorganics	Pollutant Categories
Acetaldehyde	Arsenic Compounds	Dioxin
Acrolein	Chromium Compounds	DPM + DEOG
Benzene	Lead Compounds	POM
1,3-Butadiene	Manganese Compounds	
Ethylbenzene	Mercury Compounds	
Formaldehyde	Nickel Compounds	
n-Hexane		
MTBE		
Napthalene		
Styrene		
Toluene		
Xylene		

Air toxics differ from criteria air pollutants in that air toxics are not subject to a national ambient air quality standard (NAAQS). Without an ambient standard, research on air toxics includes the following risk assessment steps: emissions, ambient concentrations, exposure, and adverse health effects. EPA's MOBILE6.2 model has some capability to estimate air toxic emission factors. Available air quality dispersion models have sometimes been adapted for toxic assessments. Tools for modeling air toxics exposure and characterizing risk are available, but are less familiar to the transportation practitioner.

Because of the potential importance of DPM + DEOG as a mobile source air toxic, and the similar importance of evaluating the effect of diesel and gasoline engine emissions on ambient particulate (PM_{10} and $PM_{2.5}$) concentrations, there are a number of instances in this work plan where PM is discussed and specific recommendations made related to PM. These PM references are an acknowledgment of the difficulty in separating the research needs for DPM + DEOG as a mobile source air toxic from those for diesel and gasoline vehicle emissions as a criteria air pollutant. Nevertheless, because this is an air toxics research plan, its orientation is towards research needed to better understand and evaluate air toxics. However, it is expected that particulate air toxics research and criteria pollutant PM research will ultimately be coordinated efforts that provide valuable information to both research areas.

There are acknowledged weaknesses in the basic analytic tools and data for air toxics analyses. In particular, air pollution control agency staff charged with responding to concerns about exposures to air toxics are challenged by factors such as a limited understanding of the spatial distribution and atmospheric reactions of toxic air pollutants, inaccurate and incomplete emissions inventories, and inadequate emissions models. Attempts to require or apply common stationary source air toxic analysis techniques have to date been inconclusive or impractical to implement. The gaps in information necessitate targeted research focused specifically on the needs of the transportation community, including tools to assess MSAT risks for specific toxics, as often requested by air pollution control agency staff.

FHWA's Role in Air Toxics 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 is one of eight program goals established in the Strategic Plan for Environmental Research.

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

- **Bringing a Transportation Focus to the Study of Air Toxics Issues**. Research gaps remain in terms of understanding the formation, characteristics, source apportionment, and modeling of air toxics, particularly in relation to transportation sources.

  Developing better information about the characteristics and source apportionment of air toxics 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 to develop the information and tools needed to support future policies and programs.

- **Developing Applied Research Products that Respond to Needs of Transportation and Air Quality Planning Practitioners**. Transportation-focused air toxics 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 air toxics science knowledge base;
  - Supply an objective information foundation suitable for developing the next generation of transportation-related analysis tools and techniques;
  - Coordinate the air toxics research program for transportation sources with existing and future research initiatives; and
  - Develop justifiable interim/short-term techniques and policies for appropriate transportation project and planning-level analysis of air toxics.

Integrating Research Focus Areas and Policy Questions

Figure 2 summarizes the priority mobile source air toxics research areas based on the discussion at the May 2003 workshop. 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 questions.

Most emphasis, however, has been placed on research to help understand the contribution of transportation sources to air toxics, 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.

FHWA acknowledges that the technical complexity and broad scope of the projects contained in the workplan will require a coordinated, multi-agency approach. The multi-disciplinary range of projects outlined in Figure 2 will likely require coordination among FHWA, State Departments of Transportation, and metropolitan planning organizations, involvement by academic and applied research organizations, as well as State and Federal air quality agencies, and industry groups. 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.

Appendix C lists recent, relevant air toxics research papers and reports submitted by the workshop participants at the time of the workshop. These research works are not included in the companion literature review that was prepared and distributed to participants prior to the workshop.

Key Questions:	**Do we have adequate emission measurement methods for MSATs?**	**How do the existing ambient monitoring sites/networks assist in providing data about the mobile source contribution to ATs?**	**What improvements to existing models, or new modeling techniques, need to be developed to provide viable assessments of AT levels (emissions and concentrations) in situations where direct measurements are not available?**	**Which are the most cost-effective control strategies for transportation sources?**
Proposed Research Programs and Projects:	P1: Fund research for improvements in emission measurement technology that are needed to measure the lower emission levels of air toxic compounds expected with improved emission control technologies and lower sulfur fuels expected in the 2005 to 2007 time frame.	P4: Fund research to identify what additional monitoring information needs to be collected to enhance existing monitoring networks to meet transportation sector needs.	P7: Develop a protocol on the appropriate methods to be used in emissions modeling, atmospheric dispersion modeling, and exposure modeling at varying spatial scales applicable to transportation projects (e.g., project-level, urban scale).	P11: Performing studies of potential control measures and their cost effectiveness is predicated on there being observed harmful levels which can be ameliorated by reducing motor vehicle emissions. Therefore, any programmatic initiatives to reduce air toxic emissions need to be informed by research on existing ambient air toxic concentrations, estimated associated risks, and the mobile source contributions to them.
	P2: Design and initiate experiments to examine near roadway concentration patterns (especially for highways). There is evidence that air toxic concentrations near roadways are appreciably higher than those 300 to 500 meters or more downwind. Experiments to examine these gradients are likely to assist in steering future research toward examining pollutant emissions, fate, and transport in the immediate vicinity of highways compared with examining regional scale chemistry and transport.	P5: Fund research to understand existing, and develop new, practical tools for local and regional organizations to assess MSAT impacts and evaluate results.	P8: Conduct research and develop methods on variability and uncertainty analysis of on-road emission estimates. Identification of key sources of uncertainty can be used to target resources to reduce uncertainty.	*Sub-Area 1:* Research the expected multi-media MSAT benefits or dis-benefits of the control measures that are expected to be the leading candidates for adoption in upcoming 8-hour ozone and $PM_{2.5}$ nonattainment plans.
	P3: Conduct research to expand the available set of information about air toxic emissions and activity patterns for the on-road and off-road vehicle types with the most significant contributions to ambient air toxic concentrations of concern and the greatest uncertainty in their emission estimates. Given the current state-of-knowledge and planned research projects in this area, two sub areas within this programmatic initiative have been identified as likely first priorities for study.	P6: Determine whether the existing knowledge about transportation air toxics can be enhanced by further examining current data.	P9: Develop improved inputs for emissions and receptor modeling. Some improvements are expected via incorporating already available data. Gap filling research may be needed in selected topics.	*Sub-Area 2:* Determine the emissions and potential emission reductions for measures that could be applied to mitigate the emissions from non-road construction equipment that is typically used in constructing/widening highways.
	Sub-Area 1: There are needs to investigate the differences in fleet populations and travel characteristics for important sub-categories of trucks. These sub-categories can be defined as: long-range fleet, regional fleet (300 to 500 miles), and local fleet (primarily delivery trucks).		P10: Research the atmospheric chemistry of mobile source air toxics. Incorporate this information into distributed modeling tools.	*Sub-Area 3:* Research the effectiveness of control strategies on toxics. This initiative specifically focuses on identifying the most cost effective control strategies available for reducing air toxic emissions. What would provide the best and most cost effective results where the most cost effective air toxics control strategies could differ from the most cost effective criteria pollutant options?
	Sub-Area 2: For off-road engines/vehicles, diesel-powered construction equipment is a major emissions source (of PM) with large uncertainties in emission estimates.			
Focus Areas:	**Characterization**	**Ambient Monitoring**	**Analysis**	**Control Measures/Strategies**

Figure 2. Connection Between Transportation Issues and Research Agenda

1.0: CHARACTERIZATION

A. INTRODUCTION

1. Background

This workshop session focused on ways to improve vehicle emission measurements. The primary methods for measuring criteria air pollutants from motor vehicles have been laboratory/dynamometer tests, onboard measurements, and remote sensing. Some of the same techniques may be viable for air toxics emission measurement, but there are additional steps, or research efforts, needed to extend current measurement methods in order to measure air toxic compound emissions.

2. Current Information Summary

Current tailpipe and evaporative emissions testing for organics involves collecting samples in canisters and sending these canisters to a laboratory for analysis of toxic species. Because most of the organics measurements available to date measure only total hydrocarbons (HCs), emission estimates for specific HC compounds typically rely on applying species profiles to the total HC values. With species profiles being based on a limited number of samples, estimates derived using this technique are extremely uncertain. For metals and particulate emissions, samples are collected on particulate filters and analyzed. Metals analysis provides estimates of the total amount of metal emitted.

Existing references for developing motor vehicle emission values for air toxics include the Auto/Oil Air Quality Improvement Research Program (light-duty gasoline), the European Programmes on Emissions, Fuels and Engine Technologies (light-duty gasoline and diesel), Heavy-Duty Vehicle Chassis Dynamometer Testing for Emissions Inventory – Coordinating Research Council (CRC) Projects E55-E59 (heavy-duty diesel), recent studies by the Center for Environmental Research and Technology completing detailed chemical speciation of diesel exhaust (primarily heavy-duty), and the Clean Fleet Study – which mostly consists of tests of Federal Express vehicles (medium- and heavy-duty gasoline and alternative fuels).

The EPA, CRC, National Renewable Energy Laboratory (NREL), FHWA, State and Territorial Air Pollution Program Administrators/Association of Local Air Pollution Control Officials (STAPPA/ALAPCO) study is an active effort to characterize exhaust emissions from light-duty gasoline-powered vehicles (LDGVs). It is planned that 480 randomly selected LDGVs in the Kansas City area will undergo emissions testing. Study goals include determining PM emission distributions, identifying high emitter percentages, and characterizing gaseous and PM toxics exhaust from a portion of these vehicles.

Emissions measurements for the Kansas City study include dynamometer testing with gaseous air toxics analyses planned. Samples are being collected by summa canisters [for volatile organic compounds (VOCs)] and DNPH cartridges (for aldehydes or ketones).

Aldehydes and ketones are two classes of oxygenate HCs. (Acetone is an example of a ketone.) HC, carbon monoxide (CO), oxides of nitrogen (NO_x), and PM continuous measurements are also being obtained, in addition to the HAP samples.

In addition to dynamometer testing, researchers have been using portable emissions measurement systems (PEMS) that make onboard emission (and activity) measurements during actual driving. Current PEMS devices record measurements second-by-second for environmental conditions (ambient temperature, humidity, barometric pressure, etc.), vehicle parameters (engine revolutions per minute, vehicle speed, air conditioning on, onboard diagnostic codes, etc.), date/time, and emissions [HC, NO_x, and carbon dioxide (CO_2)]. PEMS primary advantages are that they capture real world driving, and they are less expensive than dynamometer testing. Disadvantages include being less accurate than dynamometer tests, and an inability to measure emissions at low concentrations.

Remote sensing of vehicle emissions works by measuring the absorption of beams of infrared or ultraviolet (UV) light by the CO, CO_2, HCs, and NO_x in vehicle exhaust plumes. Based on the absorption, a computer is able to calculate the ratios of CO, HC, and NO_x to CO_2 in the exhaust. From this information, it is possible to compute the concentrations of CO, HC, and NO_x in the exhaust at the instant the vehicle passes the remote sensing device. Videos of license plates are made at the time the vehicle passes the remote sensing device, so that emission concentrations can be correlated with makes and model years of vehicles. Remote sensing technology currently does not measure air toxic compound emissions although some recent advances show promise for a subset of the air toxic compounds. Evaluations performed to date have been limited to single lane situations, and some 2-lane interstates. An advantage of remote sensing is its ability to provide a large number of emission measurements for vehicles in on-road conditions. Its main disadvantages are that it does not provide accurate measurements at very low emission levels and since the operating mode of the vehicle is generally controlled by the site selected for testing, vehicle operating modes are restricted.

B. WORKSHOP DISCUSSION SUMMARY

1. Introduction

The workshop participants recommended that researchers continue to consider examining compounds that do not appear on EPA's MSAT list. This is especially true for PM. Other potential sources and compounds, besides diesel PM plus diesel exhaust organic gases, that may prove to be important in toxic PM include the following:

- Portions of ambient elemental carbon (EC) and organic carbon that are not diesel-emitted;
- Re-suspended road dust;
- Gasoline vehicle-emitted PM;
- Semi-volatile organics (these may be addressed in the diesel organic gas part of the EPA definition); and
- Secondary formation.

In designing a research plan for vehicle emissions characterization, it was specifically recommended that two works in progress be consulted before implementing any plans to collect additional emissions measurements. These include the Department of Energy (DOE)-sponsored study of diesel/gasoline vehicle contributions to ambient PM in the South Coast Air Basin and the Health Effects Institute (HEI) study of PM, which may identify a health effects marker other than EC. Researchers want to know whether EC is an adequate surrogate for diesel-emitted PM in the atmosphere. The current method is to begin by estimating how much diesel exhaust is comprised of EC. Then, how much ambient EC is contributed by diesels is estimated. Then, these two estimates are used to estimate how much diesel exhaust is in the atmosphere. Research by the California Air Resources Board (ARB) has shown that EC is not always a good marker of diesel or other mobile source exhaust. Depending on the area and season, there may be other significant or overwhelming sources such as residential wood burning.

The South Coast research study mentioned above is known as DOE's Gasoline/Diesel PM Split Study, because DOE's Office of Heavy Vehicle Technologies is the primary sponsor. The study is designed to assess the relative contribution of PM from spark ignition (SI) and compression ignition (CI) engines in California's South Coast Air Basin. In this study, 59 light-duty vehicles were emissions tested over a modified Unified Cycle, and 34 heavy-duty vehicles were tested over a variety of test cycles. In addition, ambient sampling was conducted at a variety of locations in the Los Angeles area in the summer of 2001. Data analyses are still ongoing, with results expected to appear in the peer-reviewed literature. This study is a follow-up to the 1996/97 Northern Front Range Air Quality Study (NFRAQS), which concluded that emissions from SI engines were three times those from CI engines in the Denver area in wintertime (Norton, et al., 1998). These NFRAQS study findings were counter to the findings in previous South Coast analyses, which showed diesels being much more significant PM contributors than SI engines.

The HEI study mentioned above is a diesel epidemiology project that was initiated in 1998. This is a multi-faceted research and assessment effort to (1) develop new research initiatives, including feasibility studies to identify potential new cohorts or to improve exposure assessment methods, and (2) evaluate the strengths and limitations of the published epidemiologic studies available for quantitative risk assessment. As part of this project, the expert panel reported its findings and recommendations in the 1999 HEI Special report "Diesel Emissions and Lung Cancer: Epidemiology and Quantitative Risk Assessment." Other reports and publications are listed on the reference page of this report.

In 2000, the Diesel Epidemiology Working Group was formed to continue the work of the Diesel Epidemiology Expert Panel. It was charged with reviewing reports from six feasibility studies funded by HEI, and developing an agenda for research that would provide better information for assessing quantitative risk from diesel exposure and adverse health effects, including lung cancer.

In its report, the Diesel Epidemiology Working Group (2002) concluded that full studies of cohorts that had been characterized in the feasibility studies would not generate substantially more accurate exposure-response information. The Working Group also concluded from the feasibility studies that the available methods for assessing exposure to diesel exhaust were not sufficiently specific. Working Group members also found that EC may be a useful marker for exposure to diesel exhaust if diesel engines are the dominant source of particles. The Working Group noted, however, that EC by itself lacks the necessary sensitivity and specificity to serve as a signature of diesel exhaust in ambient exposure settings, where particles typically include EC from other combustion sources. Therefore, they recommended identifying more specific markers, or a set of markers (a signature), for diesel exhaust that could be used to enhance exposure assessment for past studies, strengthen future epidemiologic studies, and assess population exposures.

2. Emission Measurements

New emission measurement programs should include size segregated PM measurements wherever possible. This means that data collection should include measurements/laboratory analysis of particle size, mass, number, shape, as well as chemical and biological characterization. (Note that methods first need to be developed to allow laboratory collection of size segregated emissions. Besides the need to measure PM size distributions for motor vehicle emissions, the capability to measure PM continuously should be utilized in some programs. Differentiating operating mode contributions to PM emissions is also important.)

There are some emission measurement and sampling issues that need to be solved in order for emission characterizations to properly support analyses. These emission measurement issues are likely to become more challenging with lower-emitting new technology vehicles that meet 2005-2007 emission standards. One issue raised during the workshop was that there can be occasions when the exhaust concentrations of a pollutant are lower than the concentration measured in ambient air. (This is an issue for organics, and it may also be for metals, as well.) Hence, there is a general need for an up-to-date look at measurement technology.

Measuring ultrafine particles from vehicles is relatively new and may prove to be more significant from a health perspective than the mass concentrations now used for regulatory purposes. There are many significant trace species whose emissions will be affected by controls – with increases and decreases being possible. Examples include the potential for increased ultrafine particle emissions when total mass is lowered, the possible increase in the ratio of ammonia and nitrous oxide to NO_x when NO_x emissions are lowered, and potentially increased ratios of nitrogen dioxide/NO_x and concentrations of nitro- polycyclic aromatic (e.g., 1-nitronaphthalene) hydrocarbon formation with diesel PM controls. Emission control systems need to be evaluated with respect to all pollutants before they are applied on a widespread basis.

EPA has promulgated Tier 2 motor vehicle emission standards and gasoline sulfur control requirements (Tier 2) and heavy-duty engine and vehicle standards and on-highway diesel fuel sulfur control requirements. Compliance with these emission standards and changes to fuel characteristics are likely to result in significant changes to the combustion chemistry and emission characteristics of these vehicles. Emission measurements need to be performed for these vehicles/fuel combinations. Vehicle types/technology types that need to be included in new emission testing programs include hybrid-electric vehicles, heavy-duty gasoline-powered vehicles, and diesels equipped with oxidation catalysts.

It is also important to study the emissions performance of current technology vehicles on these low sulfur fuels because low sulfur fuels will be in widespread use by the end of this decade. Knowing how these (diesel) engines operate with low sulfur fuels will provide evidence to help us determine whether these current technology engines are candidates for certain retrofit technologies (PM traps, for instance).

For any measurement studies, it was strongly suggested that they be designed to obtain repeat measurements. This is important because there is often more variability in individual vehicle emission performance than there is in the measuring devices. Replicate testing should be performed until the variability (or lack thereof) is shown not to be an issue. High emitter variability is what we need to know the most about because of skewness, with the mean, median, and mode being located at very different points of the cumulative frequency distribution.

Conditions/control measures for which emissions data will be needed include: before and after diesel emission inspections and repairs, with pollution control retrofits, emulsion fuels, and to capture fuel variability. It was noted that the renewable fuels mandate may change fuel characteristics. Renewable fuel standards are important because they will affect the magnitude of HC/PM emissions and the proportion of toxics emitted. Ethanol, which contains oxygen, in fuel increases the proportion of the carbonyl compounds (acetaldehyde, formaldehyde, and acrolein) in exhaust HC. It will also increase permeation (evaporative) HC emissions in excess of what is predicted by Reid vapor pressure changes alone. The use of gasoline oxygenate blends in areas which also have non-oxygenated gasoline results in commingling of the two types of fuels in a vehicle's fuel tank. The combination of the oxygenate and non-oxygenate fuel results in increased vapor pressure, which will be higher than that of either fuel individually. Because virtually all of the current testing has been performed on renewables-free fuel, the effect of renewable fuel standards on air toxic emissions is poorly understood.

For heavy-duty diesel trucks, a lack of speciated HC emission measurements was noted as a data gap. At the time of the workshop, there were about 50 runs (measurements) of speciated HCs on chassis dynamometers available for use in establishing gaseous toxic emission rates (Lev-On et al., 2002). Since May 2003, there are an additional 60 to 80 samples from studies sponsored by the National Renewable Energy Laboratory and the Coordinating Research Council. This can be contrasted with there being 8,000 measurements from about 2,000 separate heavy-duty diesel vehicles (HDDVs) for particulates. Note that most of these PM measurements are not speciated. It is estimated that a few hundred of these measurements have had elemental carbon and organic carbon determined from the filters. Very few PM samples have been speciated beyond that.

For all vehicle types, it is important to identify the relative importance of cold start emissions. Then, it can be determined how much effort should be devoted to sampling during other modes. It is also important to test a certain fraction of gross emitters in any sampling scheme. Numerous studies have shown the relative importance of gross emitters to total motor vehicle emissions in urban areas.

New HDDV emissions testing should include tests that isolate idle emissions. Test samples should include trucks equipped with exhaust gas recirculation and after treatment.

3. Real World Conditions

There is also a data gap between the lab measurements that are available now, and real world in-use diesel activity. We need to fill this hole, especially for HDDVs. Suggestions for additional data collection techniques to fill this data gap included PEMS and remote sensing. One of the strengths of PEMS is its ability to include measurements of activity patterns. Remote sensing helps by collecting data from many vehicles, and provides estimates of emissions variability, although there are associated site limitations. It was noted that the current remote sensing status for estimating PM emissions is based on UV-fuel specific (CO_2 specific) opacity. Testing programs are needed to assess how well this technology can estimate PM emissions. Two firms currently have the capability to perform such measurements.

For PEMS, it was suggested that there are instrument and data quality issues that need to be resolved before researchers can gain confidence in the data being collected. Inexpensive units have proved to produce inaccurate emission measurements. Therefore, protocols need to be developed that define the required repeatability of measurements that must occur, plus other data quality objectives to be met before an instrument can be used in a research study. PEMS do not currently have the ability to measure toxic compounds. It was suggested that more emphasis be placed on developing the technology to measure some toxic compound emissions using PEMS.

What can be done to inform the remote sensing industry about the needed measurement capabilities for air toxics from this technology? A remote sensing industry representative suggested that they need to know what some appropriate surrogates are that they might have the ability to measure (1 or 2 surrogates for HC species, for example). This would allow them to focus on developing the instrumentation to measure those surrogates. It was mentioned that benzene emissions would be very difficult to measure via remote sensing because of interference from CO_2 and water vapor. Recent technology advances indicate that measurement of 1,3-butadiene, acrolein, acetaldehyde, and formaldehyde may be feasible using special remote sensing techniques. If such techniques prove useful, a key question is "Can these (or a subset of these) be useful surrogates to predict total MSAT content?"

Users of emissions data (and those who generate it) need to understand the conditions under which the data was generated. Lab-based vehicle and engine emissions measurement and test methods were developed and are intended for use in supporting regulatory activities (i.e., emissions certification). The methods mandated for use in certification testing are not necessarily suited to generating data for ambient air modeling or exposure assessment. An example is the choice of driving cycle. Most light-duty vehicle emissions measurements make use of the regulatory test cycle (FTP-75) which is notoriously unrepresentative of real-world driving cycles – so much so that a small industry has developed that produces "adjustment factors" for use in emissions modeling to attempt to predict emissions from modes of operation that are outside the FTP-75 test procedure. Another example is the new 2007 heavy-duty diesel engine test procedure that requires PM samples to be collected at $47 \pm 5^{o}C$. The reason for this requirement is to have a test procedure that is repeatable day to day and lab to lab. Using this sampling procedure to collect samples for toxic compound analysis (e.g., PAH) will produce a sample that is quite different from what a person would be exposed to in the real world. Finally, the chemical composition of emissions will be changing significantly over the next few years as new emissions standards come into effect. This requires a comprehensive screening of emissions to identify new, exotic, and previously unidentified pollutants that may be generated as a result of the new technologies and fuels.

4. Activity Data Collection

As more sophisticated emission measurements are made, it may be necessary to examine associated travel data needs in order to perform more complex analyses of transportation networks, whether it is at the micro-scale (intersections or roadway segments) or urban scale. For example, if operating modes are important, then traffic data collection will need to be redesigned to capture this information. So, part of this issue is to be able to describe to the transportation practitioner what is needed from them to support the use of more sophisticated emissions data (modal, or the equivalent). Thus, pursuit of this research will require interagency cooperation (environmental and transportation agencies). One specific travel data improvement that was identified was the need to be able to estimate truck travel percentages by roadway type. In most situations, analysts are using a single fraction [truck vehicle miles traveled (VMT) as a percentage of total VMT] to estimate truck emissions. It is likely that truck travel is not distributed evenly across roadway types (freeway, arterial, etc.).

For trucks, there are separate needs to investigate the differences in fleet populations and travel for important sub-categories of trucks. These sub-categories can be defined as: long-range fleet, regional fleet (300 to 500 miles), and local fleet (primarily delivery trucks). For each of these categories, it is expected that there will be spatial operating characteristic differences and time-of-day operating differences that need to be enumerated. Evaluations of the long-range fleet need to provide data about potential out-of-country trucks, especially in areas near the northern and southern US borders. An important operating characteristic to study for these truck sub-categories is idling time. Some studies have estimated that heavy trucks in urban areas spend as much as 45 percent of their operating time in idle mode. The result of any research on truck operating characteristics by sub-category should include the ability to link spatial operating characteristics to geographic information system (GIS) and truck travel detail by facility. Truck activity characteristics should include estimates of volumes, speeds, and time-of-day of travel. Especially useful would be good activity data for on-road and non-road sources at ports, intermodal terminals, large distribution warehouses, and other similar locations. Information on idling and other activity at these facilities is sparse, while public interest in air quality analysis of these facilities is increasing.

5. Off-Road Engines/Vehicles

For off-road engines/vehicles, diesel-powered construction equipment was identified as a major emissions source (of PM) with large uncertainties in emission estimates. There are many long-term construction projects that involve diesel-powered construction equipment. The error bounds in estimating these engine populations alone were estimated to be plus or minus 50 percent. Activity patterns and emission rates are added sources of uncertainty. It was noted that there is more instrumentation now (PEMS) that can be used to measure activity patterns. Then, emissions can be measured in a laboratory setting replicating the activity patterns that are measured in the field. An important issue for this source type is identifying surrogates for toxic air pollutants. In other words, which measured pollutants can serve as surrogates for the specific toxic compounds that are of interest, because it is unlikely that all toxic pollutants emissions can be measured directly? Also useful would be identification of thresholds; i.e., what level of activity at a construction site would be significant enough that mitigation is warranted to protect public health?

There is already a need in California to have a tool that can be used to estimate the emissions from highway construction projects. Projects are being criticized on this basis. Projects in Boston and New Haven have required mitigation measures (though not directly on air toxic grounds) for diesel construction equipment, including retrofit of diesel oxidation catalysts, and limitations on certain types of diesel activity and idling in sensitive areas.

6. Near Roadway Pollutant Behavior

It was also suggested that experiments be carried out to examine near roadway concentration patterns (especially for highways). There seems to be evidence that concentrations of air toxics near roadways may be appreciably higher than those 300 to 500 meters or more, downwind. Experiments to examine these gradients are likely to assist in steering future research toward examining pollution emissions, fate and transport in the immediate vicinity of highways compared with examining regional scale chemistry and transport.

One of the expected outcomes of any such near-roadway situation would be specification of the needed data precision for different data uses. This could be thought of as identifying different tiers of needs, such as more precision being needed for intersection scale analyses (modal information, that is), and less for regional scale work.

7. Coordination with Planned Research

At one of the sessions, the upcoming joint agency funded light-duty gasoline powered vehicle emission measurement effort scheduled in Kansas City was discussed. It was suggested that the FHWA piggyback some additional data collection efforts on this project, where possible. This might include some PEMS data collection, although it was noted that PEMS data collection was already planned as part of the work scope. There was also additional discussion of the use of the resulting emissions data set to develop facility-based versus trip-based emission estimates. Note that the current plan in the Kansas City study is to conduct dynamometer testing using an aggressive test cycle [the Los Angeles 1992 (LA92) Unified Driving Cycle]. While this is an aggressive test cycle, it also encompasses a number of operating conditions that are representative of typical urban driving. The LA92 cycle consists of a cold start Phase 1 (first 310 seconds), a stabilized Phase 2 (311-1,427 seconds), a 600 second engine off soak, and a warm start Phase 3 (repeat of Phase 1 of LA92). It was mentioned that data from this cycle will not provide information about any operation on specific facilities, and concerns were expressed about having these test results in a form that could provide inputs to MOBILE6, or the planned EPA Motor Vehicle Emission Simulator (MOVES) model.

The above project is one example of the need for performing research that is coordinated with other agencies and organizations. There are many others provided in this report.

8. Quantifying Uncertainty

For all new vehicle emissions characterization studies, the importance of characterizing variability and uncertainty in the emission estimates was noted. Variability refers to real differences in emissions among multiple emission sources at any given time, or over time, for any individual emission source. Variability in emissions can be attributed to variation in fuels, ambient temperature, technology, maintenance, or operation. Uncertainty refers to the lack of knowledge regarding the true value of emissions. Sources of uncertainty include small sample sizes, bias or imprecision in measurements, non representativeness, or lack of data. Quantitative methods for characterizing both variability and uncertainty are available.

Uncertainty in emission factors, and in emission inventories, is typically not quantified (Frey and Li, 2003). Therefore, it is not known, in many cases, how robust regulatory or management decisions are with respect to uncertainty. If management decisions are based upon point estimates of emissions that are biased, or if the range of uncertainty in emissions is much larger than any predicted change in emissions resulting from an air quality management strategy, then the decision-making process for developing management strategies could be ineffective.

Participants mentioned that there is significant uncertainty in estimating PM emissions from re-entrained road dust on paved road surfaces. Many researchers believe that EPA's models overestimate these emissions, and that new measurement studies are needed to provide estimates of whether such emissions are important components of regional transport. Because the conventional wisdom is that re-entrained road dust emissions are unlikely to be important contributors to regional haze and fine particle nonattainment, it has been difficult to attract funding for efforts to provide new measurement studies for this source type.

Meanwhile, PM emission estimates made using EPA's current AP-42 emission factors will continue to identify re-entrained road dust as a major PM source in many attainment plans until such time that research provides enough new data to revise the emission factor algorithm.

C. PRIORITY RESEARCH RECOMMENDATIONS

Three major research areas emerged as being consistently important to researchers and transportation practitioners in meeting needs for air toxics emissions characterization. These include funding work to improve emission measurement technology so that lower emission levels can be measured, establishing experiments to examine gradients in near roadway concentrations of air toxics, and expanding the available set of information about air toxic emissions and activity patterns for on-road and off-road vehicles.

Proposed Programmatic Initiatives

Programmatic Initiative P1: Fund research for improvements in emission measurement technology that are needed to measure the lower emission levels of air toxic compounds expected with improved emission control technologies and lower sulfur fuels expected in the 2005 to 2007 time frame.

EPA has promulgated Tier 2 motor vehicle emission standards and gasoline sulfur control requirements and heavy-duty engine and vehicle standards and on-highway diesel fuel sulfur control requirements. Compliance with these emission standards and changes to fuel characteristics are likely to result in significant changes to the emission characteristics of these vehicles. Emission measurements need to be performed for these vehicles/fuel combinations in order to provide appropriate data sets.

There are some emission measurement and sampling issues that need to be solved in order for researchers to have confidence in these emission estimates. These emission measurement issues will be more challenging with lower-emitting new technology vehicles that meet 2005 to 2007 emission standards. The conference summary paper from the Coordinating Research Council Workshop on Vehicle Exhaust Particulate Emission Measurement Methodology, October 21, 2002 (www.crcao.com) provides an excellent summary of relevant issues here. The purposes of the Workshop were to: discuss recent progress in understanding the formation and fate of vehicle exhaust particulate emissions, discuss new measurement techniques (particle size, number, surface area, and composition) that supplement current mass measurements, discuss types of PM measurements and identify knowledge gaps that hinder their development, and to discuss what needs to be done to progress toward agreed upon methods for regulatory and research needs.

For PEMS, onboard instrumentation of vehicles during on-road operation enables data collection under real-world conditions. However, PEMS do not currently have the ability to measure toxic compounds. More emphasis should be placed on developing the technology to measure some toxic compound emissions using PEMS.

For remote sensing, studies should be performed to assess ability to measure and to predict PM mass, and surrogates for various classes of MSATs should be identified that the remote sensing instruments might have the ability to measure. This would allow the remote sensing technology development to proceed with developing the instrumentation to measure those surrogates.

Estimated Cost:	$2 million
Duration:	2 years

Programmatic Initiative P2: Design and initiate experiments to examine near roadway concentration patterns (especially for highways). There is evidence that air toxic concentrations near roadways are appreciably higher than those 300 to 500 meters or more downwind. Experiments to examine these gradients are likely to assist in steering future

research toward examining pollutant emissions, fate, and transport in the immediate vicinity of highways compared with examining regional scale chemistry and transport.

This program area would generate field study data collection efforts similar to those of the Los Angeles Catalyst Study during the 1970s. The Los Angeles Catalyst Study occurred because of public concern over the possible adverse impact of emissions from catalyst-equipped automobiles in ambient air. The study was to be a comprehensive long-term investigation of the ambient levels of sulfuric acid aerosol, sulfates, and other potential catalyst emission products in areas adjacent to a heavily traveled freeway in Los Angeles. EPA ultimately designed a roadway study to monitor pollutant levels on both sides of a freeway for a 3-year period (EPA, 1977).

A more recent measurement effort involving ultrafine particulate measurement near a major highway is described in the May 2002 issue of *JAWMA* (Zhu et al., 2002). Similar research applied to MSAT emissions or an established surrogate will aid in the future development of practical tools for roadway assessments. Several studies under various conditions will be necessary to establish fate and transport of MSAT pollutants for a micro-scale assessment.

Estimated Cost: $3-5 million
Duration: 2 – 3 years

Programmatic Initiative P3:

Conduct research to expand the available set of information about air toxic emissions and activity patterns for the on-road and off-road vehicle types with the most significant contributions to ambient air toxic concentrations of concern and the greatest uncertainty in their emission estimates. Given the current state-of-knowledge and planned research projects in this area, two sub areas within this programmatic initiative have been identified as likely first priorities for study.

Sub-Area 1: There are needs to investigate the differences in fleet populations and travel characteristics for important sub-categories of trucks. These sub-categories can be defined as: long-range fleet, regional fleet (300 to 500 miles), and local fleet (primarily delivery trucks).

For each of the three truck categories, it is expected that there will be spatial operating characteristic differences and time-of-day operating differences that need to be enumerated. Evaluations of the long-range fleet need to provide data about potential out-of-country trucks, especially in areas near the northern and southern U.S. borders. An important operating characteristic to study for these truck sub-categories is operating time.

Estimated Cost: $500,000
Duration: 18 months

Sub-Area 2: For off-road engines/vehicles, diesel-powered construction equipment is a major emissions source (of PM) with large uncertainties in emission estimates.

There are many long-term construction projects that involve diesel-powered construction equipment. The error bounds in estimating these engine populations have been estimated to be plus or minus 50 percent. Activity patterns and emission rates are added sources of uncertainty. There is more instrumentation now that can be used to measure activity patterns (e.g., portable activity monitors). Then, emissions can be measured in a laboratory setting replicating the activity patterns that are measured in the field.

An important issue for this (and other) source types is identifying surrogates for toxic air pollutants. In other words, which measured pollutants can serve as surrogates for the specific toxic compounds that are of interest, because it is unlikely that emission measurement programs would have sufficient funding for all toxic pollutant's emissions to be measured directly.

Estimated Cost: $750,000
Duration: 24 months

2.0: AMBIENT MONITORING

A. INTRODUCTION

1. Background

EPA's ambient air quality monitoring program provides the data needed to track air quality throughout the United States. The data gathered by the existing monitoring networks provide a major source of information for the designation of future nonattainment areas, tracking compliance, and developing resources such as emissions modeling tools, emissions inventories, and control programs. There are many questions of interest in this area, including whether the ability to monitor and measure volatile organic compounds in the ambient air exists, and if so, what are we measuring and how?

It should be noted that EPA and FHWA are far from the only organizations interested in the information that can be gained by analyzing air toxics monitoring data. In addition to local and state stakeholders, at the national level, organizations such as the Office of Homeland Security are interested in the impacts of various types of air contaminants. Though not strictly relevant to the workplan, workshop participants did encourage FHWA to consider efforts and methods of pooling technological and information resources with such organizations to provide a more complete picture of the air toxics situation. Along with shared resources, FHWA should be aware of concerns that are common to all involved in air quality monitoring, for example, the need for standard methods of measurement and reporting of air toxics.

When considering research recommendations, it is important to note that there is distinct overlap between the subdivisions presented in this report. Therefore, when a priority recommendation seems equally valid under two categories, it is presented under the category associated with the sessions under which it was developed.

2. Current Information Summary

One of the primary considerations regarding ambient monitoring is the availability of data. For air toxics, there is both archived historical data and several active networks providing relevant data. The archived monitoring data has information on hundreds of hazardous air pollutants from approximately 2500 sites and across 37 years. Unfortunately, the archive only maintains limited information about the monitoring methods, as well as, duplicate records and unclear minimum detection limit information.

There are three major monitoring networks of note actively providing data. The air toxics monitoring pilot city project study focused on a year long study of 18 *core* pollutants, including acetaldehyde, formaldehyde, 1,3-butadiene, and benzene. The Photochemical Assessment Monitoring Stations (PAMS) network focuses on areas with persistently high ozone levels. The network collects information on VOCs, several carbonyls, nitrogen oxides, ozone levels, and meteorology. Finally, the National Air Toxics Trends Stations (NATTS) network is composed of

22 sites, sited in both urban and rural locations. The NATTS network samples once every six days and measures, among other compounds, 1,3-butadiene, benzene, acrolein, arsenic, hexavalent chromium, and formaldehyde. Note that EPA is also investigating the potential of conducting community scale monitoring in conjunction with the trends sites.

In addition to monitoring networks, information can be gleaned regarding highway air toxics from at least two other sources. Tunnel studies can provide controlled information about vehicle emissions. Since the volume of traffic through and dimensions of a tunnel can be known precisely, a tunnel can represent an almost ideal laboratory to the air toxics researcher. Tunnel studies can thus be used to validate existing model forecasts, as well as to evaluate the effects of new regulations over time. On the other hand, biomonitoring, that is, the use of biological organisms to monitor air toxics, may also have some use. Namely, biological monitors may provide lower cost surrogate measures of certain highway air toxics.

B. WORKSHOP DISCUSSION SUMMARY

1. Introduction

It should be noted that the following discussion summary does not necessarily explicitly include all conversations had during the workshop. An attempt has been made to limit the comments to only those associated most directly with transportation-related air toxics. For instance, while discussions of air quality often lead to discussion of particulate matter, we have removed certain PM-specific comments from this summary.

2. General Ambient Air Quality Monitoring

Participants were interested in there being more consideration of the various uses of air quality monitoring when studies are planned and executed. In the opinion of the participants, too often the ambient monitoring studies do not include sufficient emissions-specific information. This is true of bio-monitoring studies, as well as studies to measure ambient air concentrations of toxics.

For measuring outdoor air toxic levels, it was suggested that a modest air monitoring network be designed to measure roadway-related contributions. This might include measuring air toxic concentrations versus downwind distance from the roadway. Other vehicle-related air toxic concentration measurement sites might include truck rest stops, warehouses with large truck populations, border crossings, and highway construction projects. Some monitors need to be sited so that their data can be used to assess air toxic concentration trends, while others need to have a project orientation. This would likely be a collaborative transportation-air pollution agency research effort.

Ambient monitoring needs for toxics include shorter sampling times, such as one hour averages, that allow us to distinguish long range transport/secondary formation from local, primary emissions. Pollutants for which we need shorter sampling times in urban areas include formaldehyde and acetaldehyde. We also need the ability to be able to distinguish weekday from weekend emission and concentration patterns. The ambient data collection strategy needs to give analysts the ability to understand emissions differences and the atmospheric response during these periods. In addition, we need more information from ambient monitoring studies to assist in improving our understanding of the sources of black carbon/elemental carbon. While some research indicates that diesel engines are the dominant source, other studies have indicated a significant contribution from SI engines, wood smoke, wildfires, agricultural burning, and other combustion sources.

There was general interest in using monitors to better understand air toxics concentrations near roadways, and how these air toxic concentrations and characteristics change with distance from the roadway. This would provide a base of knowledge for evaluating project-level impacts. Two questions that were of specific interest and that might be addressed in this manner were: What are the differences in ambient air toxics characteristics with distance from roadways? How can such information be used to evaluate public safety?

3. Vehicular Monitoring

It was noted that most air toxic monitoring networks are designed to not be overly influenced by roadway contributions. Most monitor siting is designed for health effects studies. At the same time, there is little measurement in passenger compartments of cars and transit buses. Exposures there may be to higher air toxic concentrations than in outdoor air. For example, an Environment Canada study showed that the highest wintertime passenger compartment exposures were to windshield washer fluid solvents. As a result, more careful monitoring of roadway emissions and vehicle specific air toxics levels may be in order.

Related to ambient monitoring is local activity data collection. Traffic counts are needed at sites near monitor locations. Such information is relevant to associating air toxics levels to sources or classes of sources. For example, stations might be established in locations that facilitate learning more about the difference between light-duty and heavy-duty dominated situations.

Another approach might be to measure concentrations inside vehicles during actual operation, as well as measuring tailpipe emissions, near highway concentrations, and concentrations at various downwind distances. The results of such measurements could be used to estimate exposures to motor vehicle-emitted air toxics in different locations, and could potentially be used to validate air dispersion models. In addition, research is needed to define the conditions and driver actions that exacerbate or mitigate exposure to toxics while driving/riding.

4. Monitoring Technology

A potentially underutilized air toxic concentration data source is the PAMS sites, which provide speciated HC concentration estimates in urban areas that are serious, severe or extreme ozone nonattainment areas for the one hour ozone NAAQS. It was suggested that these data might be better utilized for assessing vehicle contributions in the urban areas with PAMS sites. (Note that some of these data have been used for related criteria pollutant – VOC and NO_x emissions – assessments.) The PAMS data have 1 to 3-hour average resolution, so they are more time resolved than many air toxic concentration estimates.

In establishing monitoring networks and instrumentation, it was noted that no perfect system is or will be available for air toxics. More work is needed to improve our ability to measure acrolein, and specific constituents of PM, for example. We need to be able to determine the level of data quality and quantity that is needed to assess air toxic concentrations, exposures and control strategies. The participants believe there is a need to identify and evaluate current technologies in order to make the desired innovations.

Participants also expressed interest in knowing whether the existing/planned set of air toxic monitors will be able to measure the changes associated with new technologies and fuels. They expressed a desire that any monitoring system provide data to help assess the impact of such changes.

Plant-based bio-monitoring of highway air toxics was discussed. Bio-monitoring deals with using biological organisms, living or dead, to assess vehicle emission levels. Bio-monitors may be able to provide information about historical changes in air toxic levels; however, it was noted that they may be limited in their ability to separate out the effects of temperature and rainfall.

A logical way to proceed might be to have an initial effort that resulted in setting monitoring objectives that serve the transportation community (and others). Investigation should be done into the specific pollutants and monitoring objectives of interest for highway air toxics research. It should be determined if monitoring data can be used to identify the spatial impact of air toxic exposure (regional versus hot spot) and if currently collected data is sufficient to validate air quality dispersion models. Guidance should be developed for the design and implementation of studies to address highway air toxics specific questions. Existing technologies should be reviewed and improved with respect to monitoring air toxics of concern to the highway community. This should include the identification of compounds not currently measurable and the investigation of monitors to measure them, as well as, the development of continuous, low maintenance monitors routine deployment by agencies.

An additional suggestion was made to begin by identifying one or more surrogates for the air toxics of interest. Then simple monitoring methods could be used to set priorities. Then, more sophisticated equipment could be used to provide a more complex analysis.

Is there a potential application for remote sensing in measuring near roadway air toxic concentrations, or a surrogate for these MSATs? This could be considered a supplement to standard ambient monitoring networks.

5. Monitoring Network Planning

The participants expressed a need for some established data quality objectives for highway needs. EPA has some guidelines that could serve as a starting point, but these should not be handcuffs.

There was a general interest in the current monitor siting strategies, and if they were the same for criteria pollutants and air toxics. The general answer to this question is that the initial air toxics monitoring strategy was to identify hot spot situations (peak concentrations). Now the emphasis is on choosing representative sites.

What does the available information about health effects and exposure periods under which those effects are found tell us about what time periods are important to capture in our air monitoring efforts? Are we concerned about acute exposures to elevated levels or chronic exposures to long-term average concentrations? Monitoring strategies designed to capture peaks might be considerably different from those designed to estimate long-term average concentrations in residential neighborhoods. In addition, we need to know whether there are seasonal issues that might influence network design, and needs for short-term versus continuous monitoring. There might also be continued work to evaluate how well motor vehicle-emitted pollutants like carbon monoxide serve as a marker for specific MSATs, such as benzene, or 1,3-butadiene. Given the cost and sparseness of the existing/planned air toxics monitoring network, perhaps a more commonly monitored pollutant like CO, could serve to fill data gaps where air toxic concentrations are not monitored nearby.

Another transportation-related issue is how a transportation agency might use monitoring data. We need to evaluate what the potential uses are for project-level analyses. These might include identifying affected populations in the vicinity of roadway projects, with this affected population differing according to whether peak or long-term average exposures are of interest. For criteria pollutants, the interest is in keeping ambient concentrations below the NAAQS. For toxics, although there are no regulatory requirements at this point, the long-term goal is to reduce the level of risk to public health. Another important reason for monitoring is validation of dispersion models for air toxics.

There need to be guidelines for performing project-level air toxics studies. These guidelines should address the highway construction phase of the project as well, with recommendations for investigating and mitigating emissions from construction equipment. Thresholds need to be established so that transportation agencies know where there is likely to be a measurable difference in ambient air toxics concentrations near a project. Guidelines are needed to help identify when a project environmental impact study is warranted for toxic air pollutants.

The set of current air toxic monitoring sites were established by State and local agencies. More recently, EPA has interfaced their national program with the programs previously established by States/locals. If other agency initiatives, including those at FHWA, are going to produce more monitoring, then these new activities need to be integrated into existing objectives, and be consistent with EPA goals.

C. PRIORITY RESEARCH RECOMMENDATIONS

Three major ambient air toxics monitoring research areas seemed to be consistently important to experts and stakeholders in the area of transportation air toxics. Experts are interested in the development of possibly modest, possibly tiered transportation air toxics monitoring networks that address temporal and spatial distributions. Regional end-users are interested in a suite of practical tools to help define and implement policies and procedures. Among these tools, there is interest in enhanced technologies, and practical guidance and protocols. Finally, stakeholders expressed an interest in surrogates, linkages, indicators, and synergies. While accurate, specific, direct measurements are preferable, there is a desire to further define relationships and technologies to link air toxics to various continuous measurements with validation.

<u>Proposed Programmatic Initiatives</u>

Programmatic Initiative P4: Fund research to identify what additional monitoring information needs to be collected to enhance existing monitoring networks to meet transportation sector needs.

EPA and other national, State, regional, and local organizations sponsor monitoring networks to measure various air toxics nationwide. It is desirable for FHWA to incorporate the data from such networks into their ambient monitoring research; however, transportation needs are sufficiently unique that additional information may be desirable. Key questions might include:

- Can spatial components associated with locations along a road, away from a road, and off-road be appropriately estimated using current monitoring data?
- Is there sufficient historical information available to combine measurements from all monitoring sites in a meaningful way to inform future studies?
- Do the current networks provide sufficient information about the short- and long-term decay of air toxics?
- What siting criteria might be developed to guide the placement of future monitors and monitoring networks to provide additional information for transportation air toxics studies?
- Are there new or improved technologies that would better serve transportation needs?

Investigation of tiered network design might facilitate the collection of data that meets unmet transportation sector needs. By tiered network, we refer to a network designed to measure both spatially and temporally at various scales. One scale of the network might be distributed broadly and collect integrated measurements. A finer scale might be distributed at a narrow spatial scale and collect continuous measurements, but only be located in a small overall range of locations. Such a network might also include portable monitors to be used in specific locations for a limited time before being moved to a new location and re-used.

Estimated Cost: $250,000
Duration: 1 year

Programmatic Initiative P5: Fund research to understand existing, and develop new, practical tools for local and regional organizations to assess MSAT impacts and evaluate results.

There is a great perceived need for practical application of theoretical research in the area of transportation-related air toxics monitoring. Regional, State, and local organizations would like specific tools for conducting monitoring and addressing environmental regulatory needs. A practical suite of highway air toxics monitoring tools that could be used consistently nationwide would include improved monitoring technologies, validated models, and suggested protocols. Specific questions which might help guide the development of such tools include:

- How can the background levels of air toxics be best determined to inform the impacts of transportation projects?
- What improvements can be made to current monitoring techniques and technologies to collect more accurate information about air toxics levels that are below current minimum detection limits?
- Does sufficient knowledge exist to develop consistent, temporal, vehicle specific source signatures and source apportionment?

It is important that such practical tools do not limit the ability of transportation personnel to collect data, but instead, provide them with assistance to facilitate meaningful collection.

Estimated Cost: $250,000
Duration: 1 year

Programmatic Initiative P6: Determine whether the existing knowledge about transportation air toxics can be enhanced by further examining current data.

A significant amount of data already exists from current ambient monitoring networks. However, often this data exists separately from information that helps put the data into context. It is important that more complex relationships be identified, validated, and be applied to the development of future analyses and policies. Thus, it is recommended that the relationships of individual air toxics be more carefully identified. Further, investigation into the use of measures of CO, traffic flow and other transportation characterizations, and even meteorological or other non-toxics measurements as surrogates for specific transportation related air toxics is desirable.

While accurate, specific, direct measurements are always preferred, surrogate relationships may be useful to facilitate future monitoring in place of specific technology development.

Estimated Cost: $200,000
Duration: 18 months

3.0: ANALYSIS

A. INTRODUCTION

1. Background

The Analysis workshop session included atmospheric dispersion modeling, receptor modeling, exposure modeling, emissions modeling, and other quantitative methods that might be used to estimate emission rates or ambient concentrations of air toxics. Differing atmospheric dispersion modeling approaches are often characterized into micro-scale, meso-scale, and regional scale modeling methods. Modeling methods originally developed by EPA to assess criteria pollutant impacts have largely been adopted to address impacts from air toxics.

2. Current Information Summary

Micro-scale modeling methods have been applied to estimate ambient concentrations at local levels (e.g., downwind of specific roadway projects) up to urban scales (e.g., less than 50 kilometers). However, for the purposes of modeling the impacts from transportation projects, downwind distances are often in the range from 10's of meters to a few hundred meters. Micro-scale models have also been developed to assess impacts adjacent to traffic intersections. Examples of micro-scale models include EPA's Industrial Source Complex model (and its successor, AERMOD), CALINE3, CALINE4, CAL3QHC, and box models. All of the above except box models are Gaussian models.

Meso-scale models use Lagrangian or "puff" modeling methods to simulate the transport, decay, and transformation of pollutants in discrete air parcels (puffs) over distances of 10's to 100's of kilometers. For the purposes of assessing transportation impacts, meso-scale models would be used to assess impacts on a domain up to 10's of kilometers (urban scale air quality) often with the incorporation of other air pollution sources. CALPUFF is an example of a meso-scale model.

Regional scale models are based on Eulerian or "grid-based" methods. These models are used to estimate ambient concentrations at urban to regional and even continental scales. These models are also used for assessing regional impacts of mobile source control measures compared with those from other emission sources. Examples include EPA's Community Multi-Scale Air Quality model, the Urban Airshed Model, and the Regulatory Modeling System for Aerosols and Deposition (REMSAD).

Receptor models are used to estimate source contributions to ambient concentrations. Hence, in addition to detailed knowledge of the chemistry of measured ambient concentrations, detailed knowledge of the chemical composition of sources is needed. Exposure modeling is performed using either modeled or measured ambient air concentrations to estimate a receptor's exposure over a specified time-frame. Historically, 70-year continuous exposures have been used to estimate chronic and carcinogenic health risks to residential receptors. Recently, more realistic assessments of the duration of exposure have been incorporated into assessments, including multiple exposure scenarios (e.g., standing near a roadway, commuter inside a car, and living near a roadway).

Mobile source emission rates are generally estimated using EPA's MOBILE6 model or the California ARB's EMFAC model for on-road sources. Nonroad engine emissions are often modeled using EPA's NONROAD model or ARB's OFFROAD model. EPA is currently developing a next generation model referred to as MOVES, which will handle both on-road and nonroad emissions. MOVES will use modal emission estimation methods to incorporate the effects of speed, grade, and other factors (i.e., those affecting engine load). MOBILE6 uses average emission factors for different roadway (facility) types. Among the foreseen capabilities of the MOVES model are the ability to estimate emissions at varying spatial scales (e.g., roadway segment to regional level) and incorporating modules to estimate uncertainty.

B. WORKSHOP DISCUSSION SUMMARY

1. Introduction

Workshop participants identified research needs in the three following areas: air quality modeling, including atmospheric chemistry of MSATs; development of data to support modal emissions modeling methods; and receptor modeling. Underlying each of these three areas, variability/uncertainty analysis and model reconciliation were considered to be important areas for additional work. Model reconciliation relates to making comparisons of modeled results with ambient measurements to evaluate model performance. For example, data from the PAMS monitoring stations could be useful for this task since 1- and 3-hour averaged concentration data are available for some pollutants (i.e., benzene). Also, model results should also be compared with each other as appropriate (e.g., differing air quality modeling methods). Finally, participants noted that there is a need for systematic documentation at all phases of mobile source air quality impacts assessments (e.g., emissions modeling, air quality modeling, health risk assessment).

In addition to the three research areas above, participants noted that appropriate inputs for exposure assessments should be evaluated and further developed. Specifically, these include the development of the various exposure scenarios applicable to the assessment of transportation project impacts.

2. Air Quality Modeling

In the atmospheric dispersion modeling area, one of the more important research needs identified by workshop participants was in the atmospheric chemistry of toxic air pollutants, where little is currently known about the atmospheric behavior of some of the MSATs (e.g., acrolein, 1,3-butadiene). Certain species (e.g. acetaldehyde, formaldehyde) may be formed from precursors. Other reactive toxic species may degrade following chemical or photo-chemical reactions in the atmosphere (1,3-butadiene). Research is needed on these issues specific to MSATs and on how best to incorporate these reactions into micro- to -meso-scale analyses.

There is currently no standard protocol for the transportation community on which modeling methods to apply in specific situations. For example, a protocol could specify which models to apply to assess air quality impacts at different spatial scales. The areas of most interest are methods to apply in micro- (e.g., local roadway projects) to meso-scale (e.g., transportation corridor) studies. The protocol should also provide methods for quantifying uncertainty in the modeled concentrations from these studies. Given the direct association between emissions modeling, air dispersion modeling, and exposure modeling (described below), a protocol covering all of these areas would be beneficial.

3. Emissions Inventory Development

Another common theme was the need to incorporate modal emissions modeling methods into standard practices to assess the effects of speed, acceleration, and road gradient. EPA has proposed using vehicle specific power (VSP) to characterize modal emission rates for the MOVES model (Koupal et al., 2003). The proposed light-duty VSP bin distributions in MOVES will be based on the MOBILE6 framework for facility-specific driving patterns. Another set of facility-based cycles will be produced for heavy-duty vehicles (both sets would include the 12 highway performance monitoring system roadway types). A general lack of toxic air pollutant emissions data to support modal emission estimation methods was noted (e.g., differing toxic air pollutant compositions for idling versus in-use heavy-duty diesel vehicles). As part of this, toxic air pollutant emission dependencies on driving cycles should be identified and characterized.

Also related to improved emissions modeling methods, toxic air pollutant emission profiles for high-emitters need to be incorporated into the new models. Until these new methods are available, there is a need to update the MOBILE6/MOBTOX emission factors derived from the COMPLEX model because they are outdated and inaccurate. In addition, there is a need to validate the air toxic emission factor estimates produced by these models.

Participants agreed on the need to *data-mine* sources of toxic air pollutant emissions data to develop these new methods or refine existing ones. The group pointed out that care must be taken while evaluating these data, as emission measurements are often collected using sampling techniques that may not be comparable with each other. It was noted that *data-mining* efforts were also likely to help identify toxic air pollutant surrogates that are needed due to the large expense associated with the measurement of multiple chemical compounds.

Workshop participants were divided on the issue of re-entrained road dust and its potential contribution to toxic air pollutant emissions. Some felt that the issue was highly uncertain and in need of study, while others felt that re-entrained road dust is typically deposited near the source and was therefore less important. The ARB is currently incorporating re-entrained road dust emissions into its detailed study of toxic air pollutant health risks in the Wilmington, California Air Quality Study (Sax, 2003). It should be noted that, in multi-media exposure assessment, both direct inhalation exposure as well as indirect exposure pathways are considered (e.g., deposition to soils or vegetation that can then be ingested, etc.).

Also, relative to emissions, accurate VMT data to support new generation emission models (i.e., based on modal methods) are needed. Essentially, the group recommended gathering and evaluating link-based VMT and characteristics (e.g., hourly speed, grade, altitude).

4. Receptor Modeling

Analogous to issues discussed under the monitoring issues area, participants noted the need to identify source-specific marker compounds for use in source apportionment/receptor modeling studies. Unique marker compounds are used to apportion the contributions of toxic air pollutants to sources, as well as to differentiate the contributions of various mobile source sectors (e.g., light-duty gasoline and heavy-duty diesel) that are similar in emissions composition. It was also suggested that research be performed to determine if the marker compounds change under varying motor vehicle operating conditions.

Relative to receptor modeling, questions arose as to the accuracy of tools such as Positive Matrix Factorization that only use ambient data to estimate source contributions. There is a need to validate these results using source data (e.g., chemical mass balance or emissions and dispersion modeling). Reviews of existing data are also needed to refine PM and VOC speciation profiles, especially related to source apportionment efforts. It should be noted that EPA is currently funding work to update the SPECIATE database with many new profiles from data obtained from the California ARB, the Texas Commission on Environmental Quality, and research organizations.

C. PRIORITY RESEARCH RECOMMENDATIONS

Priority program areas for research in emissions and air quality analysis to support the transportation community's need for air toxics modeling tools are described below. These four priority research areas cover emissions and air quality (atmospheric dispersion) modeling; developing methods on how to perform and interpret on-road vehicle emissions uncertainty analyses; developing improved inputs for emissions and receptor modeling of toxic air pollutants; and performing research on the atmospheric chemistry of MSATs.

Proposed Programmatic Initiatives

Programmatic Initiative P7: Development of a Protocol on Emissions, Atmospheric Dispersion, and Exposure Modeling for Transportation Projects.

A protocol that provides the appropriate methods to use to estimate emissions, perform dispersion modeling, and conduct exposure assessments is needed. The focus of this protocol should be on project-level analyses (e.g., roadway improvement projects, intersections), although it should also include methods to assess impacts at meso-scales (e.g., transportation corridors). The protocol should address which air dispersion models to use at varying spatial scales (i.e., what is the spatial point-of-departure from micro-scale methods). An exploration of the use of GIS tools to assess exposure to project-level impacts would also be useful (e.g., GIS data sources and methods to characterize the population adjacent to roadway projects).

Due to the inter-dependence of exposure assessment with the selection of the appropriate emissions and dispersion models, they should all be addressed in a single document. Among other issues in emissions modeling, the protocol should cover alternatives to the use of emission factors from MOBILE6/EMFAC that may be based on trip averages or facility averages in micro-scale applications (e.g., intersections or off-ramps where emissions from stops and starts are much different than represented by the underlying average emission factor). As part of this effort an assessment will be needed as to how well EPA's upcoming MOVES model will satisfy the transportation community's needs, particularly for micro-scale impacts analysis.

The protocol should also include a plan for phased implementation. This should include descriptions of how existing models can be used for micro-scale analysis, and how standard adjustments can be applied to allow modeling results for relatively inert gases like CO to be used to provide ballpark estimates of air toxic concentrations. If new or revised models are needed, the protocol should allow for phased implementation, with descriptions of needed computational and data resources provided.

Estimated Cost: $350,000
Estimated Duration: 12 – 18 months

Programmatic Initiative P8: Conduct Research on Appropriate Methods to Estimate Variability and Uncertainty of On-Road Emission Estimates. Identification of key sources of uncertainty can be used to target resources to reduce uncertainty.

There is a need to develop systematic estimates of uncertainty in mobile source emission inventories. However, the focus of this work needs to be determined. For example, should these efforts focus on establishing uncertainty estimates for new generation models (e.g., modal emissions models) or for existing emissions models (e.g., MOBILE6, EMFAC)? For MOVES, FHWA should partner with EPA to develop uncertainty estimation methods during the development of MOVES inputs (e.g., distributions of each parameter used in estimating emissions). Hence, the first step under this program area is to develop a needs assessment for uncertainty analysis. It is also expected that an expert workshop would be convened in order to incorporate expert input into the process.

Estimated Cost: $250,000
Estimated Duration: 24 – 30 months

Programmatic Initiative P9: Develop Improved Inputs for Emissions and Receptor Modeling

The improved inputs take on a variety of forms including better speciation data for VOC and PM, improved toxic air pollutant information on high emitters, and information to assess modal emissions for mobile source air toxics. There is a need to assess how well the current toxic air pollutant emissions data represent the current make-up of the fleet. Recommendations for improvements to emissions models need to be developed for both current modeling methods (e.g., MOBILE6/EMFAC), as well as next generation methods (e.g., MOVES). As part of this program area, monitoring data from selected PAMS sites could be analyzed to reconcile modeled versus monitored concentrations of selected toxic air pollutants (e.g., benzene).

Relative to receptor modeling, research should be conducted and *data mining* should take place to identify the organic marker compounds that can be used to characterize mobile source contributions (especially the contributions of on-road diesel and light-duty gasoline vehicles). Using these marker compounds, different source profiles may be needed based on different operating modes (e.g., idling versus in-use heavy-duty diesel). Another objective of this program area is to define where additional testing is needed to fill the observed data gaps.

Another set of inputs that requires additional study is the toxic air pollutant composition of re-entrained road dust and brake/tire wear. There is likely not a lot of information in the literature in this area, so testing programs will need to be developed.

Estimated Cost: $750,000
Estimated Duration: 24 months

Programmatic Initiative P10: Research the Atmospheric Chemistry of MSATs

In this program area, a review of the atmospheric chemistry of MSATs will be performed. Sources of information include the scientific literature, work supporting EPA's National Air Toxics Assessment project, and ongoing work at EPA to incorporate toxic air pollutant chemical mechanisms into air quality models (e.g., Community Multi-Scale Air Quality). The objective would be to develop recommendations for incorporating formation/degradation/condensation algorithms or other adjustments (deposition velocities for particulate toxic air pollutants) into standard micro-scale and meso-scale models that are important tools in assessing transportation project impacts. One product of this research would be to provide the information needed to develop a better line source model for the purpose of evaluating transportation projects for near roadway dispersion of air toxics and PM. This model should be able to simulate secondary formation of air toxics and PM. The results of this work could be incorporated into the protocol described under Programmatic Initiative A1 above.

Estimated Cost: $250,000
Estimated Duration: 12 months

4.0: CONTROL STRATEGIES/MEASURES

A. INTRODUCTION

1. Background

Control options for on-road and off-road vehicles are normally of one of four types: engine standards, fuel standards, in-use emission/compliance programs, and travel management. This organization is useful for enumerating the control possibilities for air toxics as well as criteria air pollutants.

For engines, the technologies differ for gasoline (spark ignition) and diesel (compression ignition). Emission control technologies on today's SI engine-powered vehicles include electronic control systems, three-way catalysts, evaporative emissions control, and onboard vapor recovery systems. New gasoline-powered vehicle requirements include Tier 2 emission standards, lower sulfur content gasoline [30 parts per million (ppm)], and a change in the HC emission standard to 0.075 grams per mile non-methane organic gas from the current 0.25 grams per mile non-methane hydrocarbon. Future replacements for gasoline-powered vehicle technologies could include hybrid electric, battery electric, and fuel cells.

HDDV emission control technology has included injection timing retard, low sac volume and valve covering nozzle, turbo-charging, charge cooling, and improved fuel injection. New HDDV requirements in EPA's HDDV rule include fuel sulfur limits for motor vehicle diesel fuel, and PM certification levels that are 90 percent lower than those applied to truck engines being sold today. Transit and school buses have traditionally been diesel-powered, but alternative technologies include natural gas and battery electric.

For gasoline fuels, most areas in the United States currently have either regular unleaded gasoline, Federal reformulated gasoline (RFG), or California RFG. The primary change to gasoline characteristics in the next few years is a lowering of the sulfur content to 30 ppm. Light-duty vehicle alternative fuels that have been evaluated in some form have included methanol, ethanol, oxygenated fuel, natural gas, and liquefied petroleum gas (LPG).

Motor vehicle diesel fuel regulations as part of the EPA heavy-duty vehicle rulemaking will require that the sulfur in diesel fuel be lowered to a maximum of 15 ppm in 2007 from a current sulfur level of 500 ppm with the phase-in to low sulfur diesel beginning in mid-2006. The next tier of diesel emission standards begins with the 2007 model year. Heavy-duty diesel alternative fuels include bio-diesel, fuel additives, as well as alternative engine lubricants.

In-use compliance programs include vehicle emission inspections, remote sensing to flag high emitters, and vehicle replacement and retrofit programs. For gasoline-powered vehicles, emission inspections programs have taken a variety of forms including inspection and maintenance IM-240-based, Accelerated Simulation Mode tests, 2 speed idle tests, on-board diagnostic system checks, gas cap checks, and general anti-tampering programs. In-use compliance testing of diesel trucks is limited to random smoke emissions evaluations.

Travel management programs, which have been investigated or adopted with at least one of the purposes being reducing motor vehicle emissions in urban areas, fall into the categories of: intelligent transportation systems, market-based pricing mechanisms, land use and growth management policies, alternative work or trip schedules, and use of information technology as travel substitutes.

There has also been recent interest in studying HDDV operating practices with an interest in reducing excess idling emissions. Diesel engines operate at truck stops to provide power, heat and air conditioning to cabins. There are alternative technologies that can meet these power demands at lower emission rates. Truck stop electrification has been identified as a cost-effective technology. Truck stop electrification can take one of two forms. One option is to install electrical outlets at each parking space. This requires trucks to be equipped with power conversion systems. The second option provides climate control at the truck parking area without requiring modification, or added equipment, on each truck. Transit and school bus operating practices may also include excess idling emissions that could be mitigated as well.

2. Recent Information Summary

As noted in the companion literature review report, control strategies for mobile source air toxics have primarily focused on technological changes, such as tailpipe controls and changes to fuels for both diesel and gasoline engines. Development and evaluation of new and improved fuels includes fuel reformulation, fuel additives, fuel blends, alternative fuels, and alternatively fueled vehicles. Advances in this area have typically focused on fuel efficiency and reduction of ozone precursors. However, fuel changes can have a significant effect on toxic emissions, both positively (e.g., compressed natural gas [CNG]) and negatively (e.g., MTBE).

The primary tool available to transportation practitioners for estimating emission factor changes of mobile source strategies is MOBILE6.2. This EPA model allows users to estimate emission factors for six air toxics directly, and many more with modifications to input files. Therefore, any area can use MOBILE6.2 to estimate the air toxic emission reductions associated with control options such as reformulated gasoline and vehicle emission inspection programs in the same way that criteria pollutant emission reductions are estimated. The current practice for estimating the air pollution benefits of transportation control measures is explained in the National Cooperative Highway Research Program Report 462 "Quantifying Air-Quality and Other Benefits and Costs of Transportation Control Measures" (Cambridge, 2001). This report also addresses potential improvements to analytical frameworks for assessing transportation control strategies. While the report's focus is on criteria pollutants, the same principles apply for air toxic analyses.

B. WORKSHOP DISCUSSION SUMMARY

1. Introduction

Part of the discussion in the control measures sessions was identifying the appropriate/needed metrics for evaluating measures. Such metrics would be included in any control measure evaluation regardless of whether it affects engine technology, fuel characteristics, in-use vehicle programs, or travel management. Suggested metrics included the following:

- Total cost.
- Cost per pound or ton of pollutant reduced.
- Will emission reductions be short term, or last a vehicle's lifetime?
- Will reductions in one pollutant be offset by increases in other pollutant emissions?
- Do emission controls affect speciation?
- What gives the best emission reduction for the money?
- Identify any potential undesirable side effects or co-benefits of measures.
- Need performance measures for control technologies.
- Identify potential surrogates for toxics, such as total VOC, where individual compounds cannot be measured.
- Changes in PM particle size and number.
- Implementation cost.

There need to be surrogates established as markers for the air toxics of interest because direct measurement of all air toxic compounds for all strategy evaluations will not be possible. Where appropriate, key toxic compounds should be delineated and control strategy research should focus on providing information for these compounds.

The crossover between this session topic and emissions characterization is the need to establish a link between emission measurements and control strategies. This means that there would be a discernable link between control strategies with an understanding of emissions and a focus on the biggest sources.

There needs to be more research on the full effects of control strategy options across air pollution issues (PM and toxics) and media (air, water, soil). The potential consequences of implementing a strategy need to be identified. State and local agencies are concerned with creating further situations like using MTBE in gasoline and later learning that a consequence of this action is finding MTBE in water bodies.

There needs to be more research on market-based incentive programs, and how behavior is likely to change under these stimuli. Likely responses to education programs are needed as well. Study incentives for fleet upgrades and other actions that might reduce air toxic emissions. This would include voluntary programs with rewards. Research which incentives work best. An example might be a tax incentive that would get fleet owners to replace older engines with new ones earlier than they might otherwise make this change.

Research needs to define toxics emissions reduction benefits that result from criteria pollutant controls. The next set of control strategy decisions that individual areas will face is for attainment of 8-hour ozone standards and $PM_{2.5}$ standards. Before these decisions/selections are made, it would be informative to have estimated air toxic emission changes available, so that strategies can be selected with full knowledge of the likely air toxic emission changes. This air toxic information does not have to be quantitative, it can be directional changes in situations where quantitative information is not available.

Research atmospheric chemistry so that we can identify the air concentration benefits of measures as well as the tailpipe emission changes. This would include evaluating how particle size distributions might be changing with PM control applications. Also include assessments of greenhouse gases, toxics, criteria air pollutants, energy use, congestion measures, etc. Focus on identifying and adopting measures with positive results for all of these metrics. One example of what is needed here involves public transit agency bus purchases. Criteria pollutant analyses would probably show that a CNG-powered bus would be favored over a diesel-powered bus. However, CNG buses have a greenhouse gas disbenefit relative to diesel, depending on whether both direct and indirect greenhouse gas emissions are counted, and this may not be known by transit agencies, or incorporated in their decision-making process. The other issue related to atmospheric chemistry is that with respect to ozone, some areas of the country are VOC limited and others are NO_x limited. Strategy selection in these areas will be strongly influenced by this, therefore the need to distinguish atmospheric changes in the strategy selection process.

For air toxics, workshop participants thought that it would be valuable to make drivers aware of what they emit, and what they breathe as they drive. One example would be to have portable signs that displayed the emission readings to drivers after they passed a sensor. This would have to be combined with studies of what real-time feedback does to driver/vehicle owner behavior. It was noted that the UC-Davis studies of in-vehicle dashboard lights that show when a vehicle is in enrichment mode are usually ignored after about 16 hours of driving.

Research is needed into the effectiveness of control strategies on toxics. This initiative specifically focuses on identifying the most cost effective control strategies available for reducing air toxic emissions. What would provide the best and most cost-effective results in situations where the most cost-effective air toxics control strategies could differ from the most cost-effective criteria pollutant options?

2. Fuels

There needs to be information available that compares alternative fuels and fuel blends, both technically (emission differences) and economically (cost). A recent analysis that was published in *Environmental Science and Technology* provided a cost-effectiveness analysis for various urban transit bus fuel types (Cohen et al., 2003). This was noted as an example of the type of analysis that is needed for air toxics. As with most analyses in the literature, this paper addresses criteria pollutant and CO_2 emission differences (not air toxics).

3. Off-Road Engines/Vehicles

Non-road construction equipment control measure assessments (and those for any other non-road equipment of interest) need to provide more information about the different applications of such equipment, and how the effectiveness of controls might differ according to those applications. With the many applications of non-road equipment, they are more challenging to understand. It appears that there are many examples of non-road technology installations, such as using ultra low sulfur fuel, retrofits, and early adoption of filter technology, but cost-benefit information about these installations is not readily available.

Identify the potential emission benefits of clean contracting for construction projects to encourage emission reductions from non-road diesel equipment. Can contracts include requirements for cleaner than Federally mandated equipment, or is providing bonus evaluation points a better approach? Can FHWA evaluate how approaches to such contracting have been applied in practice thus far, and whether these have been successful? Are there instances where the additional costs to use clean (low sulfur) diesel or to retrofit engines have been paid, or subsidized by, FHWA, or other agencies?

4. In-Use Compliance Programs

What is the need for and effectiveness of diesel vehicle emissions inspection programs? What is the effectiveness of these programs in reducing air toxics? What kind of a diesel inspection and maintenance (I/M) program might actually work? Part of such a research study would involve identifying whether there are excess diesel truck emissions that are not captured by MOBILE6, or the equivalent models, and what the relationship was between vehicle age or accumulated mileage and emissions. Then, different methods for estimating vehicle emissions in-use could be studied, as well as techniques for reducing the excess emissions when they are found.

5. Retrofits

Near-term research should be practical and focus on what we are already doing and have some information for. One focus should be on the effectiveness of retrofits. This is important because they are occurring. The information needed for retrofits includes in-use emissions performance and durability. In-use is important because we need to be sure that the analyses capture all of the duty cycles associated with real world operation.

There needs to be more research on PM filter effectiveness in reducing emissions (retrofits for diesels). Since the workshop was held, there has been much experience gained with school bus retrofits, though.

C. PRIORITY RESEARCH RECOMMENDATIONS

Sound strategies to manage air toxics risks will require an improved understanding of relationships among air toxic sources, the atmospheric processes that transport and transform them, and the ambient concentrations to which people are exposed. Technical materials or computer models based on such understanding will provide State and local agencies with the tools necessary to determine how best to control emissions in ways that (1) focus on the pollutants and geographic areas with the highest risks and (2) identify cost-effective strategies for reducing population exposure to those pollutants.

Proposed Programmatic Initiatives

Programmatic Initiative P11: Performing studies of potential control measures and their cost effectiveness is predicated on there being observed harmful levels which can be ameliorated by reducing motor vehicle emissions. Therefore, any programmatic initiatives to reduce air toxic emissions need to be informed by research on existing ambient air toxic concentrations, estimated associated risks, and the mobile source contributions to them.

This research then focuses the control strategy evaluations on area-wide versus localized occurrences of high air toxic concentrations, specific air toxic compounds, and certain vehicle types.

While there are significant uncertainties in what is known about current air toxic concentrations, their variability, associated risks, and mobile source contributions, there are existing and ongoing urban scale studies that can be used to develop initial assessments of key factors. This includes EPA's Mobile Source Air Toxics Study, recently completed or ongoing EPA-sponsored efforts to evaluate air toxics concentrations in Houston, Texas, Portland, Oregon, and Philadelphia, Pennsylvania, as well as an FHWA-sponsored effort to examine EPA Supersite measurements along with nearby traffic data to examine relationships between traffic volumes and air toxic concentrations, as well as the Multiple Air Toxic Exposure Study-II, and recently initiated Multiple Air Toxic Exposure Study-III studies.

Priority program areas for research to provide more information to the transportation community about air toxic control strategies/measures are described below. These include a near-term need for adding information about potential air toxic emission benefits or disbenefits to the control measure studies being performed to support 8-hour ozone or $PM_{2.5}$ SIPs, the need for more information about how to reduce emissions from the non-road construction equipment used in highway projects, and a longer-term need to research highly cost effective measures for reducing transportation-related air toxic emissions.

Sub-Area 1: Research the expected multi-media MSAT benefits or dis-benefits of the control measures that are expected to be the leading candidates for adoption in upcoming 8-hour ozone and $PM_{2.5}$ nonattainment plans.

The next set of control strategy decisions that individual areas will face is for attainment of 8-hour ozone standards and $PM_{2.5}$ standards. Before these decisions/selections are made, it would be informative to have estimated air toxic emission changes, so that strategies can be selected with full knowledge of likely air toxic emission benefits or disbenefits. This air toxic information does not have to be quantitative, it can be directional changes in situations where quantitative information is not available.

The schedule for when the control strategy information will be needed is probably most directly related to the State Implementation Plan (SIP) submittal schedule for the 8-hour ozone NAAQS. Designations for attainment and nonattainment areas were made by April 15, 2004. On May 28, 2003, EPA issued the proposed rule that outlines the steps areas would have to take to meet the new standard. In this proposal, EPA is seeking comment on options for how States should apply ozone control requirements when developing their SIPs.

Part of the scope of work for this project would be to enumerate the appropriate/needed metrics for evaluating measures. Such metrics would be included in any control measure evaluation regardless of whether it affects engine technology, fuel characteristics, in-use vehicle programs, or travel management. Some suggested metrics are listed earlier in this chapter.

Estimated Cost: $150,000
Duration: 1 year

Sub-Area 2: Determine the emissions and potential emission reductions for measures that could be applied to mitigate the emissions from non-road construction equipment that is typically used in constructing/widening highways.

Non-road construction equipment control measure assessments (and those for any other non-road equipment of interest) need to provide more information about the different applications of such equipment, and how the effectiveness of controls might differ according to those applications. With the many applications of non-road equipment, they are more challenging to understand.

A project might include observations/measurements of activity at existing highway construction sites to develop population estimates and activity patterns by equipment type. PEMS are one option for measuring activity information, although the technology for measuring on-board emissions/activity may not yet be commercial for non-road CI engines. Evaluations should include studies of different-sized projects to allow transportation agencies to develop likely emissions and mitigation options by project size.

This program area study should address the potential emission benefits of clean contracting for construction projects to encourage emission reductions from non-road diesel equipment. Can contracts include requirements for cleaner than Federally mandated equipment, or is providing bonus evaluation points a better approach? Evaluate how approaches to such contracting have been applied in practice thus far, and whether these have been successful. Are there instances where the additional costs to use clean (low sulfur) diesel, or to retrofit engines, have been paid, or subsidized by FHWA or other agencies? Are there significant limitations on what can be required of construction contractors due to public contracting or other laws?

Estimated Cost: $100,000
Duration: 9 months

Sub-Area 3: Research the effectiveness of control strategies on toxics. This initiative specifically focuses on identifying the most cost effective control strategies available for reducing air toxic emissions. What would provide the best and most cost effective results where the most cost effective air toxics control strategies could differ from the most cost effective criteria pollutant options?

There are a number of potential needs for information about the effectiveness and cost of control strategies for reducing MSATs. One might be to mitigate a situation in an urban area where estimated risks resulting from air toxics exposure in some parts of the city were unacceptably high. Transportation and air pollution agencies would need information about the control strategies likely to provide the most cost effective reductions of the MSATs of concern. A second need would be for a project-level situation (a practical example is adding one or more new lanes to an existing freeway) where there might be a need to reduce near roadway exposures to specific MSATs. The types of air toxic mitigation measures for project-level situations could be considerably different from those to be applied in an urban-scale mitigation effort.

Emission reduction strategies should differentiate vehicle model year/technology groups and PM characteristics whenever possible. This will be especially important when EPA's heavy-duty vehicle and diesel fuel sulfur limits are implemented. In situations where diesel PM emission reduction strategies are being evaluated, these results need to define the expected emission reductions by model year/technology group and fuel characteristics. Another potential area for research is whether roadway design elements hold any promise for air toxics mitigation. Roadway design elements could include noise walls, depressed/elevated sections, landscaping, etc.

Estimated Cost: $150,000
Duration: 1 year

5.0: CONCLUSIONS

Figure 3 summarizes the priority research recommendations from the May 12, 2003 workshop. 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. Research to help understand the contribution of transportation sources to air toxics is emphasized because this is a critical need. The blueprint shows how the research priorities in this plan seek to answer the transportation community's critical research questions.

FHWA acknowledges that the technical complexity and broad scope of the projects contained in the workplan will require a coordinated, multi-agency approach. The multi-disciplinary range of projects outlined in Figure 3 will likely require coordination among FHWA, State Departments of Transportation, and metropolitan planning organizations, as well as involvement by academic and applied research organizations as well as State and Federal air quality agencies, and industry groups. 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.

Figure 4 displays information about the expected staging of the research initiatives and related sub-areas and their relationships to each other. For each programmatic initiative, the *timing* is identified as either early, intermediate, or late to indicate the possible relative ordering with which this research might be pursued. For each programmatic initiative, Figure 4 also lists the *related research* areas. This indicates situations where one programmatic initiative intersects with others. Similarly, Figure 4 also indicates where a programmatic initiative, or a sub-area, is expected to be *informed by* research efforts that would be expected to be performed at an earlier stage in the research process.

Workshop Sessions: Characterization	Ambient Monitoring	Analysis	Control Measures/Strategies
P1: Fund research for improvements in emission measurement technology that are needed to measure the lower emission levels of air toxic compounds expected with improved emission control technologies and lower sulfur fuels expected in the 2005 to 2007 time frame.	P4: Fund research to identify what additional monitoring information needs to be collected to enhance existing monitoring networks to meet transportation sector needs.	P7: Develop a protocol on the appropriate methods to be used in emissions modeling, atmospheric dispersion modeling, and exposure modeling at varying spatial scales applicable to transportation projects (e.g., project-level, urban scale).	P11: Performing studies of potential control measures and their cost effectiveness is predicated on there being observed harmful levels which can be ameliorated by reducing motor vehicle emissions. Therefore, any programmatic initiatives to reduce air toxic emissions need to be informed by research on existing ambient air toxic concentrations, estimated associated risks, and the mobile source contributions to them.
P2: Design and initiate experiments to examine near roadway concentration patterns (especially for highways). There is evidence that air toxic concentrations near roadways are appreciably higher than those 300 to 500 meters or more downwind. Experiments to examine these gradients are likely to assist in steering future research toward examining pollutant emissions, fate, and transport.	P5: Fund research to understand existing, and develop new, practical tools for local and regional organizations to assess MSAT impacts and evaluate results.	P8: Conduct research and develop methods on variability and uncertainty analysis of on-road emission estimates. Identification of key sources of uncertainty can be used to target resources to reduce uncertainty.	*Sub-Area 1:* Research the expected multi-media MSAT benefits or dis-benefits of the control measures that are expected to be the leading candidates for adoption in upcoming 8-hour ozone and $PM_{2.5}$ nonattainment plans.
P3: Conduct research to expand the available set of information about air toxic emissions and activity patterns for the on-road and off-road vehicle types with the most significant contributions to ambient air toxic concentrations of concern and the greatest uncertainty in their emission estimates. Two sub areas within this programmatic initiative have been identified as likely first priorities for study.	P6: Determine whether the existing knowledge about transportation air toxics can be enhanced by further examining current data.	P9: Develop improved inputs for emissions and receptor modeling. Some improvements are expected via incorporating already available data. Gap filling research may be needed in selected topics.	*Sub-Area 2:* Determine the emissions and potential emission reductions for measures that could be applied to mitigate the emissions from non-road construction equipment that is typically used in constructing/widening highways.
Sub-Area 1: There are needs to investigate the differences in fleet populations and travel characteristics for important sub-categories of trucks. These sub-categories can be defined as: long-range fleet, regional fleet (300 to 500 miles), and local fleet (primarily delivery trucks).		P10: Research the atmospheric chemistry of mobile source air toxics. Incorporate this information into distributed modeling tools. This area could be considered a sub-area of P7 above.	*Sub-Area 3:* Research the effectiveness of control strategies on toxics. This initiative specifically focuses on identifying the most cost effective control strategies available for reducing air toxic emissions. What would provide the best and most cost effective results where the most cost effective air toxics control strategies could differ from the most cost effective criteria pollutant options?
Sub-Area 2: For off-road engines/vehicles, diesel-powered construction equipment is a major emissions source (of PM) with large uncertainties in emission estimates.			

Figure 3. Priority Mobile Source Air Toxic Research Areas

Characterization	Ambient Monitoring	Analysis	Control Measures/Strategies
P1: Measurement Technology Improvements	**P4: Network Enhancements**	**P7: Modeling Protocols**	**P11: Where Needed?**
Timing: Early	Timing: Early or Intermediate	Timing: Early	Timing: Early
Related Research: N/A	Related Research: P1	Related Research: N/A	Related Research: P3
Informed by: N/A	Informed by: N/A	Informed by: P10	Informed by: N/A
P2: Near Roadway Experiments	**P5: Tools for State and Local Agencies**	**P8: Uncertainty Analysis**	**Sub-Area 1: SIP Related Benefits**
Timing: Early	Timing: Early	Timing: Intermediate	Timing: Intermediate
Related Research: P7 and P10	Related Research: N/A	Related Research: N/A	Related Research: N/A
Informed by: N/A	Informed by: P2	Informed by: N/A	Informed by: P11
P3: Emissions/Activity Patterns by Vehicle Type	**P6: Data Analysis**	**P9: Improved Model Inputs**	**Sub-Area 2: Non-Road Measures**
Timing: Early	Timing: Early or Intermediate	Timing: Intermediate	Timing: Late
Related Research: P8 and P11	Related Research: P11	Related Research: N/A	Related Research: P3
Informed by: N/A	Informed by: N/A	Informed by: All	Informed by: P11
Sub-Area 1: Trucks		**P10: Research Air Chemistry**	**Sub-Area 3: Focused Air Toxic Measures**
Timing: Intermediate		Timing: Early	Timing: Late
Related Research: N/A		Related Research: P2	Related Research: N/A
Informed by: P2 and P11		Informed by: N/A	Informed by: P11
Sub-Area 2: Diesel Construction Equipment			
Timing: Late			
Related Research: P11 Sub-Area 2			
Informed by: P11 and P2			

Figure 4. Research Area Relationships and Timing

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Appendix B

FHWA Air Toxics Workshop (May 12, 2003) – Breakout Session Organization

SESSION 1 (11 a.m. – 12 noon)			
Room 706	**Room 806**	**Room 906**	**Room 1006**
Ambient Monitoring	**Characterization**	**Analysis**	**Control Strategies**
Byers (FAA)	Watson (Hillsborough Co.)	Koerber (LADCO)	Wayson (Volpe)
Hafner (STI)	Zamurs (NY DOT)	Baldauf (EPA- OTAQ)	Block (NESCAUM)
Jordan (TX DOT)	Billings (Wasatch Front)	Berg (Southeastern MI)	C. Bailey (EPA- OTAQ)
Pepple (HGA Council)	Kircher (Puget Sound)	Brady (CALTRANS)	Bingham (UT DOT)
Gilroy (Puget Sound)	Valentinetti (VT DEQ)	Claggett (FHWA)	Brecher (Volpe)
R. Cook (EPA- OTAQ)	Kimbrough (EPA- ORD)	Scheffe (EPA- OAQPS)	Niemeier (UC- Davis)
Graham (Env. Canada)	French (EMA)	B. Bailey (CRC)	Vescio (ESP)
Fitz (UC-Riverside)	Gertler (DRI)	Bortnick (Battelle)	Chan (EFEE)
Lax (API)	Heishman (Ind. Consultant)	Clark (WVU)	Lawson (NREL)
Robinson (Carnegie- Mellon)	High (RSG)	Eisinger (Sonoma Tech)	Hulsey (Sierra Club)
Carr (ICF)	Full (ESP)	Nizich (EPA-OAQPS)	Wang (Argonne)
Lenox (ORNL)	Frey (NC State University)		
	Heiken (AIR)		

SESSION 2 (1 p.m. – 2 p.m.)			
Room 706	**Room 806**	**Room 906**	**Room 1006**
Ambient Monitoring	**Characterization**	**Analysis**	**Control Strategies**
French (EMA)	Graham (Env. Canada)	Wayson (Volpe)	Lenox (ORNL)
Full (ESP)	B. Bailey (CRC)	Kircher (Puget Sound)	Koerber (LADCO)
Scheffe (EPA-OAQPS)	Niemeier (UC- Davis)	Pepple (HGA Council)	Kimbrough (EPA- ORD)
C. Bailey (EPA- OTAQ)	Robinson (Carnegie Mellon)	Vescio (ESP)	R. Cook (EPA-OTAQ)
Block (NESCAUM)	Baldauf (EPA- OTAQ)	Frey (NC State University)	Bortnick (Battelle)
Valentinetti (VT DEQ)	Jordan (TX DOT)	Chan (EFEE)	Berg (Southeastern MI)
Bingham (UT DOT)	Wang (Argonne)	Gertler (DRI)	Carr (ICF)
Zamurs (NY DOT)	Eisinger (Sonoma Tech)	Heiken (AIR)	High (RSG)

SESSION 2 (1 p.m. – 2 p.m.)			
Ambient Monitoring	**Characterization**	**Analysis**	**Control Strategies**
Billings (Wasatch Front)	Fitz (UC- Riverside)	Brecher (Volpe)	Lax (API)
Brady (CALTRANS)	Lawson (NREL)	Watson (Hillsborough Co.)	Heishman (Ind. Consultant)
Nizich (EPA-OAQPS)	Clagget (FHWA)	Hulsey (Sierra Club)	Clark (WVU)
	Byers (FAA)	Gilroy (Puget Sound)	Houk (FHWA)
	Hafner (STI)		

SESSION 3 (2:15 p.m. – 3:15 p.m.)			
Ambient Monitoring	**Characterization**	**Analysis**	**Control Strategies**
Wayson (Volpe)	Gilroy (Puget Sound)	Wang (Argonne)	Heiken (AIR)
Clagget (FHWA)	R.Cook (EPA- OTAQ)	Zamurs (NY DOT)	Eisinger (Sonoma Tech)
Brecher (Volpe)	Lax (API)	Graham (Env. Canada)	Scheffe (EPA- OAQPS)
Watson (Hillsborough Co.)	Lenox (ORNL)	Carr (ICF)	Jordan (TX DOT)
Koerber (LADCO)	Clark (WVU)	Billings (Wasatch Front)	Brady (CALTRANS)
Kimbrough (EPA- ORD)	Berg (Southeastern MI)	Valentinetti (VT DEQ)	Fitz (UC- Riverside)
Frey (NC State University)	Block (NESCAUM)	French (EMA)	B. Bailey (CRC)
Niemeier (UC- Davis)	C. Bailey (EPA- OTAQ)	Heishman (Ind. Consultant)	Pepple (HGA Council)
Hulsey (Sierra Club)	Bingham (UT DOT)	High (RSG)	Baldauf (EPA-OTAQ)
Bortnick (Battelle)	Vescio (ESP)	Full (ESP)	Nizich (EPA-OAQPS)
Gertler (DRI)	Nizich (EPA-OAQPS)	Robinson (Carnegie Mellon)	Kircher (Puget Sound)
Houk (FHWA)		Lawson (NREL)	Chan (EFEE)
		Byers (FAA)	
		Hafner (STI)	

Appendix C
Bibliography

This appendix lists recent, relevant air toxics research papers and reports submitted by the workshop participants at the time of the workshop. These research works are not included in the companion literature review that was prepared and distributed to participants prior to the workshop.

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