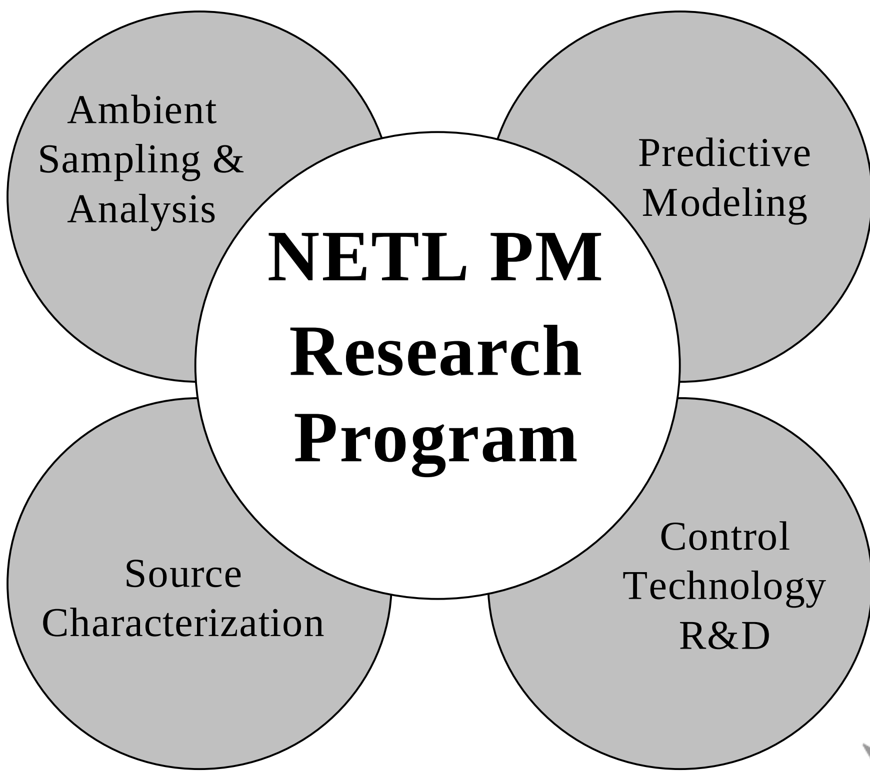
# U.S. Department of Energy National Energy Technology Laboratory

# Five Year Research Plan on Fine Particulate Matter in the Atmosphere

# FY2001-FY2005



# TABLE OF CONTENTS

## TABLE OF CONTENTS
(Continued)

# LIST OF TABLES

**LIST OF FIGURES**

# I. INTRODUCTION

## A. Background

In response to growing concerns over fine particulate matter (PM) emitted into the atmosphere from anthropogenic sources, the Department of Energy's (DOE) National Energy Technology Laboratory (NETL) has initiated a major research program to clarify the options for reducing the PM contribution from energy production, especially from coal-fired power plants. The program builds on a history of NETL air pollution emission control development, and the community experience of previous investigations of source-receptor relationships between power plant emissions and ambient air quality (e.g., Hidy, 1994). This report is a 5-year research plan that extends the early description of NETL's program (FETC, 1998), and outlines how NETL (formerly FETC) will continue this program to further the scientific understanding of the origins and characteristics of ground level aerosols of human origin, while adding to the national portfolio of emission reduction options.

The NETL program is highly leveraged with parallel activities supported by national and regional stakeholders, including the Environmental Protection Agency (EPA), regional, State, and local air quality management organizations, and the electric utility and coal production industries. NETL also participates in several U.S. Government interagency research-planning groups and regional public/private research-planning groups to ensure that NETL research is strategically designed to contribute to the needs of the larger scientific community. These strategic planning groups include (1) the Air Quality Research Subcommittee (AQRS), under the National Science and Technology Council's Committee on the Environment and Natural Resources (CENR) that consists of 14 member departments and agencies of the U.S. Government and (2) the North American Research Strategy for Tropospheric Ozone (NARSTO), a public/private partnership whose membership spans government, industry, the utilities, and academia throughout North America. Both of these organizations have developed strategic plans for scientific research on airborne particulate matter, and the NETL research program described in this document has been developed to contribute to the common goals and objectives set forward in these research plans (Committee on the Environment and Natural Resources Air Quality Research Subcommittee, 1998; NARSTO, 2000). The NETL research program gives particular emphasis to the mid-Atlantic and Appalachian regions because they have a major concentration of coal-fired power plants, and are upwind of the largest regional complex of urban areas in the United States.

Improved scientific knowledge of atmospheric PM is especially urgent in light of the Environmental Protection Agency's (EPA's) recently adopted National Ambient Air Quality Standard (NAAQS) for fine particulate matter, $PM_{2.5}$ (particles with aerodynamic mean diameters at or below 2.5 µm). This standard supplements the previous standard for airborne particles at or below 10 micrometers in aerodynamic diameter ($PM_{10}$), and EPA's new regulations addressing the reduction of regional haze. Currently, the full implementation of the $PM_{2.5}$ standard is delayed pending a judicial review. The process of formulating the $PM_{2.5}$ standard is being examined by the U.S. Supreme Court after a lower court found that Congress over-delegated its responsibility to EPA in the standard setting process. EPA is also reviewing the underlying scientific basis for the $PM_{2.5}$ standard as part of its normal 5-year NAAQS administrative cycle. Even though these reviews are in progress, the expectation is that reduction in $PM_{2.5}$ concentrations will be required to levels at or near the specified standards (Table 1) within the next decade.

The research program for fine PM in the atmosphere at NETL began in 1998 when Congress appropriated funds to the DOE Office of Fossil Energy (DOE-FE) to be directed to NETL for this purpose. The stated Congressional goal of this program was to … "ensure that the best science and technology are available for any future regulatory decision-making related to the health and environmental impacts of ambient fine PM and regional haze."

**Specific Goals of the NETL 5-Year PM Program**

- *Relate emissions from energy production to ambient PM concentrations.*
- *Inform decision-makers about energy management options for achieving $PM_{2.5}$, visibility, and related air quality standards.*

**TABLE 1. National Ambient Air Quality Standards for Airborne Particles**

| Category | National Standard or Objective | Comments |
|---|---|---|
| Fine Particulate Matter ($PM_{2.5}$) | 65 µg/m$^3$ in 24 hours; not to be exceeded in 3-year average of 98$^{th}$ percentile spatially averaged across designated area. | First stage of implementation proceeding; standard on hold pending judicial resolution. |
| Fine Particulate Matter ($PM_{2.5}$) | 15 µg/m$^3$ annual arithmetic mean, spatially averaged | First stage of implementation proceeding; standard on hold pending judicial resolution. |
| Suspended Particles ($PM_{10}$) | 50 µg/m$^3$ annual arithmetic average | Existing annual standard is supplemented by 24-hour $PM_{10}$ standard of 150 µg/m$^3$ remains pending resolution of $PM_{2.5}$ standard. |
| Visibility Impairment | No standard; prevention of significant deterioration and remedy for existing anthropogenic haze in Class I areas | EPA is proceeding with states to plan for PM emission reductions to achieve reduction of man-made regional haze down to natural background levels over the next decade. |

The overall goals of the NETL fine PM program are to:

- Provide the applied science needed to quantitatively relate the emissions from energy production (and use), particularly from coal-fired power plants, to ambient air PM concentrations at downwind receptors, and
- Inform decision makers about management options applicable to coal-fired power generation to achieve the national PM standards, integrating new knowledge of the origin and

characteristics of airborne particles, their health and environmental effects, and the outlook for new or improved emission control technologies.

To address these two goals, the NETL program was launched in 1998 with four components:

1. Application of advanced methods for using ambient PM data to determine local and regional source-receptor relationships for a complex of multiple power plant, urban and industrial sources;

2. Enhancement of the ability to chemically characterize PM and PM precursor source emissions from power production, including the ability to evaluate the significance of in-plume processes on PM related atmospheric chemistry;

3. Establishment of the relationships between the power production contributions to $PM_{2.5}$ and environmental effects through linkages with human exposure and visibility impairment; and

4. Exploration of new opportunities for PM and PM precursor emission reductions using advances in the research and development of control technology.

**Components of the NETL Program**

- *Ambient Sampling and Analysis.*
- *Characterization of Emissions and Plumes.*
- *Source-Receptor Modeling and Evaluation.*
- *Emissions Control Technology R&D.*

The urgency of the congressional mandate required NETL to move quickly in 1998 to organize and implement elements of the program, especially the ambient measurements. With the early initiation, DOE began planning for continued development of the program. In doing so, DOE requested the assistance of the National Research Council (NRC) to review the scope and the future directions of the program. A NRC panel was formed in 1999 to conduct this review. Its report "Review of DOE's Office of Fossil Energy's Research Plan for Fine Particulates" was published in October 1999 and a summary of the recommendations of the panel can be found in Appendix A. One important recommendation of this panel suggested preparing a 5-year research plan as a guide for the execution of the program. This plan has been prepared in response to this NRC recommendation.

B. Outlook for PM and the Environment

Particulate matter in the lower atmosphere has long been a concern because of its identification with adverse human health effects, as well as its contribution to environmental effects, including visibility impairment, and acid deposition. This concern led to the promulgation of a national ambient air quality standard (NAAQS) for particulate matter through the Clean Air Act Amendments of 1970 (CAAA, 1970). Subsequently the standard evolved in 1986 to focus on $PM_{10}$, and in 1997 on $PM_{10}$ and $PM_{2.5}$. The current PM standards are listed in Table 1. These are based primarily on the risk of adverse human health effects and a secondarily other environmental factors such as visibility impairment. Fine particles contribute an important component to the scattering of light, which in turn restricts visibility. Other environmental concerns relevant to PM are the apparent persistence of the ecological effects of acidity in North American precipitation (acid rain), and the influence of PM on the earth's radiation balance (effects on climate alteration). There also are a number of hazardous air pollutants found in PM which are listed for reductions in the ambient air.

The basis for the NAAQS historically has relied mainly on epidemiological studies of human health effects. Attempts to identify a "toxicological component" in atmospheric particles have been unsuccessful to date. Thus, the standard remains non-specific chemically, but identified with mass concentrations differentiated by particle size. The ambiguities in studies associating health effects with PM have continued to create controversy, both in terms of the agent(s) responsible for such effects, and the level of human exposure to ambient air given the indoor-outdoor activities of the public. To substantially improve the knowledge of ambient PM in relation to health effects, Congress has requested that EPA, assisted by the National Research Council (1998), launch a major research program to elucidate the origins and characteristics of $PM_{2.5}$ which are relevant to the health concerns identified earlier.

Based on the persistence of epidemiological study results linking PM in ambient air to human health effects, the nation has committed to major reductions in ground level PM concentrations to reduce the risk of public exposure to this pollutant. In addition, under the Clean Air Act Amendments of 1977 and 1990, the nation has committed to the protection of air quality in pristine areas, including provisions for improvement of visibility over wide regions of the United States. Given the long standing qualitative linkage between energy production, ambient PM levels, and visibility impairment, an aggressive component of the current national PM research strategy includes investigation of methods to establish quantitative relationships between these variables.

Parallel to the NAAQS process, the CAAA (1977) and CAAA (1990) addressed the problem of the release of airborne toxic compounds, hazardous air pollutants (HAPs). Currently there are more than 189 of these chemicals listed; many of them are in the condensed phase, associated with particles. Since a number of HAPs are identified with fossil fuel combustion and are contained in particle emissions from energy production (Table 2), consideration of management of these components of PM are also relevant. Of particular concern at present are mercury compounds from coal combustion. This category is believed to be the major mercury source in the U.S. at the present time. The concern for the HAPs adds another important dimension to the reduction of airborne particle concentrations.

Another regulatory driver that may affect airborne fine particle management strategies is EPA's Toxic Release Inventory (TRI) Program. Under TRI, individual industrial facilities, including electric utilities, must report the releases of more than 600 designated toxic chemicals to the environment (above a certain threshold activity level for each chemical). Many of the same chemicals that are listed as HAPs are also listed as reportable under TRI, and have been associated with coal combustion processes (Table 2). EPA maintains the TRI release information in a

**TABLE 2. Hazardous Air Pollutants (HAPs) and Toxic Release Inventory (TRI) Compounds Identified With Coal Combustion (EPA, 1998)**

| Compound | Category |
|---|---|
| Arsenic | HAPs, TRI |
| Beryllium | HAPs, TRI |
| Cadmium | HAPs, TRI |
| Lead | HAPs, TRI |
| Manganese | HAPs, TRI |
| Mercury | HAPs, TRI |
| Nickel | HAPs, TRI |
| Hydrogen Chloride | HAPs, TRI |
| Hydrogen Fluoride | HAPs, TRI |
| Acrolein | HAPs |
| Dioxins/Furans | HAPs, TRI |
| Formaldehyde | HAPs |
| Sulfuric Acid | TRI |
| Copper | HAPs, TRI |
| Chromium | HAPs, TRI |
| Zinc | TRI |
| Barium | TRI |

publicly accessible database. Although TRI does not mandate reductions in releases, the public knowledge of the quantities released typically results in considerable pressure on industry to reduce emissions of the listed chemicals, particularly airborne emissions.

Assuming that improvements in knowledge will reinforce the basis for the current mass concentration standard and refine the linkages between fine PM, visibility, and HAPs, the next step will focus on the knowledge necessary to reduce ambient $PM_{2.5}$ concentrations through new emission control programs. Historical studies have indicated that much of the fine particle content of the atmosphere derives from the products of fossil fuel combustion (EPA, 1999b). Coal combustion produces direct emissions of "primary" (solid and liquid) particles, and gases which react chemically in the air to form "secondary" particles. The pollutant gases of concern include sulfur dioxide, nitrogen oxides, and certain carbon-containing compounds. Chemical characterization of ambient $PM_{2.5}$ samples collected to date suggests that secondary particles containing sulfates and/or nitrates constitute a significant component of $PM_{2.5}$ mass in many areas of the U.S. More importantly, sulfate has often been identified as the largest single constituent chemical of $PM_{2.5}$, on a mass basis, in the east and southeast. Coal combustion is known to be a primary source of sulfur dioxide, an important precursor for particulate sulfate. Therefore, reductions in sulfur dioxide from coal combustion sources would almost certainly be considered as a part of any management strategy to reduce ambient $PM_{2.5}$ mass.

However, because of the complexity of atmospheric conversion and deposition processes, the relationship between sulfur dioxide emissions and ambient sulfate particle concentrations may be highly non-linear, i.e., reductions in $SO_2$ emissions may not translate into equivalent reductions in sulfate particles and $PM_{2.5}$ mass. Furthermore, research to date has been unable to establish a clear mechanism by which sulfate or nitrate salts cause adverse human health effects, so reductions in $PM_{2.5}$ mass resulting from reductions in $SO_2$ and $NO_X$ emissions may not have the desired effects on human health. Therefore, to be cost effective, emission control technology and management strategies must take advantage of ongoing research in atmospheric PM formation processes, as well as toxicology studies that are attempting to find the $PM_{2.5}$ components that have the most direct link to adverse human health effects.

The NETL research program provides one element of the current national research effort to inform decision-makers about effective methods for implementing airborne PM reductions, and reductions in key co-pollutants such as ozone and mercury. The NETL program is one of many initiated or expanded in 1998; it fulfills a niche in the national activities and is appropriately coordinated with other programs to ensure its effectiveness in achieving its stated goals. While the program does not address directly human health effects, it has key linkages to ongoing human health studies considered high priority in Congress' and EPA's interest in the PM problem. If NETL is successful in completing its stated goals, key decision-makers within EPA and state and regional air quality planning organizations will be provided with a body of information that will help guide the implementation of emission control strategies for compliance with the NAAQS $PM_{2.5}$ and regional haze requirements.

## II. OVERVIEW OF THE PROGRAM

The NETL $PM_{2.5}$ program conceptually was designed to address several key elements of a broad national action plan for the management of $PM_{2.5}$, as indicated in Figure 1.

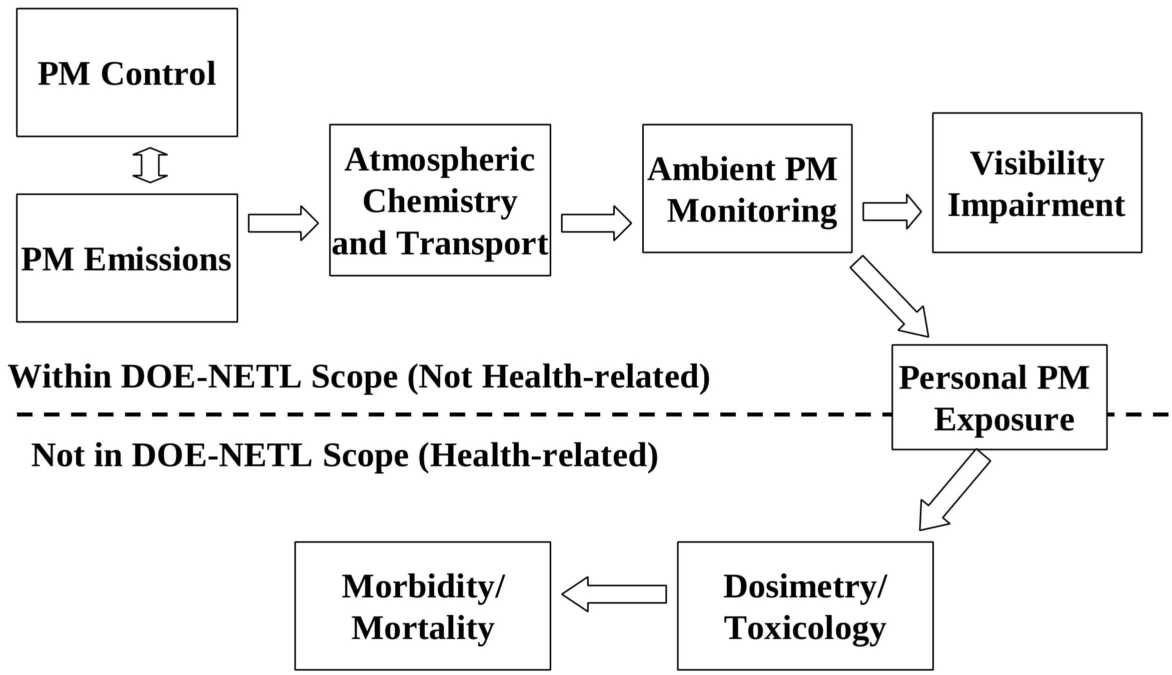



**FIGURE 1. A Logic Diagram of DOE-NETL's Role in National Program Elements for Fine Particle Research**

In developing the design of the NETL program, the importance of advancing the methodology for estimating the contributions of energy production sources to pollution at receptors on multiple spatial and temporal scales was recognized. Over the past decade, considerable progress in methods development has occurred for single, isolated coal-fired power plants in several geographical locations, especially in the western U.S. However, the more difficult problem of quantitative source attribution where many sources exist and their contributions intermix remains largely unresolved. To address this problem, NETL has chosen to focus on the upper Ohio River valley as the region of interest because of its high concentration of large coal-fired power plants whose emissions are intermingled with one of the largest regional urban complexes in the U.S. This region represents an ideal "field laboratory" to apply advanced methods for establishing a combination of local and regional source-receptor relationships, providing a severe "stress test" for these methods. The study of $PM_{2.5}$ in a region that is believed to be heavily influenced by power plant emissions will also provide guidance for the emission reduction technology performance needed to address PM standards. If advanced modeling and control methodologies are able to substantially improve the ability to efficiently and selectively manage power plant sources in this region, then widespread application of these principles will be a critical aid to address management options nationwide where pollution from large energy sources are involved.

The upper Ohio River valley region also is one of concern for exposure to coal combustion related HAPs. Over the next several years, it is expected that increasing attention will be given to the reduction of these compounds in air and in other media. Within the resources available, the NETL program will investigate aspects of the HAPs, especially mercury. Such studies will be planned around interest expressed, for example, in EPA's urban toxics program (e.g., U.S. EPA, 1999b).

Major advances in air quality modeling for $PM_{2.5}$ are expected in the next 5 years, and important advanced emission control technologies are being developed in the same timeframe. The NETL program as currently envisaged will provide a key and unique evaluation of these two elements that will come to completion in a timeframe shown in Figure 2. This schedule is compatible with the proposed timing for state and local implementation of $PM_{2.5}$ pollution reduction strategies. The regulatory schedule for addressing specifically the reduction of HAPs is somewhat uncertain. However, concern is already being raised for mercury contamination, and actions at the state level are under way through the route of water quality improvement specified by the total maximum daily loading (TMDL) for mercury called for under the Clean Water Act. Despite these early actions, it is anticipated that the schedule for addressing HAPs regionally will lag that of $PM_{2.5}$. Thus the planning for HAPs studies is considered a lower near-term priority for the NETL program over the next 2 years. However, if attention increases on reduction of the HAPs, the NETL program could shift resources, or continue beyond 5 years to account for needs in this area relevant to fossil fuel combustion, as indicated in Figure 2.

Several scientific and managerial challenges exist with respect to the implementation of the research plan outlined in this document. From a scientific standpoint, the plan relies on the ability of external researchers to identify the specific components of PM that result in adverse health effects, and to develop scientifically valid models for predicting the evolution of PM as it moves from sources to ambient receptors. Advancements in emissions characterization from a wide range of sources, some of which will be addressed under the NETL program, will also be required. The main managerial challenge will be to define the scope and goals of the individual projects under this program such that they will produce results that support the overall program goals described in Section I. A considerable amount of interaction among internal and external research teams will be required, and maintaining the required coordination and information flow will be one of the top priorities of NETL. Funding levels are also an obvious constraint that must be appropriately managed. The program outlined here represents a level of effort could be achieved over 5 years, with the scope and pace of the work being dictated by actual funding levels.

## A. Program Components

As shown in Figure 2, NETL's activities in fine PM research are designed to address four primary program components: (1) ambient air sampling and analysis, (2) characterization of emissions and plumes, (3) source-receptor modeling and evaluation, and (4) research and development of advanced emission control technologies relevant to energy production. To date, the NETL

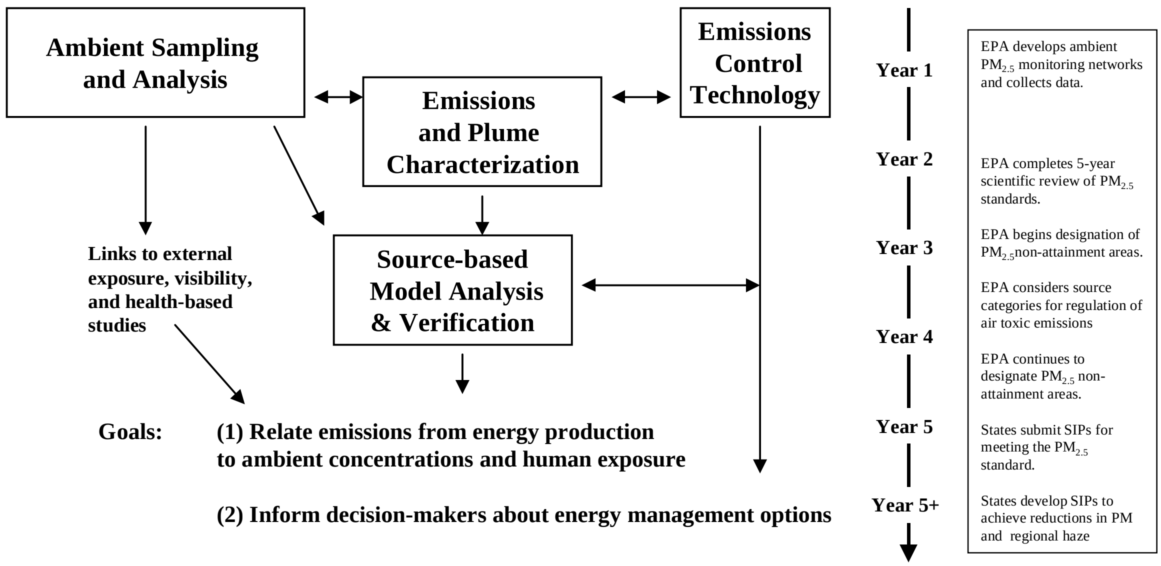



**FIGURE 2. Conceptual Schedule for NETL Fine PM Program in Relation to Projected Regulatory Schedules**

program has focused mainly on the establishment of two major projects for ambient air measurements (Component 1). The first of these is the Upper Ohio River Valley Project (UORVP) and the second is the Steubenville (OH) Comprehensive Air Monitoring Project (SCAMP). A comprehensive in-house ambient PM monitoring station has also been established at NETL's Pittsburgh, Pennsylvania, laboratory to supplement these studies and to serve as a proving ground for PM instrumentation. Other NETL activities have involved the building of external stakeholder support by cost-sharing of ongoing initiatives that support NETL's main program components, such as TVA studies of the chemistry of coal-fired power plant plumes and regional visibility impairment in the southeast (Components 2 and 3), ambient PM and human exposure studies in Atlanta, Georgia (ARIES project) and in the southeastern U.S. (SEARCH project, Components 1 and 3), and visibility impairment along the U.S. - Mexico border (BRAVO project, Components 1 and 3). NETL is also supporting various PM emission control technology studies as an extension of its prior R&D program to reduce emissions of $NO_X$ and air toxics.

As the program continues, less emphasis will be placed on Component 1; more emphasis will be placed on source characterization (Component 2) and the analysis, interpretation, and application of the data acquired under the intensive field monitoring projects (Component 3). A key element in the program will be the application of advanced methods of establishing the contribution of energy sources to $PM_{2.5}$ using theoretically based, source-oriented models, and measurement-based receptor models (e.g., Hidy, 1994). The development of emission control technology options (Component 4) will be assessed, modified, and expanded or reduced as necessary to meet the needs identified in the modeling studies. Linkages with external stakeholders will be strengthened and expanded throughout the program.

Each of the four program components has a set of specific objectives that are being addressed by current and future projects. These objectives are summarized below:

- Component 1 -- Application of advanced methods for using ambient air quality data to determine local and regional source-receptor relationships.

  - Complete the ambient air quality measurements in the ongoing UORVP and SCAMP efforts.

  - Analyze and interpret the UORVP and SCAMP data using receptor-based modeling techniques.

  - Examine the implications of the UORVP and SCAMP data for the influence of regional versus local energy production sources.

- Component 2 -- Chemical characterization of primary PM emissions and PM precursor emissions, and in-plume processes associated with energy production sources.

  - Complete current project to characterize primary PM emissions from experimental low-$NO_X$ burner.

  - Collect and evaluate available state and Federal emissions inventory data to identify key local and regional sources of energy production emissions relevant to the UORV/mid-Appalachian environment, with the Pittsburgh metropolitan area and Steubenville as the target receptors.

  - Select and characterize the chemical nature of key sources of energy production emissions relevant to establishing source receptor relationships in the UORV/Mid-Appalachian region.

  - Integrate the results of TVA in-plume chemistry experiments and other plume studies into the interpretation of the UORVP results.

- Component 3 -- Evaluation of the power production contributions to ambient $PM_{2.5}$ levels and to their influence on human exposure and environmental effects.

  - Evaluate the applicability of source-based and receptor-based models for determining how reductions in emissions from energy production sources will affect $PM_{2.5}$ concentrations and chemical composition at selected receptor sites in the UORV region.

  - Use the UORVP and SCAMP data to estimate the potential contribution of energy production sources to human exposure in the Steubenville area, and infer the exposure levels expected in the Pittsburgh metropolitan area.

  - Interpret the SCAMP results in the light of other $PM_{2.5}$ studies, including the results from the 1999 ARIES project in Atlanta, Georgia.

- Interpret the results of the NETL-TVA measurement program of $PM_{2.5}$ characterization and visibility variation in the Great Smoky Mountains, and extrapolate these to the mid-Appalachian region, using available visibility and $PM_{2.5}$ relationships.

• Component 4 -- Exploration of opportunities for PM emission reduction through new control technologies.

  - Integrate the results of NETL ongoing development program for emission control technologies into a general review of new technologies for the reduction of emissions of fine particles and PM precursors from energy production sources.

B. Current Program Highlights

The major projects initiated by NETL thus far have focused on the ambient sampling and analysis component of the program (Component 1). These types of projects typically require long lead times (3 or more years) before they begin to yield meaningful and useful results. Since these results form the basis of all work conducted under the other three components of the program, it was critical that the early focus of the NETL program be directed toward Component 1. The general location of the NETL ambient sampling and analysis projects are shown in Figure 3, while the schematic diagram of Figure 4 shows how the various ambient sampling and analysis efforts are integrated with other components of the NETL PM program and external studies.

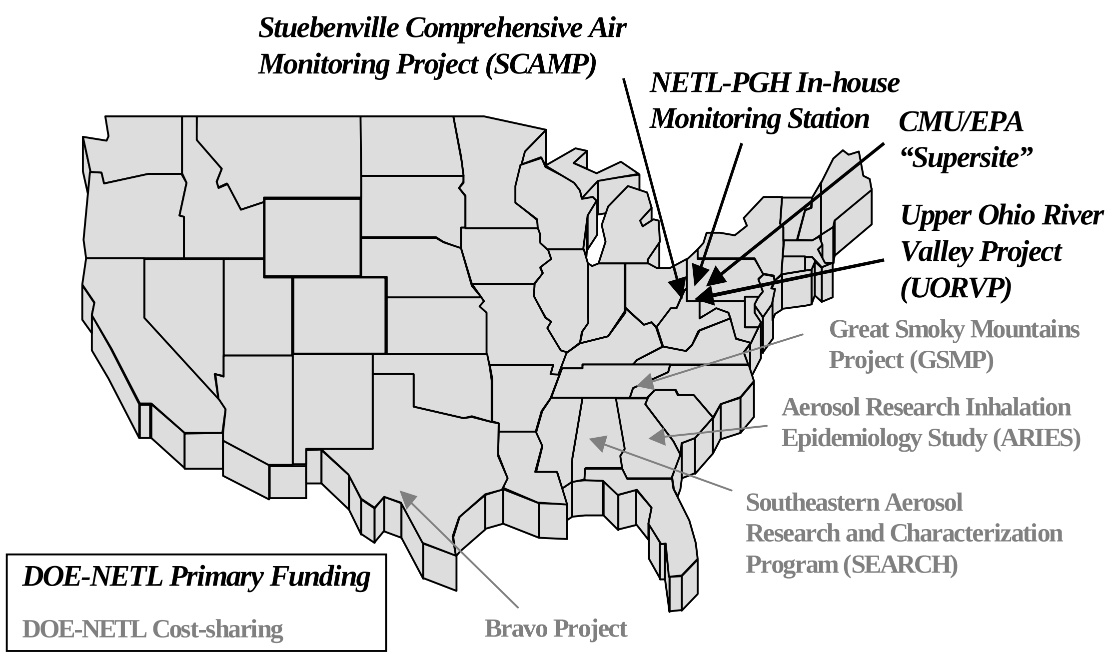



**FIGURE 3. Locations of NETL-Supported Ambient Sampling and Analysis Projects**

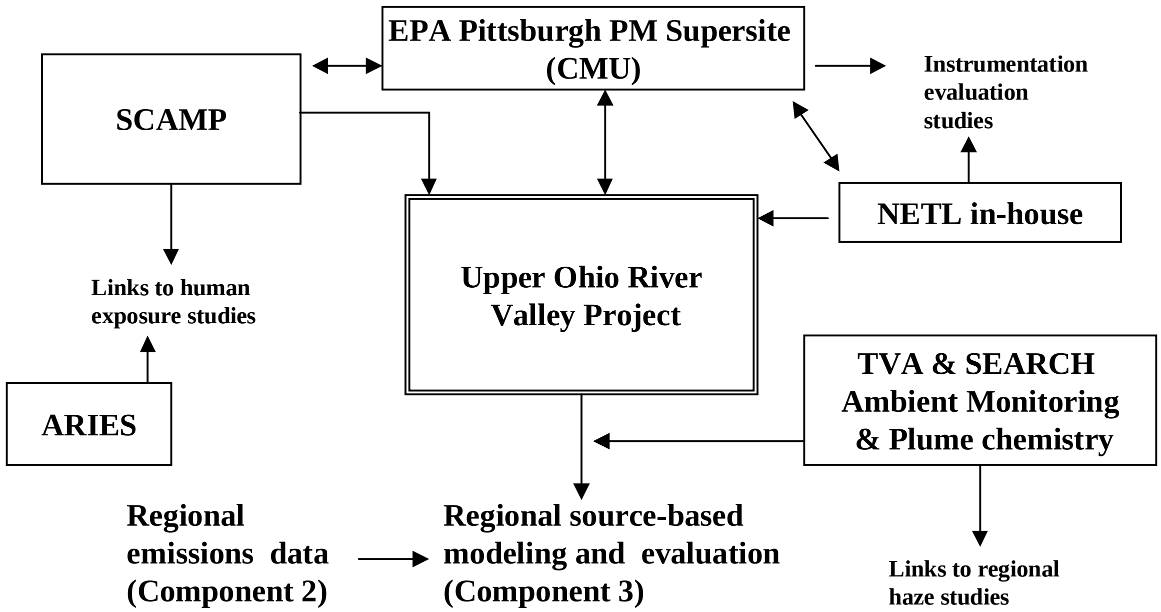



**FIGURE 4. Integration of NETL Ambient Sampling and Analysis Projects**

The Upper Ohio River Valley Project (UORVP) was the first major project initiated by NETL, and forms the core around which the remainder of the program is developed. The UORVP is directly complemented by the Steubenville (OH) Comprehensive Air Monitoring Project (SCAMP) which investigates the linkage between ambient air conditions and human exposure to pollution in the region, and by the NETL in-house PM monitoring site, where a wide variety of ambient PM sampling devices are being evaluated. The UORVP, SCAMP, and NETL in-house teams have been cooperating closely with researchers from Carnegie-Mellon University (CMU), which has been selected by EPA to develop a "Supersite" for ambient PM monitoring in Pittsburgh. In July 2000, NETL expanded this cooperation to include a significant level of co-funding of the EPA-CMU supersite, which is scheduled to begin its measurements in 2001. An Interagency Agreement between NETL and TVA, along with cost sharing in the SEARCH (Southeastern Aerosol Research and Characterization) project, provides NETL with a key link to investigations of plume, and local and regional air interactions in the southeastern Appalachian mountain environment, another dense concentration of major power plant sources. A similar involvement in the ARIES (Aerosol Research Inhalation Epidemiological Study) project in Atlanta provides a connection to ongoing health-based studies in the southeast, while the BRAVO project provides linkages to visibility issues in the southwest.

Progress thus far in the NETL-initiated projects has consisted of the establishment of comprehensive ambient monitoring sites and collection and verification of field data in the upper Ohio River valley. Although data interpretation and analysis is a continual part of the NETL program plan, during the next 5 years, the program will shift from its current emphasis on ambient measurements to analysis and interpretation of ambient or plume observations. The cooperative studies with TVA involving $PM_{2.5}$ characterization and visibility impairment in the Great Smoky Mountains will also evolve into a modeling, analysis, and interpretation phase in 2001.

At this time, the NETL PM program has no focused, ongoing investigations of HAPs issues, other than the fine particulate control projects that may be able to reduce airborne emissions of some HAPs. However, as discussed in Section III.C., the program is being coordinated with a parallel NETL program in the evaluation and control of mercury emissions from coal-fired power plants.

Similarly, although NETL does not currently emphasize visibility and regional haze issues in its current program, its cost-sharing contributions to the BRAVO and TVA-Smoky Mountains projects and a sulfuric acid emissions control project represent its interest in this topic. These collaborations provide the opportunity for NETL's involvement in visibility issues to grow over time, as the linkages between power plant emissions and regional haze become more well defined and EPA schedules for regional haze reduction come into place.

Brief summaries of the major ongoing NETL-initiated efforts -- UORVP, SCAMP, and NETL in-house -- are provided here. Appendix B contains a more detailed information on the UORVP, while Appendix C describes the tasks to be completed under SCAMP. Since the collaboration with the EPA-CMU Pittsburgh Supersite may eventually become a vehicle for building upon the current ambient sampling and analysis efforts, a detailed description of the work to be performed at the Supersite is contained in Appendix D. Appendix E contains brief overviews of the co-sponsored ambient monitoring projects currently included in the NETL program.

### 1. The Upper Ohio River Valley Project (UORVP)

The first major element of the NETL program, the UORVP, includes two urban and two rural monitoring sites. The four sites, shown in Figure 5, were all part of existing local and/or state air quality programs. One urban site is located in the Lawrenceville section of Pittsburgh, Pennsylvania. This site is an air quality monitoring station operated by the Allegheny County Health Department. One rural site is collocated with the Pennsylvania Department of Environmental Protection (PADEP) at a former NARSTO-Northeast site near Holbrook, Greene County, Pennsylvania. The Lawrenceville and Holbrook sites constitute the primary site pair in the UORVP because both of these sites contain several types of filter-based PM monitoring equipment ($PM_{2.5}$ and $PM_{10}$), continuous samplers for co-polluting gases (CO, $SO_2$, $NO_X$, $NH_3$, etc), and surface meteorological stations. Sampling at Lawrenceville and Holbrook consists of one filter-based sample every sixth day throughout the year, along with month-long intensive (four samples daily at Lawrenceville and one sample daily at Holbrook) periods during the summer and winter of 1999 through 2001. A "satellite" urban site is collocated at a West Virginia Division of Environmental Protection (WVDEP) monitoring station at the Morgantown, West Virginia, airport, while a satellite rural site is collocated at a site operated by the Ohio Environmental Protection Agency (OHEPA) near Athens, Ohio. Samplers at Morgantown and Athens collect one filter-based $PM_{2.5}$ sample every sixth day. The UORVP will complete its planned measurements in the summer of 200l, and will enter its principal analysis and interpretation phase later that year.

A summary of the data collected during the first year of the UORVP includes the following observations and conclusions: (1) continuous Tapered Element Oscillating Microbalance (TEOM) equipment is performing as well as filter-based samplers in accounting for ambient $PM_{2.5}$ masses; (2) trending in the $PM_{2.5}$ levels is similar for Lawrenceville and Holbrook, which represent an

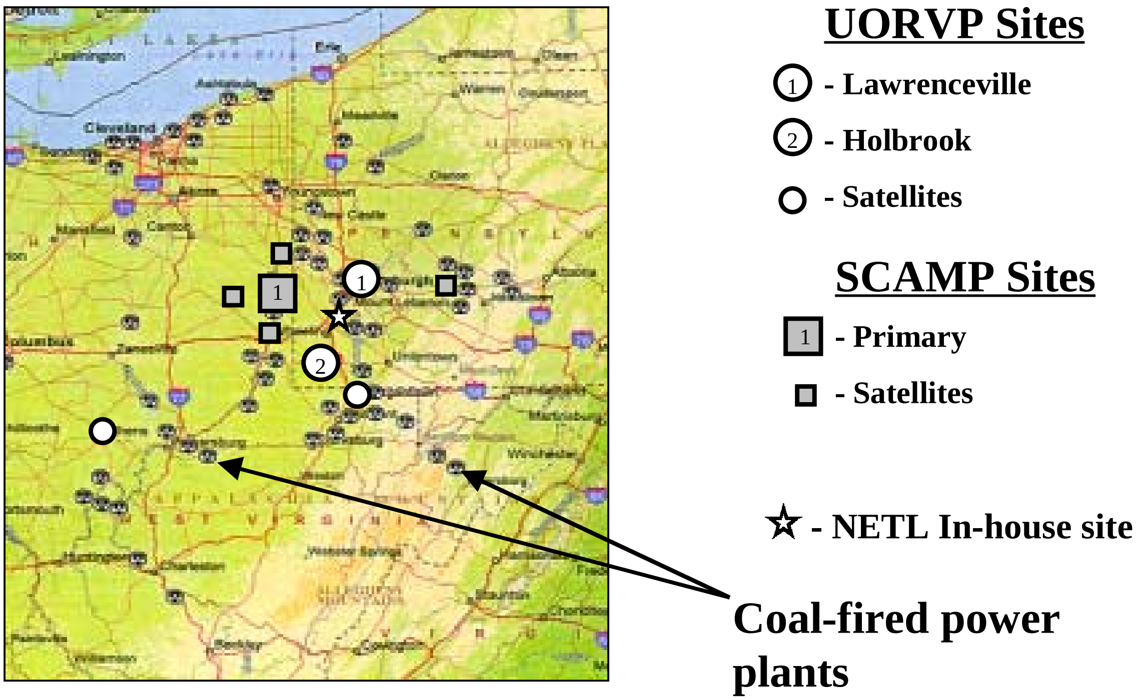



**FIGURE 5. Location of UORVP Ambient Air Quality Monitoring Sites**

urban and a rural site 65 miles apart; (3) the absolute median $PM_{2.5}$ levels are the same for Lawrenceville and Holbrook; (4) $PM_{2.5}$ levels appear to be impacted more by regional than by local effects; (5) sulfate is the dominant chemical species at both the Holbrook and the Lawrenceville sites during the winter months; and (6) $PM_{2.5}$ and $PM_{10}$ mass concentration levels are consistently higher in summer than in winter, with intermediate levels being observed in the fall.

Figures 6 and 7 illustrate some of the results from the UORVP Lawrenceville site. Figure 6 shows the relationship for a 1-month time period (June 1999) between the TEOM equipment, the filter-based, 24-hour averaged federal reference method (FRM), and a more sophisticated sequential filter sampler (SFS). For Lawrenceville, the two methods correlate quite satisfactorily, indicating that the use of the TEOM for future monitoring of $PM_{2.5}$ is equivalent to the FRM. In Figure 7, the composition of the sampled $PM_{2.5}$ indicates that the major components of the sampled particles are airborne sulfate and carbonaceous material, as expected from historical data in the region. As the UORVP progresses, its emphasis will shift towards relating the aerometric measurements to local and regional scale emissions of sources of primary and secondary fine particles using existing air quality models.

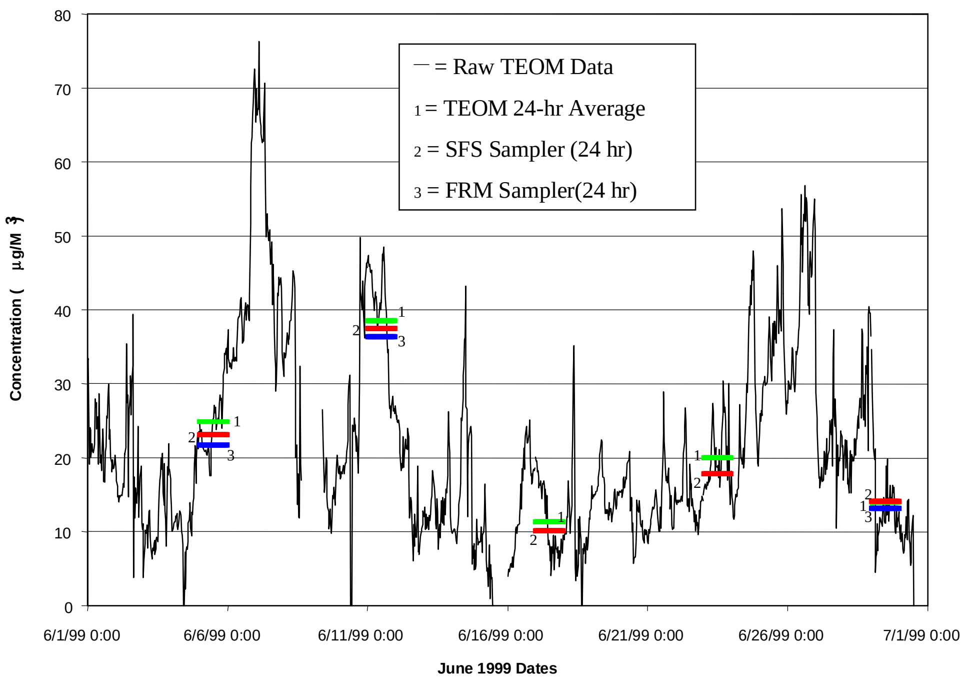



**FIGURE 6. Correlation Between FRM, SFS, and TEOM $PM_{2.5}$ Samples, UORVP Lawrenceville Site, June 1999**

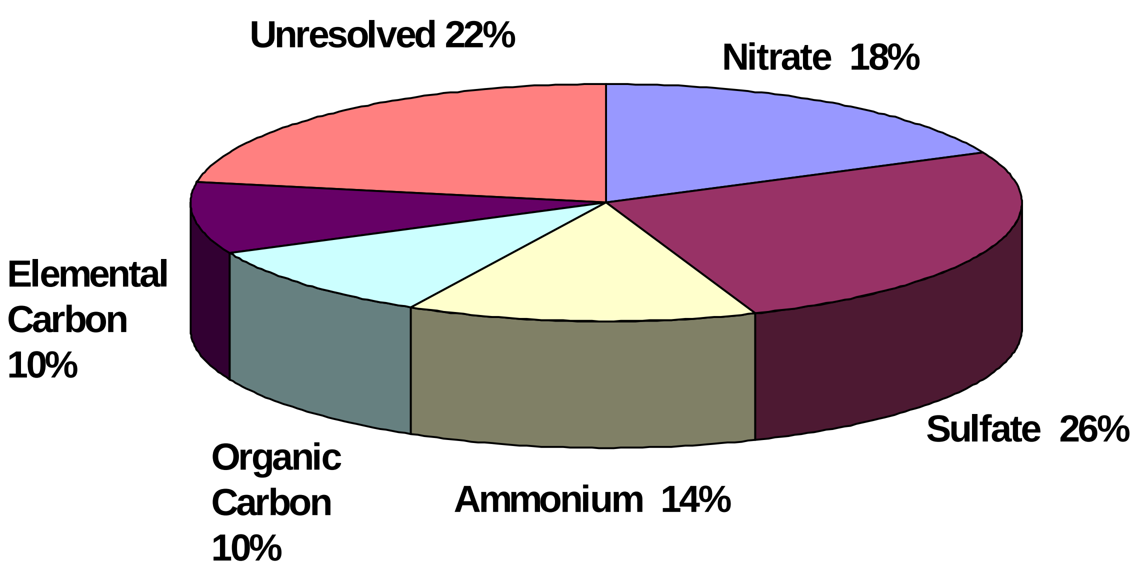



**FIGURE 7. Chemical Composition of $PM_{2.5}$ at UORVP Lawrenceville Site (Average of 36 6-Hour Samples, Winter 1999)**

## 2. The Steubenville Comprehensive Air Monitoring Project (SCAMP)

The objective of SCAMP is to measure the concentrations of $PM_{2.5}$ and other air pollutants at ambient monitoring stations in and around Steubenville, Ohio (see Figure 5), and relate them to the pollutant concentrations actually breathed by persons living in the area. Steubenville was chosen by NETL for this study not only because of the ability to integrate its results with those of the UORVP, but also because Steubenville was one of the "Six Cities" where correlations between ambient $PM_{2.5}$ mass and adverse health effects had been noted. These correlations had been cited by EPA as one of the primary justifications for its 1997 ambient $PM_{2.5}$ standards. Complete characterization of the relationships between ambient $PM_{2.5}$ and human exposure, including the chemical components of $PM_{2.5}$ at various locations, will provide a comprehensive data base for use in subsequent epidemiological studies, long-range transport studies, and State Implementation Program Development. CONSOL Energy is the primary performer of SCAMP and will provide the necessary coordination and data integration between the various components of the study.

SCAMP comprises two major components which are most easily identified by sampling location: "outdoor" and "indoor." NETL is supporting the outdoor study, which includes daily measurements of $PM_{2.5}$ mass, composition at a central urban site, four remote sites, and outside the homes of people who have agreed to participate in the research project. Gaseous co-pollutants are being measured continuously at the central urban site and outside participants' homes. For the outdoor study, which will begin measurements in the summer of 2000, CONSOL has formed a team with the Harvard University School of Public Health, Ohio University, Franciscan University of Steubenville, Wheeling Jesuit University, and Saint Vincent College. The indoor component of SCAMP is being performed mainly by the Harvard University School of Public Health under subcontract to CONSOL, and is supported by a consortium of non-DOE sources -- the Ohio Department of Development's Coal Development Office (OCDO), EPRI, the National Mining Association, the American Iron and Steel Institute, and the American Petroleum Institute. The indoor study is measuring $PM_{2.5}$ and co-pollutants inside the homes of participants and will collect data from personal samplers worn by the participants. The personal samplers will be worn by a panel of older adults during the summer of 2000 and the winter of 2001, and by a panel of children during the winter and summer of 2001. An additional panel of older adults may be monitored in the summer of 2001.

## 3. NETL In-House Ambient Monitoring Site

As part of the overall air quality sampling and analysis activities in the upper Ohio River valley region, NETL's Office of Science and Technology (OST) has initiated an in-house ambient monitoring program that builds upon the NETL's core capabilities and competencies in inorganic and organic analyses and instrumentation. The program involves a fine particulate/air toxics sampling station at NETL's research laboratory in Pittsburgh. This air monitoring station consists of a new 715 $ft^2$ indoor facility housing equipment to monitor continuously $PM_{2.5}$, $PM_{10}$, gaseous pollutants $O_3$, $SO_2$, $NH_3$, $NO_y$, $NO_x$, CO, $H_2S$, peroxide, and polyaromatic hydrocarbons. OST will also collaborate with CONSOL, CMU, and the Allegheny (PA) County Health Department in evaluating the performance of $PM_{2.5}$ FRM samplers. The location of the NETL sampling station will take advantage of an existing 10-meter meteorological tower that has been collecting weather-related data for the past 7 years.

The four major long-term goals of the NETL in-house PM research team are:

- Improve the Characterization of the Organic Component of Fine Particles -- A detailed identification of the semi-volatile compounds and organic HAPs in ambient air will be performed. OST researchers are experienced in the application of high-resolution gas chromatography and mass spectrometry to comprehensively identify the organic components in very complex mixtures. A thermal extraction technique will be used to volatilize the compounds from the particles directly into a variety of sophisticated analytical equipment. OST possesses an extensive database of gas chromatographic retention indices to identify organic compounds, and maintains a large inventory of authentic standards for gasoline and diesel range compounds, phenols, PAH, and nitrated PAH to aid in the unequivocal identification organic compounds.

- Investigate Correlations Involving Free Radicals -- Since free radicals are suspected agents for a variety of health effects, the free-radical content of fine particles sampled from ambient air will be determined. OST researchers have made quantitative measurements of the total free-radical content of fossil fuels using electron spin resonance techniques for decades. However, determination of the free-radical content of fine PM will be substantially more difficult because the free-radical concentration of particulate matter is expected to be several orders of magnitude lower than that of fossil fuels. The free-radical concentration in fine PM will be correlated with the amounts of ozone, peroxides, and UV intensity present when the samples were obtained.

- Assess Contributions of Spherical Aluminosilicates (SAS) -- Since spherical aluminosilicate (SAS) particles are a unique emission from high-temperature coal combustion, they may represent a widely applicable, routine method of assessing the contribution of coal-fired electric power-generating stations to ambient PM. OST will develop a rapid, precise, highly automated scanning electron microscopic method to identify and count $PM_{2.5}$ and SAS particles. Knowing the number of SAS particles and the total number of all primary particles will allow an accurate estimation of the primary particle contribution that coal-fired electric utilities make to the total ambient fine PM load.

- Chemical Imaging Via Raman Microscopy -- OST researchers, working with industrial partners ChemIcon and R. J. Lee Group, Inc., will develop a routine method for determining the organic functional group distribution on the surfaces of ambient fine PM using Raman microscopy. This chemical-imaging technique combines molecular spectroscopy and digital imaging to provide molecular images that detail material morphology, composition, and structure. The technique may be able to produce organic functional group maps of the surfaces of particles as small as 0.5 microns.

Beginning in July 2000, scientists from the Atmospheric Science and Applied Technology Division of Battelle in Columbus, Ohio, will visit the NETL in-house monitoring facilities to conduct a research program funded by EPA as part of its Environmental Technology Verification Program.

The purpose of the program is to provide objective and quality-assured performance data on environmental technologies so that users, developers, and consultants can make informed decisions about these technologies. Advanced ambient air monitoring instrumentation from the following manufactures will be co-located at NETL: Andersen Instruments, BGI, Dekati Ltd., EcoChem Analytics, Met One, Opsis AB, Rupprecht & Patashnick Co., and TSI, Inc. The performance of these instruments will be evaluated and compared and contrasted with data generated by NETL's instrumentation. The NETL fine PM program will benefit from the increased amount of advanced scientific data generated on fine particles at the NETL in-house ambient monitoring site.

C. Coordination With External PM Research Activities

Coordination of the NETL fine PM program with external, related research efforts must occur at two levels -- program and project. At the higher, or "program" level, this coordination requires NETL to shape its overall program to supplement, but not duplicate, major research initiatives being conducted by other Government agencies and industry. As discussed earlier, this Plan, its two major goals, and the four-component approach toward achieving those goals were formulated as the direct result of feedback received from the 1998 NRC review of the NETL program (Appendix A). NETL's continued participation in NARSTO and in the fine PM Working Group of the Air Quality Research Subcommittee, under the National Science and Technology Council's Committee on the Environment and Natural Resources, will ensure that similar coordination with the broader PM research community is continued.

It is especially important for NETL to make sure its program fits in properly with related activities within the Department of Energy. For example, the NETL program, which focuses on the impact of coal-fired power plants on ambient PM levels, complements the activities sponsored by the Oil and Gas Program of DOE's Office of Fossil Energy (DOE-FE), which address PM issues related to oil and gas production and use. NETL maintains a regular dialogue with DOE's National Petroleum Technology Office (NPTO), which is implementing DOE-FE's oil and gas PM research program. The NETL program was also designed to be complementary to programs within DOE's Office of Science (SC), including the PM component of SC's Atmospheric Chemistry Program, the aerosol component of its Atmospheric Radiation Program, and its Tropospheric Aerosol Program. The SC programs have a more basic research focus than the NETL program, so the applied focus of the NETL program fills a complementary role. DOE's Office of Energy Efficiency and Renewable Energy (EE) also has a PM component of its Environmental Sciences and Health Effects Program. Thus, while NETL's program is not comprehensive, it is a key part of a larger DOE research effort that addresses many of the important aspects of the PM issue.

It is also important, wherever possible, to achieve coordination with external PM programs at the "project level." While the overall goals of the external agencies' research may be different from those of NETL, many individual projects, especially those involving ambient sampling and analysis, are aimed at advancing knowledge of the origins and characteristics of fine particles in the troposphere. For example, NETL's support of regional PM modeling in the southeastern U.S. can be viewed as an investment in its core program because coal-fired power plants are major sources of PM precursors in this region also. The methods used by TVA and its partners to perform this work, and the results of these studies, will provide valuable guidance to NETL when formulating its regional modeling framework.  Similarly, the BRAVO project is examining the role of coal-fired power plants in regional visibility issues, which may eventually become more critical in the Appalachian and mid-Atlantic regions.  Table 3 lists the "project level" linkages developed by NETL during the initial stages of its fine PM program.

As the NETL PM program evolves, the list of collaborating agencies and projects is likely to change.  Although primary emphasis in the future will be placed on the development and expansion of its core projects (see Section III.A.), NETL will continue to collaborate in selected external initiatives where the results are of direct relevance to NETL's program goals (e.g., potential impacts on coal-fired power plants).  Combining the core program with key external cost-sharing opportunities will allow NETL to meet its goal of "informing decision-makers about management options applicable to coal-fired power generation" in the most cost-effective manner.

**TABLE 3. Collaborative Contributions to the NETL $PM_{2.5}$ Program**

| Cooperating Organization | Project(s) | Program Component | Type of Collaboration |
|---|---|---|---|
| Advanced Technology Systems, Inc. | UORVP | 1 | Main DOE Contractor |
| Desert Research Institute | UORVP | 1 | Major Subcontractor |
| Pennsylvania DEP | UORVP | 1 | Field Site Support |
| West Virginia DEP | UORVP | 1 | Field Site Support |
| Allegheny County Health Department | UORVP | 1 | Field Site Support |
| Ohio EPA | UORVP, SCAMP | 1 | Field Site Support |
| Carnegie Mellon University | EPA PM Supersite<br>UORVP, SCAMP | 1<br>1 | DOE-Funded Subtasks<br>Sampling Program Coordination |
| Consol Energy | SCAMP | 1 | Main DOE Contractor |
| EPRI | SCAMP, SEARCH<br>ARIES<br>Sulfuric Acid Control | 1<br>1, 3<br>4 | Co-Sponsor |
| Ohio Coal Development Office | SCAMP<br>Primary PM Characterization | 1<br>2 | Co-Sponsor |
| National Mining Association<br>American Petroleum Institute<br>American Iron and Steel Institute | SCAMP | 1 | Co-Sponsor |
| Harvard University | SCAMP | 1 | Major Subcontractor |
| Tennessee Valley Authority | Cumberland Plume<br>Smoky Mountains<br>ARIES | 2<br>1<br>1, 3 | Co-Sponsor and Main Project Performer |
| U.S. EPA | BRAVO | 1, 3 | Co-Sponsor |
| USDI National Park Service | BRAVO | 1, 3 | Co-Sponsor |
| Brookhaven National Laboratory | BRAVO | 1, 3 | DOE-Funded Subtasks |
| Southern Company | ARIES, SEARCH | 1 | Co-Sponsor |
| Southern Research Institute | SEARCH | 1 | DOE-Funded Subtasks |
| McDermott Technology, Inc. | Primary PM Characterization | 2 | Main DOE Contractor |
| North Dakota Energy and Environmental Research Center | Advanced Hybrid Particle Collector | 4 | Main DOE Contractor |
| ADA Environmental Solutions, LLC | ESP Additives | 4 | Main DOE Contractor |
| LSR Technologies, Inc. | Electrocore Separator | 4 | Main DOE Contractor |
| Radian International LLC | Sulfuric Acid Control | 4 | Main DOE Contractor |
| First Energy | Sulfuric Acid Control | 4 | Co-Sponsor |

## III. PLAN DETAILS

### A. Core Program: Ambient Measurements, Source Characterization, and Source-Receptor Modeling

The core of the NETL 5-year plan involves the integration of the first three components of the program outlined in the previous section. The overall objective of these three integrated components is to develop a methodology for estimating the contribution of energy-related sources to ambient fine particle concentrations in a manner that is applicable to complex local and regional conditions. The methodology will be developed first for the upper Ohio River valley region, then extended to determine its applicability to other regions of the United States. The plan begins with the current UORVP and SCAMP studies, and continues with future emissions characterization, emissions inventories, and source-receptor modeling studies that build directly upon these projects.

In order to reach the stated objective, seven basic steps must be completed in the next 5 years. Addressing these seven steps will require the major fraction of the resources available to the NETL PM Program.

#### 1. **Step 1. Complete Ambient Measurements**

This step will involve completion of the scheduled suite of observations at the two main sites in the UORVP, and the satellite sites in Ohio and West Virginia. The basic and intensive measurements collected thus far under the UORVP are to be supplemented with two additional intensive periods of operations, one in summer 2000 and one in summer 2001. In at least one of these intensive periods, most likely the summer of 2001, upper air measurements using an aircraft are envisioned to enhance the ground level database (Seaman, et al., 1995; and Kuo and Guo, 1989), and document conditions aloft that may yield direct evidence of local versus long-range air mass transport. The ambient air quality database will be integrated with appropriate aerometric data from the local and state (Pennsylvania, Ohio, and West Virginia) government monitoring programs, the EPA $PM_{2.5}$ stations, and the National Weather Service ground and radiosonde networks for the region. This database will be structured in an EPA- or NARSTO-compatible format and will be accessible through NETL.

Data from the $PM_{2.5}$ research site at the NETL facilities in Pittsburgh, which include $PM_{2.5}$ measurements, as well as surface meteorological data, will be incorporated into the regional database in a format compatible with the external UORVP program. The site includes laboratory support for specialized instrumentation and methods development and test for comparison of current $PM_{2.5}$ monitoring techniques. Data and results from this internal NETL program are beginning to appear in year 2000. Similarly, the EPA/CMU Pittsburgh "Supersite" is scheduled to begin obtaining ambient PM and related measurements in 2001. As they become available, the data will be incorporated into the regional database.

The regional ambient air quality database also will embody the observations initiated in 2000 at the Steubenville, Ohio, sites. Here a major station equivalent to the Pittsburgh sites is included, along with four satellite stations obtaining filter samples. Sampling will take place from 2000 to

2002. The data will be incorporated into the UORVP database and will be used not only to meet the $PM_{2.5}$ characterization component, but also the human exposure component through its integral link to the indoor and personal sampling study being supported by industry and the Ohio Coal Development Office.

Individual researchers from the UORVP, SCAMP, CMU, and NETL in-house projects have already initiated discussions to determine how all the individual data sets can be structured to yield a regional database that can be of use to both internal and external parties. One step toward achieving this integration, at least internally would be to adopt the data-sharing protocols now being developed for the nationwide EPA Supersites Program; NETL's involvement with the EPA/CMU Pittsburgh Supersite will help facilitate this. However, since none of the current research projects carries the mandate to develop such a regional database, this development will have to occur as a separate NETL initiative. Ideally, the database would be internet based and would allow external researchers to query, plot, and download data from all of the NETL-sponsored research work. The feasibility of developing such a database will depend on the availability and coherence of the various data sets, appropriate software structure, quality control issues, data ownership issues, and availability of funding to perform the data integration. While broad, comprehensive integration and distribution of all data is desirable, it should be recognized that this becomes more complex, technically difficult, and costly as the amounts and types of data expand and the number of locations increases. The NETL program will seek to develop a database that strikes the appropriate balance between data accessibility, user-friendliness, cost, and other considerations.

## 2. **Step 2. Aerometric Data Analysis**

Conventional practice for field projects calls for extensive manipulation of the observations to create a variety of basic profiles by frequency of occurrence, seasonal, diurnal patterns, and annual averages. The data will be compared with meteorological conditions experienced to differentiate conditions representative or regional transport of pollution versus local build up of pollution during stagnation conditions. As a part of this exercise, regional-scale air mass trajectory analysis will be used to segregate conditions that represent potential regional-scale transport from the accumulation of source emissions from different mean wind directions. Identification of the impact of regional power plants on Pittsburgh as a "receptor" will include the analysis of a "southwest source group" (primarily assumed to be urban areas in the Ohio River sector, combined with rurally located power plants), a northwest source group (primarily assumed to be a blend of urban sources extending to the Great Lakes combined with rural power plants), and an Atlantic coast group composed mainly of coastal urban source mixes. The data also will be inspected for parallels using coarse gas tracers, e.g., consistency with carbon monoxide (CO), volatile organic compounds (VOC), which can serve as a "transportation" or "urban" indicator versus sulfur dioxide ($SO_2$) and silica spheres, which can serve as a "coal combustion source" indicator.

Results from the SCAMP and NETL in-house laboratory programs also will be analyzed and compared with the results derived from the UORVP. The internal laboratory work performed under these two efforts will add to and complement the analysis and interpretation of the UORVP data.

The characterization of Pittsburgh air quality resulting from the NETL projects will be compared with the findings from earlier programs aimed at identifying regional and local source contributions to particle and pollutant gas concentrations. These studies include the 1970's Sulfate Regional Experiment (SURE) and the 1980's program, the Eulerian Model Evaluation Study (EMEFS) (e.g., Hidy, 1994). The NETL data also will be examined in the light of developing experience from more recent studies, including NARSTO-NE, the ongoing Philadelphia $PM_{2.5}$ study, and the EPA-Carnegie Mellon Pittsburgh supersite.

The results of this analysis and interpretation step will provide a general understanding of the observations in the light of previous and parallel studies, and will be the first step in developing an updated conceptual model of source-receptor relationships in the mid-Appalachian region.

### 3. Step 3. Emissions Inventory

The emissions inventories by means of EPA and state records for the Pittsburgh and surroundings in a spatial and temporal grid suitable for modeling will be acquired for $SO_2$, $NO_X$, primary particles, VOC, and ammonia ($NH_3$) and compared with the results from the aerometric characterization (Step 1). These data also will be used to screen for large contributors to the sulfate, nitrate, and carbon fractions of $PM_{2.5}$, as well as key elements that may be usable as tracers for sources. Emission profiles developed for coal-fired power plants in the UORV will be compared with profiles from similar facilities nationwide to assess the variability in emissions from similar facilities in the mid-Appalachian region. The gridded emissions inventory will be used in Steps 5 and 6 for the modeling evaluations.

### 4. Step 4. Source Characterization

After identifying large source contributors to the ambient measurement sites, a selection of a few key local or regional sources will be selected and sampled for chemical profiling. Recent advancements in technology for accurately simulating the chemical changes that occur immediately after coal combustion flue gases are released, such as dilution sampling and models of chemical changes that occur within power plant plumes, will be employed in this effort. This profiling will attempt to characterize the variability in emissions associated with different fuel blends and other operating variables. The results of the current project to characterize primary PM emissions from an experimental low-$NO_X$ burner will also be integrated into this step. These data will be used to assist in the application of receptor modeling (Step 5).

### 5. Step 5. Receptor Modeling

Using the results of Steps 1 through 4, combined with previous receptor modeling experience in eastern and western conditions, present day receptor modeling methods (Fugita, et al., 1998; and Seigneur, et al., 1997) will be applied to the Pittsburgh region to try to account for local and regional sources of $PM_{2.5}$, especially for the coal-fired power plant sources. This work will attempt to extrapolate the experience of adopting receptor models to estimate source attribution from isolated sources to the situation where numerous sources are potential contributors. Segregation of the analysis by wind direction and persistence, as well by the use of chemical tracers is expected to assist in assessment of source contributions under different meteorological conditions characteristic of local air mass stagnation as compared with conditions identified with long-range transport of pollutants. It is expected that this effort will result in the identification of individual power plants or power plant clusters that appear to be having an influence on the various ambient receptor sites. The receptor modeling results also will be used as a means of confirming the results of the modeling to be done in Step 6.

6. **Step 6. Emission-Based Modeling**

There are at least two Eulerian models that can be applied to estimating PM concentrations from sources in the UORV region. These include the EPA REMSAD code, and the new Models 3 CMAQ code. The REMSAD is considered perhaps the more primitive of the two, but nevertheless it has been used for some regulatory analyses, and is based on the URM-V, a regional model used recently for ozone impact assessment (OTAG). The models embody, at least in a limited way, some of the non-linear chemical and physical processes that affect ambient PM concentrations. The two models can be readily used for evaluation of the regional influence of large sources of $SO_2$ and $NO_X$; as well as account for the interaction of various urban areas throughout the eastern U.S.

The exact model that will be applied to the UORV regional data has yet to be determined. In order to help clarify this, NETL is currently collaborating with TVA in a comparison between Models-3 and URM. In this study, scheduled to be completed during 2001, Models-3 and URM would each be run for one or two base cases (depending on the feasibility of converting the existing Southern Appalachian Mountain Initiative [SAMI] data to the Models-3 format), and the predicted $PM_{2.5}$ and ozone levels from the two models would be compared. Several emission control strategies proposed by SAMI will be simulated for the base case(s) and the consistency between the two models will be evaluated. Results of this collaborative work are expected to provide guidance to NETL in its selection of models for the UORV regional modeling effort.

To evaluate at least one of the models available for this project, a set of meteorological data will be prepared or accessed that can be used as input to the model along with the emissions inventory. A set of prognostic calculations for regional meteorological conditions will be prepared that will cover one of the years adopted for the field measurements. These data will be used for investigation of both the annual average PM conditions, and a subset of representative 24-hour average conditions. The latter will be chosen from the meteorological and air quality data to represent typical high and low concentration data in seasonal conditions that favor photochemical oxidation processes versus non-photochemical conditions.

The model(s) will be run for the appropriate input and selected boundary conditions to evaluate its (their) performance, with comparison to the UORVP and related ambient data as a “standard” of quality. Comparisons also will be made with the receptor modeling results to establish consistency of the source attribution methods. Assuming that the models adopted perform according to expectations from other evaluations, then the contributions of local and regional major sources will be estimated for the chemical components of $PM_{2.5}$ (e.g., sulfate, nitrate, elemental and organic carbon, and crustal material). If these estimates give results that are mutually consistent with receptor modeling, then the model will be used to estimate future conditions and the response of the local and regional ambient concentration to projected changes in emissions in the

UORV region. If the models yield significantly different results, then a re-assessment of the source profiles used in the receptor modeling, the emission estimates from the emission inventory, and the regional models themselves will be evaluated for errors and/or the possibility of missing sources.

The models also can be run with a sub-program to evaluate the impacts on regional haze associated with power plant emissions and emissions from other sources. If the results simulating PM concentration patterns are acceptable, then the results for regional visibility impairment will be examined and evaluated for the mid-Appalachian region, and compared with available light scattering or visibility observations.

It should be emphasized that the goal of the modeling work under the NETL program will be in the application of existing models to identify regional PM and precursor sources, and to examine the effects of various PM reduction strategies, especially those involving coal-fired power plants, on PM levels at regional ambient receptors. The purpose of the work is not to examine the individual atmospheric reactions and underlying technical issues that constitute the development and refinement of the modeling systems. These issues are being addressed by other initiatives supported by DOE (specifically, the Office of Science Programs), EPA, and others. It is expected that the outcome of the modeling studies will be an improved description of the relative contribution of coal-fired power plants to ambient PM levels, and a set of general guidelines that inform decision-makers of what to expect if emission reductions on coal-fired power plants in the modeled region are implemented.

### 7. Step 7. Generalization of Modeling to Other Situations

If the performance of the applied model(s) yields reliable results for the complex situation of the UORV region, the model(s) will be applied to at least two other regions in the U.S. containing large concentrations of power plants. For example, these might be the southeastern U.S., and/or the southwest, including southern and central California. Application of the model to additional regions will require the acquisition of relevant $PM_{2.5}$ air quality data from Federal and state sources, emissions inventories, and meteorological observations. In addition, the source profiles will be evaluated for their applicability in different regions. These data will be developed into suitable input sets to run the model(s) as in the case of Step 5. The models then will be tested using available ambient PM and gas data representing urban and regional conditions in the selected test areas. If the model(s) are generally applicable to conditions in the U.S., the evaluations conducted in the task and in Step 5 should be uniformly consistent, taking into account the quality of the observations used in each case. If a positive outcome is achieved, the model(s) will be considered suitable for DOE evaluation of the response of local and regional ambient PM concentrations that are affected by large energy producing sources using fossil fuels.

## B. Research and Development of Advanced PM Emission Control Technologies (Component 4)

The objective of this component of the NETL program is to develop technology that will eventually reduce emissions of both primary $PM_{2.5}$ and its secondary precursors ($SO_X$ and $NO_X$) from coal-based energy sources to negligible levels. However, unlike the three core components of the program, the primary driver for Component 4 was not the inclusion of $PM_{2.5}$ standards in the 1997 NAAQS. NETL had supported the research and development of cost-effective technologies for reduction of priority pollutants (ozone, $SO_2$, $NO_X$, and $PM_{10}$) throughout the 1980s and 1990s, and it was logical to incorporate this activity into the fine PM program by providing support for technologies that can potentially reduce $PM_{2.5}$ and its precursors. However, the projects currently supported by this component of the program, while applicable to $PM_{2.5}$, were selected on the basis of their potential for more efficiently controlling HAPs (assuming that HAPs are concentrated in the fine particles that escape existing collection devices) and TRI-related acid gases (via $SO_3$ control) rather than by their potential to reduce $PM_{2.5}$ mass.

During the mid to late 1990s, NETL supported the development of several technologies that are relevant to $PM_{2.5}$ issues, including a pilot-scale advanced hybrid particle collector (AHPC) that combines the best features of ESPs and baghouses, several methods for improving the efficiency of existing ESPs, and a range of technologies applicable to the reduction of $NO_X$ emissions. As the result of a 1999 solicitation, NETL added to this portfolio by selecting several other projects that are relevant to the control of $PM_{2.5}$ emissions, including (a) resolving some of the engineering scale-up questions associated with the AHPC; (b) the development of the electrocore separator, a post ESP-separation and recycling unit to enhance fine particle removal associated with under-performing ESPs; (c) improved ESP collection performance via addition of low-cost, non-toxic flue gas conditioning agents; and (d) alkaline sorbent injection for sulfuric acid removal from flue gas.

These ongoing control technology projects, described individually in Appendix F, will add to the existing R&D portfolio of options for $PM_{2.5}$ emission control technologies already available in the private sector. These projects also will add to the technology options available for hypothetical application to coal-fired power plants in the assessment of management options for reduction of $PM_{2.5}$ emissions planned as part of the last phases of this NETL program.

Depending on the outcome of the developmental programs noted above, and the needs for improving coal-fired power plant emission controls, NETL may consider additional technology evaluation late in the current program. Component 4 of the program must constantly evolve as new information becomes available on the origins of air toxics in coal-fired emissions (Component 2) and the chemical components of $PM_{2.5}$ that are responsible for human health effects (health-based research not included in the DOE-NETL program scope).

## C. Investigation of Airborne Toxics

The current NETL research program into fine particulate matter is an outgrowth of a previous DOE-sponsored program, conducted in the early to mid 1990s, to achieve a comprehensive assessment of air toxics emitted from U.S. coal-fired, electric-generating facilities. These studies (Energy and Environmental Research Center, 1996) revealed that metals were the class of utility-generated air toxics of greatest concern, and that almost all metals were generally associated with primary particulate matter. However, the studies also found that existing particulate control devices (electrostatic precipitators and fabric filters) were generally effective in reducing most airborne releases of toxic metals. Therefore, the control technology component of the current program is a *de facto* method of addressing the air toxics issue, especially projects that are aimed at controlling ultrafine primary PM. The remaining components of the NETL fine PM program also touch on air toxics issues because the in-depth chemical characterization of ambient PM and primary PM from coal-fired power plant emissions performed under this program will help identify which air toxics may be uniquely associated with power plants.

Mercury is the most notable exception to the fine PM-air toxics relationship described above. In DOE studies of the 1990s, mercury was identified as the air toxic of greatest environmental concern to coal-fired power plants because of its bioaccumulative properties, and because existing air pollution control devices do not remove mercury from flue gases as effectively as they remove other metals. For this reason, mercury is currently the focus of an independent, parallel DOE-NETL program initiative whose level of activity and importance to DOE is equivalent to that of the fine PM program described here. The mercury and fine PM programs are similar in that both contain a control technology component, in keeping with DOE-NETL's historic emphasis on control technology. However, rather than focusing on ambient sampling, analysis, and modeling, the mercury program has thus far emphasized the in-depth characterization of mercury emissions from coal-fired power plants. This knowledge is crucial to the development of appropriate mercury emission control technologies because methods that are effective in the removal of oxidized mercury ($Hg^{2+}$) from flue gases are not as effective in removal of elemental mercury ($Hg^0$). The control technology component of the mercury program is also of greater immediate importance than it is for fine PM because EPA is expected to issue a regulatory determination in December 2000 that could require coal-fired power plants to reduce mercury emissions. In anticipation of the potential for mandated emission reductions, DOE-NETL is now in the process of soliciting proposals and selecting projects to develop a suite of novel mercury control technologies for coal-fired power plants. Further information on the DOE mercury program can be obtained at the DOE-NETL web site (www.netl.doe.gov) or the DOE Fossil Energy website (www.fe.doe.gov).

In the future, NETL will strengthen the interaction and coordination between the current mercury and fine PM programs, but complete integration of the programs is not envisioned. This will allow both programs to maintain the proper focus and allow them to respond appropriately to scientific advancements that pertain specifically to those topics. One example of the synergism between the programs is expected to occur in the area of emissions characterization, where the advancements in understanding of mercury behavior in flue gases may improve the understanding of the behavior of other air toxics associated with fine PM. Similarly, the ambient, sampling, analysis, and modeling studies of the fine PM program may help clarify the transport and deposition phenomena pertinent to mercury. Investigation of the wet deposition of atmospheric mercury is one of the key areas of synergism between the NETL fine PM and mercury programs. For example, the ratio of oxidized to elemental mercury in power plant emissions appears to be important in establishing whether mercury is deposited (as $Hg^{2+}$) within 100s of kilometers downwind of specific sources, or whether mercury is transported on a global scale (mainly $Hg^0$) (EPRI, 2000). Observations of speciated mercury concentrations in the air and at least in precipitation remain an important gap in knowledge of regional atmospheric chemistry. Continuing research on sampling and analytical methods are needed for airborne mercury speciation measurements, and observations in power plant plumes are needed under different weather and climate conditions to improve knowledge about the plume chemistry for mercury air quality model development. As part of its fine PM program, NETL will examine opportunities to undertake after 2001 experiments relevant to this gap in knowledge.

NETL will also follow developments that occur in connection with EPA's Integrated Urban Air Toxics Strategy. Under this program, EPA has and will continue to develop a number of national standards for stationary and mobile sources to improve air quality in urban and rural areas. The strategy complements the existing national efforts by focusing on achieving further reductions in air toxics emissions in urban areas. The strategy outlines actions to reduce emissions of air toxics, as well as assessment activities to improve EPA's understanding of the health and environmental risks posed by air toxics in urban areas. The strategy includes a list of 33 air toxics that pose the greatest potential health threat in urban areas and also a list of area sources responsible for a substantial portion of the emissions of these air toxics. This list includes 29 area source categories: 13 new area source categories and 16 area source categories which are under development or already subject to standards. NETL will adjust its fine PM program to the extent that this program identifies coal-fired power plants as a key source of urban air toxics.

1. Mercury Deposition -- An Adjunct to PM Monitoring at Holbrook

Since the upper Ohio River Valley area is believed to be susceptible to local and regional mercury deposition, expansion of the UORVP project to include a linkage with the national mercury deposition network in this region is a potential important future option for the NETL program. Provisions for such measurements were subsequently added to the Holbrook, Greene County, Pennsylvania, site of the UORVP. This site was augmented with a collector (Figure 8) to measure the wet deposition of mercury on May 27, 1999. Along with $PM_{10}$ and $PM_{2.5}$ mass measurements, the data from analyses of samples from the mercury collector will be combined with meteorological data to form a better understanding of the regional transport and deposition of mercury. The NETL-sponsored mercury monitoring activity at the Holbrook site is integrated with the mercury deposition network (MDN), operated nationwide by the Illinois State Water Survey. The MDN's primary objective is to determine long-term geographic and temporal distributions of the wet deposition of mercury in North America. The Holbrook site is only the second MDN site located in the industrialized Ohio River Valley and is one of only a few sites in the MDN that also measures trace gases, e.g., $SO_2$, CO, $O_3$, and reactive nitrogen. The MDN is itself part of National Atmospheric Deposition Program/National Trends Network (NADP/NTN), a nationwide network of precipitation monitoring sites that is a cooperative effort between many different groups, including the State Agricultural Experiment Stations, U.S. Geological Survey, U.S. Department of Agriculture, and numerous other governmental and private entities.


**FIGURE 8. Mercury Deposition Sampler at UORVP Holbrook Site**

NETL plans to review the need and opportunity for such measurements in the 2002 time period to determine if they should be initiated in the later phases of the $PM_{2.5}$ program. If mercury observations are initiated in the post 2002 time period, it will be determined if instrumentation is sufficiently fast in response to obtain estimates of dry deposition. This element of deposition of mercury species has not been measured, and needs to be characterized relative to the wet deposition component.

## D. Summary, Assessment, and Integration

The activities of the NETL fine PM program planned for the next 5 years are summarized and prioritized in Table 4. Although the complete realization of the program objectives would require all of the listed activities to be performed, it is recognized that budget constraints or allocations may limit the full implementation of the program over the next 5 years. Therefore, the current activities and critical near-term gaps in the "core program" (Section III.A. of the plan) have been given a higher priority than activities that support or "round out" the program, or activities which can be delayed until near-term core program activities have been completed. Similarly, projects relying on NETL as a primary funding source are given a higher priority than external projects that receive NETL cost sharing.

**TABLE 4. Prioritized Summary of NETL Fine PM Program Activities**

| Activity | Program Component | Priority | Status |
|---|---|---|---|
| **Core Program** | | | |
| Ambient Measurements | 1 | 1 | Several Field Programs Currently Active |
| Aerometric Data Analysis | 1 | 1 | Effort Begun in 2000 |
| Emissions Inventory | 2 | 1 | Work to Begin in 2000 |
| Source Characterization | 2 | 1 | Work to Begin in 2001 |
| Receptor Modeling | 3 | 2 | Work to be Conducted in 2001-2003 |
| Emissions-Based Modeling | 3 | 2 | Work to be Conducted in 2002-2004 |
| Generalized Modeling | 3 | 3 | Work to be Conducted in 2004-2006 |
| Integration of Results | 1, 2, 3 | 1 | Work to be Conducted in 2002-2006 |
| Cumberland Plume Chemistry | 2 | 3 | Field Work Completed; Analysis Ongoing |
| Smoky Mountains Visibility | 1 | 3 | Field Work Ongoing |
| ARIES Project | 1, 3 | 3 | Field Work Completed; Analysis Ongoing |
| SEARCH Project | 1 | 3 | Field Work Initiated in 2000 |
| BRAVO Project | 1, 3 | 3 | Field Work Completed; Analysis Ongoing |
| Primary PM from Low-$NO_X$ Burners | 2 | 2 | Field Work Completed; Analysis Ongoing |
| Advanced Hybrid Particle Collector | 4 | 2 | Active Project to be Completed in 2002 |
| Electrocore Separator | 4 | 2 | Active Project to be Completed in 2002 |
| ESP Additives | 4 | 2 | Active Project to be Completed in 2003 |
| Sulfuric Acid Control | 4 | 2 | Active Project to be Completed in 2002 |
| Hg and HAPs Emissions Characterization | 1 | 3 | Projects Not Yet Defined |
| Hg Emission Control | 4 | 3 | Solicitation Issued in 2000 |
| Assessment and Integration | All | 1 | Work to be Conducted in 2004-2006 |

In order to bring the NETL fine PM program to a useful end point, the results of the various studies need to be assessed, integrated, and interpreted with respect to the technical requirements for future environmental management practices.  This will require the synthesis of the results of both NETL and external studies of $PM_{2.5}$, its origins, characteristics, and human health implications, along with knowledge of emission control technology for coal-fired power plants to provide a generalized discussion of options and opportunities for reducing human exposure to $PM_{2.5}$ and improving visibility in the eastern United States.

An important conclusion of the NETL program will be a report integrating the results of the UORVP, SCAMP, the subsequent NETL-sponsored modeling studies, and related external programs to inform decision-makers about strategic options for reductions in $PM_{2.5}$ associated with energy production.  In addition, consideration will need to be given to results emerging from EPA's supersite measurement program, including the site in Pittsburgh, initiated in 2000.  Also of interest are observations derived from EPA's national $PM_{2.5}$ monitoring program, as well as projects such as the EPA/NARSTO-NE sponsored Philadelphia study, the NARSTO mid-Atlantic project, and Harvard University New England studies.

## IV. PROGRAM PERFORMANCE MEASURES

It is important for any research program to have clearly defined goals and objectives and methods for measuring progress. Although it is not always straightforward to quantitatively measure scientific progress and increments of increased scientific understanding, some general measures are possible. Examples include the production of user-friendly databases of scientific measurements and data statistics, written reports that provide data analysis and interpretation, publications in peer-reviewed journals, presentations at scientific meetings, and citations of research results in the publications of others. The 5-year NETL PM research plan sets forth the strategic path for achieving these results.

To determine measurable progress for the NETL program, a set of deliverable products is identified which will describe the results of the studies incorporated into the planned program. These products will emerge at different times during the next 5 years, and will represent important milestones measuring progress toward the overall objectives established for the program. Listed first are the key deliverables expected from the program along with their expected timetable.

### A. Key Deliverables: Databases and Reports

### 1. **Upper Ohio River Valley Project (Current Project)**

- Data archive by site for all measurements including particle chemistry and gas concentrations (including site characteristics, location, terrain, sampler height, etc.) in a format compatible with EPA or NARSTO data management systems. Data would include hourly, daily, and longer term statistics of concentrations. Database initiated in 2000 and completed in 2002.

- Supporting aerometric data, including regional surface meteorology, estimated wind fields, and air quality data and visibility or light scattering data from national and state sites in the upper Ohio River Valley region. Database assembled and complete in 2002.

- Interim report on data summary with site description, particle and gas concentrations, and discussion of limitations in the data set. Report available in 2002.

- Interim report on aerometric analysis of data, including basic statistics, classification of meteorological conditions, and classification of transport versus stagnation days. Report available in 2002.

### 2. **Steubenville Comprehensive Air Monitoring Project (Current Project)**

- Data archive by site for particle chemistry, gas concentrations integrated in a format compatible with the UORVP data, including summary statistical results. Database initiated in 2001 and completed in 2003.

- Summary data compatible with outdoor measurements of indoor observations and personal PM sampling. Database to be obtained from participating institutions available in 2003.

- Interim report on data summary, including particle chemistry statistics, context of regional concentration patterns and commentary on limitations of database. Report available 2003.

- Final report of results from the exposure study, including analysis of the data in terms of potential sources of $PM_{2.5}$. Report available through participants 2004.

3. **Source Characterization and Modeling Studies Evolving from UORVP and SCAMP**

- Emission inventories for $SO_2$, $NO_X$, VOC, $NH_3$, and primary $PM_{2.5}$ for the mid-Appalachian region applicable to the 2000-2002 time period. Database prepared from state and Federal archives in 2001.

- Source profile data obtained from source characterization or stack sampling analysis conducted under the NETL auspices. Database initiated in 2002 and completed in 2004.

- Air quality model output data from the test and evaluations undertaken as part of the UORVP. Database available in 2005.

- Interim report on emissions inventory and selection of key regional sources of interest to mid-Appalachian $PM_{2.5}$ conditions. Report available in 2002.

- Interim report on selected source sampling for $PM_{2.5}$ characterization. Report available in 2004.

- Interim report on model evaluation design and preliminary results for mid-Appalachian region and eastern U.S. Report available in 2005.

- Final report on modeling studies evolving from the UORVP, including data analysis and interpretation, and integration of results with historic or parallel studies. Report available in 2006.

- As part of the ongoing accrual of knowledge from the UORVP, it is anticipated that a series of presentations at technical meetings and conferences, and publications in the peer reviewed technical literature will result between 2001 and 2006. These will be written by contractors and NETL staff. While the number of these contributions is difficult to determine at this point, one anticipates *a posteriori* that they will be important measures of productivity of the program.

4. **External Cooperative Programs**

- Summary data from TVA plume chemistry experiments. Data to be provided by TVA 2001.

- Summary daily, monthly, and seasonal averages for particle chemistry and visibility (light scattering) for the TVA Smoky Mountain site compatible with EPA and

IMPROVE data management systems. Data to be provided by TVA and National Park Service in 2003.

- Summary data and final report from BRAVO project, describing results and limitations of project, to be provided by DOE-sponsored participants in 2002.

- Summary data from ARIES project, to be provided by DOE-sponsored participants (TVA) and EPRI in 2002. Series of scientific papers describing ARIES aerometric measurements and results of exposure and epidemiological studies, from mid-2000 through 2005.

- Summary of TVA plume chemistry results, including a series of scientific papers presented at meetings and published in peer reviewed literature. Initial series of papers at AGU fall meeting 2000.

- Summary of TVA/NPS studies on $PM_{2.5}$ and visibility in the Smoky Mountains. Final TVA/NPS report available in 2002 (expected cooperation with Colorado State University).

### 5. Emission Control Technology Research and Development

Series of final reports on technology evaluation and development, including technology performance, cost, and limitations:

- Final report on Advanced Hybrid Particle Collector project in 2002.

- Final report on Electrocore Separator project in 2002.

- Final report on Sulfuric Acid Emission Control project in 2002.

- Final report on Advanced Flue Gas Conditioning project in 2003.

### 6. Final Integrative Assessment Report to DOE

A final report integrating the findings of the NETL PM 5-year research will be prepared in an assessment format with conclusions and recommendations for decision-makers. The report will be prepared in conjunction with scientific and policy related community (e.g., NARSTO). The report is planned to be available in 2006.

## B. Milestones of Progress

Aside from the reports prepared from the elements of NETL program, a series of milestones are projected which will be used to measure progress towards the overall objectives of the program. These are listed below by year of expected completion as a complement to the dates listed for availability of reports.

**TABLE 5. Progress Milestones for NETL Fine PM Program**

| Year | Milestone |
|---|---|
| 2001 | • Completion of the UORVP field program, including field measurement quality control and assurance initiatives.<br>• Assembly and evaluation of emissions inventories, identifying key sources for chemical fingerprint identification.<br>• Identification of key sources for development of source chemical profiles.<br>• Preliminary aerometric analysis of the field data to identify daily regimes of long-range transport potential versus local source influences. |
| 2002 | • Completion of chemical analysis of selected filters from UORVP field study.<br>• Initiation of key source characterization for chemical profile development.<br>• Initiation of receptor and emissions-based model evaluation and application component. |
| 2003 | • Completion of aerometric data analysis integrating UORVP and SCAMP results.<br>• Completion of the key source chemical profile studies. |
| 2004 | • Completion of receptor and air quality modeling evaluations. |
| 2005+ | • Completion of integration studies and model applications to selected areas.<br>• Preparation of final report(s), presentation of report to NETL management, DOE-FE staff, regional community of interested scientists, and stakeholders. |

## C. Program Coordination

In its review, the NRC panel recommended that an external advisory committee be appointed for the NETL PM program. An advisory group was organized for the UORVP in its early stages, but has been inactive. To provide guidance and program evaluation through the remainder of the program, NETL will reorganize an external advisory group for the analysis and interpretation of the UORVP results, and for the air quality modeling component. This committee will be formed with recognized experts from academia, Government, and industry. It will be organized to meet at least once per year through the remainder of the program to provide NETL with notes about the progress of the program and suggestions for improvements to insure that the objectives are achieved.

While the NETL PM program is well underway toward achieving its objectives in the next 5 years, the achievement of a methodology for establishing source-receptor relationships in areas where complex mixes of energy sources, and major urban and industry activity exist remains problematic. The duration and extent of work in the NETL program may not address all of the necessary elements of this problem in the next 5 years. The analysis and interpretation of the data in combination with the modeling will reveal if there are gaps in knowledge remaining that will require continuing attention. A review of the program results in 2004 by an external review panel, for example organized by the National Research Council, will be organized to advise DOE on the progress made on the $PM_{2.5}$ problems. Given their review, a determination will be made about extending the life and objectives of the program over another increment of commitment.

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APPENDIX A

NRC Review of DOE-FE (NETL) Research Plan for Fine Particulates:
General Findings and Recommendations

BACKGROUND

FY 98 Congressional appropriations call for DOE-FE to initiate research program in fine particulate matter (PM).

In 1998, DOE-FE Deputy Assistant Secretary for Coal and Power Systems requests National Research Council (NRC) review of DOE-FE fine PM research plan.

March 24-25, 1999: DOE-NETL and FE-HQ staff present DOE-FE fine PM program to NRC Review Panel in Washington, DC.

October 12, 1999: NRC issues final report, "Review of DOE's Office of Fossil Energy's Research Plan for Fine Particulates."

NRC REVIEW PANEL

- Richard Magee (Chair) - New Jersey Institute of Technology
- Jan Beyea, Consulting in Public Interest
- John Godleski, Harvard School of Public Health
- Manoj Guha, American Electric Power Service Corporation
- George Hidy, University of Alabama at Birmingham
- Rudolph Husar, Washington University
- John Longwell, Massachusetts Institute of Technology
- Spyros Pandis, Carnegie Mellon University
- George Wolff, General Motors Corporation
- Ronald Wyzga, EPRI
- Frederick Lipfert, Environmental Consultant

NRC GENERAL FINDINGS

- The program was implemented in a relatively short time under Congressional mandate.

- The DOE-FE fine PM program is focused on emissions from the use of coal for electric power generation. In its entirety, the program has considerable merit and should produce useful information.

- The program would benefit from more long-term strategic planning.

- The present budget is not sufficient to achieve objectives across all program areas.

- The program should include a quantitative means of linking sources and ambient particle composition.

- The program needs to establish linkages with other programs and studies.

- Given limited funding and current trends, control technology development may be premature.

- Additional DOE staff is needed in support of the program.

Interagency coordination is critical; allocation of resources and personnel is required to facilitate interaction.

NRC GENERAL RECOMMENDATIONS

- Recommendation No. 1: DOE-FE should develop a 5-year strategic plan for the fine PM program consistent with EPA $PM_{2.5}$ NAAQS implementation schedule.

  NETL Response:

  - Develop a multi-year strategic plan for the NETL fine PM research program.
  - Secure outside assistance if necessary to develop draft.
  - Obtain input from industry and environmental groups.

- Recommendation No. 2: Sufficient resources should be allocated to high priority items over a 5-year planning horizon to support research necessary to meet program goals.

  NETL Response:

  - Strengthen program elements dealing with emissions characterization and source-receptor modeling.

- Recommendation No. 3: Expertise to supplement the NETL staff should be formally included in the planning and execution of the program.

  NETL Response:

  - Capability/availability of NETL staff resources in PM is currently being assessed.
  - Possible acquisition of external expertise for planning of source characterization and source-receptor modeling studies.

# APPENDIX B

## Description of Upper Ohio River Valley Project (UORVP)

### INTRODUCTION AND OBJECTIVES

The overall goal of the Upper Ohio River Valley Project (UORVP) is to investigate the nature and composition of fine particulate ($PM_{2.5}$) and its precursor gases in the Upper Ohio River Valley and provide a better understanding of the relationship between coal-based power system emissions and ambient air quality in the upper Ohio River Valley region.

Advanced Technology Systems, Inc. (ATS), with Desert Research Institute (DRI) as the subcontractor, was contracted by DOE-NETL in September 1998 to manage the UORVP. Specific objectives of the UORVP include:

- Provide improved chemical, size distribution, and time resolution of urban and rural ambient fine particulates (both particles and gas-phase components) in the Upper Ohio River Valley region.
- Provide a platform to compare the performance of the Federal Reference Methods (FRMs) and other "routine" monitoring programs with advanced methods designed to account for semi-volatile components of the ambient aerosol.
- Conduct sufficient sampling and chemical analysis of ambient $PM_{2.5}$ to estimate the impact of local and regional sources on ambient air quality related to both particle concentrations, composition and regional visibility relationships.
- Support related exposure and health-risk assessments in the region by advancing the understanding of the chemical and physical nature of $PM_{2.5}$ and directly supplying ambient measures for exposure, epidemiological, and clinical field studies.
- Conduct a minimal measurement program at ground level to establish linkages between local visibility change, ozone concentrations, and airborne fine particle concentration variations.
- Evaluate and compare different methods of sampling aerosol particles, both filter based and continuous, over size ranges less than 10 micrometers, but with primary focus on sub-2.5-micrometer particles, using complementary instrumentation.
- Conduct sufficient sampling and chemical analysis of ambient $PM_{2.5}$ to estimate by receptor modeling the impact of local and regional sources on ambient air quality and to support related human exposure and epidemiological studies in the region.

UORVP STATEMENT OF WORK

Task I -- Quality Integrated Work Plan

The contractor will develop and submit a Quality Integrated Work Plan (QIWP). The QIWP is a project work plan with the critical quality assurance, quality control, and data management activities integrated into a single working document. This format provides for discussion of science and data quality issues, identification of quality objectives and other pertinent technical and management criteria, and description of how the objectives will be achieved. At a minimum, the QIWP will address project: (1) planning and organization, (2) management assessment, (3) implementation, (4) data acquisition, (5) data management, (6) records management, (7) routine controls and procedures, and (8) technical assessment and response. This document presents a clear and explicit description of the activities to be conducted, and includes all relevant Standard Operation Procedures (SOPs) and Research Protocols (RPs). The SOPs will detail the method for an operation, analysis, or action with thoroughly prescribed techniques and steps.

The QIWP will be modeled after the template that has been developed for the North American Research Strategy for Tropospheric Ozone (NARSTO) and described in NARSTO's *Quality Planning Handbook* which is posted on the Internet as a *www.cgenv.com/Narsto* website.

Task II -- Equipment and Instrumentation Procurement

The contractor will be responsible for procuring all equipment and instrumentation listed in Tables 1, 2, 3, and 4 for the planned UORVP monitoring stations. The contractor will also procure the computer hardware and software necessary to operate the monitoring equipment and manage the resultant data, as well as the electronic equipment needed for remote data access and transfer (e.g., phone modems, etc.). The Contractor will also procure the necessary shelter/housing to protect sensitive instruments and equipment from the outdoor environment.

Task III -- Equipment Installation and Shakedown

The contractor will be responsible for installing the acquired equipment and instrumentation. It assumes that the equipment for the urban site will be collocated at a monitoring site operated by the Allegheny County (PA) Health Department (AHCD) at its Lawrenceville, Pittsburgh site and AHCD will allow for additional site development if needed. Site development may include pouring of concrete pads, arrangements for air conditioning and heating of shelters, and working space. Additional utilities (i.e., electricity, water) may also be necessary. Accessibility to the site year-round and on a 24-hour basis will also be required. Installation and shakedown of the air monitoring and meteorological equipment will need to be completed in a timely fashion to allow site operation to begin in early 1999. The Holbrook, Greene County site, as well as the "bare-bones" monitoring sites at Athens, Ohio, and Monongalia, West Virginia, will also go on-line in Phase I of this project.

Task IV -- Site Operation and Maintenance

The contractor will operate the sites to acquire meteorological data, gas-component data, and filter-based samples. Operation will require an experienced field staff and supervisory personnel. The contractor will be responsible for the scheduled calibration of all instrumentation, for data recording and transmittal, and for sample collection and storage to prevent contamination of the samples in accordance with prescribed protocols. Table 5 provides the overall sampling requirements for both continuous and intermittent samplers. Table 6 presents further additional detail concerning the intermittent sampling frequency and schedule.

The UORVP is arranged to obtain a base level of intermittent samples every third day at both sites. This will allow for estimates of monthly, seasonal, and annual averages that can be compared with data obtained from other EPA/state programs and with other parallel research projects in the eastern United States. To investigate the differences between months of high production of secondary particulates from atmospheric reactions, 1 month in the summer will be used for sampling every day, with $PM_{2.5}$ material obtained on a 12-hour schedule to evaluate diurnal variations in sample composition. Sampling for particulate (ammonium) nitrate and gaseous nitrogen species, as well as ammonia, will provide data to investigate the apparent low nitrate levels found in eastern $PM_{2.5}$ catches.

For comparison with summer conditions, a 1-month daily sampling period is projected for mid-winter. Cool temperature conditions and low biological activity may create a tradeoff for ammonium nitrate production that differs from the summer months. Any sulfate production is likely to derive from minimal photochemical activity during winter, and secondary organic material is expected to be absent from particles at this time. The mid-winter particulate sampling program is planned to be a duplicate for the summer sampling protocol.

To provide for comparability with stations to be set up as part of the national $PM_{2.5}$ monitoring network, the basic sampling will be conducted using $PM_{2.5}$ FRM sequential filter-based samplers. In addition, a $PM_{10}$ FRM sequential sampler will be installed at each site. Appropriate filter media will be necessary for all desired analyses shown in Table 6. The UORVP sampling protocol will allow for a comparison of the $PM_{10}$ and $PM_{2.5}$ mass and chemistry, but the emphasis of the project is on the $PM_{2.5}$ component.

The FRM $PM_{2.5}$ sampler will also be compared with a $PM_{2.5}$ monitor that will capture the semi-volatile components (e.g., semi-volatile organics and nitrates) of the aerosol, such as those that employ denuders and/or back-up filters. The comparison between the semi-volatile sampler and the FRM sampler will allow for a better understanding of the potential loss or gain in chemical components during ambient sampling. Moreover, speciation samplers that capture the semi-volatile species are necessary for complete characterization of ambient fine particulate matter. The final selection of the speciation sampler(s) to be used in the UORVP has not yet been determined. The selection will be based to a large degree on guidance provided by EPA regarding $PM_{2.5}$ speciation monitoring.

The measurement of several gases that are relevant to characterizing photochemistry, or are precursors for particle formation, are also required. These include ozone and its precursors ($NO_X$, $HNO_3$, and $NH_3$) as well as carbon monoxide (CO) and sulfur dioxide ($SO_2$). Continuous measurement of total gaseous mercury will also be carried out using a Tekran or equivalent analyzer only at the Holbrook site.

The observations will be completed with the acquisition of surface meteorological data at all sites, including wind speed and direction, temperature, relative humidity, precipitation, and UV radiation and insolation.

In order to allow the effects of seasonal weather conditions on the $PM_{2.5}$ and gaseous co-pollutant concentrations to be accounted for more accurately, operation and maintenance of all four sites shall continue until April 30, 2001. This will improve the reliability of the data and allow better year-to-year comparisons to be made, especially for the intensive summer sampling periods. The nature of site operation (frequency of sampling, number and type of samplers operated at each site, etc.) will remain the same, with intermittent (every sixth day) sampling at Lawrenceville and Holbrook to be supplemented by month-long intensive sampling periods during the summer of 2000 and the winter of 2001.

Task V -- Sample Collection and Analysis

The contractor will be responsible for the collection and storing of samples for subsequent chemical analysis and for the calibration and maintenance of the sampling equipment and instrumentation. The contractor will have overall responsibility for the analysis of samples collected at the urban Pittsburgh site, as well as the samples collected at the UORVP rural sites. The contractor will analyze the collected samples following the guidance presented in Table 5. The contractor will perform a statistical-design evaluation of the analytical protocol and suggest modifications, as appropriate, that will result in a more cost-effective project, will optimize data acquisition, and will maximize the information obtained from the statistical evaluation of the data, while still achieving the objectives of the UORVP.

The contractor will also provide a *Sample Collection and Analysis Plan* as part of its overall QIWP that details the procedures that will be followed for filter preparation, sample collection, sample handling, sample splitting, and sample storage and transport, and sample analysis including all applicable quality assurance/quality control requirements.

Due to funding constraints, only 20 percent of the collected samples (one sample out of every five collected) were receiving complete chemical analysis by the subcontractor (DRI) under the original Statement of Work, with the remainder of the samples being marked and stored for future analysis. This modification allows the contractor to provide for the chemical analysis of at least 50 percent of the collected samples throughout the sampling effort. Performance of this task shall continue until September 30, 2002, to accommodate the extension of the sampling effort described under Task IV.

Task VI -- Quality Assurance and Quality Control

The contractor will be responsible for implementing the quality assurance and quality control (QA/QC) procedures and methods described in the QIWP for the UORVP sites.

Task VII -- Data Management

Data management will be a critical component of the success of the UORVP. The contractor will include in the QIWP the data management process that will define data quality objectives, data acquisition procedures, data validation checks, data transfer pathways, and data formats. The contractor will also develop and implement the process by which the data will be maintained and made available to various end-users, such as through homepages.

The data management activities that are included in the QIWP are the minimum needed to support the UORVP implementation plan and data acquisition, evaluation, and validation activities. The data management component of the QIWP should address, at a minimum, the following:

- Types of data to be collected, processed, and utilized.
- Data sources.
- Data management resources needed.
- Data collection activities.
- Data processing activities.
- Data verification and validation activities.
- Data management and geographic information systems (GIS) to be used.
- Data, database, and systems controls and administration.
- Data reporting needs.
- Data archival.

Data management will also require the identification of reporting conventions, minimal detectable limits, calibration values and uncertainty estimates, qualifying data, data validation, data formatting, documentation, and transmission, and data achieving and dissemination. DOE/NETL will serve as the primary repository for all quality assured UORVP data and final data products, with direct linkages to other key air quality databases and websites, such as EPA AIRS and NARSTO Langley DAAC. The contractor will get data management guidance as provided in the NARSTO *Data Management Handbook*.

Task VIII -- Reporting and Project Review

The contractor will be required to submit quarterly and annual progress reports and a final report. The contractor will also be required to formally meet with the DOE-NETL Project Manager at least once a month to review project status during the first 6 months of the project. For the remainder of the project, the status review meetings will be held on an as-needed basis, but no less than once a quarter. The contractor will also attend three meetings of national scope at which they may be asked to give formal presentations on their work.

**TABLE B-1. Equipment to be Installed at the Lawrenceville, PA, Monitoring Site**

| Unit | Number Required |
|---|---|
| Surface Meteorology | 1 |
| Federal Reference Method (FRM) for $PM_{2.5}$ (Sequential) | 2 |
| FRM for $PM_{10}$ (Sequential) | 1 |
| $PM_{2.5}$ TEOM | 1 |
| $PM_{10}$ TEOM | 1 |
| Combined Semi-Volatile and Filter Sampler (Speciation Sampler) | 1 |
| Ozone (Continuous Analyzer) | 1 |
| Reactive Nitrogen (Continuous Analyzer) | 1 |
| CO (Continuous Analyzer) | 1 |
| $SO_2$ (Continuous Analyzer) | 2 |
| Data Logger/Acquisition | 1 |
| Gas Particle Sampler Calibrator | 1 |
| Shelter and Site Preparation (Including Utility Connections) | 1 |
| Portable Audit Sampler | 1 |

**TABLE B-2. Equipment to be Installed at the Holbrook, PA, Monitoring Site**

| Unit | Number Required |
|---|---|
| Surface Meteorology | 1 |
| Federal Reference Method (FRM) for $PM_{2.5}$ (Sequential) | 2 |
| FRM for $PM_{10}$ (Sequential) | 1 |
| $PM_{2.5}$ TEOM | 1 |
| Total Gaseous Hg Analyzer (Tekran or Equivalent) | 1 |
| Combined Semi-Volatile and Filter Sampler (Speciation Sampler) | 1 |
| Ozone (Continuous Analyzer) | 1 |
| Reactive Nitrogen (Continuous Analyzer) | 1 |
| CO (Continuous Analyzer) | 1 |
| $SO_2$ (Continuous Analyzer) | 1 |
| Data Logger/Acquisition | 1 |
| Gas Particle Sampler Calibrator | 2 |
| Shelter and Site Preparation (Including Utility Connections) | 1 |

**TABLE B-3. Equipment to be Installed at the Athens, OH, Monitoring Site**

| Unit | Number Required |
|---|---|
| Federal Reference Method (FRM) for $PM_{2.5}$ (Sequential) | 1 |

**TABLE B-4. Equipment to be Installed at the Monongalia, WV, Monitoring Site**

| Unit | Number Required |
|---|---|
| Federal Reference Method (FRM) for $PM_{2.5}$ (Sequential) | 1 |

## TABLE B-5. Instrumentation and Sampling Requirements

| Parameter | Sampling Schedule | | Comments |
|---|---|---|---|
| | Continuous | Intermittent | |
| Surface Meteorology (Winds, Temperature, Relative Humidity, Insolation) | X | | Basic data to establish meteorological conditions. |
| Radar Acoustic Sounding System (RASS)[1] | X | | Establish conditions aloft. |
| FRM $PM_{2.5}$ Teflon and Quartz Filter | | X | Gravimetric mass and organics/inorganics. |
| FRM $PM_{10}$ Teflon and Quartz Filter | | X | Gravimetric mass and organics/inorganics. |
| TEOM $PM_{2.5}$ (Mass) | X | | Mass concentration. |
| TEOM $PM_{10}$ (Mass) | X | | Mass concentration. |
| Semi-Volatile and Filter-Based Sampler (Speciation Sampler) | | X | Determination of semi-volatile inorganics and organics (e.g., $NH_3$, $NO_3$, VOCs) and other filter chemistry. |
| Light Scattering, Humidity-Controlled Inlet (Nephelometer) | X | | Determination of light scattering coefficient and liquid water. |
| Light Absorption and Elemental Carbon (Aethalometer) | X | | Absorption coefficient correlated to elemental carbon concentrations. |
| Burkard 7-Day Spore Trap or Equivalent | X | | Microscopic measurement of biologically derived fine particulates. |
| Low-Pressure Staged Impactor (MOUDI) | | X | Size fractionated chemistry into ultra-fine range. |
| Condensation Nuclei | X | | Ultra-fine number concentration. |
| High-Volume Sampler ($PM_{2.5}$) | | X | Sample for organic chemical speciation (GC-MS) and isotope analysis. |
| Tekran or Equivalent Hg Analyzer | X | | Provide continuous total gaseous mercury measurements. |
| Ozone | X | | Provide ozone concentration and a measure of photochemical activity. |
| Reactive Nitrogen (e.g., $NO_x$, $NO_2$, $NO_y$) | X | | Oxidant and nitrate precursors; important energy production by-product. |
| PAN | X | | Oxidant formation by-product; potentially important sink for $NO_x$. |
| CO | X | | Tracer for motor vehicles. |
| $SO_2$ | X | | Tracer for coal combustion; co-factor in PM exposure. |
| VOC ($C_1$ - $C_9$) | X | | Oxidant precursor; source of condensed organics. |
| VOC ($C_{10}$ - $C_{20}$) | | X | Likely source of condensed organics. |
| Oxygenates | | X | Oxidant precursor; possible particulate source. |
| Peroxides | | X | Oxidant source and photochemical product; may have health implications. |
| Free Radicals | | X | Oxidant intermediates; chemical indicators. |

[1] RASS equipment located at an existing NARSTO-NE site near Holbrook, Greene County, Pennsylvania. Equipment will not need to be procured by the contractor.

## TABLE B-6. Annual Intermittent Sampling Schedule

| Sampler/Parameter | Analytical Method | Sampling Frequency |
|---|---|---|
| **FRM $PM_{2.5}$ 1-Teflon Filter; 2-Fired Quartz Filter** | | 10 months, every 3 days (24-hour sample);<br>2 months (1 summer and 1 winter) every day. |
| Mass | Gravimetric | |
| Soluble Ions | Ion Chromatography (IC) and Automated Colorimetry (AC) | |
| Elements | X-Ray Fluorescence (XRF) | |
| Organic Carbon (OC), Elemental Carbon (EC) | Thermal Analysis | |
| **FRM $PM_{10}$ 1-Teflon; 2-Fired Quartz Filter** | | 12 months every 6 days. |
| Mass | Gravimetric | |
| Soluble Ions | IC/AC | |
| Soluble Ions | XRF | |
| OC, EC | Thermal Analysis | |
| **Semi-Volatile Sampler (With Filters and Denuders)** | | 10 months every 12 days; 2 months (1 summer and 1 winter) every day. |
| Mass | Gravimetric | |
| Soluble Ions | IC/AC | |
| Elements | XRF | |
| OC/EC | Thermal Analysis | |
| Denuder (Nitrate, $NH_4$)<br>Nylon or Citric Acid Impregnated Filters | IC/AC | |
| Quartz Backup Filter (OC, Speciation) | Thermal Analysis; Gas Chromatography (GC)-<br>Mass Spectroscopy (MS) | Same for OC; GC-MS (6 summers, 6 winters). |
| **Low-Pressure Impactor** | | Five 24-hour samples -- 12-hour days, 12-hour nights (summer and winter intensives). |
| Mass | Gravimetric | |
| Solubles Ions | IC | |
| Elements | XRF | |
| OC/EC | Thermal Analysis | |
| **Hi-Vol Sampler** | | Five 24-hour samples -- 12-hour days, 12-hour nights (summer and winter intensives). |
| Isotopes | IC/AC | |
| Speciation | Solvent Extraction; GC-MS | |
| **Burkard 7-Day Spore Trap or Equivalent** | Microscopic Analysis | 2 samples summer; 2 samples winter. |
| **VOC Canister ($C_{10}$ - $C_{20}$)** | GC-MS | 6 canisters (0800-1000 hours) summer;<br>3 canisters same time in winter. |
| **Oxygenates** | DNPH Cartridge or Other | 6 samples (0800-1000 hours); 6 samples (1300-1500 hours) summer; 3 samples same time in winter. |
| **Peroxides** | Luminal Based or Other | Semi-continuous for 15 days in summer; semi-continuous or 15 days in winter. |
| **Free radicals** | Hastie Method | Semi-continuous (14 days in summer). |

APPENDIX C

Description of Steubenville Comprehensive Air Monitoring Project (SCAMP)

## INTRODUCTION AND OBJECTIVES

The Steubenville Comprehensive Air Monitoring Project is comprised of two complementary and interrelated studies which cannot stand independently. One project is funded through the Ohio Department of Development (ODOD) Coal Development Office (CDO) under Grant Agreement No. CDO/D-98-2. The other project is described in Unsolicited Proposal No. P9908026 "Characterization of the $PM_{2.5}$, $PM_{10}$, and Gaseous Priority Pollutants in Steubenville, Ohio, and the Surrounding Region" submitted to the U.S. DOE/NETL January 29, 1999.

The goals of the program are:

- To measure the fine and coarse outdoor particulate matter ($PM_{2.5}$ and $PM_{10}$) and co-pollutant concentrations at a central urban site, four remote sites, and at the homes of participating individuals.
- To measure the indoor $PM_{2.5}$ and co-pollutant concentrations in the living environment of participating individuals.
- To measure the $PM_{2.5}$ and co-pollutant concentrations of the "personal environment" of participating individuals.
- To evaluate the relationships between concentrations and personal exposure to indoor, outdoor, and personal $PM_{2.5}$, and indoor, outdoor, and personal co-pollutants.
- To evaluate the relationships among indoor, outdoor, and personal $PM_{2.5}$ concentrations and indoor, outdoor, and personal co-pollutants.
- To compare $PM_{2.5}$ and $PM_{10}$ collected at urban and remote sites.
- To characterize the indoor, outdoor, and personal $PM_{2.5}$ physical and chemical nature.
- To evaluate the toxicological effects of fine particles.
- To collect hourly weather data and daily pollen and mold spore counts.
- To provide a comprehensive data base for use in epidemiological studies, long-range transport studies, and State Implementation Program compliance.

SCAMP STATEMENT OF WORK

Tasks are delineated by sampling location: "Outdoor (O)" and "Indoor (I)." Outdoor includes sampling and analyses of samples obtained at the central urban site, the four remote sites, and outside the homes of participating individuals. In addition, the tasks include statistical analyses of these data and the data base resulting from this work. Indoor includes sampling and analyses of samples obtained in the homes of participating individuals and the "personal" air of those individuals. The corresponding statistical analyses tasks and resultant data base from the samples collected indoors are included with the indoor sampling and analyses tasks. A cross comparison between the indoor and outdoor data is shared by both projects to meet the overall SCAMP objectives.

Outside Tasks (O)

- **Task O1. Outside Project Management**

  The proposed work will be conducted under the direction of a project management team headed by CONSOL, Inc., Research and Development Department. CONSOL will be the prime contractor to the Department of Energy (DOE) and will form a team with DOE, Harvard University School of Public Health, the Ohio University, Wheeling Jesuit University, and St. Vincent's College. The project team will determine the direction of the research, finalize the work plan, and carry out the work. The participants will form a Project Advisory Committee (PAC) with representation from the project team, DOE, Ohio EPA, the Ohio Coal Development Office, the Electric Power Research Institute, individual electric utilities, and several industrial and trade organizations. The PAC will provide input to the Work Plan. The PAC will review the project status and will review status reports.

- **Task O2. Outside Sampling, Data Collection, and Analyses**

  This task is subdivided into three subtasks:

  - Subtask O2.1 -- Urban Central Site Outdoor Air Sampling, Data Collection, and Analysis

    The purpose of this subtask is to establish and operate an ambient air monitoring super site at an urban Steubenville, Ohio, location. $PM_{2.5}$, $PM_{10}$, priority gaseous pollutants (CO, $SO_2$, $NO_2$, total hydrocarbons, and $O_3$), and ammonia concentration data will be collected. Meteorological data (wind speed and direction, air temperature, relative humidity, barometric pressure, precipitation, and solar radiation) and pollen and mold spore counts also will be collected at this site. Samples and data will be collected daily for 2 years using Federal Reference Methods (FRM) for the particulate matter and continuous monitors for the gases. $PM_{2.5}$ samples also will be collected daily on a quartz filter (instead of a Teflon filter as required by the FRM) to provide particle samples suitable for carbon (organic and elemental) determinations.

Approximately one-fourth of the collected $PM_{2.5}$ samples will be characterized to determine average composition. Samples collected every fourth day will be characterized. Additional analyses will be performed on samples collected during episodes of high $PM_{2.5}$ concentration. Routine analysis of the PM samples will include water-soluble sulfate, nitrate, and ammonium concentrations using ion chromatography; water-soluble elemental analysis using inductively coupled plasma-atomic emission spectrometry (ICP-AES) and inductively coupled plasma-mass spectrometry (ICP-MS); and total carbon content using a combustion-$CO_2$ collection gravimetric method. Non-routine analyses to be performed on selected samples will include organic and elemental carbon content using thermal optical reflectance spectroscopy or Fourier Transform Infrared Spectrometry, single particle characterization using Raman chemical imaging, total elemental analysis using ICP-AES and ICP-MS, and alveolar tissue response using bioassay.

The ambient outdoor air in Steubenville, Ohio, an inland U.S. city, will be characterized. The variability in particulate and gaseous pollutant concentrations and average particulate composition will be examined as a function of day-of-the-week, season-of-the-year, and weather conditions. The collected data will be used to assess whether $PM_{2.5}$ or $PM_{10}$ concentrations correlate with the gaseous pollutant concentrations or the pollen and mold spore count.

- Subtask O2.2 -- Remote Outdoor Air Sampling and Analyses

  The purpose of this subtask is to install and operate Federal Reference Method (FRM) $PM_{2.5}$ monitors at four remote sites centered around the super site location near Steubenville, Ohio. The four locations will be located at approximately the four compass points in relation to Steubenville. Samples will be collected daily for 2 years using the FRM for $PM_{2.5}$. Additional $PM_{2.5}$ samples will be collected daily on quartz filters to provide particle samples suitable for carbon (organic and elemental) determinations. Approximately one-fourth of the collected $PM_{2.5}$ samples will be characterized to determine average composition using the same methods described in Subtask O2.1 above.

  The ambient outdoor $PM_{2.5}$ concentration in the region surrounding Steubenville, Ohio, will be characterized. The temporal and seasonal variability in $PM_{2.5}$ concentration also will be examined. The data collected in Subtask O2.2 will be used in combination with the data collected in Subtask O2.1 to determine if the regional and urban $PM_{2.5}$ concentrations and compositions correlate.

- Subtask O2.3 -- Local Home Outdoor Sampling and Analyses

  The purpose of this subtask is to measure the daily pollutant concentration immediately outside of the homes of people considered to be particularly at risk for adverse health effects from airborne pollutants. The field work for this subtask will be performed by the Harvard University School of Public Health (HSPH). The outdoor concentrations of particulate matter ($PM_{2.5}$ and $PM_{10}$) and gaseous pollutants (CO,

$SO_2$, $NO_2$, and $O_3$) will be measured outside of 30 homes chosen from volunteers in the Steubenville area. Data will be collected at each location for 1 week in the winter 1999-2000, 1 week in summer 2000, and 1 week in the winter 2000-2001, using an integrated multi-pollutant monitor recently developed at HSPH. The sensitivity, accuracy, and precision of this monitor has been demonstrated in previous studies performed by HSPH. HSPH will provide the monitors for this study. Approximately one-fourth of the PM samples collected will be characterized to determine average composition using the same methods described in Subtask O2.1 above.

The air quality immediately outside of the homes of the at-risk groups will be determined. The temporal and seasonal variability in particulate matter and gaseous pollutant concentrations will be examined as a function of location. The data will be used to assess whether $PM_{2.5}$ or $PM_{10}$ is correlated with gaseous pollutant concentrations.

In addition to characterizing the local outdoor air quality, the data collected in this task, in combination with the data collected in Subtask O2.1, will be used to determine the association between outdoor air quality at several local home sites and air quality at a central urban site for each of the measured pollutants.

- **Task O3. Statistical Analysis of Outside Data**

The objective of this task is to develop the correlations among urban central site, local home site, and remote site $PM_{2.5}$ concentrations and the correlations among the outdoor ambient concentrations of $PM_{2.5}$, $PM_{10}$, and gaseous pollutants. Ultimately, these correlations will determine the appropriateness of the exposure assessment methods typically used in epidemiological studies. The data collected in Task O2 will be analyzed using descriptive statistics and graphs. Analyses will focus on how pollutant concentrations vary with location, season, and weather conditions. The data also will be analyzed to determine whether a correlation can be found between central site ambient outdoor concentrations and the concentrations measured outside of individual homes. The data will be examined to determine if the particulate matter concentrations correlate with (or are confounded by) other pollutants, meteorological conditions, or pollen and mold spore count.

- **Task O4. Reporting of Outside Data**

The purpose of this task is to ensure effective communication among project participants. CONSOL R&D, as prime contractor, will assume the responsibility for delivery of all reporting. CONSOL will submit all reports in accordance with the DOE Uniform Reporting System for Federal Assistance.

Monthly status reports will be used to communicate monitoring results on an interim basis. A final technical report will provide a compilation of the monitoring results and a detailed description of the statistical analyses and results. One element of reporting includes meetings with project participants and stakeholders at the urban and remote sampling sites:

Washington, DC, and Research Triangle Park, North Carolina. Results will be presented at scientific and technical meetings.

Inside and Personal Tasks (I)

- **Task I1. Inside Project Planning and Management**

  CONSOL R&D shall prepare and submit a Project Management Plan to the OCDO Project Officer within 30 days following the contract initiation. This plan shall be self-contained and shall present in detail all activities that will be performed for the successful completion of the work outlined in this Statement of Work.

- **Task I2. Inside Sampling, Data Collection, and Analyses**

  CONSOL R&D will subcontract with the Harvard University School of Public Health (HSPH) to perform the test subject selection and the sample collection. HSPH will subcontract with Ohio colleges/universities (or as appropriate, Ohio hospitals) for some of the sample collection and data analysis. Prior to the full test, the personal sampler design will be modified and a pilot test will be performed. CONSOL R&D will subcontract with HSPH to perform the sampler modifications and pilot test sample collection.

  - Subtask I2.1 -- Methods Development and Pilot Study

    The design of the Harvard multi pollutant personal sampler used in previous studies will be modified. The current design collects samples to measure $PM_{2.5}$, $PM_{10}$, sulfate, $O_3$, $NO_2$, $SO_2$, and CO in personal breathing space. After modification, the samplers also will measure nitrate, water-soluble elements, and organic and elemental carbon. A pilot study will be conducted in Steubenville, Ohio, to test the new design. To determine the accuracy of the design, a modified sampler will be co-located with a fine particulate Federal Reference Method instrument and gaseous criteria pollutant measurements. In addition, three adults will be selected to wear the personal sampler for the pilot study. Ten (10) measurements will be made for each adult.

    The filter samples collected in the pilot study will be used to compare XRF and ICP-MS methods for elemental analysis of particulate matter samples. XRF is typically used for elemental analysis of ambient air particulate matter samples; however, ICP-MS is more sensitive than XRF for the detection of most elements. Sample digestion is required for ICP-MS analysis, but not for XRF analysis. Selected samples will be analyzed by XRF first, followed by analysis of the same samples using ICP-MS, and the results will be compared. In addition, samples containing known concentrations of common particulate matter elements will be prepared and analyzed by both methods for comparison.

    Particulate and gaseous concentrations measured using the Harvard multi-pollutant samplers will be compared to those measured using reference samplers for each pollutant of interest. The Harvard multi-pollutant samplers will be used to measure

$PM_{2.5}$, elemental and organic carbon (EC/OC), nitrate, sulfate, ozone, and sulfur and nitrogen dioxide concentrations. $PM_{2.5}$ concentrations will be obtained on two filters, both of which will be weighed for total mass.

In the method inter-comparison tests, two multi-pollutant samplers will be collocated with one reference sampler for each pollutant of interest. All samplers will be collocated at a SAM site. A total of 10 to 20 sample sets will be collected to assess the performance of the multi-pollutant samplers. Sampler performance will be assessed individually for each pollutant by comparison of the concentrations measured using the multi-pollutant sampler with those measured using the reference sampler.

Laboratory inter-comparisons will be conducted to ensure that the laboratory gravimetric and ion chromatographic analysis was performed correctly. Ten (10) to 20 sets of three samplers (at a minimum) will be collocated at the SAM site. $PM_{2.5}$ and inorganic ion concentrations will be determined independently by Harvard and CONSOL laboratories, with a third laboratory used if the laboratory results do not agree.

- Subtask I2.2 -- Summer 2000 and Winter 2001 (Panel Study of Older Adults)

This subtask is intended to characterize the particulate and gaseous exposures of independently living, older adults. Planning for Subtask I2.2 will begin in November 1999. Monitoring for Subtask I2.2 will be performed after satisfactory completion of the Task I2.1 inter-comparison studies. The monitoring component is expected to begin in June 2000.

In Subtask I2.2, the indoor concentrations and personal particulate and gaseous exposures will be characterized for a panel of 25 older adults living in Steubenville, Ohio, community housing complexes. Each of these individuals will live "independently" and will control their own home ventilation conditions.

Study participants will be recruited from a population of older adults living in community-based housing. Participants will be selected based on their non-smoking status, their ability to live independently, and their ability and willingness to participate in this project and in a concurrent project on heart rate variability.

Subtask I2.2 will be performed in two seasons: summer 2000 and winter 2001. In each season, repeated 24-h indoor particulate and gaseous air pollutant monitoring will be performed inside the homes of 25 individuals. For each individual, indoor monitoring will be performed 2 days each week for a total of 10 weeks (Figure 1). Indoor samples will be collected for 5 or 10 participants each day. Twenty (20) indoor samples will be collected for each participant each season, for a total of 500 indoor samples.

Corresponding 24-h personal particulate and gaseous exposures will be measured for 10 of the 25 individuals. Personal exposures will be measured for two or four participants each day. Each season, 20 personal samples will be collected for each of the 10 participants, for a total of 200 personal particulate and gaseous samples.

All indoor samples will be collected using the multi-pollutant sampler, which will be used to measure 24-h $PM_{2.5}$, EC/OC, nitrate, sulfate, water-soluble and total element, $O_3$, $SO_2$, and $NO_2$ concentrations. Indoor samplers will be placed inside the main activity room of each participant's home, with the inlets placed at 4 feet high to correspond to the breathing level of the individual. Each of the $PM_{2.5}$ PEMs will sample at a flow rate of 4 LPM; the speciation samplers for EC/OC and nitrate/sulfate will each sample air at 0.8 LPM.

The same multi-pollutant sampler will be used to measure the 24-h personal particulate ($PM_{2.5}$, EC/OC, nitrate, sulfate, water-soluble and total elements) and gaseous ($O_3$, $SO_2$, $NO_2$) exposures for 10 of the participants. Each of these 10 individuals will be asked to wear a sampler for 2 days each week. (Personal monitoring will be performed on the same days as indoor monitoring.) The multi-pollutant sampler inlet will be placed at breathing height. The pump, battery pack, and tubing will be stored in a backpack. Each of the $PM_{2.5}$ PEMs will sample at a flow rate of 1.8 LPM; the speciation samplers for EC/OC and nitrate/sulfate will each sample at 0.8 LPM.

In addition to the air pollutant monitoring, time/activity and housing characteristics data will be obtained for each of the study participants for each 2-day monitoring period. Participants will be given a time/activity diary at the beginning of each monitoring day, on which the participant will be asked to record information about each new activity, including a brief description of the activity as well as its location, start time, and stop time. At the end of each monitoring day, field technicians will administer a housing questionnaire to each participant, who will be asked questions about home ventilation characteristics and household activities that occurred within the home.

Harvard will recruit the study participants and will coordinate and supervise the indoor and personal sampling. Harvard will provide all of the monitors and filters for the study. Harvard will pre-weigh all Teflon filters prior to sampling. The Franciscan University of Steubenville (FUS) will perform indoor and personal sampling. After sampling, FUS will transfer the $PM_{2.5}$ samples to Harvard, where they will be weighed. Upon completion of the gravimetric analysis, weighed filters will be to transported to CONSOL R&D in Library, Pennsylvania, for elemental analyses. Cartridges containing nitrate, sulfate, EC/OC, $O_3$, $SO_2$, and $NO_2$ samples will also be sent to Harvard, who will transfer the sample filters to sample vials. The sample vials will be sent to CONSOL R&D for ion chromatographic and EC/OC analyses. Harvard will be responsible for all time/activity and housing characteristics data and will provide the data to CONSOL R&D to be entered into the program database. CONSOL will provide the completed program database in database (or spreadsheet) format to Harvard.

- Subtask I2.3 -- Winter 2001 and Summer 2001 (Panel Study of Children)

  Indoor concentrations and personal particulate and gaseous exposures will be characterized for 15 children living in Steubenville, Ohio. For each child, simultaneous indoor and personal particulate ($PM_{2.5}$, EC/OC, nitrate, sulfate, water-soluble and total elements) and gaseous ($O_3$, $SO_2$, $NO_2$) samples will be collected for 24-h periods on 7 days in each season. Three children will be measured concurrently each week, with all monitoring to occur over a 6-week period. 24-h air exchange rate, time/activity, and housing characteristics data will also be collected for each child on each monitoring day. For each pollutant, a total of 210 personal, 210 indoor, and 210 outdoor samples will be collected.

  All personal and indoor particulate and gaseous samples will be collected using the Harvard multi-pollutant sampler, which will simultaneously measure $PM_{2.5}$, EC/OC, nitrate, sulfate, water-soluble, and total elements, $O_3$, $SO_2$, and $NO_2$ concentrations. On each of the monitoring days, each child subject will wear an integrated multi-pollutant monitor for a 24-h period. The monitor will be attached to the shoulder strap of a backpack, with the inlet of the monitor placed at breathing height. The pump, battery pack, and tubing will be stored in the backpack. Indoor multi-pollutant monitors will be placed in the main living area of the child's home. The inlet of these indoor monitors will be placed at 4 feet high to correspond to the child's breathing height. Harvard with assistance from FUS will recruit the study participants from local schools and youth centers and will coordinate and supervise the indoor and personal sampling. Harvard will provide all of the monitors and filters for the study. Harvard will pre-weigh all Teflon filters prior to sampling. The Franciscan University of Steubenville (FUS) will perform indoor and personal sampling. After sampling, FUS will transfer the $PM_{2.5}$ samples to Harvard, where they will be weighed. Upon completion of the gravimetric analysis, weighed filters will be to sent to CONSOL R&D in Library, Pennsylvania, for elemental analyses. Cartridges containing nitrate, sulfate, EC/OC, $O_3$, $SO_2$, and $NO_2$ samples will also be sent to Harvard, which will transfer the sample filters to sample vials. The sample vials will be sent to CONSOL R&D for ion chromatographic and EC/OC analyses. Harvard will be responsible for all time/activity and housing data and will provide the data to CONSOL R&D to be entered into the program database. CONSOL will provide the completed program database to Harvard.

- **Task I3. Statistical Analysis of Inside Data**

  HSPH will analyze the data collected in Task I2. Personal exposures will be compared for each of the measured pollutants across seasons using paired t-tests, independent sample t-tests, or their non-parametric equivalents. Activity patterns will be analyzed across seasons and sensitive population subgroups using multivariate methods for discrete data. More complex analytical methods, such as generalized estimating equations and mixed models, will be used to account for correlations that arise as a result of repeated observations over time on the same individuals.

The relationship between personal exposures and corresponding outdoor concentrations will be evaluated for each of the measured pollutants using Spearman correlation coefficients, linear and multivariate regression techniques, and generalized linear modeling techniques. Data will be analyzed to examine whether the observed associations between particulate matter concentrations and adverse health effects can result from confounding by gaseous pollutants. The relationship among ambient particulate and gaseous concentrations and among personal particulate and gaseous concentrations will be assessed using similar statistical techniques, with results from the analysis of outdoor concentrations and of personal exposures compared.

- **Task I4. Reporting of Inside Data**

  CONSOL R&D will submit all status, technical management, and environmental reports in accordance with the reporting requirements checklist.

# APPENDIX D

## Description of Carnegie-Mellon University, EPA Pittsburgh PM "Supersite"

Immediately after EPA selected Carnegie-Mellon University (CMU) as one of its National "Supersites" for fine PM research in the spring of 2000, investigators from the UORVP, SCAMP, and NETL in-house teams began cooperating closely with CMU researchers to determine how the various programs can cooperate most beneficially. In July 2000, NETL expanded this cooperation to include partial co-funding of the EPA-CMU supersite, which is scheduled to begin its measurements in 2001.

### INTRODUCTION AND OBJECTIVES

The EPA-CMU Pittsburgh PM supersite entails a comprehensive, multi-disciplinary PM investigation to characterize the ambient PM in the Pittsburgh region, to improve the understanding of the links between ambient PM and public health, to improve our knowledge of the relationship between sources and ambient PM, and to develop and evaluate new PM measurement instrumentation. This study will address most of the recommendations made by the recent NRC review of the DOE fine particulate program (NRC, 1999). The centerpiece of this effort will be an ambient PM monitoring study that is the focus of the current DOE effort. The resources of DOE/NETL will be combined with the EPA resources to support a unique combination of experts and state-of-the-art measurements in an important airshed. Several collaborations have been arranged for the EPA Supersite. These collaborations will be of great benefit to the proposed project.

The effort will feature a central supersite located near the Carnegie Mellon University campus in the central Pittsburgh urban area and a set of satellite sites. Baseline monitoring is planned for an 18-month period that will include detailed characterization of PM size, surface, and volume distribution, PM chemical composition as a function of size and on a single particle basis. Three 14-day long intensive sampling periods are planned to examine temporal variation and to collect detailed data for model testing and validation. A collaborative team of 20 research groups from 13 universities, 2 companies, a national laboratory, and a Federal agency will participate in the project. Local and state air pollution agencies are supporting the effort.

The Pittsburgh supersite will build upon and substantially expand the DOE/NETL UORVP by adding a wide range of state-of-the-art measurements and increasing the frequency to at least daily. An epidemiology study, a comprehensive modeling study, and an indoor exposure study are also planned in parallel to leverage the results from the ambient PM monitoring. These additional studies provide the opportunity to test critical hypotheses relating to health effects, exposure, and control strategies. This additional work will not be supported by DOE/NETL; however, these studies are an important part of the overall EPA-CMU research.

### OBJECTIVES

The main objectives of the DOE-funded ambient monitoring components of the Pittsburgh Supersite Program are:

1. Characterization of the PM in the Pittsburgh region. Measurements include the PM size, surface, volume, and mass distribution; chemical composition as a function of size and on a single particle basis; temporal and spatial variability.

2. Creation of a database of ambient PM measurements for source-receptor and deterministic modeling in the Pittsburgh region.

3. Estimation of the impact of the various sources (transportation, power plants, natural, etc.) to the PM concentrations in the area.

4. Development and evaluation of current and next generation aerosol monitoring techniques.

Combining the ambient monitoring study with proposed indoor, health, and modeling studies (funded from other sources) will allow:

1. Elucidation of the links between PM characteristics and their health impacts in this area.

2. Quantification of the relationship between indoor and outdoor concentrations in the area.

3. Quantification of the responses of the PM characteristics to changes in these emissions in support of the emission control decision making in the area (SIP development, etc.).

AMBIENT MONITORING AND ANALYSIS PLAN

The central sampling site will be located next to the Carnegie Mellon University campus in a heavily urbanized area of Pittsburgh. Extensive measurements are also planned for a rural site located in Holbrook, Pennsylvania (a UORVP sampling locations). Discussions are currently underway with the Air Quality Program of the Allegheny County Health Department and the EPA to determine the location of additional satellite sites. Logical additional satellite sites include the current UORVP sites in Athens, Ohio; Morgantown, West Virginia; and South Park, Pennsylvania (a suburb of Pittsburgh), and existing PM sampling sites of the regulatory network. The measurement campaign will last for 18 months (May 2001 to October 2002) to include two summers and will consist of regular measurement periods and three 14-day intensive periods.

The measurements can be summarized as follows:

1. <u>PM Size Distributions</u> -- Number and size distributions will be determined at the central site and at the Holbrook rural site using a variety of real-time measurements. These instruments will provide data in the full range 3 nm to 10 mm. Surface area distributions will also be measured.

2. <u>PM Mass Characterization</u> -- The PM mass concentration will be measured using the gravimetric approach and a variety of samplers.

3. <u>PM Chemical Composition</u> -- Filter samples will be collected and analyzed through the sampling period for ionic species, inorganic, organic, and trace elements. The sampling

frequency will be once per day during the regular period and five times per day during the intensives, with 4-hour samples during the day and 6-hour samples at night.

4. Single Particle Characterization -- An on-line single particle analysis technique (RSMS-II) will be used to measure the particle-by-particle size and composition over the size range from 10 nm to 2 microns. A new RSMS-II instrument will be built for the Supersite that will require relatively little operator intervention and will have improved analytical capabilities. The capabilities of the RSMS-II will be expanded to examine the polar organic compounds in single particles using an aerosol matrix-assisted laser desorption ionization (MALDI) technique to obtain mass spectra of highly polar compounds. Laser-induced breakdown spectroscopy will also be used to measure the elemental composition of single particles in the atmosphere. During the intensive periods, samples will also be collected for analysis by scanning electron microscopy (SEM).

5. Continuous and Semi-Continuous PM Composition -- In addition to the previously mentioned continuous (or semi-continuous) measurements of the aerosol size distribution, OC and EC, and single particle size and composition a number of additional state-of-the-art techniques will be further developed and used in the proposed Supersite Program. The concentration of 18 metals species (As, Cu, Mn, Ni, Cr, Cd, Se, Ag, Pb, Al, Fe, Zn, Ca, Bi, V, Ti, Be, and Ba) will be measured semi-continuously during the intensive periods at both the central supersite and the rural satellite site in Holbrook. The initial target collection rate will be six samples per hour, pending ambient concentrations. Automated, near-continuous measurements will be made of aerosol nitrate, sulfate, and carbon in airborne particles below 2.5 µm diameter over the 18-month sampling period.

6. Bioaerosols -- Laboratory and field studies will investigate the combined utility of high volume sampling, direct epi-fluorescent microscopy, and newer molecular biology methods to characterize outdoor bioaerosols in the size range between 0.2-20 µm.

7. Aerosol Light Scattering -- The aerosol scattering coefficient and backscatter will be measured using a three-wavelength (450, 550, and 700 nm) integrating nephelometer (TSI Model 3653). The visual range will also be measured during the measurement periods and additional observations will be collected from the airports in the area and archived. Pictures (in electronic form) of the area surrounding the supersite will be taken every hour during the intensive sampling period and every 6 hours during the rest of the study period for the calculation of the visual range and documentation of the prevailing conditions.

8. PM Hygroscopicity -- The ability of ambient fine particles to absorb water and grow will be quantified using the Tandem Differential Mobility Analyzer (TDMA) technique. The measurement of aerosol size as function of RH (from around 10 to 95 percent) will allow the quantification of the aerosol liquid water content at the RH of PM mass measurement and will provide input for the visibility calculations.

9. Meteorology -- Several meteorological parameters will be measured during the sampling period, including temperature, relative humidity, precipitation, windspeed and direction, UV intensity, and solar intensity. In addition, backward 10-day airmass trajectories will be

computed twice daily over the 18-month sampling period. This will provide (a) an assessment of the day-to-day variability in transport pathways and source regions for air sampled at the Supersite, (b) an assessment of the dependence of aerosol chemical composition on the altitude of transport and possible source regions, and (c) an atmospheric transport climatology for the Pittsburgh region.

10. Gases -- Several gases will be measured continuously during the 18-month period and reported as 1-hour average concentrations. These include $O_3$, NO, $NO_2$, CO, and $SO_2$. In addition, air will be collected in canisters and analyzed for VOCs by GC-FID and GC-MS techniques.

11. Fogs and Clouds -- Cloud and fog composition will be measured during the winter period using the compact version of the Caltech Active Strand Cloudwater Collector known as the CASCC2. Collected fog/cloud samples will be analyzed on site for pH, and sample aliquots will be prepared for later analysis of major anion and cation concentrations. A subset of samples will also be aliquotted and stabilized for later analysis of total organic carbon (TOC), formaldehyde, and trace metal catalysts (Fe and Mn).

The Pittsburgh Supersite Program will allow the further development of a number of PM measurement methods and will serve as a platform for field comparisons of emerging methods that have the potential of addressing current PM measurement needs. Several of the proposed developments such as single particle MALDI experiments have been previously described. An important component of instrument development is the intercomparison of existing measurement approaches and the new and emerging approaches. Many such comparisons will be made using supersite data.

The Pittsburgh Supersite Program has been designed to test a wide range of complementary hypotheses, using the ambient air quality data collected at the Supersite and the satellite sites. Primary hypotheses include:

- Hypothesis 1 -- The measured aerosol mass can be fully explained if one accounts for the water retained by organics and inorganics and the full crustal contribution.

- Hypothesis 2 -- Single particle mass spectrometers can be used to obtain the full number and mass composition distributions of ambient aerosols.

- Hypothesis 3 -- There is a negative artifact from sampling nitrate over several hours and it can be avoided by employing semi-continuous techniques.

- Hypothesis 4 -- Aerosol nucleation (biogenic precursors or $SO_2$) can be a major source of aerosol number in both urban and rural areas in the study region.

- Hypothesis 5 -- Biogenic primary and secondary aerosols are a major component of the organic aerosol in the Pittsburgh region.

- Hypothesis 6 -- Fogs and low clouds are responsible for extreme acid sulfate conditions in the Pittsburgh region since (a) there is substantial $SO_2$ imported from the west and (b) aqueous phase oxidizers, such as hydrogen peroxide, are present in significant concentrations.

- Hypothesis 7 -- The response of $PM_{2.5}$ to changes in sulfate is highly non-linear during the winter and linear during the summer and is controlled by the ammonia availability.

- Hypothesis 8 -- The secondary aerosol contribution to OC exceeds 50 percent during the peak PM days, but is around 20 percent on a yearly average basis (based on similar contributions estimated for the western U.S.).

- Hypothesis 9 -- The regional contributions to the $PM_{2.5}$ levels in the Pittsburgh region for some compounds exceed the local contribution, whereas for others the local exceeds the regional.

- Hypothesis 10 -- An increase in temporal resolution of elemental constituents of atmospheric aerosol coupled with sulfate and carbon analyses of comparable frequencies will permit resolution of plumes from individual stationary sources impacting the site, and resolution of local and regional sources.

# APPENDIX E

## NETL External Cost-Sharing Projects

In the early stages of the NETL PM initiative, several projects were undertaken under cooperative agreements with sister institutions or ongoing activities that were relevant to the NETL objectives. These initiatives represent a valuable component of the NETL program because they provide the opportunity for external stakeholder support and input to the NETL core program and will yield valuable results that can help guide the NETL program in future years. The NETL cost-shared external projects are summarized here to describe the complete profile of the NETL program.

- The Cumberland Plume Chemistry Study

  The objective of this work is to determine, for southeastern conditions in summer, the chemistry of $PM_{2.5}$ formation from sulfur and nitrogen oxides, including the role of oxidation processes, in a large coal-fired power plant plume.

  This TVA experiment, conducted in 1999, was partially supported by the NETL $PM_{2.5}$ program. The project follows from a series of ozone-related observations of the plume of the Cumberland power plant in the Nashville area during a southern oxidant study (SOS) campaign in 1996. The experiment was repeated in this plume, with added measurements to characterize the $PM_{2.5}$ formation from $SO_X$ and $NO_X$ emissions during the summer SOS campaign of 1999. The data are currently being analyzed and will be reported as part of broader study. The initial results are to be reported at the Fall 2000 American Geophysical Union Meeting. The results will be included in the reviewed scientific literature by 2002 and will be used to support general conceptual modeling of power plant plume chemistry of $PM_{2.5}$ under southeastern summer conditions.

  No additional NETL funding is projected for this experiment.

- The Smoky Mountains $PM_{2.5}$-Regional Haze Study

  The objective of this project is to estimate the contribution from selected major coal-fired power plants to the regional haze observed in the Great Smoky Mountain National Park.

  This is a second TVA project partially sponsored by the NETL $PM_{2.5}$ program to obtain physical and chemical speciation data at a location in the Smoky Mountains that complements the National Park Service (NPS) sampling in the IMPROVE network, and the optical scattering and absorption observations in the park. The project has continued from its inception in 1998. The data will be used with receptor modeling techniques to estimate the contribution of TVA power plant emissions to $PM_{2.5}$ sulfate and nitrate, which in turn will affect visibility in the Smoky Mountains. The data have been collected for approximately a year and will continue to be collected in 2000-2001. The results will be analyzed with the

National Park Service data, and a report will be prepared describing the findings by 2004 or earlier.

Under an Interagency Agreement between NETL and TVA, continued funding for this project will provided through 2001 to support the analysis and interpretation of the data.

- The Atlanta Epidemiology (ARIES) Study

  This cooperative study is aimed at creating a database from which an estimate of human exposure to pollutant gases and particles can be used for epidemiological analysis of disease response in a population representative of the Atlanta, Georgia, area.

  The NETL $PM_{2.5}$ program has contributed in 1999 to the sponsorship of a major exposure and epidemiological study of human response to pollution in the Atlanta area called ARIES (Bahadori, et al., 2000). The study has included the Southern Company, EPRI, and academic institutions in the Atlanta area, and has involved the pilot testing of an EPA supersite, combined with sampling at regional sites of the SEARCH project, along with the state and local air monitoring programs. The ambient air quality data and the human health data have been collected during the summer of 1999. The data are currently being analyzed, and preliminary results have been described at an Air and Waste Management Association Conference in January 2000. A component of the results will address the possible contribution of coal-fired power plant related emissions ($SO_X$ and NOx) that may influence adversely respiratory disease or cardio-pulmonary disease in the population studied. Analysis of the combined set of data will be continued through 2001, and will be reported at appropriate scientific forums and in the literature. The project should be completed in 2003 or before.

  No further NETL funding is projected for this experiment.

- Southeastern Aerosol Research and Characterization (SEARCH)

  With support from NETL, Southern Research Institute (SRI) will establish and operate an ambient fine particulate research station in North Birmingham, Jefferson County, Alabama, in collaboration with the Southeastern Aerosol Research and Characterization (SEARCH) Program. The project's results will be available for future decision making regarding the need for further controls on emissions from coal-based power systems.

  The North Birmingham site is currently one of two continuous $PM_{10}$ sites in Jefferson County and is currently operating with FRM $PM_{2.5}$ samplers and a SEARCH batch-type speciation sampler. The site is slated to be a core $PM_{2.5}$ mass monitoring and chemical speciation station in the new EPA $PM_{2.5}$ network. The existing platform has adequate space and infrastructure to support the instrument package that SRI will bring to the site under NETL sponsorship. The continuous fine particle mass and composition instruments include (1) $PM_{2.5}$ TEOM, (2) particulate organic and elemental carbon, (3) particulate $NH_4^+/NO_3^-$, (4) particulate $SO_4^=$, and (5) particle size distribution. In addition, continuous gas analyzers including active nitrogen oxides, sulfur dioxide, and carbon monoxide will be included, along with meteorological data. Supplementing NETL's funding support are SRI's collaborative relationships with the local Jefferson County Health Department, the EPA, and the Electric Power Research Institute/Southern Company project. Data from this station will augment data from other monitoring and analysis efforts such as the Interagency Monitoring of Protected Visual Environments (IMPROVE) Program at national park sites and the Southern Oxidant Study (SOS).

The SRI project is scheduled to begin in mid-year 2000. Other than the initial NETL investment, no additional NETL funding is projected for this research.

- Big Bend Regional Aerosol and Visibility Observational (BRAVO) Project

  Big Bend National Park is located at the U-turn the Rio Grande River makes in southwest Texas along the Mexican border. Regional haze has increased in the park over the last several years and has led to complaints to the National Park Service by visitors to the park.

  The objective of the BRAVO study is to quantify the impacts on Big Bend of major air pollution sources, source areas, and source types in both Mexico and the United States. Major sources in the region include coal-fired power plants, refineries, smelters, and population source areas. The study will characterize the chemical composition of the particulate pollutants and determine the role of meteorology on Big Bend haze. This activity will clarify the extent to which visibility in a National Park has been impaired by industrial and population sources in the United States and Mexico.

  During the summer and fall of 1999, chemical (perfluorocarbon) tracers were released from two electric power plants in Texas and at a location in southcentral San Antonio. A monitoring network was set up to detect the presence of these tracers. A final report covering the scientific findings of the BRAVO study is to be released early in 2001.

  No further funding is projected from NETL for this experiment.

- Characterization of Primary PM Emissions from Low-$NO_X$ Burners

  McDermott Technology, Inc. (Babcock & Wilcox), is carrying out a research effort to characterize particulate emissions associated with low-$NO_X$ burner technology. The objective of the project is to collect and chemically characterize the primary $PM_{2.5}$ emissions representative of coal-fired power plants. Primary $PM_{2.5}$ emissions will be quantified and characterized, or "fingerprinted," as functions of coal properties, boiler/combustion conditions, and emissions control equipment configuration and operation. These tests will represent the emissions associated with current utility combustion and flue gas cleanup practices. The tests will also investigate the impact of existing low-$NO_X$ burners, ultra low-$NO_X$ combustion technology, and particulate removal equipment on the characteristics of primary $PM_{2.5}$. The data provided by these tests will determine how the characteristics of $PM_{2.5}$ emissions are influenced by the amount of particulate removal and ultra-low $NO_X$ combustion conditions.

This program is currently being completed, and reports on the test results will be available in 2000-2001.

- Related Parallel Studies in the Northeast

  A major NARSTO-NE Program has been initiated in the Philadelphia area under the direction of the Pennsylvania State University. This study which began in 1999, includes a characterization of air quality, including $PM_{2.5}$ in the greater Philadelphia area, which is generally downwind of the upper Ohio River valley complex of sources. The database compiled by Penn State will complement that of the UORVP and the Stuebenville project. No NETL funding for this project is anticipated in this plan, but efforts will be made to coordinate intensive periods of sampling by the Penn State researchers and the NETL-sponsored research teams. A particularly interesting area of potential collaboration is the joint sponsorship of aircraft-based upper level meteorological and air quality measurements to be conducted at a time when all researchers are concurrently involved in intensive sampling efforts.

APPENDIX F

Emission Control Technology Research and Development Projects

The overall objective of these projects is to explore new technological options for control of fine particle emissions, and incorporate the results of similar studies of $NO_X$ emission reduction options to enhance the portfolio of control options available for power production facilities.

In 1999, NETL initiated a multi-year program to sponsor new technological options for fine PM and $NO_X$ emission reductions. Descriptions of the projects that are most pertinent to $PM_{2.5}$ and air toxics issues are described here; $NO_X$ emission control technology options have been separated administratively from $PM_{2.5}$ program. All of the projects are multi-year initiatives whose results will be reported by 2003 or earlier.

## ADVANCED HYBRID PARTICLE COLLECTOR

The primary technologies for state-of-the-art particulate control are fabric filters (baghouses) and electrostatic precipitators (ESPs). However, each of these has limitations that prevent it from achieving ultra-high collection of fine particulate matter. A major limitation of ESPs is that the fractional penetration of 0.1- to 1.0-μm particles is typically at least an order of magnitude greater than for 10-μm particles, so a situation exists where the particles that are of greatest health concern are collected with the lowest efficiency. Fabric filters are currently considered to be the best available control technology for fine particles, but they also have weaknesses that limit their application. Emissions are dependent on ash properties and typically increase if the air-to-cloth (A/C) ratio is increased. In addition, many fabrics cannot withstand the rigors of high SO flue gases, which are typical for bituminous fuels. Fabric filters may also have problems with bag cleanability and high-pressure drop, which has resulted in conservatively designed, large, costly baghouses.

Under DOE contract, a new concept in particulate control, called an advanced hybrid particulate collector (AHPC), was developed by the University of North Dakota, Energy and Environmental Research Center (UND-EERC). In addition to DOE, the project team includes the Allied Environmental Technologies Company and W.L. Gore & Associates, Inc., as technical and financial partners.

The AHPC concept consists of a combination of fabric filtration and electrostatic precipitation in the same box, providing major synergism between the two collection methods, both in the particulate collection step and in the transfer of the dust to the hopper. Under Phase I of the project, a pilot-scale unit (200 acfm) was built and tested at UND-EERC's laboratories. In the recently completed Phase II, the pilot AHPC was scaled up by a factor of 45 (to 9000 acfm capacity) and installed to handle a slipstream of flue gas from Otter Tail Power Company's 400-MW Big Stone Power Station, Big Stone City, South Dakota. Testing has been conducted under a variety of real-world conditions since July 29, 1999. Pressure drop was well controlled at less than 8 inches of water, and there has been no sparking between bags and electrodes and no bag alignment problems. To date, the AHPC has achieved over 99.99 percent removal of particulate matter from the Big Stone flue gas.

Phase III (DOE Cooperative Agreement No. DE-FC26-99FT40719) will build on the successful completion of Phases I and II to answer a number of engineering scale-up questions. Specific engineering data that will be determined in Phase III include:

- The effect of the entrance baffle configuration on flow distribution and AHPC performance.
- The effect of specific collection area on AHPC performance at an air-to-cloth ratio of 16 ft/min.
- Whether the 9000-acfm AHPC can function properly with nonconductive bags (or an alternative fabric material).
- Optimum bag-to-electrode spacing.
- Bag-pulsing parameters to facilitate full-scale engineering design.
- Performance at a temperature that is at the peak resistivity of the fly ash.

Successful completion of the tests will facilitate scaleup of the AHPC to near-term commercialization of this technology.

ADVANCED ELECTROCORE SEPARATOR TO ENHANCE ESP PERFORMANCE

LSR Technologies and its subcontractors will design and build a 8,500 $m^3$/hr (5,000 acfm) Advanced ElectroCore system and test it using an exhaust gas slipstream at Alabama Power Company's Gaston Steam Plant. The exhaust gas will be from Unit #4 of a 270-MWe subcritical, pulverized coal boiler burning a low-sulfur Powder River Basin (PRB) coal. The Advanced ElectroCore system will consist of a conventional upstream ESP, a dry $SO_2$ scrubber, a particle precharger, and an Advanced ElectroCore separator. Particle concentrations and size distributions will be measured at the ESP inlet, at the dry scrubber outlet, and at the ElectroCore outlet. The concentration of 12 common HAPs will be measured at these locations as well. For purposes of project organization and monitoring, the work will be divided into eight tasks:

- <u>Task 1: Advanced ElectroCore Electrode Evaluation</u> -- In the Advanced ElectroCore, an energized central electrode is added along the vertical centerline. LSR will evaluate the new electrode design using an existing ElectroCore unit and modifying it to accept the central electrode. The purpose of this task is to perfect the design for both supporting and electrifying the electrode. The design will be tested with over a period of weeks to determine if there are any problems with fouling or cleanability.
- <u>Task 2: Advanced ElectroCore System Component Design</u> -- The second task will be to design the components of the 8,500 $m^3$/hr (5,000 acfm) Advanced ElectroCore system. Since the ESP is already in place, the dry scrubber, precharger, and the Advanced ElectroCore will need to be designed.

- Task 3: System Construction -- The Advanced ElectroCore construction drawings that are created in Task 1 will be released for bidding to local fabrication shops. LSR will oversee the fabrication of the dry scrubber and the connecting ductwork. The precharger will be manufactured by Merrick Environmental and shipped to the field site directly.

- Task 4: System Transport and Installation -- The components will be truck-mounted and shipped to Gaston Station on a flatbed truck. At Gaston station, the components will be off-lifted by crane and placed alongside the Unit #4 ESP. The installation process will be performed by Southern Energy Constructors, a local contractor with union labor and an approval contractor of Alabama Power Company. LSR will have representation on site to oversee the assembly process and to ensure that the installation is performed properly.

- Task 5: System Shakedown -- The shakedown tests will be conducted by LSR to ensure that the gas flow rates are within specification and that the power supplies for the pre-charger and ElectroCore are operating at proper output. Preliminary traverses called for in EPA Method 5 will be performed at the ESP inlet, the dry scrubber outlet, and at ElectroCore outlet. This will ensure that the Method 5 test planes are properly set up and the ducts can be traversed in both planes. The power supplies and control system will be thoroughly checked out. The shakedown will be performed by LSR engineers with assistance from Merrick Environmental and Alabama Power personnel.

- Task 6: Field Testing -- Field testing will be divided into three subtasks. In the first subtask, efficiency of the ElectroCore system will be measured as a function of gas flow rate and ESP efficiency. The purpose of the second subtask is to demonstrate that the ElectroCore system can operate with high collection efficiency when sorbents are injected into flue gas stream. The final subtask will be the measurement of the removal of hazardous air pollutants (HAPs).

- Task 7: Data Analysis/Cost Analysis -- The field test results will provide data to evaluate performance and determine the size of the ElectroCore needed to achieve 99.99 percent capture efficiency for a given gas flow rate. This information will be used to update the cost analysis data prepared for the conventional ElectroCore in 1996 by Sargent & Lundy, LLC.

- Task 8: Dismantle Equipment/Site Restoration -- The final work to be done at the Alabama Power Company field site is to remove the ElectroCore equipment and restore the test site to its original condition.

## ADVANCED FLUE GAS CONDITIONING AGENTS FOR FINE PARTICULATE CONTROL

The overall objective of this project is to develop a family of cohesivity modifying flue gas conditioning agents that can be commercialized to provide utilities with a cost-effective means of complying with particulate emission and opacity regulations. Improving the cohesivity and agglomeration of fly ash particles via flue gas conditioning is a proven means of increasing the collection efficiency of an electrostatic precipitator (ESP). However, a new class of additives is needed because currently available agglomerating aids on the market require the storage and handling of large quantities of ammonia, which under recent legislation has been classified as extremely hazardous and necessitates extensive risk assessment and emergency response plans. There are also operating conditions and coals where the ammonia-based technologies are not as effective and the treated ash treated is difficult to dispose of because of the odor produced by ammonia. Advanced methods for flue gas conditioning may provide the most cost-effective means of optimizing the overall collection efficiencies of ESPs in today's deregulated utility market. Such efficiencies are essential for plants to meet DOE's goals of 0.01 lb/MBtu and 99.99 percent collection efficiency in the particle size 0.1 to 10 microns.

The technical tasks are summarized below:

- Task 1: Upgrade Existing Laboratory Test Apparatus -- Improve the capability of existing equipment to directly measure cohesivity and tensile strength.

- Task 2: Identify and Evaluate Candidate Cohesivity Enhancement Additives -- Perform screening tests to identify the most promising candidate additives, followed by an intensive series of parametric tests to assure the additives meet the requirement in terms of performance, ability to integrate easily with the plant process and cost. The classes of additives to be tested will include various synthetic anionic and cationic polymers.

- Task 3: Demonstrate Performance at Full Scale and Optimize Product -- Prepare and install equipment for the demonstration of the most promising additive or additives on at least a portion of a full-scale ESP. This test will confirm anticipated performance and identify properties that cannot be simulated in laboratory tests.

- Task 4: Identify Potential Longer Term Demonstration Sites -- To meet DOE's goal that the newly developed technology be applicable for a variety of coals and configurations, demonstrations will be conducted at several sites. In this task additional test sites will be identified and contacted.

- Task 5: Conduct Demonstrations to Confirm Performance for Different Coals and Configurations -- Additive performance will be evaluated at several different sites. The coals will be representative of types widely used. The two primary groups of interest are Powder River Basin Subbituminous and a low sulfur washed eastern bituminous with ash silica-alumina content above 85 percent. Also of interest is a site that fires a high sulfur bituminous coal with a scrubber-ESP configuration.

- Task 6: Determine Waste Characteristics -- Determine the effect of the additive on fly ash disposal and reuse properties.

- Task 7: Perform Economic Analysis -- Develop the economics of the conditioning technology following EPRI-approved techniques, where costs are presented as normalized busbar costs.

- Task 8: Management and Reporting -- Define project schedule, milestones, and costing for internal project tracking. Prepare and submit DOE required reports.

FURNACE INJECTION OF ALKALINE SORBENTS FOR SULFURIC ACID CONTROL

Sulfuric acid is present in most flue gases from coal combustion because a small percentage of the $SO_2$ produced from the sulfur in the coal (approximately 0.5 to 1.5 percent) is further oxidized to form $SO_3$. The $SO_3$ combines with flue gas moisture to form vapor-phase or condensed sulfuric acid at temperatures below 500 °F. Besides being a toxic release inventory substance and a potential precursor to acid aerosol/condensable emissions from coal-fired boilers, sulfuric acid in the flue gas can lead to boiler air heater plugging and fouling, and a visible plume at some plants. These issues will likely be exacerbated with the retrofit of SCR for $NO_X$ control on some coal-fired plants, as SCR catalysts are known to further oxidize a portion of the flue gas $SO_2$ to $SO_3$. Further, it has been postulated that $SO_3$ may react with $NH_3$ and Hg in the flue gas to form a particulate-phase mercury compound.

DOE/NETL awarded a cooperative agreement to Radian International in September 1999 to demonstrate the use of calcium- or magnesium-based alkaline reagents injected into the furnace of coal-fired boilers as a means of controlling sulfuric acid emissions. The coincident removal of hydrochloric acid and hydrofluoric acid will also be determined, as will the removal of arsenic, a known poison for $NO_X$ selective catalytic reduction (SCR) catalysts. The project is being co-funded by the U.S. DOE/NETL, EPRI, the Tennessee Valley Authority (TVA), First Energy Corporation, and the Dravo Lime Company. Radian International LLC will serve as the prime contractor for this testing.

The project will be conducted by testing the effectiveness of furnace injection of four different calcium- and/or magnesium-based alkaline sorbents on a full-scale utility boiler. These reagents will be tested during four 12-day tests to be conducted on a First Energy unit. One of the sorbents to be tested can be produced from an FGD system waste stream, particularly from those that employ the thiosorbic lime wet scrubbing process. The other three sorbents are commercially available in large quantities.

After completion of the four 12-day tests, the most promising sorbent(s) will be selected for longer term (30-day) testing. The longer term tests will be used to confirm the effectiveness of the sorbents tested over extended operation, and to determine balance of plant impacts. This longer term testing will be conducted on two full-scale utility boilers, most likely one First Energy unit and one TVA unit. The units will be selected to represent diverse configurations so as to make the test results applicable to a wider range of utility boilers. If two effective sorbents are identified in the 12-day tests, it is likely that both would be tested, one on each host boiler.

At the completion of the project, sufficient full-scale test data should be available to confidently design and implement commercial installations of the sulfuric acid control technologies demonstrated.