Strategies for Clean Air and Health

CONFERENCE CONCEPT DOCUMENT

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Network *for* Environmental Risk
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Policy Context for Air Quality Management

Premise

In many locations throughout the world air quality is considered to be unacceptable and unhealthy. Both short term and long term exposures to particulate matter and other air pollutants are statistically associated with serious human health effects including premature mortality, cardiovascular and respiratory-related hospital admissions and emergency room visits, and exacerbations of asthma conditions. Chronic PM exposure, on the order of years or decades, appears to be associated with life shortening well beyond that accounted for by the simple accumulation of the more acute effects of short-term PM exposures. While the existing process of setting regulatory air quality standards is necessary and important, the scientific basis for setting policy is not clear due to the extensive uncertainties For example:

- It is not clear which components of the air pollution mix are responsible for health effects.
- It is not clear which sources of air pollution are most damaging to human health.
- There is no single "correct" approach to modeling ambient PM-health effects associations that will provide the "right" answer with regard to precise quantification of PM effect sizes for different health outcomes.
- The extent to which air quality models can accurately predict ambient levels of air pollution is weak.
- Air modelling long term effects presents difficulties, apart from the additional input data requirements, running a model for a year quickly becomes cost prohibitive.

The AIRNET/NERAM Colloquium on *Strategies for Clean Air and Health* is designed to provide expert opinion on directions for clean air policy in North America and Europe based on scientific evidence on air pollution health effects, air quality modeling and policy analysis tools to identify effective strategies and options. The identification of uncertainties in each of these areas and its relevance to decision-making will be an important focus. Figure 1 illustrates the purpose of this document which is to characterize the policy context for air quality management and particularly issues associated with the interface between science and policy as an input to decision-making.

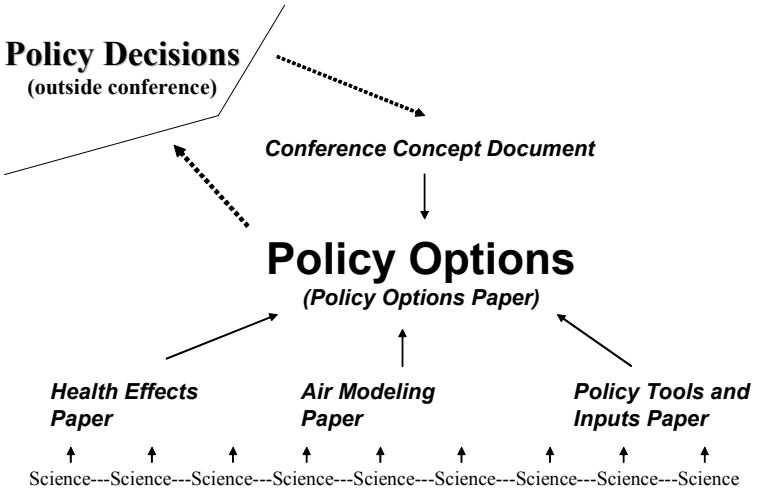


Figure 1. Conference Science-Policy Interface for Air Quality Policy Development

Figure 1 also shows the role of the four background papers, one of which identifies existing policy options and strategies (and their advantages and disadvantages) and the three background papers that present the science side of the science-policy interface, including scientific gaps and uncertainties.

This document is organized into the following six issues that have been identified by the conference planning committee as critical to informing air quality policy. These issues will be also discussed in the background science papers. These issues provide one possible evaluation and decision-making process that policy and strategy development might follow, for any given location and that location's particular level of air pollution. In conceptual terms, these issues exist in a framework of improving public health at reasonable cost.

- What does health effects research tell us about the risks from air pollution, including who should be protected, and from what sources or components of the air pollution mixture? What are the uncertainties and inherent limitations of the health effect studies on air pollution?
- In addition to scientific evidence and its uncertainties, what is the role of public risk perception in public policy development and what are the requirements for risk communication and consultation?
- What sources contribute to risks to public health, and what methods are available to link sources to exposures? How can air quality modeling inform local, regional and continent wide air management strategies?
- What are the expected future benefits of existing policies for pollution reduction for cars, power plants, etc.?
- What are the advantages and disadvantages of alternative policy approaches (e.g. NAAQS, limit values, best available technologies?).
- What are currently the most prominent research priorities to improve air quality management and is the science community targeting these priorities?

For each issue, the current state of science and as well as key uncertainties are documented from recent North American and European science, policy and strategy reports. This is a "living document" that will be updated prior to and following the conference to reflect i) perspectives of policymakers on air quality management issues and strategies and ii) key messages from forthcoming science and policy reports iii) background papers on Health Effects, Air Quality

Modelling, Policy Tools and Inputs, and Policy Strategies and Options currently being prepared for the conference and iv) findings from the conference presentations and discussions.

Issue 1: What does health effects research tell us about the risks from air pollution, including who should be protected, and from what sources or components of the air pollution mixture? What are the uncertainties and inherent limitations of the health effect studies on air pollution?*(Note: results from NRC PM research program will be included when they are available)*

Numerous epidemiologic (human population) studies carried out in North America and Europe have shown statistically significant associations between ambient levels of PM and other air pollutants and a variety of human health endpoints, including mortality, hospital admissions for cardiovascular and respiratory disease, emergency department visits, and physiologic changes in pulmonary function. Researchers have found statistically significant associations between both short and long term PM exposure and these endpoints. These studies cannot identify the actual components of the air pollution that might be responsible for this association, or attribute any fraction of these adverse events to any single monitored component of air pollution.

The fourth external review draft EPA PM criteria document (24) notes that while overall consistency in epidemiological study findings demonstrate that human health effects are associated with pollutant concentrations now experienced in the United States, many uncertainties remain to be addressed. For example, uncertainties exist with regard to the magnitudes and variabilities of risk estimates for ambient PM, the ability to attribute observed health effects to specific components of the ambient mix, the time intervals over which PM health effects are manifested, the extent to which findings in one location can be generalized to other locations, the mechanisms underlying health effects, and the nature and magnitude of the overall public health risks imposed by ambient PM exposure**.** As discussed below, it has been recently demonstrated that issues related to study methodology in short-term exposure studies, including model specifications and approaches for statistical analysis, can have an important influence on risk estimates. The draft EPA criteria document offers the following cautions regarding methodological issues affecting the interpretation of short term and long term air pollution epidemiological studies:

> *i) "it is extremely important to recognize that there is no single "correct" approach to modeling ambient PM-health effects associations that will provide the "right" answer with regard to precise quantification of PM effect sizes for different health outcomes. Rather it is clear that emphasis needs to be placed here on (a) looking for convergence of evidence derived from various acceptable analyses of PM effects on a particular type of health endpoint (e.g., total mortality, respiratory hospital admissions, etc.);(b) according more weight to those well-conducted analyses having greater power to detect effects and yielding narrower confidence intervals; and (c)evaluating the coherence of findings across pertinent health endpoints and effect sizes for difference health outcomes (24 p. 8-189).*
>
> *ii) one major methodological issue affecting epidemiology studies of both short-term and long-term PM exposure effects is that ambient PM of varying size ranges is typically found in association with other air pollutants, including gaseous criteria pollutants (e.g., O_3, NO_2, SO_2, CO), air toxics, and/or bioaerosols. Available statistical methods for assessing potential confounding arising from these associations may not yet be fully adequate. Much progress in sorting out relative contributions of ambient PM components versus other co-pollutants is nevertheless being made and, overall, tends to substantiate that observed PM effects are at least partly due to ambient PM acting alone or in the presence of other covarying gaseous pollutants. However, the statistical association of health effects with PM acting along or with other pollutants should not be taken as an indicator of a lack of effect of the other pollutants. Indeed,*

the effects of the other pollutants may at times be greater or less than the effects attributed to PM and may vary from place to place or from time to time (24, p. 279).

It is important to note that while morbidity endpoints (such as emergency room visits and hospitalizations for respiratory and cardiovascular conditions) affect greater numbers than mortality, policy documents typically focus on all-cause mortality as a health endpoint because mortality is a well-defined health outcome and dominates over morbidity endpoints in estimates of health benefits of regulatory standards when a dollar value is assigned to them. An alternative approach to assessing air pollution effects is to estimate changes in life expectancy. Several authors have concluded that at current ambient PM levels in Europe, the effect of PM on life expectancy many be up to one to two years (9). The NRC Committee on Estimating the Health Risk Reduction Benefits of Proposed Air Pollution Regulations (13) noted the need for improved morbidity data, especially if the value assigned to mortality decreases and morbidity outcomes begin to play a more dominant role in benefits analyses.

Short term Exposure and Mortality

Short term exposure studies use a time-series approach to relate short-term changes (often day to day) in air pollutant concentrations with changes in daily mortality. Multi-city studies offer an advantage over single city studies of consistency in data handling and model specifications that eliminates variation due to study design. Of particular importance are two large multi-centre time series studies of daily levels of air pollution from the United States (*National Morbidity, Mortality, and Air Pollution Study, NMMAPS*) and Europe (*Air Pollution and Health: a European Approach, APHEA*).
The NMMAPS focused on time-series analyses of PM_{10} effects on mortality during 1987-1994 in the 90 largest U.S. cities (25, 26), in the 20 largest cities in more detail (27), and PM_{10} effects on emergency hospital admissions in 14 U.S. cities (25, 26). No other study has examined as many US cities in such a consistent manner. The APHEA project is a multi-center study of short-term effects of air pollution on mortality and hospital admissions within and across a number of European cities. APHEA1 analyzed the link between SO_2 and PM and mortality in 12 European cities using mostly black smoke (BS) as a PM index, except for Paris, Lyon (PM_{13}); Bratislava, Cologne, and Milan (total suspended particulates, TSP); and Barcelona (BS and TSP). The APHEA2 (23) project assessed the short-term effects of ambient particles on total nonaccidental mortality, using data from 29 European cities. In APHEA2, 10 out of the 29 cities used actual PM_{10} measurements; and, in 11 additional cities, PM_{10} levels were estimated based on regression models relating collocated PM_{10} measurements to BS or TSP. In the remaining 8 cities, only BS measurements were available (14 cities had BS measurements).

Recently, questions were raised by NMMAPS and Health Canada investigators, concerning the statistical model used to control for time varying factors such as weather, and other unmeasured risk factors that may affect health outcomes in time series studies. Generalized additive models (GAMs) have been the preferred method since 1996. NMMAPS investigators at Johns Hopkins University discovered that part of the GAM[1] programming involving convergence criteria and number of iterations in S-Plus statistical software which they and many others have used to fit GAMS to time series data was not appropriate for this purpose. The default convergence criteria were too lax to attain convergence in the setting of air pollution, weather, and mortality/morbidity parameters where small PM regression coefficients were estimated and at lease two covariates were modeled with non-parametric smoothers. When the NMMAPS data were reanalyzed using a more strict

[1] A GAM is a methodology used in environmental epidemiology to estimate an effect of one or more variables (i.e. air pollution, weather, and time) on an outcome (i.e. daily deaths) when it cannot be assumed that the relationship takes a particular function (e.g. linear) form. The GAM estimation procedure, as implemented in standard statistical software (S-PLUS, SAS) relies upon default convergence criteria.

convergence criteria for the GAM estimation procedure, estimates of the air pollution effect across the 90 largest U.S. cities changed from a 0.41% increase to a 0.27% increase in daily mortality per 10 $\mu g/m^3$ $PM_{10.}$ (11) In the original and reanalyzed study the risk estimates varied by geographic regions, with the estimate for the Northeast being the largest (approximately twice the nation-wide estimates). While the extent of regional heterogeneity in the reanalysis was reduced slightly, the pattern of heterogeneity remained the same. The reanalysis also included a sensitivity analysis to alternative degrees of freedom for adjustment of the confounding factors: season, temperature, and dewpoint. The results indicated that the magnitude of sensitivity of the results due to model specification (in this case degrees of freedom) can be as great as the potential bias caused by the GAM convergence problem.

The revised analyses for the APHEA2 project suggested that the reported estimated effects were reasonably robust to the application of alternative modeling strategies (30). Heterogeneity was also apparent among effect estimates for PM and SO_2 in the APHEA studies. In APHEA2, several city-specific characteristics, such as NO_2 levels and warm climate were found to be important effect modifiers.

The revised effect estimates from APHEA2 and NMMAPS are presented in Table 1.

Table 1: Estimated effects of air pollution on daily mortality and hospital admissions from revised APHEA2 and NMMAPS studies

	Study	
	APHEA2	**NMMAPS**
Increase in total deaths per 10 $\mu g/m^3$ PM_{10} (95% confidence limits)	0.6% (0.4 - 0.8%)	0.27% (0.17 – 0. 37%)
Increase in COPD (APHEA2:COPD + asthma) hospital admissions in persons >65 yrs per 10 $\mu g/m^3$ (95% confidence limits)	1.0% (0.4 – 1.5%)	1.5% (1.0 – 1.9%)

Adapted from (9) to include revised NMMAPS analysis results

NMMAPS investigators and the HEI Special Review Panel concur that while the estimates of effect decreased substantially, the following qualitative conclusions did not change (11):

1. there is strong evidence of an association between acute exposure to particulate air pollution (PM10) and daily mortality, one day later;

2. this association is strongest for respiratory and cardiovascular causes of death;

3. this association can not be attributed to other pollutants including NO_2, CO, SO_2 or O_3 nor to weather.

Results of reanalyses carried out by the primary authors of 37 published time series studies using more appropriate convergence criteria varied greatly across the studies. In some studies, stricter convergence criteria had little impact. For example applying GAMS with more stringent convergence criteria to the APHEA2 data did not practically affect the estimated effects of PM10 on mortality (30). In no study were conclusions based on the original analyses changed in a meaningful way by the use of stricter criteria. In general, the extent of reduction of PM_{10} excess risk estimates due to the change in the convergence criteria using GAM models in the NMMAPS study appeared to be greater than those reported in most of the other reanalysis studies. The draft EPA criteria document suggests that the inclusion of several weather terms with more degrees of freedom in the NMMAPS studies most likely provides “conservative” PM risk estimates. The HEI Special

Review Panel reinforced the need to qualify estimates of impact based on observational air pollution studies by specifying the uncertainties and assumptions
on which the estimates are based. The Panel noted that these revised analyses have renewed the awareness of the uncertainties present in estimates of short-term air pollution effects based on time-series data. Neither the appropriate degree of control for time, nor the appropriate specification of the effects of weather, has been determined for time series analyses. (11) The draft EPA Criteria document concluded that *"nearly all of the newly reported analyses with a few exceptions continue to show statistically significant associations between short term (24 hr) PM exposures indexed by a variety of ambient PM measurements and increases in daily mortality in numerous US and Canadian cities, as well as around the world* (21, p. 8-29). *"In summary, considering all the options in model specifications that can affect the PM risk estimates, the reported combined PM_{10} total non-accidental mortality risk estimates from multi-city studies are in good agreement, in the range of 1.0 to 3.5% per 50 $\mu g/m^3$ increase in single or two-day average PM_{10}".*

Long Term Exposure and Mortality

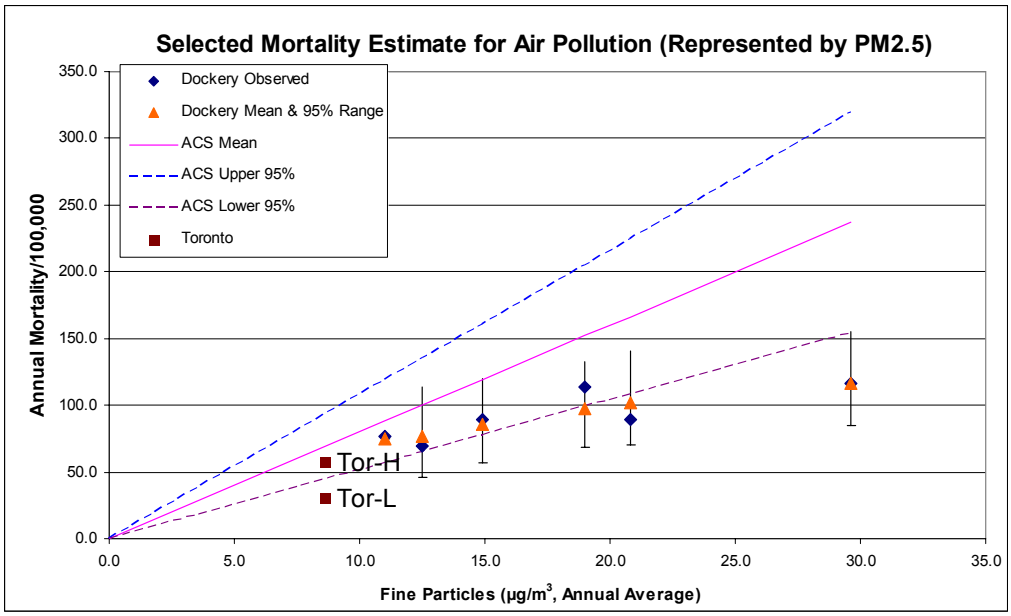
Long term studies examine the potential relationship between community-level PM exposures over multiple years and community-level annual mortality rates. Prospective cohort studies of mortality associated with chronic exposures to air pollution have provided valuable insights into the adverse health effects of long term PM exposures. These studies use subject-specific information about relevant covariates (such as cigarette smoking, occupation, etc.) typically providing more certain findings of long-term PM exposure effects than are purely "ecological studies".

The most extensive study and analyses of the effects of long term exposure has been based on data from two prospective US cohort groups, referred to as the Harvard Six City study (17) and the "American Cancer Society or ACS study" of 151 cities (16). These studies agreed in their findings of statistically significant positive associations between fine particles and excess mortality, although the ACS study did not evaluate the possible contributions of other air pollutants. The Six City study examined various PM and gaseous pollutant indices (including total particles, $PM_{2.5}$, SO_4^{-2}, H^+, SO_2 and ozone) and found that sulfate and $PM_{2.5}$ fine particles were most strongly associated with mortality.
The excess relative risk estimates originally reported for total mortality in the Six-Cities study (and 95 percent confidence intervals, CI) per increments in PM indicator levels were: Excess RR = 18% (CI = 6.8%, 32%) for 20 $\mu g/m^3$ PM_{10}; excess RR = 13.0% (CI = 4.2%, 23%) for 10 $\mu g/m^3$ $PM_{2.5}$; and excess RR = 13.4% (CI = 5.1%, 29%) for 5 µg/m3 SO_4^{-2}. The estimates for total mortality derived from the ACS study were excess RR = 6.6% (CI = 3.5%, 9.8%) for 10 $\mu g/m^3$ $PM_{2.5}$ and excess RR 3.5% (CI = 1.9%, 5.1%) for 5 $\mu g/m^3$ SO_4^{-2}. The ACS pollutant relative risk estimates were smaller than those from the Six-Cities study, although their 95% confidence intervals overlap. The draft EPA criteria document notes the following differences in the two study designs. The pollutant exposure estimates in the ACS study were based on concentrations at the start of the study (during 1979-1983) while the 6 cities study used more current PM measurements to estimate chronic exposures. In addition, the average age of the ACS cohort was 56, which could overestimate the pollutant RR estimates and perhaps underestimate the life-shortening associated with PM associated mortality.

Figure 2 illustrates the relationship between annual incremental mortality and annual average $PM_{2.5}$ levels in U.S. cities based on the findings of the Harvard Six Cities Study and the American Cancer Society (ACS) Study. The ACS plot reflects the concentration-response function derived from adjusted mortality risk ratios for the most polluted areas compared with the least polluted area and the assumption that there is no threshold of effect. This assumption is justified since there is no evidence of a threshold for PM, however if there were a threshold then the health effects would be

smaller.[2] The Dockery plot indicates the observed annual mortality for each of the six cities and the 95% confidence limits are constructed from the given risk ratios. For purposes of comparison, risk estimates for Toronto, based on a 2000 Toronto public health department report (2) are illustrated. The lower estimate for Toronto is based on Burnett et al. (1998) multipollutant time series studies of daily mortality conducted in Toronto[3] and the higher estimate is based on the risk ratio from the ACS study.

Figure 2. Selected Mortality Estimate for Air Pollution for US cities (based on cohort studies) and Toronto (based on time series studies)



The evidence for long-term effects of PM on mortality has been expanded by a reanalysis of the original Six Cities and ACS cohort study by the Health Effects Institute (32) and an extension of the ACS cohort study to include an additional eight years of follow up (31). The Six Cities and ACS study Reanalysis has largely corroborated the findings of the original two US cohort studies, which both showed an increase in mortality with an increase in fine PM and sulfate. The increase in mortality was mostly related to increased cardiovascular mortality. A much larger number of confounding variables and effects modifiers were considered in the Reanalysis study than in the original Six City and ACS studies. Because of the limited statistical power to conduct most sensitivity analyses for the Six Cities Study, the Reanalysis Team conducted the majority of its sensitivity analyses using only the ACS Study dataset with 154 cities. In that dataset, when a range of city-level (ecologic) variables (e.g. population change, measures of income, maximum temperature, number of hospital beds, water hardness) were included in the analyses, the results generally did not change. Two exceptions were that associations for both fine particles and sulfate were reduced with city-level measures of population change or sulfur dioxide were included in the model. The Reanalysis study showed a significant modifying effect of education in both studies, with relative risk of mortality associated with fine particles declining with increasing educational attainment. The regional association of sulfur dioxide with sulfate and sulfur dioxide with $PM_{2.5}$ was very high and the effects of the separate pollutants could not be distinguished. The Reanalysis

[2]Relevant here are two statements from the WHO Working Group report (7): "Increasingly sensitive epidemiological study designs have identified adverse effects from air pollution at increasingly lower levels". However "observational (epidemiological) studies have limited statistical power for characterizing thresholds."

[3] Note that the Burnett et al. study measured PM_{10}, therefore a simple assumption was made that the number of deaths would be reduced by 50% to derive an estimate of $PM_{2.5}$ related deaths for plotting in Figure 2.

report discusses the limitations inherent in generalizing the results of the Six Cities and ACS studies to the United States Population. In the Six Cities study, fine particles and sulfate were measured at the city level; therefore for most analyses, this study had six city-wide data points (this limitation is also true for the ACS Study but has less impact because the number of cities is larger). This limits the ability to detect whether intercity variation in health risks might be a result of city characteristics other than air quality. The results of the ACS study have been more central to the regulatory policy debates. The ACS study data are also limited, however because the subjects were friends, relatives, and neighbors of ACS study volunteers and were not necessarily representative of the population in any given city. The ACS study cohort was more highly educated and racially homogeneous (white) than the US population as a whole. Whether this sampling bias confounds or limits the ability to generalize the findings of these studies to the greater US population is not known. The investigators concluded that mortality may be attributed to more than one component of the complex mix of ambient air pollutants in urban areas of the United States. The HEI reanalysis determined that "*overall the reanalysis assured the quality of the original data, replicated the original results, and tested those results against alternative risk models and analytic approaches without substantively altering the original findings of an association between indicators of particulate matter air pollution and mortality" (32).*

The extended ACS analysis yielded somewhat smaller estimates than the original study, but are similar to the estimates from the HEI reanalysis of the original data set. Fine particles were associated with elevated total, cardiopulmonary and lung cancer mortality risks. Education was found to be an effect modifier, with larger and more statistically significant PM effect estimates for persons with less education. All endpoints but lung cancer mortality were very significantly associated with sulfates, except for lung cancer with 1990 sulfate data. (24)

Another prospective cohort data set comes from the California based Adventist Health and Smog (AHSMOG) Study of a relatively young sample of non-smoking 7th Day Adventists (Abbey et al., 1999) which reported associations between long-term PM_{10} exposure and non-malignant respiratory deaths in men and women, and on lung cancer mortality in men. In contrast to the Six Cities and ACS studies, no association with cardiovascular deaths was found. The 1996 PM criteria document placed less emphasis on this study as total suspended particles (TSP) was used as the PM exposure metric rather than PM_{10} or $PM_{2.5}$, included fewer subjects than the ACS study, and considered a shorter follow-up time (10 years) than the Six Cities (15 years). In a more recent ASHMOG analysis the mortality status of subjects was determined after 15 years of follow up. The study used PM_{10} as its PM mass index and found some significant associations with total mortality and deaths with contributing respiratory causes, even after controlling for potentially confounding factors (including other pollutants). However no pattern of consistent, statistically significant associations between mortality and long-term PM exposure was found. A statement by the UK Committee on the Medical Effects of Air Pollutants (COMEAP) noted that given the substantially different lifestyle of 7th Day Adventists, the implications of the results for the general population are unclear (6).

A cohort of 70,000 adult male veterans diagnosed with hypertension has been examined (33) in the EPRI-Washington University Veterans' Cohort Mortality Study. This cohort differs from the ACS, Six-Cities and 7th Day Adventist cohort studies with respect to income, race, and smoking status. Unlike previous long-term analyses, this study found some associations between mortality and ozone, but found inconsistent results for PM. The investigators stated that the relatively high fraction of mortality within this cohort may have depleted it of susceptible individuals in the later periods of follow up and concluded that *"the implied mortality risks of long-term exposure to air pollution were found to be sensitive to the details of the regression model, the time period of exposure, the locations to be included, and the inclusion of ecological as well as personal variables"* (24, 33).

The draft EPA Criteria document concludes that the lack of consistent findings in the AHSMOG study and negative results of the VA study do not negate the findings of the Six Cities and ACS studies, as both have been validated through exhaustive reanalyses. The results of reanalysis and the ACS study extension provide substantial evidence for positive associations between long-term ambient PM (especially fine PM) exposure and mortality.

The relative risks associated with long term ambient PM exposure for each of these US cohort studies are summarized in Table 2.

Table 2 . Effect Estimates Per Increments* in Long Term Mean Levels of Fine and Coarse Fraction Particle Indicators From U.S. and Canadian Studies

Type of Health Effect Study and Location	Indicator	Change in Health Indicator per Increment in PM	Range of City PM Levels ** Means ($\mu g/m^3$)
Increased Total Mortality in Adults		**Relative Risk (95% CI)**	
Six City[A]	$PM_{15/10}$ (20 $\mu g/m^3$)	1.18 (1.06-1.32)	18-47
	$PM_{2.5}$ (10 $\mu g/m^3$)	1.13 (1.04-1.23)	11-30
	$SO_4^=$ (15 $\mu g/m^3$)	1.46 (1.16-2.16)	5-13
ACS Study[B] (151 U.S. SMSA)	$PM_{2.5}$ (10 $\mu g/m^3$)	1.07 (1.04-1.10)	9-34
	$SO_4^=$ (15 $\mu g/m^3$)	1.10 (1.06-1.16)	4-24
Six City Reanalysis[C]	$PM_{15/10}$ (20 $\mu g/m^3$)	1.19 (1.06-1.34)	18.2-46.5
	$PM_{2.5}$ (10 $\mu g/m^3$)	1.14 (1.05-1.23)	11.0-29.6
ACS Study Reanalysis[C]	$PM_{15/10}$ (20 $\mu g/m^3$) (dichot)	1.04 (1.01, 1.07)	58.7 (34-101)
	$PM_{2.5}$ (10 $\mu g/m^3$)	1.07 (1.04-1.10)	9.0-33.4
ACS Study Extended Analyses[D]	$PM_{2.5}$ (10 $\mu g/m^3$)	1.04 (1.01-1.08)	21.1 (SD=4.6)
Southern California[E]	PM_{10} (20 $\mu g/m^3$)	1.091 (0.985-1.212; males)	51 (±17)
	PM_{10} (cutoff = 30 days/year >100 $\mu g/m^3$)	1.082 (1.008-1.162; males)	
	PM_{10} (20 $\mu g/m^3$)	0.950 (0.873-1.033; females)	51 (±17)
	PM_{10} (cutoff = 30 days/year >100 $\mu g/m^3$)	0.958 (0.899-1.021; females)	
Veterans Cohort[F]	$PM_{2.5}$ (10 $\mu g/m^3$)	0.90 (0.85, 0.954; males)	5.6-42.3

Source: Adapted from (21)

* Results calculated using PM increment between the high and low levels in cities, or other PM increments given in parentheses; NS Changes = No significant changes.

** Range of mean PM levels given unless, as indicated, studies reported overall study mean (min, max), or mean (±SD); NR=not reported.

*** Results only for smoking category subgroups.

References:

[A]Dockery et al. (1993)
[B]Pope et al. (1995)
[C]Krewski et al. (2000)
[D]Pope et al. (2002)
[E]Abbey et al. (1999)
[F]Lipfert et al. (2000b)

Examples of Location Specific Risk Estimates

Toronto, Canada

The *Air Pollution Burden of Illness in Toronto* (2000) study estimated that the six common air pollutants (PM_{10}, SO_4, CO, NO_2, SO_2, O_3) were responsible for between 730 and 1,400 premature deaths and between 3,300 and 7,600 hospital admissions each year among Toronto's 2.4 million residents (2). The range in estimates reflect two different methods for health effects estimation and *"provides insights into the problems of estimates of this type, as well as revealing the competing scientific approaches to determining regulatory policy for air pollution"* (2, *p. 47*). The higher estimate is based on risk coefficients identified in a worldwide epidemiological literature review undertaken for the Hamilton Air Quality Initiative (34), the Canadian ozone and particulate matter

Science Assessment Documents (35, 36, 37) and other recent studies. The lower estimate is based on risk coefficients from multipollutant models including particulates, CO, NO_2, SO_2 and O_3 for Toronto (21, 22). The burden of illness estimates for the two approaches are provided in Tables 3 and 4. Although the calculations were based on 1995 data, the report indicates that air quality in Toronto has not shown any significant improvement since then, so it is reasonable to expect that these health effects estimates reflect the current situation.(2)

Table 3: Burden of Illness Summary for Toronto (based on HAQI approach, 1997)

Pollutant	No. of People with Adverse Health Outcome[b]			
	Non-traumatic Mortality	Respiratory Hospital Admissions	Cardiac Hospital Admissions	Congestive Heart Failure in Elderly
PM_{10}	226	555	812	
SO_4	119[a]	170	169	
CO	441		274	439
NO_2	511	1,234	2,207	
SO_2	119	172		
O_3	59	199	2,155	
Total (using PM_{10} but not SO_4)	1,356	2,160	5,448	

[a] 405 when based on chronic exposure, rather than 24 hr exposure.
[b] Blanks indicate no coefficients available to enable estimates to be calculated. Health outcomes for O_3 and PM_{10} based on excess morbidity and mortality beyond that associated with 'background' levels.

Source: (2) p. 43

Table 4. Burden of Illness Estimated from Multi-pollutant Models (based on (21) (22)

POLLUTANT	OUTCOME						
	NT Mortality	Respiratory Admissions			Cardiac Admissions		
		Asthma	Obstructive Lung Disease	Respiratory Infection	Dysrhythmia	Heart Failure	Ischemic Heart Disease
PM_{10}	121	23	37	163	47	55	
CO	608	124	44		124	148	
NO_2				309		382	1052
SO_2		17		44			72
O_3		206	153	247	80		
Totals	729	1367			1960		

Source: (2) p. 46

United Kingdom

The UK Department of Health *Committee on the Medical Effects of Air Pollutants (COMEAP)* estimated the short-term impact of air pollution on health based on the results of time series studies (5). Evidence of health effects associated with particles, sulphur dioxide and ozone was considered sufficiently robust for quantification. The effects of particles and sulphur dioxide were estimated assuming no threshold for the health effects of these pollutants. The report emphasized two points in interpreting the results i) co-variation of pollutants means that in some instances we do not know which individual pollutant or mixtures of pollutants has caused the recorded effects or whether some additive or synergistic effects have taken place ii) it follows that a reduction in the concentration of a single pollutant may produce different benefits than predicted by exposure-response relationships based on observational studies.

Table 5. Numbers of deaths and hospital admissions for respiratory diseases affected per year by PM_{10} and sulphur dioxide in urban areas of Great Britain

Pollutant	*Health Outcomes*	*GB Urban*
PM_{10}	Deaths brought forward (all cause)	8100
	Hospital admissions (respiratory) brought forward and additional	10500
SO_2	Deaths brought forward (all cause)	3500
	Hospital admissions (respiratory) brought forward and additional	3500

Estimated total deaths occurring in urban areas of GB per year = c430,000
Estimated total admissions to hospital for respiratory diseases occurring in urban areas of GB per year – c530,000
Source: (5)

Table 6: Numbers of deaths and hospital admissions for respiratory diseases affected per year by ozone in both urban and rural areas of Great Britain during summer only

Pollutant	*Health Outcomes*	*GB Threshold = 50 ppb*	*GB threshold=0 ppb*
Ozone	Deaths brought forward (all causes)		
	Hospital admissions (respiratory) brought forward and additional	500	9900

In March 2001, COMEAP released a statement that quantified the possible long-term effects of particles on mortality in the UK (6). The Committee considered it unwise to report a single estimate of effects due to the many factors affecting mortality and susceptibility and uncertainties about the transferability of US-based epidemiology results to the UK. A range of estimates were provided based on mortality risk estimates from US time series studies, the HEI Six Cities and ACS study reanalysis and the original ACS study. The results were expressed in terms of a 1 $\mu g/m^3$ drop in annual mean $PM_{2.5}$ and apply to the population of England and Wales alive in 2000, assuming that the pollutant reduction is maintained for the rest of their lifetime. Coefficients range from a 0.1% to 0.9% decrease in hazard rate based on relative risks and confidence intervals from the ACS study. The estimates range from 0.007 (short term effects based on PM_{10} time series studies) to 4.1 million life years gained (based on the upper confidence interval of the ACS study) over the rest of the lifetime of the population alive today. This could be expressed as up to 1 month per person on average if the entire population was affected but could also represent a larger gain for fewer people.

The estimate considered most likely (0.2 to 0.5 million life years or 1.5 to 3.5 days per person for all 52 million people; 5 days for 25 million people; nearly 2 months for 2.5 million people or 4.5 months for 1 million people or a mixture of these) takes into account the small number of confounding factors that substantially reduced the relative risks in the HEI reanalysis. The report emphasized the need for further research to address the following key uncertainties: i) whether the results can be explained by undetected confounding, ii) whether high exposures in the past lead to an overestimation of the effect, iii) what lagtimes and what duration of exposure are required for the effect and iv) a lack of understanding of the underlying mechanisms.

Susceptibility

Toxicology studies on PM have consistently shown that older animals or animals with certain types of compromised health, either genetic or induces, are more susceptible to instilled or inhaled particles, although the increased animal-to-animal variability in these models has created greater uncertainty in the interpretation of the findings (24).

A consistent finding from both the acute and chronic exposure epidemiological findings is that PM effects are most substantial in susceptible sub-populations. These include elderly individuals (> 65 years), individuals with pre-existing diseases of the respiratory and cardiac systems, smokers and ex-smokers, and individuals with asthma, especially children. There is recent, though limited, evidence of prenatal effects on cardiac development and potential mortality impacts on infants within the first two years of life. (24)

The Role of PM Components

The USEPA Fourth External Review Draft Criteria document for PM (June, 2003) concludes the following concerning links between specific particulate matter components and health effects (24):

- *To date, toxicology studies on PM have provided only limited evidence for specific PM components potentially being responsible for observed cardiopulmonary effects of ambient PM. Studies have shown that some components of particles are more toxic than others. For example high concentrations of residual oil fly ash and associated soluble metals have produced clinically significant effects (including death) in compromised animals. The relevance of these findings to understanding the adverse effects of PM components is tempered, however, by the large difference between metal concentrations delivered to the test animals and metal concentrations present in the ambient urban environment.*

- *The issue regarding the relative importance of $PM_{2.5}$ and $PM_{10-2.5}$ has not yet been fully resolved. Caution in interpreting size-fraction PM studies is warranted due to the problem of measurement error and the correlation between the two size fractions. Epidemiology studies conducted in U.S., Canadian, and European cities showed mortality associations with specific fine particle components of PM, including sulfate, nitrate, and CoH; but their relative importance varied from city to city, likely depending on their levels. Coarse particles of crustal origin may be relatively non-toxic under most circumstances compared to those of combustion origin. However, under some conditions, crustal particles may be sufficiently toxic to cause human health effects. Resuspended particles, for example, may carry toxic trace elements and other components from previously deposited fine PM, e.g., metals from smelters (Phoenix) or steel mills (Steubenville, Utah Valley) or PAH's from automobile exhaust.*

Issue 2. In addition to scientific evidence and its uncertainties, what are the key considerations for public policy development, for example the role of uncertainty, public risk perception,

requirements for risk communication and consultation. (*Note: Material to be added from interviews and conference discussions*).

Public Opinion

According to a 1998 study conducted by Environics International entitled, *Public Opinion and the Environment: A Summary of Major Trends in the Toronto Region*, nine out of every ten citizens in **Toronto** are concerned about environmental problems, with air quality being the number one environmental concern. Environics International reported that respiratory problems came out as the greatest health concern, superseding even cancer (3). Southern Ontario and the Greater Toronto Area have recently experienced an unprecedented number of smog advisory days. There have been 28 smog alert days in Ontario in 2003, 19 in 2002 and 22 in 2001. This is a significant increase from 1993 to 1999 during which there were between 1 and 9 smog days per year. Smog alerts in 2001 and 2002 lasted up to five days, longer than ever before.

Similarly in the **UK**, results from public consultation (see web link) undertaken by the Mayor of London on his draft air quality strategy suggest that the majority of Londoners are concerned about London's air quality and want to see it improved. Seventy-one per cent of respondents believed that air pollution is a problem in London and 66 per cent of respondents believed that air quality in London affected their quality of life. Contrary to what has actually happened, 43 per cent thought air pollution in London had actually got worse in the last five years. Measures in the Mayor's Air Quality Strategy and other Mayoral strategies will improve London's air quality and London is expected to achieve the national targets for five of seven air pollutants. It is estimated that London will not achieve targets for annual nitrogen dioxide (NO_2) target set for 2005, and the daily particulate matter (PM_{10}) target set for 2004 (7) . Even in 2010, achieving the national objective for NOx will be challenging in London. Present 'business as usual' air pollution maps for 2010 show widespread exceedances of the annual mean nitrogen dioxide objective (Figure 18 and 19 (see web links for figures) under both good and poor atmospheric dispersion conditions.

Risk Communication

Public education and awareness initiatives are in integral part of a comprehensive air quality management strategy. Providing information to the public can help to achieve a number of aims (20):

- To assist the public to understand the impact of air pollution on their health or the wider environment
- To encourage the public to reduce emissions of pollutants within their control (for example by changing their driving habits)
- To allow those who may be affected by air pollution to take timely precautions to avoid such effects; and
- To enable the public to assess progress towards the achievement of national air quality objectives

Maynard and Coster (20) note that providing such data is not easy and not a matter of trivial cost; however its importance is beyond question. Issues concerning how to effectively communicate air quality risks with the public have been a recent focus of attention in North America and Europe. For example, recent revisions to the Ontario Air Quality Index have been, in part, a response to criticisms raised by public health professionals concerning the extent to which air quality ratings and the resulting public messages appropriately reflected the burden of illness suggested by scientific studies. Given the widespread media attention to air quality issues, it is important that

messages concerning health effects and health protection provide an accurate reflection of the risks in a form that is easily understood (19, 20).

Issue 3: What sources contribute to risks to public health, and what methods are available to link sources to exposures? How can air quality modeling inform local, regional and continent wide air management strategies?

Receptor and emission-based analyses to date point out that on average, greater than 2/3 of $PM_{2.5}$ is traceable back to anthropogenic sources. Several major source categories are important contributors to PM and its precursors and should be the focus of further regional and local policy analysis, in particular:

- Fossil-fuel combustion sources, including electric utilities and internal-combustion engines
- Residential wood burning, wildfires, and other biomass burning
- Ammonia from intensive agricultural operations

Particles in the atmosphere are strongly influenced by open or fugitive source emissions (e.g., agricultural operations, road and soil dust suspension, sea salt, and vegetation detritus) and supplemented by sulfate from SO_2 and nitrate from NOx emissions. Typically the sulfate and nitrate accounts for 40 to 60 percent mass fraction in $PM_{2.5}$. (1)

Short-term epidemiological studies suggest that a number of source types are associated with health effects, especially motor vehicle emissions, and also coal combustion. These sources produce primary as well as secondary particles, both of which have been associated with adverse health effects. A Dutch cohort study focused on traffic-related air pollution specifically, and suggested the importance of this source of PM (40). Toxicological studies have shown that particles originating from internal combustion engines, coal burning, residual oil combustion and wood burning have strong inflammatory potential. In comparison, wind-blown dust of crustal origin seems a less critical source. (9)

Conceptual models based on currently available information have been prepared for nine North American areas and reported in *NARSTO'S PM Assessment Particulate Matter for Policy Makers* (see web link). The models provide the following source specific insights (1):

- The Lower Fraser Valley airshed of the Pacific Northwest (including Vancouver) will likely need future controls on mobile sources, agricultural NH_3, and road dust emissions to offset future growth where levels are currently below standards.

- For the San Joaquin Valley of California, reduction of secondary particles via VOC and/ or NOx source controls appears important during peak periods. Uncertainties remain regarding the relative importance of VOC or NOx reductions. Motor vehicles are key contributors and biomass burning may also be a significant. Both urban and regional source reductions are needed.

- For the Los Angeles Basin, reduction of secondary particles via controls on VOC and/or NOx appears important with transportation and agriculture being the key sources to be addressed. Primary organic compounds emitted from transportation, wood burning, and food cooking may contribute significantly to annual average $PM_{2.5}$ and PM_{10} concentrations. Sulfate particles associated with regional transport are also a significant source to be considered.

• Mexico City's PM problems could benefit from control of diesel vehicles to reduce primary OC and BC emissions. SO_2 and NOx controls may be more important than NH_3 controls for reducing secondary PM, and thus should also be examined.

• For the southeastern United States, high regional levels combined with local urban sources point to within-region source reductions needed from coal powered utilities, gasoline and diesel vehicles, and residential wood burning. Rural areas can have both important local and distant source contributions, and some sulfate reduction will be offset by nitrate, with likely increasing NH_3 emissions.

• Median sulfate in the northeastern United States continues to drop from 1990 levels likely due to SO_2 precursor reductions, but peaks remain, and regional transport in the summer from the Ohio River Valley when $PM_{2.5}$ is at its peak, points to further reduction in regional and local SO_2 being beneficial. Control of local sulfate, OC, and nitrates in coastal urban areas will be important for winter $PM_{2.5}$ mass concentration reductions.

• Reducing $PM_{2.5}$ in the southwest Windsor- Quebec Corridor will require both local measures and cooperation with the United States likely aimed at both SO_2 and NOx controls, and similar source controls in Ontario will be needed to reduce Quebec's $PM_{2.5}$. Further consideration is warranted for OC source reductions in cities and wood combustion on local scales. For the Upper Midwest-Great Lakes region, reducing local and long-range contributions of OC and sulfate should be a consideration for urban areas.

• For the Canadian Southern Prairie and U.S. Northern Plains, a potential increase in urban winter nitrate and sulfate with population growth should encourage energy efficiency. Reduction of NH_3 from fertilizers applications may be supported, and smoke management is important to regional haze in these clean-air areas.

• Combined NOx and VOC management strategies for both PM and ozone can result in optimal strategies that differ from the ones that would be adopted if these problems were examined separately. An optimal strategy would require balancing VOC and NOx controls to obtain the desired reductions in ozone and PM2.5, while minimizing the potential disbenefits. The characterization of VOC interactions with PM is one of the poorly resolved issues facing atmospheric science. Early indications are that sulfate and nitrate controls for PM reduction will have a new beneficial effect on both PM and ozone, even though some localized and/or temporary counterproductive impacts may occur.

•Historically PM_{10} problems were the result of a wide range of unmanaged sources. Present-day high PM_{10} concentrations are more often associated with meteorological conditions conducive to the local suspension of mineral material such as soil dust and road dust. (1)

Examples of Location Specific Sources

Sources in the City of Toronto

In the City of Toronto, the transportation sector, (automobiles, heavy-duty diesel trucks, and off-road diesel vehicles), is responsible for about 80 percent of the nitrogen oxides and 60 percent of the sulphur dioxide released. The transportation sector is also the greatest contributor of carbon monoxide (90 percent) and the biggest contributor of volatile organic compounds (VOCs at 37 percent). Wood burning fireplaces, with 8 percent of the carbon monoxide, 16 percent of the volatile organic compounds (VOCs) and 47 percent of the total particulates, are an important source of air pollution in Toronto. Solvents and paints (outside of industrial applications) were responsible

for about 35 percent of the VOCs emitted within Toronto in 1995. Electricity generation by coal-fired stations, many of them located outside of the City boundaries, is a major source of air pollution. The Lakeview Generating Station, located just west of Toronto in Mississauga, though operating at a very low capacity in 1995, was still emitting as much sulphur dioxide as all of the sources within the entire City of Toronto. In 1998, when Lakeview was used to generate more electricity, it emitted one and a half times as much sulphur dioxide as all sources in Toronto. During that same year, the Nanticoke Generating Station on Lake Erie emitted seven times more sulphur dioxide than did Toronto sources, and the Lambton Generating Station in Sarnia, 2.5 times more. A significant portion of air pollution in Toronto comes from beyond its boundaries, much of it from the United States. (3)

Sources in London,UK

Table 4 from the Mayor of London's Air Quality Strategy (2002) shows the percentage of emissions for six of the seven priority pollutants within Greater London, together with the national percentages for comparison. Road transport emissions dominate in London much more than nationally. This is due to a combination of the high traffic levels in London, and the small number of large industrial processes and power. Figure 3 gives further information on sources of NOx and PM_{10}, the pollutants of most concern in Greater London. Road traffic is the major source of NOx in London, accounting for approximately 60 per cent of emissions. A further 21 per cent in NOx are from residential and commercial gas use. Air travel from Heathrow Airport contributes both directly and indirectly to high levels of nitrogen dioxide in west London. While 70 per cent of PM_{10} emissions occurring in London are from road vehicles, this accounts for only one-third of measured PM_{10} concentrations. The remainder comes from the conversion of other pollutants into PM_{10}, from dust swept into the air, from construction activities, industrial processes, trains, ships, aircraft, off-road vehicles and from emissions from outside London, carried in by the wind. Sources such as industry, construction, aviation, rail and shipping account for the remainder of London emissions of NOx and PM_{10}. (7)

Issue 4: What is the estimated impact of existing policies in the future for cars, power plants etc.? *(Note: data from a recent CanTox study on Tier 2 benefits for Toronto will be included here as well as the HEI accountability monograph)*

Based upon current understanding of secondary particle formation, it is anticipated that the existing management strategies in North America focused on the reduction of sulfur dioxide will reduce $PM_{2.5}$ mass concentration, as will reductions in direct particle emissions, notably of black and organic carbon. The benefits of reducing nitrogen oxides or VOCs are uncertain. (1)

Sulfate particle loadings have responded to sulfur dioxide emission reductions in both eastern North America and California. It is anticipated that more responses to currently planned changes in emission rates will appear in the next five to ten years. This information will be needed to revise and optimize PM management approaches.(1)

The current understanding of atmospheric processes shows that $PM_{2.5}$ problems are related to ground-level ozone, acid rain, and climate issues and share many of the same sources. This recognition provides the impetus for integrated and optimized management strategies that accommodate different atmospheric responses for each pollutant.(1)

Ammonia reacts preferentially with sulfate, and, if sufficient NH_3 is available, it also combines with nitrate to form particulate nitrate. Declining sulfate levels in eastern North America therefore have the potential to cause increasing ammonium nitrate concentrations until particle nitrate formation is limited by the availability of NH_3. Existing observations have illustrated this phenomenon but are

insufficient to know how broadly it occurs over all seasons or in a variety of geographical regions. (1)

Example: Tier 2 Benefits

The Tier 2 Motor Vehicle Emissions Standards and Gasoline Sulfur Control Requirements ("Tier 2 standards") for passenger cars, light trucks, and larger passenger vehicles is designed to focus on reducing the emissions most responsible for the ozone and particulate matter (PM) impact from these vehicles -- nitrogen oxides (NOx) and non-methane organic gases (NMOG), consisting primarily of hydrocarbons (HC) and contributing to ambient volatile organic compounds (VOC). The program will also, for the first time, apply the same set of federal standards to all passenger cars, light trucks, and medium-duty passenger vehicles. The program ensures that essentially all vehicles designed for passenger use in the future will be clean vehicles (12). Full compliance with the gasoline sulfur limits should be achieved by 2006. EPA assessed the benefits of the rule for the year 2030, when full implementation is expected through turnover of the existing vehicle fleet. The annual health benefits are summarized in Table 5 below. The monetized values are also provided. As indicated in the table, mortality benefits dominate the overall estimates when the benefits are monetized.

EPA reports each numerical health benefit estimate in the form of a probability distribution and summarizes the distribution by reporting its mean and 5^{th} and 95^{th} percentiles. The mean of the distribution is 4,307 avoided deaths among persons 30 years of age and older. The 5^{th} and 95^{th} percentiles are 2,671 and 5,989 avoided deaths respectively (EPA, 1999). To estimate avoided mortality for the Tier 2 rule, EPA chose an estimated concentration-response function from the American Cancer Society (16) study. For a change in concentration from 9 to 33.5 $\mu g/m^3$, the result was an estimated relative risk of 1.17 with a 95% confidence interval of 1.09 to 1.26 (14). The random sampling error represented by this confidence interval is the only source of uncertainty in the agency's probability distribution for avoided mortality. EPA assesses all other uncertainties in a second part of each health benefit analyses. For the Tier 2 analysis, alternative calculations were performed for an alternative source of the estimated concentration-response function and for life years saved rather than avoided deaths as a measure of health benefits. Sensitivity analyses were conducted for thresholds and alternative lag structures. (14). An NRC review of the EPA Tier 2 health benefits assessment was critical of the manner in which the agency deals with the large uncertainties inherent in these analyses, including the reporting of absolute numbers of avoided death or adverse health outcomes without a context of population size or total numbers of outcomes. EPA correctly notes that incorporating only the uncertainty from random sampling error in concentration-repose function estimates into its primary health benefits analyses "omits important sources of uncertainty such as the contribution of air quality changes, baseline population incidences, projected populations exposed, transferability of the concentration-response function to diverse locations and uncertainty about premature mortality and would provide a misleading picture about the overall uncertainty in the estimates (14). The NRC report recommends that EPA begin to move the assessment of uncertainties from its ancillary analyses to its primary analyses and strive to present the results in ways that avoid conveying an unwarranted degree of certainty. (13)

Table 5. Annual US Health Benefits (Avoided Cases of Mortality and Morbidity and Monetized Value) for Tier 2 Regulations in 2030

Health Outcome	**Avoided Cases**[a]	**Monetized Benefit (1997$ in millions)**[b]
PM-Related Health Outcomes		
Premature mortality (adults, ages 30 and	4,300 (2,700-5,900)	23,380

over)		
Chronic bronchitis	2,300 (600-4,100)	730
Hospital admissions		
Respiratory causes	1,200 (400-2,100)	10
Cardiovascular causes	500 (100- 1,100)	10
Emergency room visits for asthma	900 (400-1,400)	<1
Acute bronchitis (children, ages 8-12)	7,900 (0-16,300)	<1
Lower respiratory symptoms (children, ages 7-14)	87,100 (39,900-131,100)	<5
Upper respiratory symptoms (children with asthma, ages 9-11)	86,500 (25,500-144,600)	<5
Shortness of breath (African Americans with asthma, ages 7-12)	17,400 (4,700-29,500)	<1
Work-loss days (adults, ages 18-65)	682,900 (597,800-771,800)	70
Minor restricted-activity days and acute respiratory symptoms	3,628,500 (3,034,100-4,177,200)	170
Ozone-related Health Outcomes		
Chronic asthma (adults males, ages 27 and over)	400 (100-800)	10
Hospital admissions		
Respiratory causes	1,000 (200-1,800)	10
Cardiovascular causes	300 (0-500)	<5
Emergency-room visits for asthma	400 (100-600)	<1
Minor restricted-activity days and acute respiratory symptoms	2,226,500 (1,014,400-3,414,800)	100
Decreased worker productivity (adult working population)	Not reported	140

[a] Mean value provided with 5th and 95th percentile values shown in parentheses rounded to the nearest 100
[b] Mean value of monetized value provided for reference.

Source: (11) Adapted from (14)

Issue 5: What are the advantages and disadvantages of alternative policy approaches (e.g. NAAQS, limit values, best available technologies, regulation of individual pollutants vs. air pollution mixtures etc.?). *(Note: this section will include material from the policy options background paper and findings from conference discussions)*

Conceptual models for nine North American regions show that a single, uniform approach to reducing $PM_{2.5}$ levels will not be effective for all areas of North America. For example, the high levels of $PM_{2.5}$ occurring in the Los Angeles Basin and California San Joaquin Valley are dominated by winter ammonium nitrate so that balanced reductions in NOx and VOCs appear appropriate. In contrast, large regions of the eastern United States and southeastern Canada have high $PM_{2.5}$ concentrations driven by sulfate and OC concentrations in summer, pointing to the need for reductions in SOx and OC.

$PM_{2.5}$ differs in its composition and its seasonal variation across the continent such that regional strategies targeting different precursors and seasons are needed. $PM_{2.5}$, like ozone, has both regional and local contributions. Strategies that address both regional and local $PM_{2.5}$ and its precursors are likely to be needed in most areas of North America. Coincident reductions of $PM_{2.5}$ precursors (i.e.,

SO_2, NO_x, VOC, and NH_3) should be beneficial in most parts of North America in achieving desired PM mass concentrations, but some of those reductions may lead to temporary and/or localized counterproductive impacts in some areas. The current air-quality management approaches focusing on reductions of emissions of SO_2, NOx and VOCs are anticipated to be effective first steps towards reducing $PM_{2.5}$ across North America, noting that in parts of California and some eastern urban areas VOC emissions could be important to nitrate formation. The local suppression of mineral material such as soil dust and road dust continue to be the most beneficial approach in reducing PM_{10}.

Location Specific Control Options

- During the winter periods of peak $PM_{2.5}$ concentrations in Los Angeles and the San Joaquin Valley, ammonium nitrate is the dominant component and is nitric-acid (HNO_3) limited. HNO_3 can be reduced via VOC and NOx emission reductions. The possibility of seasonal strategies that emphasize different sets of VOC and NOx controls for $PM_{2.5}$ mass in winter and ozone in summer require optimization with the assistance of chemical-transport and receptor models.

- Mexico City's PM problem is amenable to control of diesel vehicles to reduce primary OC and BC emissions. The potential benefit of SO_2 and NOx controls may be more effective than NH_3 controls in reducing secondary PM based on experience to date.

- Areas in the Canadian Southern Prairie, U.S. Northern Plains and Upper Midwest-Great Lakes region with $PM_{2.5}$ concentrations near applicable standards can limit further air-quality deterioration using a combination of local and regional controls for SO_2 and OC emissions.

- For the urban areas of the Windsor-Quebec Corridor and the northeastern and southeastern United States, regional control of SO_2 to reduce summer $PM_{2.5}$ concentrations and local control of SO_2 to reduce winter concentrations along with local control of OC emissions to reduce year round concentrations is believed to be an effective approach. For areas in these regions also concerned about wintertime PM levels, e.g., cities in southeastern Canada, strategies that involve NOx reductions may be effective.

- In some cases, addressing regional contributions to $PM_{2.5}$ is as important as addressing local contributions for reducing $PM_{2.5}$ concentrations. For instance, in the northeastern United States, average regional $PM_{2.5}$ concentrations can contribute 30 to 60 percent of the total levels seen in the large urban centers, particularly along the coast. In the southeastern United States, the regional $PM_{2.5}$ contribution is 10 to 40 percent. Even in the Canadian Southern Prairie and U.S. Northern Plains, levels of $PM_{2.5}$ found in upwind rural areas can contribute up to a third of peak levels in urban centers. (1).

London, UK

A summary of the policies and proposals being considered is presented in The Mayor of London's Air Quality Strategy (2002). Since road traffic is the main source of emissions of the main pollutants of concern in London, the primary focus of the Strategy is to reduce pollution from this source. Table 26 lists 30 policies and Table 27 summarizes 87 proposals and indicates timescales, organization(s) responsible, the scope of likely air quality benefits, likely impacts on equalities, health and sustainability, relevant links to other Mayoral strategies and other drivers for the proposals. (7)

Issue 6: What are the currently the most prominent research priorities to improve air quality management and is the science community targeting these priorities?

In 1998, the National Research Council Committee on Research Priorities for Airborne Particulate Matter released its first report which proposed a conceptual framework for a national program of PM research and identified 10 high priority research topics linked to scientific uncertainties relevant to policy setting (38). The research priorities are as follows:

Research Topic 1. Outdoor Measures Versus Actual Human Exposures

What are the quantitative relationships between concentrations of particulate matter and gaseous copollutants measured at stationary outdoor air-monitoring sites and the contributions of these concentrations to actual personal exposures, especially for subpopulations and individuals?.

Research Topic 2. Exposures of Susceptible Subpopulations to Toxic Particulate-Matter Components

What are the exposures to biologically important constituents and specific characteristics of particulate matter that cause responses in potentially susceptible subpopulations and the general population?.

Research Topic 3. Characterization of Emission Sources

What are the size distribution, chemical composition, and mass-emission rates of particulate matter emitted from the collection of primary-particle sources in the United States, and what are the emissions of reactive gases that lead to secondary particle formation through atmospheric chemical reactions?

Research Topic 4. Air-Quality Model Development and Testing

What are the linkages between emissions sources and ambient concentrations of the biologically important components of particulate matter?

Research Topic 5. Assessment of Hazardous Particulate Matter Components

What is the role of physicochemical characteristics of particulate matter in eliciting health effects?

Research Topic 6. Dosimetry: Deposition and Fate of Particles in the Respiratory Tract

What are the deposition patterns and fate of particles in the respiratory tract of individuals belonging to presumed susceptible subpopulations?

Research Topic 7. Combined Effects of Particulate Matter and Gaseous Co-Pollutants (Toxicological and Epidemiological Studies)

How can the effects of particulate matter be disentangled from the effects of other pollutants? How can the effects of long-term exposure to particulate matter and other pollutants be better understood?

Research Topic 8. Susceptible Subpopulations

What subpopulations are at increased risk of adverse health outcomes from particulate matter?

Research Topic 9. Mechanisms of Injury

What are the underlying mechanisms (local pulmonary and systemic) that can explain the epidemiological findings of mortality/morbidity associated with exposure to ambient particulate matter?.

Research Topic 10. Analysis and Measurement

To what extent does the choice of statistical methods in the analysis of data from epidemiological studies influence estimates of health risks form exposures to particulate matter? Can existing methods be improved? What is the effect of measurement error and misclassification on estimates of the association between air pollution and health?

The Committee will present the results of research to address the above questions in its forthcoming final report which is currently in draft form.

Delegates of the NERAM 2001 Colloquium on Health and Air Quality (39), including more than 100 air quality policy makers, scientists, and industry and business representatives, identified the following major issues for further research to guide air quality policy development.

- Development of population health indicators to characterize the public health burden of air pollution
- Individual exposure and outcome studies to elucidate relationships between air pollution and health by population sub-group and air pollutant
- Detailed assessment of the impact of short term air pollution exposure on acute health responses of sensitive subpopulations
- Development of methods to assess the independent effect of each pollutant in the atmospheric mixture as well as joint effects of pollutant interactions on health
- Development of comparative risk assessment methods to facilitate wise decisions on how best to allocate finite health protection resources
- Development and application of methods to better characterize and communicate uncertainty
- Research to evaluate the population health benefits associated with air quality policy initiatives including development of indicators of health benefit, health studies of susceptible sub-groups, predictive modeling based on data collected in epidemiological studies, and case study analyses of temporary interventions affecting major air pollution sources
- Development of economic methods to evaluate risk management interventions and assessment of the role of economic analyses in risk management decision making
- Identification of targeted interventions that offer the greatest benefit per unit cost of reduction
- Research to identify best practice for effective engagement of stakeholders in policy development and implementation

The NARSTO PM assessment (1) concluded with the research recommendations to address science gaps that will have the greatest impact for policy makers as they implement current mass-based PM standards. The recommendations fall into six broad themes:

- Improving the understanding of the carbonaceous fraction
- Performing long-term monitoring of PM, gaseous precursors and co-pollutants
- Performing further evaluation and development of chemical transport models
- Developing improved emission estimates (including chemical speciation)
- Making a commitment to the analysis of ambient data and fostering interactions between atmospheric, climate, and health science communities

- Developing more systematic approaches for integrating diverse types of knowledge to guide development of PM management practices and tracking progress toward protecting health.

This document identifies several issues and uncertainties in the interface between science and policy decisions. These issues and uncertainties will be discussed by delegates attending the AirNet/NERAM Colloquium on Strategies for Clean Air and Health. The conference will produce a statement identifying directions for science and policy to improve air quality and protect public health.

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Web Links for Further Information

AIRNET
http://airnet.iras.uu.nl/fr_left.html

The Clean Air For Europe (CAFÉ) programme
http://europa.eu.int/comm/environment/air/cafe/

Ontario Ministry of Environment Air Quality Page
http://www.ene.gov.on.ca/air.htm

UK Department of Environment, Food and Rural Affairs (DEFRA) Air Quality Page
http://www.defra.gov.uk/environment/airquality/index.htm

UK Department of Health Air Quality Unit
http://www.doh.gov.uk/airpollution/index.htm

NARSTO
http://www.cgenv.com/Narsto/

Greater Toronto Area Clean Air Council

http://www.toronto.ca/gtacac/index.htm

California Air Resources Board
http://www.arb.ca.gov/homepage.htm

USEPA
http://www.epa.gov/oar/oaqps/