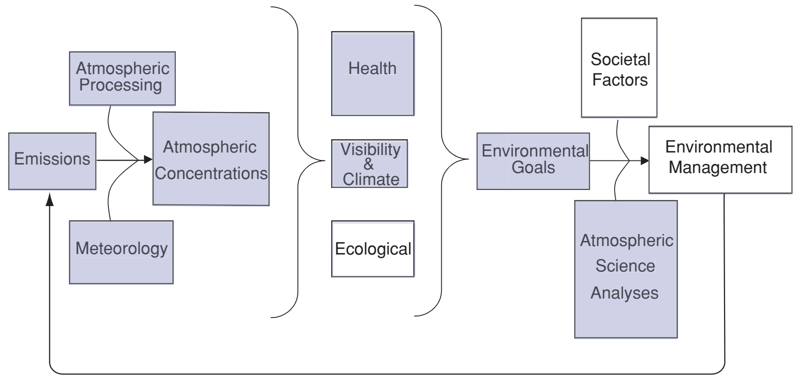
CHAPTER 11

Recommended Research to Inform Public Policy



Principal Author: Peter McMurry

Advocates on all sides of the environmental-science debate agree that good decisions should be informed by a sound understanding of science and its uncertainties. This chapter summarizes recommendations for future research that will lead to an improved scientific basis for policy decisions. These recommendations emerged through discussions among the lead authors of this Assessment and are consistent with the thrust of NARSTO's Fine Particle Research Plan (NARSTO, 1998).

Detailed discussions of scientific work needed to establish a more thorough understanding of phenomena that determine the chemical and physical properties, behavior, and spatial/temporal distributions of atmospheric PM have been published previously [AQRS (1998, 1999), DOE (2001), NARSTO (1998), NRC (1998, 1999, and 2001), Meteorological Service of Canada (2001)]. The recommendations in this Assessment focus on relevance and importance to NARSTO stakeholders, with a particular emphasis on recommendations related to filling science gaps that will have the greatest impact for policy makers as they implement current mass-based PM standards. For example, PM effects may depend on some property other than mass concentrations. For example, light scattering, which affects visibility and the earth's radiative energy balance, depends on particle shape, refractive index and size distribution. Also, the health-science community has identified hypotheses regarding particle properties that might be responsible for reported health effects, and work aimed at determining the sensitivity of human health to those properties is underway. Several of the recommendations in this chapter are aimed toward obtaining data that could be used to test those hypotheses.

Development of a new scientific tool typically precedes its availability for use by policy makers by about a decade. During this time, proof of concept, acceptance, adoption, and application on a sufficiently broad scale to have an impact take place. Some of the recommendations made in this chapter apply to tools, such as instruments for semi-continuous measurements of aerosol composition, that are or will soon be ready to deploy. Others, such as work on origins and properties of primary and secondary organic PM, apply to problems that will require a much longer time to solve. Progress over the past several decades has led to a much sounder basis for current PM management strategies. Similarly, the work recommended here will lead to better PM management strategies in the future.

The recommendations presented in this chapter fall into six broad themes:

1 Developing a better understanding of carbonaceous PM.

2 Performing long-term monitoring of mass, aerosol composition, gas-phase precursors of secondary PM, copollutants, and size distributions in parallel with measurements of appropriate health indices. The importance of using compatible measurement strategies across North America is emphasized.

3 Continuing the development and evaluation of chemical-transport models for PM.

4 Improving the characterization of source emissions, refining emission inventories, and developing more detailed emission models.

5 Investing more resources in archiving, evaluating, and synthesizing data from ambient measurements.

6 Developing more systematic approaches for integrating diverse types of knowledge on origins, properties, and effects of atmospheric PM to assist with the development of management strategies and the measurement of progress toward protecting health. These strategies must account for uncertainties.

In this chapter, a synopsis of the policy relevance for each of these broad recommendations is followed by a list of specific science needs and corresponding brief rationale. The recommendations are deliberately not prioritized, because many of them are interdependent and work must progress simultaneously in all areas in order to move forward. The chapter concludes with recommendations for future NARSTO PM assessments

Table 11.1 lists the recommendations and associated science needs. The table includes a crosslink to the scientific discussions in this assessment that support the recommendations and to similar science needs identified in NARSTO's PM Science Plan (NARSTO, 2001).

11.1 RECOMMENDATIONS

RECOMMENDATION 1. **Improve the understanding of carbonaceous aerosols.** Work should include the development of improved measurement methods, improved source characterization, and improved scientific understanding of chemical and physical properties

Table 11.1. Summary of Recommendations

Science Need	Statement	Further Discussion	NARSTO PM Science Plan (NARSTO, 2001)
Rec. 1	**Improve the understanding of carbonaceous aerosols.**		
1.1	Improve methods for measuring organic carbon (OC) and black carbon (BC) mass concentrations.	Ch. 3 5.1.2	
1.2	Obtain more information on the ratio of carbon mass to total mass for OC.	5.1.2 5.1.3	
1.3	Characterize organic PM properties and its gas-phase precursors, including factors that govern the gas-particle partitioning of semivolatile organic compounds, the hygroscopicity of particulate organic compounds, and the proclivity of gas phase organic precursors to form secondary organic aerosols.	3.4 3.5.3 5.2 8.4.1 9.1.3 Ch. 3	3.2.1.3 3.2.1.4 4.4 5.4 5.5
1.4	Develop cost-effective techniques for obtaining more detailed spatial and temporal information on carbonaceous PM species.	Ch. 2 3.5.3 4.1 5.1.2 6.2.4 Ch. 3	
1.5	Determine composition of primary and secondary organic species associated with anthropogenic and biogenic emissions.	3.5.3 4.1 5.1.2 5.1.3 7.2 7.5.1 8.4.1 Ch. 3	

Table 11.1. Summary of Recommendations (cont.)

Science Need	Statement	Further Discussion	NARSTO PM Science Plan (NARSTO, 2001)
Rec. 2	**Perform long-term monitoring of concentrations of PM components and mass as well as gas-phase precursors and copollutants of particles in parallel with studies of health impacts.**		
2.1	Monitor PM mass concentrations, PM composition, gas-phase precursors of secondary particulate species, and gas-phase copollutants.	Ch. 2 6.5	3.2.3.1 3.2.1.5 3.2.4.1
2.2	Assess trends; requires that monitoring be carried out using consistent, comparable and accurate techniques over a sufficiently long period of time and over sufficiently varied types of airsheds.	6.5 9.1.1	
2.3	Measure collocated gas and particle phases for semivolatile species in sampling networks.	3.6.3 3.6.5 8.4.3	
2.4	Measure particle size distributions and size-resolved chemical composition at selected sites.	Ch. 2 8.4.3	3.2.1.1 5.3
2.5	Replace filter samplers with instruments for real-time measurements of PM mass and composition, as these methodologies mature.	5.1.3	
2.6	Measure novel PM properties to test hypotheses regarding causal agents for human-health effects.	Ch. 2	
2.7	Design monitoring networks that provide compatible information for Canada, the U.S. and Mexico, and meet diverse needs with maximum efficiency.	Ch. 2 5.3.1 6.5 Ch. 2	3.2.4.1 3.2.4.2
2.8	Make readily available optical extinction data obtained with the Automated Surface Observing System (ASOS) and the Automated Weather Observation System (AWOS) networks that replaced human observers at airports in 1994.	9.2.1	
2.9	Carry out long-term studies of human-health effects in parallel with air-quality monitoring.	Ch. 2 Ch. 3	3.2.4.3 2.8
Rec. 3	**Continue to invest resources in evaluating and further developing the performance of chemical-transport models for PM.**		
3.1	Design intensive atmospheric field studies and long-term monitoring programs that can be used to evaluate and refine chemical-transport models for particulate matter.	8.6	7.3.1 7.3.2
3.2	Conduct model-evaluation studies to compare model predictions with observations for particulate species concentrations and size distributions.	8.4.3	7.3.2
3.3	Establish centers to facilitate communication regarding best PM modeling practices among regulatory agencies in North America.	8.1.1	
3.4	Improve our ability to model certain atmospheric processes. Of particular importance are cloud processing, processes that involve carbonaceous aerosols, and the formation of new particles by homogeneous nucleation.	3.2 3.5.3 3.6.4 8.6 9.3.3	4.4 4.5 5.1 5.4
3.5	Obtain more detailed information on the size-resolved composition of primary particulate emissions from various sources.	7.2.1 8.2.5	5.2 5.3
3.6	Develop approaches for using data from satellites or real-time sensors to obtain boundary conditions for models.	8.4.2	

Table 11.1. Summary of Recommendations (cont.)

Science Need	Statement	Further Discussion	NARSTO PM Science Plan (NARSTO, 2001)
Rec. 4	**Improve emission inventories and emission models.**		
4.1	Develop improved and standardized approaches for developing national emission inventories for Canada, Mexico and the United States, which provide compatible data.	4.2.1	
4.2	Update and expand emission inventories to include new types of information including size distributions and size-resolved composition, organic speciation, and updated source profiles.	4.4.1 7.2.7 8.2.5	3.2.5.1 4.1 4.3 4.4 4.5 5.2
4.3	Develop approaches that can be used to reconcile emission inventories with measurements of species concentrations observed in the atmosphere.	4.3 7.3.2.4 7.4.2 8.2.5	4.7 7.2.5
4.4	Extend emission inventories to include all available information from particle sources typically viewed as unmanageable, such as forest fires, and dust.	4.3 8.2.5	
4.5	Improve emission models for dust.	4.4.2 7.4.2 8.2.5	4.2
4.6	Develop emission models for NH_3.	4.4.2 8.2.5	4.6
4.7	Develop emission models that account for condensation or nucleation of semivolatile compounds, as hot emissions mix with cool ambient air.	3.2 4.4.2	3.2.4.4 5.2
4.8	Continue to improve the timeliness of emission inventories.	4.5	
4.9	Develop approaches for obtaining emission information with adequate resolution in space, time, and composition for atmospheric modeling and exposure assessments. These approaches will likely involve combinations of emission models and emission data with higher temporal resolution than is currently included in inventories.	Ch. 2 4.5	
4.10	Prepare national emission inventories over a period of years in parallel with long-term monitoring of health effects and ambient concentrations of PM and its precursors to facilitate analyses of trends and benefits.	Ch. 2 4.5	4.8
Rec. 5	**Commit adequate resources to the evaluation, synthesis and archiving of data obtained in current and future atmospheric aerosol studies, and to fostering interactions between the communities of scientists working on atmospheric science, health effects, and global climate change.**		
5.1	Establish procedures at funding agencies which ensure that atmospheric aerosol data are systematically archived in a manner that provides convenient access to all interested parties.	Ch. 5	3.2.6.1
5.2	Develop a comprehensive plan for data analysis, integral to measurement programs, and commit adequate resources to carry out such analyses.	Ch. 2	

Table 11.1. Summary of Recommendations (end table 11.1)

Science Need	Statement	Further Discussion	NARSTO PM Science Plan (NARSTO, 2001)
5.3	Foster collaborations among the communities of scientists working on PM pollution, health effects, and global climate change.	Ch. 2 9.4	3.2.5.2 4.3 7.2.6
Rec. 6	**Implement more systematic approaches for integrating diverse types of knowledge on origins, properties, and effects of atmospheric PM to assist with the development of management strategies and the measurement of progress towards protecting health.**		
6.1	Develop a more systematic approach for integrating knowledge gained from measurements, receptor models, and chemical-transport models to make optimal PM-management decisions.	1.0 7.1	
6.2	Develop an accountability framework that will enable measurement of progress towards the goal of protecting human health.	Ch. 2 1.8	

and behavior in the atmosphere. This work should also include research on gas/particle partitioning, water uptake, and the chemical mechanisms of secondary OC formation from important precursor gases.

POLICY RELEVANCE

Carbonaceous aerosols, which include organic and black carbon, make up roughly one fifth to one half of the average annual $PM_{2.5}$ mass concentration. Organic aerosols include a complex mixture of many compounds, and an understanding of organic aerosols is primitive relative to the understanding of the other major fine-particle species ($SO_4^=$, NO_3^-, and dust). Limitations in the ability to measure the composition and properties of carbonaceous particles limit the ability to identify their origins (which include both biogenic and anthropogenic sources), to develop PM models, to assess trends, and consequently to develop optimal PM control strategies. In contrast, secondary $SO_4^=$,and NO_3^- are relatively easy to measure, are produced from a few gas-phase precursors that are emitted by a few types of major sources, and they are transformed to secondary PM in the atmosphere by a small number of primary reaction pathways. An improved understanding of carbonaceous aerosols would lead to a better understanding of their sources, relative contributions of primary vs. secondary carbon to PM mass, their effects on visibility, and the linkages between PM and ozone management. Understanding of the health effects of carbonaceous aerosols will also improve with improved measurements. Furthermore, because primary organic PM often contributes significantly to PM mass, reducing primary OC emissions may, at times, be a viable approach toward controlling PM mass concentrations. Finally, it has been hypothesized that organic PM includes toxic compounds that contribute to PM health effects. If so, reductions in concentrations of those compounds could lead to improved human health.

SCIENTIFIC NEEDS

Recommendation 1.1 *Improve methods for measuring OC and BC mass concentrations.*

Rationale. Carbonaceous particles include those species that are identified as OC and BC. Because some tarry organic compounds are black, and because distinctions between OC and BC depend somewhat on analytical method, the distinction between OC and BC is not always clear. An issue that remains unresolved is the accuracy with which OC and BC can be measured. Organic PM measurements are especially prone to error due to sampling artifacts that include both the volatilization of semivolatile compounds from collected deposits of particles and the adsorption or absorption of organic gases on sampling substrates or collected particle deposits during sampling. It is likely that both positive and negative artifacts occur during sampling, and there is no consensus as to the net magnitude of these artifacts. It is likely that some compounds contribute to net negative artifacts while others contribute to net positive artifacts, and the relative magnitudes of these effects may vary with sampling location and time. An improved understanding of carbonaceous aerosols will require more detailed information on chemical characteristics. Ideally, this would include information on compounds and their thermodynamic properties. It is unlikely, however, that techniques will be available in the near future to provide complete chemical characterizations of carbonaceous aerosols with the frequency that would be required for air-quality studies, so improved techniques for OC/BC measurements are needed for the near term.

Recommendation 1.2 *Obtain more information on the ratio of carbon mass to total mass for OC.*

Rationale. The most commonly used approaches for determining organic PM mass concentrations involve measuring the amount of CO_2 released when a collected PM sample undergoes oxidation. Particulate organics contain carbon plus other elements such as oxygen and hydrogen. Because these other elements are typically not measured, it is commonly assumed that organic PM mass concentrations can be inferred by multiplying the measured carbon mass by a factor that accounts for other associated elements. This factor is typically assumed to be between 1.2 and 1.4. Recent work (Turpin, 2001) has shown that 1.4 may be a minimum value for freshly emitted urban PM, and that the mass-conversion factor may exceed 2.0 for aged aerosols that are more highly oxidized. Because this factor can significantly affect estimates of OC contributions to total PM mass concentrations, an effort should be made in the near term to assess appropriate values in different source environments and seasons.

Recommendation 1.3 *Characterize organic PM properties and its gas-phase precursors, including factors that govern the gas-particle partitioning of semivolatile organic compounds, the hygroscopicity of particulate organic compounds, and the proclivity of gas-phase organic precursors to form secondary organic aerosols.*

Rationale. Many of the compounds that make up OC are semivolatile (i.e., they are present to an appreciable extent in both the gas and condensed phases.) The relative amounts of a given compound that are found in the gas and condensed phases vary with thermodynamic properties of the compound (vapor pressure, adsorption or absorption equilibrium in particulate species, etc.) and on whether or not sufficient time has elapsed to achieve equilibrium. Because the gas-particle distribution is likely to depend on atmospheric properties including temperature and relative humidity, gas-particle distributions are likely to vary diurnally. Furthermore, because pressure, temperature and relative humidity in sampling devices typically are not identical to values in the atmosphere, changes in gas-particle distributions can be (and typically are) induced by measurement. An improved understanding of gas/particle partitioning will lead to an improved understanding of how aerosols evolve as they are transported from the source to a receptor, how humans or other organisms will be exposed to a particular compound, and how to design samplers to collect representative samples. Also, the development of improved chemical-transport models will require more information on reactivity of gases and their tendency for form secondary particulate products. Finally, recent work has shown that the hygroscopicity of organic PM is variable, and tends to increase with the length of time particles have been in the air. Hygroscopicity influences a particle's tendency to be removed by wet deposition or in the lungs as well as its optical properties. An understanding of the behavior, lifetime, and effects of organic PM will require a better understanding of its tendency to absorb water. Because these questions are complex, work over a period of one to two decades will be needed.

Recommendation 1.4 *Develop cost-effective techniques for obtaining more detailed spatial and temporal information on carbonaceous PM species.*

Rationale. Carbonaceous PM encompasses thousands of compounds displaying a vast range of properties. The most sophisticated analytical methods available to date can identify only 10 to 20 percent of these compounds, and such measurements are expensive and require highly trained personnel. Furthermore, only a few laboratories in North

America are equipped to carry out such analyses. Identifying the origins of organic PM, understanding its transformations in the atmosphere, and understanding its effects will require measurements of speciation, not simply OC/BC. Good ideas for work in this area should be pursued.

Recommendation 1.5 *Determine composition of primary and secondary organic species associated with anthropogenic and biogenic emissions.*

Rationale. A limited amount of work to date has shown that organic PM formed by chemical transformations in the atmosphere and emitted by different primary sources has distinct chemical signatures. Therefore, measurements of organic speciation at the source and in the atmosphere can provide valuable insights into the origins of ambient OC. Such measurements are currently expensive, can be applied to only a limited number of samples, require sampling by techniques that are inherently prone to artifacts due to gas adsorption on filters or the evaporation of semivolatile components from particles during sampling, and (to date) have provided only very limited information on composition as a function of particle size. Nevertheless, the information that has been obtained from these measurements is tremendously rich relative to what can be learned by merely measuring the OC and BC concentrations. More work of this type in the near term is recommended. Efforts should be made to use similar methodologies throughout North America, and to use the same methodologies to characterize emissions at the source and concentrations in the atmosphere. Such work would provide new information on the sources of carbonaceous PM, would support receptor modeling, and would improve process understanding needed to develop PM chemical-transport models. Quantitative measurements of targeted species concentrations are needed to quantify relationships between health responses and species exposures.

RECOMMENDATION 2. **Perform long-term monitoring of concentrations of PM components and mass as well as gas-phase precursors and copollutants of particles in parallel with studies of health.** Where possible, instruments that provide continuous, real-time information should be used. Similar instruments and measurement strategies should be used throughout North American networks to the extent possible to facilitate the sharing of data among Canada, the United States, and Mexico. Provision should be made to optimize monitoring networks to meet diverse information and needs. And most importantly, long-term air-quality monitoring data must be linked with human-health data for defined populations to characterize human-health impacts. A similar recommendation was made in the NARSTO Ozone Assessment (NARSTO, 2000).

POLICY RELEVANCE

Assessing the success of emission-control strategies on PM composition and concentrations and health or environmental impacts requires accurate data from monitoring networks. Measurements over a period of 5 to 10 years are typically required to assess trends. Monitoring data are also needed to evaluate transboundary transport to assess contributions of different jurisdictions to local PM and haze levels. Chemically speciated and highly time-resolved data from monitoring networks for different meteorological conditions/seasons are also needed to evaluate PM models. The availability of empirical information on trends and improved models with known accuracy would reduce uncertainties in predicted future trends. Thus, the efficacies of policy decisions regarding emission scenarios could be estimated with greater confidence.

SCIENTIFIC NEEDS

Recommendation 2.1 *Monitor PM mass concentrations, PM composition, gas-phase precursors of secondary particulate species, and gas-phase copollutants.*

Rationale. Connections exist between the chemical pathways that lead to the production of secondary gaseous pollutants (including ozone) and secondary particulate products (including NO_3^-, $SO_4^=$ and OC). These associations raise two issues of concern to the policy maker 1) To what extent will efforts to control one pollutant lead to increases or decreases in the concentrations of a copollutant? and 2) To what extent are the effects attributed to one pollutant actually due to the presence of another covarying pollutant, or to the mixture of copollutants? Long-term monitoring of the multipollutant mixture would help to ensure the availability of data required to validate chemical-transport models for PM and to assess health and ecological effects of PM and its copollutants. These issues illustrate the need to devise strategies for monitoring and emission control that take these interrelationships into account. Care also should be taken to ensure that monitoring networks provide adequate spatial coverage. There is currently a deficiency of monitoring data (either temporally, spatially, or both) in Alaska, Northern Canada, and Mexico. The conduct of epidemiological studies of air pollution requires knowledge of all major constituents in the air, thereby allowing a simultaneous assessment of the contribution of individual constituents to the overall health impacts that may be observed. Significant advances in measurement capabilities have been made over the past decade, and plans should be made now to implement these new capabilities in future monitoring networks.

Recommendation 2.2 *Assess trends; requires that monitoring be carried out using consistent, comparable and accurate techniques over a sufficiently long period of time and over sufficiently varied types of airsheds.*

Rationale. The effects of emission-control strategies on ambient concentrations of pollutants typically require about a decade to be assessed. For example, the first phase of the 1990 U.S. Clean Air Act Amendments led to changes in spatial emissions of SO_2 and NO_x that occurred over the past decade. Also, the time required to substantially change the composition of the vehicle fleet when new emission standards are enforced is about a decade. Year-to-year meteorological fluctuations cause variations in the species concentrations that add to the difficulty of assessing temporal trends. In order to obtain data that can provide information on trends, it is essential that monitoring programs include continuous, uninterrupted long-term measurements with consistent methodologies to enable the unambiguous determination of trends on the time scale of a decade. Measurement strategies should take advantage of recently-developed measurement techniques, and should be implemented now, so as to assess the impacts of emission-controls strategies that are currently being implemented. Measurements across North American networks should be designed to enable the determination of spatial and temporal trends of the multipollutant mixtures. Issues including reference standards, measurement methodologies and sampling strategies need to be considered in assessing the compatibility of sampling networks. Measurement uncertainties should be as small as possible and should be reported routinely. A similar recommendation for ozone and its precursors was made in the NARSTO Ozone Assessment.

Recommendation 2.3 *Measure collocated gas and particle phases for semivolatile species in sampling networks.*

Rationale. Ammonium nitrate and a portion of OC are semivolatile (i.e., significant fractions of these species are found in both the gas and particle phases.) The gas/particle distributions of these compounds vary with temperature, relative humidity, PM composition and the total concentration of the semivolatile compounds. In order to determine whether the formation of NH_4NO_3 is limited by the availability of NH_3 or HNO_3, monitoring networks should include measurements of NH_3 and HNO_3 gases as well as NH_4^+, NO_3^-, and $SO_4^=$. Filter-based techniques for measuring the gas- and particle-phase fractions of these inorganic compounds are available, and semi-continuous methods are being developed and may soon be available for routine measurements. It would be desirable to obtain such data to assess the impact of SO_2 control strategies on ambient NO_3^- concentrations. Although it would also be desirable to have data on gas- and particle-phase concentrations of semivolatile organic compounds, methodologies for routine measurements of such compounds are not yet available. Efforts should be made to develop such measurement methods.

Recommendation 2.4 *Measure particle-size distributions and size-resolved chemical composition at selected sites.*

Rationale. Continuous measurements of particle-size distributions could provide information on particle concentrations in all size ranges from 0.003 µm to 10 µm with a time resolution of about five minutes. Such measurements would be valuable for model-evaluation studies, for studies of PM health effects, and for understanding the relationships between emissions and emission-control strategies on aerosol properties. For example, recent evidence suggests that PM emission controls that are being adapted for new-generation diesel engines are leading to enhanced emissions of ultrafine particles. It is important that data be acquired that will enable us to determine whether these changes in emission patterns are leading to significant trends in ambient size distributions. Recent work has shown that size distributions can be measured accurately and routinely. Such measurements should be done in several locations where they can provide the greatest benefit. In addition, information on size-resolved composition is needed to evaluate the performance of chemical-transport models for PM, and to assess the contributions of species to optical extinction and climate forcing. Selected measurements of size-resolved composition should be included in network design.

Recommendation 2.5 *Replace filter samplers with instruments for real-time measurements of PM mass and composition, as these methodologies mature.*

Rationale. Real-time instruments can be less expensive to operate than filter samplers and can provide valuable information on diurnal trends. Information on short-term variations may be useful in assessing health effects and for model-evaluation studies that have been previously constrained by the availability of only daily filter measurements. Significant progress has been made in the past several years on developing instrumentation for real-time measurements of PM mass and composition. Some of these instruments have been commercialized, and it is likely that others will be commercialized in the future.

Recommendation 2.6 *Measure novel aerosol properties to test hypotheses regarding causal agents for human-health effects.*

Rationale. The health-effects community has proposed several hypotheses regarding PM properties that might be responsible for the observed association between health and particulate matter. These properties should be monitored over the long term in conjunction with health-effects studies to test these hypotheses. In some cases it will be necessary to develop new measurement methods. For example, cells are exposed only to the surfaces of insoluble particles. Therefore, any biological effects due to insoluble particles would likely depend on surface rather than on bulk composition. Because the surface and bulk composition may be very different, it is necessary to have information on surface composition. Similarly, if reactive transition metals or organic compounds were responsible for health effects, then it would be important to have measurement techniques for them. Decisions about which measurement methods to develop and how they should be deployed should be made through collaborative interactions of health and atmospheric scientists.

Recommendation 2.7 *Design monitoring networks that provide compatible information for Canada, the United States, and Mexico, and meet diverse needs with maximum efficiency.*

Rationale. Monitoring networks fill a variety of needs including the measurement of long-term trends, the measurement of baseline pollutant levels, the assessment of impacts, and the acquisition of data for model validation. The data set required typically varies with its application, and an effort should be made to ensure that existing monitoring networks meet diverse needs with maximum efficiency. Furthermore, similar instruments and measurement strategies should be used throughout North American networks to the extent possible to facilitate the sharing of data among Canada, the United States, and Mexico. The availability of monitoring data from harmonized networks is crucial to the conduct of large-scale epidemiological studies as illustrated by the recent National Morbidity, Mortality, and Air Pollution Study (NMMAPS) (Samet et al., 2000 a and b).

Recommendation 2.8 *Make readily available optical extinction data obtained with the Automated Surface Observing System (ASOS) and the Automated Weather Observation System (AWOS) networks that began to replace human observers at airports beginning in the 1990s.*

Rationale. For decades, observations of visual range taken hourly by observers at airports have been used to document the spatial and temporal pattern of atmospheric haziness and as a surrogate for trends in fine-particle mass. The automated ASOS and AWOS networks began to replace human observers in the 1990s, and include sensors in both the United States and Canada. These systems include sensors that can automatically monitor the haziness with high dynamic range, accuracy, and precision. The ASOS and AWOS systems also monitor temperature, dew point, precipitation, etc., which allows the separation of fog, rain, and snow from dust, smoke, and haze. Hence, it is also possible to relate the Sensor Equivalent Visibility (SEV) reported by ASOS to the in-situ concentrations of fine-particle dust, smoke, and haze. There are currently more than 900 ASOS stations operated by the FAA, the NWS and the DOD throughout the United States. Unfortunately, the full-resolution ASOS visibility data are not routinely reported, which significantly diminishes the value of these data for analysis of air-quality trends. The raw data from only a subset (~200 stations) of these stations are being archived at NOAA's National Climatic Data Center. Furthermore, the instruments are not being maintained or calibrated with sufficient diligence to enable collection of data with the accuracy that could be provided by these instruments. Clearly, the ASOS visibility measurements and the ancillary meteorological data represent a valuable resource for air-quality investigations. Resources should be made available to the agencies that operate and evaluate the ASOS network to make the data more widely available and in a form that represents the full dynamic range of the instruments. Optimal calibration procedures might require a coordinated effort between the U.S. NWS and other interested agencies.

Recommendation 2.9 *Carry out long-term studies of human-health effects in parallel with air-quality monitoring.*

Rationale. Long-term measurement of appropriate health indices must be carried out in parallel with measurements of air quality in order to conduct epidemiological studies on the effects of specific PM constituents. Identification of specific PM constituents as having a role in producing adverse effects will provide the opportunity for development of control strategies that target those constituents. There is a need to build on past successful collaborations between aerosol scientists and health specialists to design and conduct epidemiological studies to test the hypothesized role of certain constituents. There is a particular need for increased work directed to understanding relationships between PM and other pollutants in ambient air, in homes, and work places and ultimately, in the breathing zone (personal exposure) of people during their daily activities. This may require additional studies on the relationship between measurements made using personal-exposure monitors, and measurements of air quality made using conventional instrumentation.

RECOMMENDATION 3. **Continue to invest resources in evaluating and further developing the performance of chemical-transport models for PM.**

POLICY RELEVANCE

PM models are powerful and necessary tools for the policy maker to determine the impact of various specific and generic sources to PM in a given region or airshed, and to assess the impact of various control strategies on PM concentrations at that location. Significant progress has been made in recent years on chemical-transport models for PM that account for emissions, atmospheric transformations, transport, and removal. Significantly more work is required, however, to improve scientific understanding of certain atmospheric processes so that they can be credibly described by models and to establish the credibility of models for use by policy makers. Existing chemical-transport models do a reasonably good job of predicting the directions in which the concentrations of gases and inorganic particle species would change if the emission rates of a given precursor species were changed; however, the extents of these changes are still uncertain. Chemical-transport models are also less successful at this time at predicting absolute concentrations of species as a function of time and location, although values averaged over time can be calculated with more confidence. More work is needed to develop such models into reliable tools. In the foreseeable future, chemical-transport models need to be used by policy makers in conjunction with other supporting information in making decisions regarding PM management. As PM models improve, policy makers will rely increasingly on the predictions from such models.

SCIENTIFIC NEEDS

Recommendation 3.1 *Design intensive atmospheric field studies and long-term monitoring programs that can be used to evaluate and refine chemical-transport models for PM.*

Rationale. Model-validation studies with varied temporal and spatial scales will be needed to develop models into credible tools for policy makers. The optimal design of such studies will require close collaboration between experimentalists and modelers. A variety of types of studies will be needed. Intensive, short-term campaigns are often well suited to evaluate the performance of chemical-transport models at describing aerosol processes or microscale particle properties. There is also a need for "operational evaluations" designed to determine whether model predictions agree with observations, and for "diagnostic studies" to determine whether models get the right answers for the right reasons. Operational and diagnostic studies will require measurements over extended periods that cover differing seasons and a range of meteorological conditions, and typically cannot be carried out during short (~4-week), intensive measurement campaigns. It should also be kept in mind that models are often designed for conditions where PM concentrations are in the range of standards. Additional model-evaluation work will be needed to evaluate model performance under conditions pertinent to regional haze, where the focus is often on protecting the most pristine conditions.

Recommendation 3.2 *Conduct model-evaluation studies to compare model predictions with observations for PM species concentrations and size distributions.*

Rationale. Models that predict size-resolved composition of aerosols are being developed, and studies that are specifically designed to evaluate this aspect of their performance are needed. Such studies have been carried out in Los Angeles and in the San Joaquin Valley and as part of the EPA Supersite program in other areas. Studies of this type can help both in evaluating the model predictions, and by iteration, the quality of emission inventories and emission models used by chemical-transport models. Size-resolved measurements of temporal and spatial variabilities of the major PM chemical species and their gas-phase precursors are needed for such model evaluations, and measurements made with high temporal resolution will be particularly valuable. Because vertical distributions can vary significantly, vertical mixing in the atmosphere can significantly affect time-dependent ground-level concentrations, and measurements of vertical distributions are required for model-validation studies. Furthermore, more meteorological data, especially for complex terrain, are necessary for running and evaluating models. Priority should be given to carrying out a relatively small number of comprehensive, multi-investigator studies that include collaborations among experimentalists and modelers.

Recommendation 3.3 *Establish centers to facilitate communication regarding best PM modeling practices among regulatory agencies in North America.*

Rationale. The same model, when used by different modelers, will produce different results because the modeler must frequently apply judgments based on previous experience in configuring the model and its inputs for a particular application. As experience in using PM models increases, modelers will develop a greater awareness of how they should be used to obtain credible results. Comparisons with observations will also provide insights into the accuracy with which PM properties can be predicted with models. At present, chemical-transport models are evolving rapidly as scientific understanding improves. It is likely that such models soon will be applied by regulatory agencies, and when this occurs the users may typically be less familiar with the intricacies of the scientific underpinnings of the models. It will be necessary to ensure that individuals using these models are properly trained. Establishing a network of modelers will help to facilitate communication regarding best modeling practices. In this regard, the U.S. Western Regional Air

Partnership (WRAP) has established a regional modeling center at a university. The purpose of this center is to perform regional PM modeling in connection with managing regional haze and to train personnel to apply these models for their local needs. It would be beneficial if this approach were applied more broadly to support the use of models by policy makers.

Recommendation 3.4 *Improve the ability to model certain atmospheric processes. Of particular importance are cloud processing, processes that involve carbonaceous aerosols, and the formation of new particles by homogeneous nucleation.*

Rationale. The ability to model atmospheric PM requires an adequate scientific understanding of relevant atmospheric processes. Current understanding of some phenomena is reasonably good. For example, the chemical pathways responsible for transforming SO_2 and NO_x into secondary particle products are reasonably well understood both for the homogeneous atmosphere and for clouds and fogs. The ability to predict cloud processing is compromised somewhat, however, by the difficulty of predicting the extent to which clouds will form and process polluted air and possibly remove PM via wet deposition. The scientific basis for modeling carbonaceous aerosols is probably the greatest limitation of current chemical-transport models; detailed knowledge of anthropogenic and biogenic sources of primary carbonaceous emissions and their gas-phase precursors is not yet adequate. Furthermore, modeling carbonaceous compounds requires a good understanding of the chemical pathways by which secondary organic PM is formed as well as the physical properties of those products that influence their gas/particle distributions. Also, while recent measurements have shown that the formation of new particles by nucleation from the gas phase is an important source of ultrafine particles, the chemistry and physics of such nucleation phenomena are not sufficiently well understood to enable nucleation to be credibly included in models. Although research on these issues is underway, substantial additional work is needed.

Recommendation 3.5 *Obtain more detailed information on the size-resolved composition of primary particulate emissions from various sources.*

Rationale. The effects of PM on visibility, as well as the deposition location and efficiency of particles in the respiratory system, are also dependent on size. Much work is being done to develop chemical-transport models that predict the size-resolved composition of atmospheric PM as well as fine- and coarse-particle mass contributions. In order to bring such models to their full potential, more detailed information on the size-resolved composition of primary particulate emissions from various sources is needed. This will provide valid initial conditions for calculations, and will facilitate evaluating the differing behaviors of different particle types during transport through the atmosphere.

Recommendation 3.6 *Develop approaches for using data from satellites or real-time sensors to obtain boundary conditions for models.*

Rationale. Obtaining accurate results from models requires accurate boundary and initial conditions. This can be problematic when, for example, sources that are typically not included in emission inventories affect PM concentrations. Examples of such sources are forest fires and the intercontinental transport of dust. When this occurs, data obtained in real time from satellites or real-time sensors might be used to provide initial or boundary conditions for chemical-transport models. Approaches for making optimal use of such information should be developed and implemented when possible.

RECOMMENDATION 4. **Improve emission inventories and emission models.** North American emission inventories should be expanded to include more information on organic speciation and size-resolved composition. Information on emissions from sources typically viewed as "unmanageable" is also needed. Efforts should be continued to refine models that describe the dependence of emissions of, for example, NH_3 and soil dust on time-dependent environmental conditions such as temperature, wind speed, and soil type/moisture content. Emission models that predict size distributions formed when hot exhaust containing vapors that nucleate or condense upon mixing with cooler ambient air are also needed. This recommendation would require that significant additional resources be directed toward the characterization of emissions.

POLICY RELEVANCE

Emissions pertinent to ambient PM include primary particles, precursor gases of secondary PM, and gases that participate in chemical processes that ultimately produce secondary PM. Emissions originate from biogenic and anthropogenic sources, and include emissions from point, mobile and open sources. Appropriate information on emissions from all significant sources is required for receptor models and for chemical-transport models. Ultimately, these models are extended to estimate the personal exposure of populations of individuals. Such comprehensive information on emissions would enable policy makers to examine the efficacy of various emission-control strategies on PM management.

SCIENTIFIC NEEDS

Recommendation 4.1 *Develop improved and standardized approaches for developing national emission inventories for Canada, the United States, and Mexico, which provide compatible data.*

Rationale. Canada and the United States currently have national emission inventories. Until very recently, Mexico's emission inventory was restricted to several major cities and sources. Consistency in approaches used for emission inventories in these countries would facilitate the use of emission data for initiating and evaluating PM models. At present, it is common practice for modelers to reprocess inventory data for compatibility with their model. This process could be streamlined if a unified approach were taken to design emission inventories for North America.

Recommendation 4.2 *Update and expand emission inventories to include new types of information including size distributions and size-resolved composition, organic speciation, and updated source profiles.*

Rationale. Emission inventories should be continually updated and expanded to include information on nontraditional sources known to be important, such as cooking, vehicular emissions during cold start, and high-emitting vehicles. Planning should be initiated to investigate the feasibility of expanding emission inventories to include detailed information on size-resolved composition. Particular attention should be given to providing more detailed information on organic emissions from both anthropogenic and biogenic sources, including the speciation of both particulate and gaseous organics. Such information would provide information on organic gases that can react to form secondary organic PM in the atmosphere, or that could condense as hot emissions mix with cool air near the source. The emission of organic gases from sewers, which is known to be significant in Mexico, should also be included. The lack of information on organic species in emission inventories compromises the performance of aerosol chemical-transport models and source-apportionment models, since organics comprise a significant fraction of the fine-particle mass. Finally, many source profiles used for source-apportionment studies date from the 1970s. Changes in control technologies since then have led to significant changes in source profiles. There is a need to provide updated source profiles for current work of this type.

Recommendation 4.3 *Develop approaches that can be used to reconcile emission inventories with measurements of species concentrations observed in the atmosphere.*

Rationale. While understanding of emissions has improved markedly in the past decade, uncertainties about emissions still contribute significantly to uncertainties in ambient PM source apportionment. Much can be learned through attempts to reconcile emission inventories with species concentrations measured in the atmosphere. For example, emission data can be used with receptor models and/or chemical-transport models to determine whether or not ambient PM concentrations are consistent with expectations. Studies to reconcile emissions with ambient measurements should be carried out for a variety of representative regions in North America.

Recommendation 4.4 *Extend emission inventories to include all available information from particle sources typically viewed as unmanageable, such as forest fires and dust.*

Rationale. Ways to incorporate emission-inventory information on dust or smoke from forest fires should be found. When such species are transported over long ranges, useful information can be obtained from satellite images. This may require the sharing of information and information-gathering techniques across agencies that might not normally communicate in this way. In the United States, for example, input from NASA (satellite photographs), the EPA (controlled sources), and the National Park Service and the National Forest Service (controlled and uncontrolled forest fires) would be needed. Incorporating such diverse information would enhance the usefulness of emission inventories. Such inventories would be useful for short-term forecasting, for providing input that could be used to determine whether or not controlled burns or vehicular traffic would lead to unhealthy conditions during a specified period.

Recommendation 4.5 *Improve emission models for dust.*

Rationale. Work should be done to improve models used to predict dust emissions in emission inventories. Dust emissions depend on particle size, soil type and moisture content, terrain, and wind speed. Because they are emitted close to the surface, coarse particles (i.e., PM_{10}) tend to deposit near the source. Therefore, they are less likely to be transported between model grid cells than small particles. These dependencies need to be built into emission models to enhance the likelihood that dust concentrations, which can contribute a significant portion of $PM_{2.5}$ and an even larger portion of PM_{10}, are calculated correctly.

Recommendation 4.6 *Develop emission models for NH_3.*

Rationale. Ammonia plays an important role in regulating the concentration and composition of $SO_4^=$ and NO_3^-. Incomplete understanding of the anthropogenic and biogenic sources and sinks of NH_3 hinders the ability to perform refined modeling of $SO_4^=$ and NO_3^- formation. Plants and soils can be a sink for NH_3, but can release NH_3 depending on climate, air-chemistry, plant, or soil conditions including moisture content. A better understanding of these biological and physiological processes will contribute to refined estimates and understanding of $SO_4^=$ and NO_3^- formation. However, animal husbandry operations, especially animal waste handling and disposal, are predominant sources of NH_3. Better information is needed on the chemical and biological processes and agricultural practices that influence the timing and amounts of NH_3 released to the atmosphere.

Recommendation 4.7 *Develop emission models that account for condensation or nucleation of semivolatile compounds as hot emissions mix with cool ambient air.*

Rationale. Hot emissions often contain vapors that nucleate or condense on preexisting particles as they mix with cooler ambient air. These vapors include species such as organics in automotive exhaust and SO_3 in power-plant stacks. Such processes are not accounted for in emission inventories, nor are they included in chemical-transport models. It is necessary, therefore, to develop emission models that describe condensation/nucleation near the source. Such models will help to ensure that primary PM emissions are not underestimated, and will establish the connection between vehicular emissions and concentrations of ultrafine PM.

Recommendation 4.8 *Continue to improve the timeliness of emission inventories.*

Rationale. In the United States, recent efforts by the EPA have reduced the time required to incorporate emission data into inventories to about 30 months following the calendar year of interest, while in Canada the goal is to provide annual national inventories that combine the common air-contaminant information and toxics information on a two-year lag. Timely inventories are important in reconciling emissions with ambient concentrations and for forecasting PM concentrations. More up-to-date information would be useful to establish and validate protocols for determining the effects of emission controls on ambient air quality. Although including real-time emission data is probably not a realistic goal for the near future, it might be possible to update emission inventories more quickly than is currently done.

Recommendation 4.9 *Develop approaches for obtaining emission information with adequate resolution in space, time, and composition for atmospheric modeling and exposure assessments. These approaches will likely involve combinations of emission models and emission data with higher resolution in time and composition than are currently included in inventories.*

Rationale. Emission inventories are used for a variety of purposes including permitting and regulatory-compliance programs, tracking trends in emissions or control technologies, and providing source data for chemical-transport models. Chemical-transport models often require information on emissions that is highly resolved in space, time, and composition. Information in emission inventories is commonly aggregated across space and time. For example, area-source emissions in the United States are typically reported as annual emissions averaged over an entire county. It is common for modelers to spend significant effort to reprocess emission data to provide hourly speciated emission estimates with spatial scales consistent with those of their models. Reprocessing also often involves providing estimates of size-resolved composition. Furthermore, it is likely that future work will involve the development of models that can provide estimates of human exposure. Such models will require detailed information on local emissions. Efficiencies would be significantly improved if, in the future, emission inventories were modified to include information that is required for emission models and exposure models. Efforts to integrate this type of information into emission models will require close collaboration among experts on emission inventories, atmospheric modeling, and exposure assessment. Increased attention is being given to linking ambient atmospheric models to assessments of personal exposure. This includes individuals working in the ambient outdoor environment. In addition, these models are being joined with emission information on the "built" environment (e.g., homes and offices, where people spend substantial time) to assess overall personal-exposure. A major challenge exists in developing personal exposure profiles applicable to the diverse lifestyles of large populations.

Recommendation 4.10 *Prepare national emission inventories over a period of years in parallel with long-term monitoring of health effects and ambient concentrations of PM and its precursors to facilitate analyses of trends and benefits.*

Rational. A major deficiency in North America is the lack of a record of emission trends over an extended period of time at the population-center level. The emission-inventory record of PM and its gaseous precursors (except SO_2) is so limited that it is virtually impossible to trace the response of PM to changes in emissions over the years in urban locations, let alone the patterns of change in urban PM levels over the lifetimes of most people living in and around North American cities. This is an important aspect to interpreting patterns of change in ambient pollution concentrations and associated benefits to human health.

RECOMMENDATION 5. **Commit adequate resources to the evaluation, synthesis and archiving of data obtained in current and future atmospheric aerosol studies, and to fostering interactions between the communities of scientists working on atmospheric science, health effects, and global climate change.**

POLICY RELEVANCE

Ambient measurements are expensive. Optimal benefit from measurement programs would accrue if adequate resources were routinely committed to the analysis of data and the application of uniform standards for archiving data. The effort required to evaluate and synthesize data from major field studies is typically one-fourth to one-half of the effort expended on the total project, and adequate support for such work often is not provided. In the long term, policy makers could make better use of limited resources if they were to establish a system for archiving data, and require all investigators supported by funding from their agencies make use of that system.

SCIENTIFIC NEEDS

Recommendation 5.1 *Establish procedures at funding agencies to ensure that atmospheric aerosol data are systematically archived in a manner that provides convenient access to all interested parties.*

Rationale. All too often data obtained in atmospheric field studies are not exploited to full potential. This occurs, in part, because adequate attention is not given to archiving the data for unambiguous interpretation by groups that were not directly involved with data collection. Archiving aerosol data is a particular challenge, since such measurements involve complex data from a wide variety of instruments that require informed judgment to be properly interpreted. Uniform standards should be established for characterizing, documenting and archiving data and metadata from studies of atmospheric aerosols. Such archiving should be completed in a timely manner. In some cases, it may be possible to link this atmospheric data with human-health statistics, as was done with monitoring data in the NMMAPS study (Samet et al., 2000 a, b) to improve an understanding of the role of specific atmospheric constituents in causing adverse health effects.

Recommendation 5.2 *Develop a comprehensive plan for data analysis, integral to measurement programs, and commit adequate resources to carry out such analyses.*

Rationale. It is a commonly held view that it is easier to obtain funding for new measurement programs than to complete the analyses of data from previous studies. Given the expense and effort required for field measurement programs, this would be unfortunate if true. Care should be taken to ensure that when measurement programs are designed, adequate resources are provided for data interpretation and analysis. Opportunities to gain additional insights from the re-analysis of existing data sets need to be continually re-appraised as new analytical tools are developed. Examples of data-analysis needs include developing tools to track long-term trends in PM air quality, quantifying uncertainties in the various observation-based source-receptor models described in Chapter 7, and elucidating the impacts of the multipollutant mix on human health.

Recommendation 5.3 *Foster collaborations among the communities of scientists working on PM pollution, health effects, and global climate change.*

Rationale. Close collaboration between health-effects researchers and atmospheric scientists will be needed to establish cause-effect relationships for pollutant health effects. Such collaboration will help to ensure that atmospheric-research programs provide the data required to test health-effects hypotheses, and will also help to ensure that hypotheses tested reflect the complex realities of the multipollutant mix, as they are understood by atmospheric scientists. Furthermore, while the disciplinary skills required to investigate pollution problems overlap substantially with those required for studies of global climate change, the communities of scientists working on these problems do not interact as much as might be desirable. Research programs that are designed and carried out collaboratively are an ideal vehicle for fostering such interactions.

RECOMMENDATION 6. **Develop more systematic approaches for integrating diverse types of knowledge on origins, properties, and effects of atmospheric PM to assist with the development of management strategies and the measurement of progress towards protecting health.** The challenge here is akin to that encountered in risk assessment (NRC, 1996). Policy makers are faced with the need to make decisions based on imperfect understanding of the atmosphere and of human-health responses. These uncertainties are compounded by inherent variabilities in, for example, emissions, climate, and individual responses. There is a need to systematically account for these uncertainties and variabilities when making policy decisions, and to assess and communicate the benefits of those decisions.

POLICY RELEVANCE

The primary goal of PM management is to protect human health. Systematic approaches that would enable policy makers to integrate information from diverse sources to assist them with selecting management options do not presently exist. This problem is exacerbated by the increasing sophistication and types of science tools available for use by policy makers. Furthermore, each type of information contains inherent uncertainty, and quantifying that uncertainty and taking it into account when choosing management strategies is also problematic. An even bigger challenge is to assess relationships between management strategies, PM properties and human health. PM is only one of many variables that can affect human health, and quantifying the benefits of PM management strategies is a daunting task. Nevertheless, efforts to establish those benefits are essential.

SCIENTIFIC NEEDS

Recommendation 6.1 *Develop a more systematic approach for integrating knowledge gained from measurements, receptor models, and chemical-transport models to make optimal PM-management decisions.*

Rationale. The policy maker is faced with an increasingly complex array of information to use in managing PM. Informed judgment is required to know how best to use this information, which may arise from methods with which the policy maker has no direct personal experience and which may even appear to be contradictory. Systematic approaches for integrating diverse information from measurement networks, receptor models, and chemical-transport models would help to ensure that optimal use is made of existing knowledge when establishing PM management strategies. These approaches must account for inherent uncertainties in each type of information.

Recommendation 6.2 *Develop an accountability framework that will enable measurement of progress towards the goal of protecting human health.*

Rationale. Epidemiological studies have identified a statistical association between increased levels of PM as well as other pollutants and increased morbidity and mortality, especially cardiac and respiratory diseases. Cardiorespiratory morbidity and mortality results from a multitude of factors, several of which have greater impact than air pollution. This makes it difficult to quantify the effects of PM or specific PM constituents and other air pollutants and especially to identify positive trends in improved cardiorespiratory health and to relate these to improved emission controls and air quality. At this time it is easier to quantify improvements in air quality than it is to show by measurement the improvements in health linked to improved air quality. It is important to devise methods to measure the benefits of PM management strategies to human health so that the benefits of those strategies can be assessed. This will require an understanding of the relationship between ambient PM properties, personal exposure, and health. Such methods will need to be applied to large populations so that the wide variety of individuals exposures and responses to PM can be taken into account. This is a difficult task for which no paradigm currently exists.

11.2 FUTURE NARSTO PM ASSESSMENTS

Understanding of atmospheric PM and its effects is evolving rapidly, and significant new information is anticipated to be available in the near future. Furthermore, PM regulations intended to protect health and welfare are evolving as new information becomes available. Recognizing that this will likely be the first of a series of PM assessments, the co-chairs and authors of this report have discussed ways in which future PM assessments might evolve. NARSTO should determine how this and other assessments have been used, and should ensure that future assessments continue to meet needs that have been met by these earlier documents. Also, as understanding of particle properties that affect health becomes better understood, NARSTO should broaden the scope of future PM assessments to explicitly focus on those properties. Future assessments should go further in exploring relationships among PM and other atmospheric constituents, such as ozone, NH_3, NO_x, and anthropogenic and biogenic VOCs (especially secondary organic PM precursors). Furthermore, NARSTO should examine the value of broadening the scope to include trends in energy-utilization scenarios and developments in emission-control technologies. The possibility of using the assessment process as a vehicle to facilitate communications among the measurement, modeling, and environmental-effects communities (especially health effects and global climate change) should be considered.

Currently available sources of information enable semi-continuous assessments of spatial and temporal trends. With the development and deployment of new instruments for continuous measurements of ambient PM mass and species concentrations it soon will be possible to develop more nearly continuous assessments of these phenomena. NARSTO should address the value of examining information from such networks on a continuous or periodic basis.

Given the rapid rate at which new information on PM and its effects is becoming available, the next NARSTO PM assessment is recommended to be initiated in about 2008.

11.3 REFERENCES

AQRS, 1998. Air Quality Research Subcommittee Strategic Plan. Committee on Environment and Natural Resources, National Science and Technology Council, Washington, DC.

AQRS, 1999. Federal Air Quality Research 1998-2000. Committee on Environment and Natural Resources, National Science and Technology Council, Washington, DC.

DOE, 2001. TAP program plan. DOE/SC-0034, U.S. Department of Energy, Office of Science, Office of Biological and Environmental Research, Washington, DC.

Meteorological Service of Canada, 2001. Precursor contributions to ambient fine particulate matter in Canada. ISBN: 0-662-30650-3, Catalogue No. En56-167/2001E, http://www.msc-smc.ec.gc.ca/saib/.

NARSTO, 1998. NARSTO Executive Steering Committee atmospheric particulate matter: research needs.

NARSTO, 2000. An Assessment of Tropospheric Ozone Pollution - A North American Perspective, July 2000.

NARSTO, 2001. Part 4: Science plan for suspended particulate matter. Draft for review, February 2001, http://www.cgenv.com/Narsto/.

NRC, 1996. Science and Judgment in Risk Assessment. National Academy Press, Washington, DC.

NRC, 1998. Research Priorities for Airborne Particulate Matter I. Immediate Priorities and a Long Range Research Portfolio. National Academy Press, Washington, DC.

NRC, 1999. Research Priorities for Airborne Particulate Matter II. Evaluating Research Progress and Updating the Portfolio (1999). National Academy Press, Washington, DC.

NRC, 2001. Research Priorities for Airborne Particulate Matter III. Early Research Progress (2001). National Academy Press, Washington, DC.

Samet, J.M., Dominici, F., Zeger, S. L., Schwartz, J., Dockery, D. W., 2000a. The National Morbidity, Mortality, and Air Pollution Study. Part I: Methods and methodologic issues. Research Report, Health Effects Institute 5-14; discussion 75-84.

Samet, J. M., Zeger, S. L., Dominici, F., Curriero, F., Coursac, I., Dockery, D. W., Schwartz, J., Zanobetti, A., 2000b. The National Morbidity, Mortality, and Air Pollution Study. Part II: Morbidity and mortality from air pollution in the United States. Research Report, Health Effects Institute 94, 5-70; discussion 71-79.

Turpin, B., 2001. Species contributions to PM2.5 mass concentrations: Revisiting common assumptions for estimating organic mass, Aerosol Science and Technology 35, 602-610.