Ontario

# A Compendium of Current Knowledge on Fine Particulate Matter in Ontario

Prepared by the
Ontario Ministry of the Environment
for the
Ontario Smog Plan Steering Committee

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March 1999
*(as released to the CRESTech/NERAM Expert Panel for review)*

PIBS 3798E

# PREFACE

This document has been prepared by Ministry of the Environment staff, and reviewed by the Inhalable and Respirable Particulate Matter Options Assessment Working Group (IP/RP OAWG). The purpose of this document is to compile available technical information as a resource for public consultation. It does not imply that there was consensus or endorsement of all aspects of the information by the IP/RP OAWG.

The members of the IP/RP OAWG are as follows:

| | |
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| | |
|---|---|
| AAQC | Ambient Air Quality Criterion |
| AES | Atmospheric Environment Service (of Environment Canada) |
| AIRS | Aerometric Information Retrieval System |
| ALA | American Lung Association |
| ALAPCO | Association of Local Air Pollution Control Officials |
| AQO | Air Quality Objective |
| ASL | Approvals Screening Level |
| BATNEC | Best available technology not entailing excessive cost |
| BPEO | Best practicable environmental option |
| CCME | Canadian Council of Ministers of the Environment |
| CEPA | Canadian Environmental Protection Act |
| COPD | Chronic Obstructive Pulmonary Disease |
| CWS | Canada-wide Standard |
| EBR | Environmental Bill of Rights |
| EPA | Environmental Protection Agency (also US EPA) |
| FACA | Federal Advisory Committee Act |
| FPAC | Federal/Provincial Advisory Committee |
| IMPROVE | Interagency Monitoring of Protected Visual Environments |
| LNB | Low $_{NOX}$ burner |
| MMAD | Mass median aerodynamic diameter |
| MOE | Ministry of the Environment (Ontario) |
| NAAQO | National Ambient Air Quality Objectives |
| NAPS | National Air Pollution Surveillance |
| NEIPTG | National Emission Inventory and Projections Task Group |
| NESCAUM | North East States for Coordinated Air Use Management |
| NRC | National Research Council |
| OFA | Over fire air |
| ORIS | Occurrence Report Information System |
| PM | Particulate matter |
| $PM_{10}$ | Particulate matter with a diameter of 10 microns (micrometres, µm) or less |
| $PM_{2.5}$ | Particulate matter with a diameter of 2.5 microns or less |
| POI | Point of Impingement |
| REVEAL | Regional Visibility Experimental Assessment in the Lower Fraser Valley |
| SIP | State Implementation Plan |
| SOA | Secondary organic aerosol |
| SSI | Size selective inlet |
| STAPPA | State and Territorial Air Pollution Program Administrators |
| TEOM | Tapered element oscillating microbalance |
| US EPA | United States Environmental Protection Agency |
| VOC | Volatile organic compound |
| WGAQOG | Working Group on Air Quality Objectives and Guidelines |

# I INTRODUCTION

## I.1 BACKGROUND

Airborne fine particulate matter (PM) is emerging as a significant environmental health issue. It has long been known that high concentrations of particles in the air, such as those experienced during the famous "killer" fog of London, England in December 1952, can impact severely on susceptible people such as the sick and the elderly, even causing or contributing to death. However, during the 1970s and 1980s, it was assumed that the lower concentrations of particulate matter recorded in North America and Western European cities, were not associated with any adverse effects on health. A large number of scientific studies (referenced in Section III.5) carried out more recently in the United States, Canada, Britain and Europe have provided a growing body of evidence linking relatively low concentrations of PM, within the range experienced regularly across Ontario and Canada, to adverse cardiorespiratory impacts, including increased hospitalization and increased premature mortality, in a broader spectrum of the population. These findings have prompted re-examination of total suspended particulate matter based standards/objectives, not only in Canada and Ontario, but also in the United States, Britain, the European Community, and the World Health Organization. The findings have also prompted governments to work with stakeholders to develop inhalable and respirable particulate matter reduction strategies. The challenge of responding to this concern is great, for PM is ubiquitous, and its sources diverse and intimately linked to the industrialization of our society.

Inhalable particulate matter ($PM_{10}$; IP) is the portion of the total air particulate matter 10 micrometres (µm or microns) or less in diameter. Most particles with diameters greater than about 10 µm will be caught in the nose and throat, never reaching the lungs. The larger size fraction of the IP (between 2.5 and 10 µm; the coarse fraction of $PM_{10}$) will be caught by cilia lining the walls of the bronchial tubes, which will move the particles up and out. Respirable particles ($PM_{2.5}$; RP; the fine fraction of $PM_{10}$), 2.5 µm or smaller can penetrate deeper into the lungs, into regions where there are no cilia, and hence no mechanism to remove contaminants from the body.

As with other atmospheric pollutants, particulate matter at a given location is the result of emission from a variety of sources. Once emitted the material is subject to transport and transformation in the atmosphere. The situation for particulate matter is complicated, compared with other pollutants, because fine particles can be directly emitted (primary particles) or can be formed in the atmosphere as a result of chemical reactions involving gaseous precursors (secondary particles).

It must be recognised that PM is just one of several pollutants found in the atmosphere, and diverging opinions spark a healthy debate. In particular, opinions differ on whether causality has been demonstrated between airborne PM and health effects, and also on the relative importance of PM and co-pollutants, such as $NO_x$, $SO_2$, CO, etc. However, as will be discussed in subsequent sections of this document, many of the copollutants are actually precursors to fine particulate matter formed in the atmosphere, and a strategy for PM must therefore also consider these copollutants anyway. Furthermore, the precautionary principle suggests that ample evidence exists that PM affects human health. The wisdom of proceeding in this way has been demonstrated in the experience of other issues, including stratospheric ozone depletion, climate change and cigarette smoking.

## I.2 RECENT DEVELOPMENTS ON THE IP/RP ISSUE

Responding to concern about harmful levels of atmospheric fine particulate matter, the Ontario Smog Plan has, as an interim measure, challenged all source sectors to reduce their emissions contributing to IP/RP by at least ten per cent by 2015. This interim measure is backed up by an interim ambient air quality criterion of 50 $\mu g/m^3$ for $PM_{10}$ expressed as a 24 hour average.

Setting the interim challenge in this way recognizes the fact that the science and technology relating to IP and RP are not as mature as they are for other pollutants, including ozone, and that further work is required before a comprehensive reduction strategy can be developed. This compendium document represents the next step in the development process, and is designed to provide a basis for discussion in the development of an IP/RP strategy for Ontario.

Currently, the Canada Wide Standard (CWS) process is under way, and will involve setting targets and developing jurisdictional/provincial implementation plans. The CWS is therefore another driver for the strategy which Ontario is developing (with the current document representing the initial stages of development).

## I.3 REPORT ORGANIZATION

This document is designed to provide detailed scientific and technical information, to provide a basis for discussion in developing a strategy for IP and RP in Ontario. Following the introduction, which is Part I, the structure of the remainder of the document is as follows:

Part II: Policy and Strategic Issues: Discusses the concerns of MOE Regional Offices as they relate to particulate matter, including both citizen complaints and abatement issues. These are related to the MOE approvals process, and the links with other air pollution issues are delineated. The approach to fine particulate matter in other jurisdictions is also discussed.

Part III: Science and Technology: Provides the scientific background to the discussion, presenting information on current knowledge of the emissions of primary particulate matter, as well as the precursors of secondary particles. The atmospheric chemistry converting the precursors to particulate matter is discussed, together with information on monitoring of IP and RP, and how the measurements can be used to apportion observed IP/RP concentrations in Ontario to the sources. The effects of IP/RP on human health are also described in this section, which includes description of technologies currently available to reduce the emission of primary particulate matter and the precursors of secondary particles. Technology is interpreted in its broadest sense, to include all applicable measures.

Part IV: An assessment has been made of the benefits and costs associated with reducing ambient levels, and therefore human health effects, of fine particulate matter in the Province.

Part V: Conclusion: contains a brief discussion of the knowledge that is brought together in this document, and also identifies some of the important knowledge gaps which remain.

Appendices: There are five appendices to this Compendium Document. The first two describe respectively the methods used in constructing emission inventories, and some of the definitions used to characterise the size of fine particles. The third contains the detailed tables on which the analysis of benefits and costs is based. The remaining two give the comments on the draft of this document provided by members of the IP/RP Options Assessment Working Group, and tabulate the way in which the comments were addressed in producing this version.

# II POLICY AND STRATEGIC ISSUES

## II.1 REGIONAL PERSPECTIVES

### II.1.1 Historical Background

Particulate matter has been measured in Ontario by the Ministry of the Environment for over 25 years, mostly by high volume samplers, dustfall jars, and soiling index tape samplers. These measurements show long standing particulate matter problems in areas such as Hamilton, Sault Ste Marie and Windsor where ambient air criteria for dustfall, suspended particulate matter and soiling index have been often exceeded and nuisance particle fallout is often evident. Overall, particulate matter levels have improved (declined) since the 1970s (Figure II.1.1) but these improvements have leveled off in recent years and in some cases such as Hamilton, have worsened (Figure II.1.2).

**FIGURE II.1.1**
SUSPENDED PARTICULATE (TSP) TREND
9 STATION AVERAGE-ONTARIO

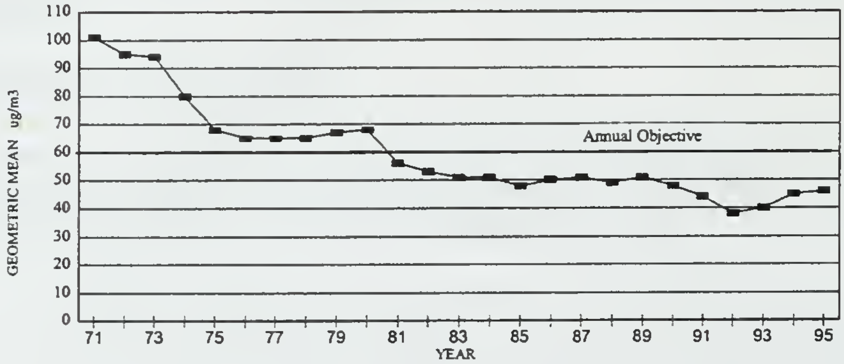
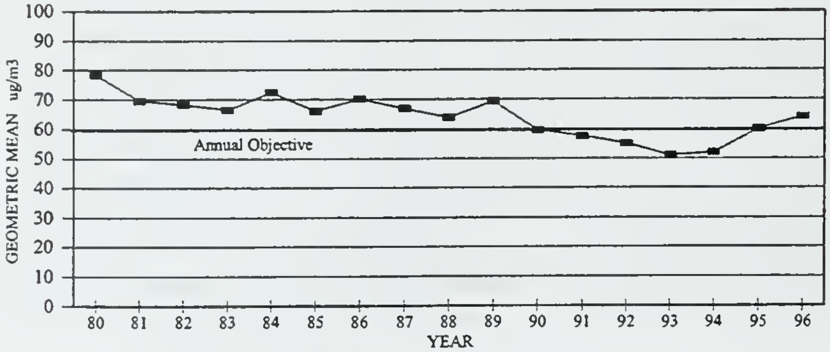


**FIGURE II.1.2**
SUSPENDED PARTICULATE (TSP) TREND*
7 STATION AVERAGE- HAMILTON



* Inhalable particulate constitutes approximately 40% of TSP

Ambient air quality criteria (AAQC)cannot be enforced but where exceedences occur, the measurements can be used as negotiation tools with industrial sources for emission reductions.

The soiling index tape sampling results were the only real time measurements of particulate matter over most of this time but the results are not well correlated with other particulate measuring devices. New real time inhalable and respirable particulate monitors offer an opportunity for improved monitoring capability, as indicated in Section III.2.3.1.

### II.1.2 Black Fallout

Black fallout is solid particles of air pollution, comprised largely of carbon, which occur in a variety of sizes. Visible particles are greater than 50 micrometres (or microns) in size.

Potential sources of black fallout include inefficient industrial combustion, the steel-making industry, vehicle emissions, poorly operated home and industrial heating systems, wood burning, and inadvertent product release such as carbon black or fugitive dust blowoff from coal fields or other storage piles.

Black fallout has become a major concern in parts of Hamilton, Sault Ste. Marie and Windsor in recent years, likely because it is highly visible. Complaints of black soot on lawn furniture, vehicles, and buildings are common.

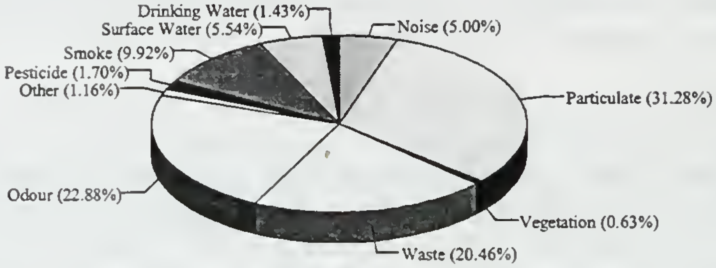
### II.1.3 Complaints

Dust fallout complaints are one of the leading issuesin the Occurrence Report Information System (ORIS) complaint records and much effort has been spent on controlling such problems. The first compliance priority of the ministry is to mitigate human health effects of pollution. Control of inhalable/respirable particulate matter is therefore a high priority because of the adverse health outcomes.

Using Hamilton-Wentworth as an example, in 1994, the Ministry of the Environment received 1,139 complaints there. Sixty-five percent (65%) of these complaints were related to overall air pollution such as dust, odours and smoke as shown in Figure II.1.3, and 41%(of the total) were related to particulate matter and smoke. Similar patterns of air pollution complaints are registered in other parts of the province, with 47% related to air pollution in northern Ontario, 51% in southeastern Ontario, and 64% in Toronto area. In the eastern and central parts of Ontario, the air pollution complaints are lower at 31%.

Figure II.1.3

HAMILTON COMPLAINTS DATA -1994
Received by Ministry of Environment

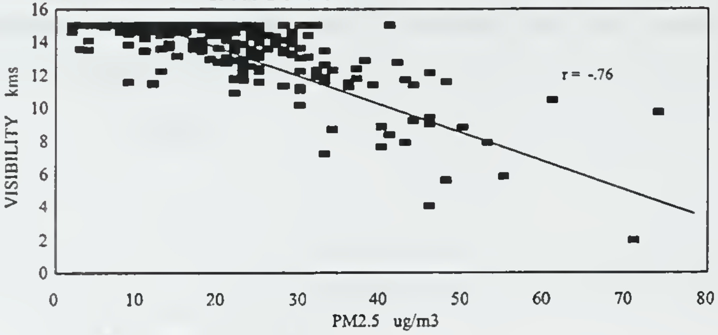


## II.1.4 Visibility

Visibility is often defined as the distance at which an object (for example, a mountain or tall building) can just be seen. Reduced visibility is often a regional phenomenon that is caused by the presence of pollutants such as fine particle sulphates and nitrates. People are also concerned over visible emissions from chimneys, even if there are no visibility degradations. For example, visible black smoke from stack emissions are often indicative of poor operation of an industrial process, which may lead to increased public awareness of poor air quality. However, these emissions by themselves may not necessarily contribute to a significant reduction in visibility across the local area or region.

Visibility reduction effects due to fine particulate matter as measured in Hamilton are shown graphically in Figure II.1.4 The visibility readings are recorded up to an upper range of 15 kilometres at this site, therefore, there are no readings above 15 kilometres.

FIGURE II.1.4
PM2.5 vs VISIBILITY*
29000-Downtown Hamilton 1994-95



* Visibility recorded to an upper limit of 15 kilometres

Reduced visibility can occur according to several different scenarios. First, temperature inversions can create pollution build-ups. Warmer air above a coolground layer acts as a cap, preventing the cool air from rising. Pollution accumulates near the top of this boundary layer, resulting in a reddish-brown layer of air pollution. The reddish browncolour is caused by nitrogen dioxide, a product of fuel burning by industry and vehicles. Particulate matter may contribute as well. The visibility of this layer depends on the time of day, the angle and direction of view, whether the sun is shining, and local geography.

Below this layer, the overall pollution load can also reduce visibility and provide condensation nuclei favourable for the production of dense fog from moist air, especially near lake settings. In Hamilton, the pollution particles near the ground act as condensation nuclei which can combine with moist air over Lake Ontario to produce fog (Hung and Liaw, 1981).

Long range transport of pollutants from the United States and other areas upwind of Ontario can create regional visibility reductions, particularly during the summer. During elevated ozone episodes on hot sunny days, ozone is often accompanied by fine particulate matter, possibly containing acid aerosols. These particles, comprised mostly of sulfates, nitrates, carbonates, and some organic compounds, are formed when gaseous pollutants react chemically in the atmosphere. Theyform a white haze which can restrict visibility (US EPA, 1977). Regional haze caused by human emissions can cover large areas and may be transported long distances.

### II.1.5 Primary Particulate Matter vs Secondary Particulate Matter

Local particulate matter emissions near industrial sources are mostly comprised of primary particulate matter, composed of carbonaceous materials, metals and soil constituents. Some secondary particles in the form of sulphates and nitrates do appear as well however. Elevated sulphate concentrations (in $PM_{10}$) above 20 $\mu g/m^3$ are usually seen in Southern Ontario during southerly wind conditions and the sources of these secondary particles are mostly from the US. However, elevated sulphate in the 10 to 20 $\mu g/m^3$ range are also seen during localized pollution episodes in Hamilton, Windsor and Sault Ste. Marie, albeit less frequently than the long range episodes, particularly in Hamilton and Windsor. Local industrial sources may be the source of this secondary particulate matter. In the Windsor case, Detroit steel mill sources andlocal Windsor sources cannot be readily distinguished from the long range US sources such as those from the Ohio Valley, but some data may indicate local contributions. Further evidence for this is given in Table III.2.2 and Figure III.2.9, which show highest sulphate levels in these three industrial cities.

### II.1.6 Ambient Monitoring

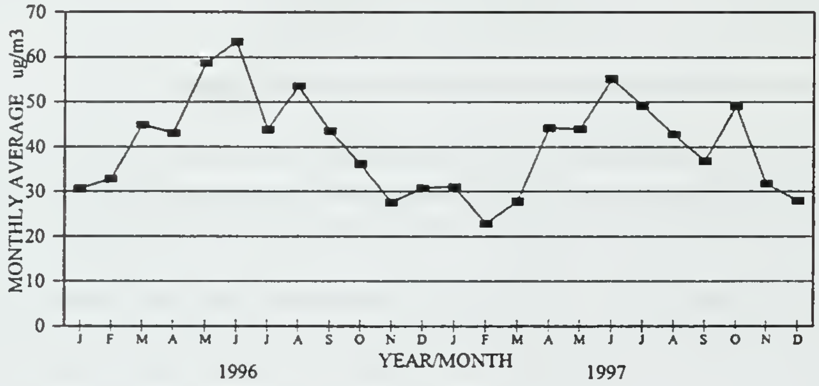
New real-time measuring devices for $PM_{10}$ near industrial sources have clearly shown industrial impacts in hourly measurements. $PM_{10}$ levels near industries in Hamilton, Sault Ste Marie, Windsor and Thorold have exceeded the new interim air quality criterion for $PM_{10}$ on as many as 100 calendar days annually at the worst locations (Table II.1).

Clearly, the nuisance soiling problem can be exacerbated by inhalable particulate matter. These dual concerns of health and nuisance are often expressed by complainants.

Examination of seasonal patterns indicates significant fugitive dust contributions to PM$_{10}$ near some industrial sources, with cold temperatures, frozen ground and snow cover reducing levels in the winter as shown in Figure II.1.5. Recent particulate matter emission estimates by Stelco and Dofasco in Hamilton suggest that 50-60% of their emissions arise from road dust from both paved and unpaved roadways within their properties. Seasonal patterns also exist at non-industrial sites with higher levels during the summer. This is likely dueto increased secondary particulate formation in summer months due to reactions of precursor gases with ozone and hydroxyl free radicals, discussed in Section III.3.

Despite the small particle sizes of inhalable particulate matter, possibly and thusa greater potential to remain airborne longer, a steep spatial gradient of concentration exists near most industrial sources.

**FIGURE II.1.5**
**SEASONAL PM10 TREND**
29531-HILLYARD, HAMILTON



## II.1.7 References

Hung R. J. and Liaw. G. S., January 1981, Advection Fog Formation in a Polluted Atmosphere, Journal of the Air Pollution Control Association, Volume 31, No.1, p 61.

US EPA.,1977. "Research Highlights 1977". US EPA Office of Research and Development. Report No. 600/9-77-044. Washington, D.C.,December

# TABLE II.1

## INHALABLE PARTICULATE MATTER ($PM_{10}$) BY 24 HOUR EVERY $6^{TH}$ DAY HIVOL SAMPLING ($\mu g/m^3$)

| YEAR | Number of Samples | Annual Average | Geometric Mean | Maximum 24 hour | # Samples >50ug/m$^3$ | Calculated Days>50ug/m$^3$ |
|---|---|---|---|---|---|---|
| *29300 Downtown Hamilton* | | | | | | |
| 1996 | 53 | 26 | 22 | 91 | 3 | 20 |
| 1995 | 53 | 24 | 20 | 88 | 3 | 20 |
| 1994 | 54 | 30 | 26 | 96 | 5 | 33 |
| 1993 | 57 | 27 | 22 | 97 | 6 | 38 |
| *29313 Near Hamilton Industry* | | | | | | |
| 1996 | 51 | 41 | 33 | 119 | 14 | 99 |
| 1995 | 53 | 37 | 33 | 88 | 13 | 88 |
| 1994 | 53 | 37 | 34 | 90 | 11 | 75 |
| 1993 | 50 | 33 | 26 | 104 | 10 | 72 |
| *27352 Near Thorold Industry* | | | | | | |
| 1996 | 43 | 31 | 28 | 74 | 6 | 50 |
| 1995 | 56 | 41 | 33 | 171 | 20 | 129 |
| 1994 | 52 | 34 | 31 | 79 | 8 | 55 |
| 1993 | 34 | 38 | 27 | 94 | 3 | 32 |
| *12513 Near Windsor Industry* | | | | | | |
| 1996 | 51 | 30 | 27 | 80 | 6 | 42 |
| 1995 | 56 | 33 | 28 | 86 | 11 | 71 |
| 1994 | 47 | 37 | 32 | 95 | 13 | 100 |
| 1993 | 49 | 35 | 30 | 90 | 9 | 66 |
| *71342 Near Sault Ste.Marie Industry* | | | | | | |
| 1996 | 52 | 42 | 32 | 164 | 17 | 118 |
| 1995 | 60 | 38 | 29 | 146 | 18 | 108 |
| 1994 | 49 | 42 | 36 | 95 | 15 | 110 |
| 1993 | 58 | 30 | 24 | 92 | 6 | 37 |

## BY CONTINUOUS HOURLY SAMPLING

| YEAR | Annual Average | Maximum 1 hour | Maximum 24 hour | Days>50ug/m$^3$ |
|---|---|---|---|---|
| *29300 Downtown Hamilton* | | | | |
| 1996 | 27 | 213 | 84 | 40 |
| 1995 | 29 | 554 | 127 | 27 |
| 1994 | 27 | 684 | 157 | 30 |
| *29531 Near Hamilton Industry* | | | | |
| 1996 | 42 | 562 | 148 | 105 |

## II.2 APPROVALS ISSUES AND INHALABLE AND RESPIRABLE PARTICULATE MATTER

### II.2.1 Introduction

There are a number of important approvals issues to consider when dealing with emissions of $PM_{2.5}$ and $PM_{10}$. With the exception of very old facilities, existing sources are required to be covered by valid certificates of approval. Construction of any new sources or modifications to existing sources are not to proceed until the appropriate certificates of approval have been obtained. The approval process ensures that environmental issues are considered during the planning stage, so that facilities that are constructed or modified will include the appropriate pollution controls to minimize any potential environmental impacts. Thus the approval process can benefit both the industry and the public, since the industry will be less likely to incur additional after-construction modifications to alleviate environmental problems and the local residents are less likely to experience adverse effects. The approval process also provides the opportunity to set enforceable requirements on the design, operation and maintenance of the facility.

### II.2.2 Requirement for a Certificate of Approval

Section 9 of the Environmental Protection Act (Act) prohibits construction, alteration, extension or replacement of things that may discharge one or more contaminants into any part of the natural environment, other than water, unless a certificate of approval has been obtained and complied with. The same requirement for a certificate of approval exists with respect to alteration of process or rate of production if a contaminant may be discharged into any part of the natural environment, other than water, or if the rate or manner of discharge of a contaminant may be altered.

Contaminant is defined in the Act to mean any solid, liquid, gas, odour, heat, sound, vibration, radiation or combination of any of them resulting directly or indirectly from human activities that may cause an adverse effect.

Subsection 9.(3) of the Act outlines a number of specific exceptions from the approval requirement. It is noted that subsection 9. (3)(d) of the Act also provides a general exemption for any source that belongs to a class that is exempted from the approval requirement by regulations enacted under the Act. The current regulations that specify exempted classes include Regulation 346 (section 3.) and Regulation 77/92 (under review). It is noted that Bill 57 which was promulgated in 1997 provides additional regulation making powers so that the Ministry can now develop regulations that set out minimum requirements for specific activities that have predictable, controllable and well-understood impacts on the environment. Proposed concepts for Standardized Approval Regulations (SARs) and Approval Exemption Regulations (AERs) have been posted in the Environmental Registry for public comment and the formal commenting period ended on April 17, 1998. In the future, if SARs are promulgated, proponents of equipment or activities covered by a SAR will be required to comply with the requirements of the respective SAR and will not be required apply for an individual Certificate of Approval.

### II.2.3 Review of an Application

Once an application for a certificate of approval is received for construction of a new source or modification of an existing source, staff of the Approvals Branch will consider all Ministry requirements, including the Act, regulations enacted under the Act, Environmental Bill of Rights (EBR) as well as all applicable policies and guidelines in order to determine whether or not the proposal is "approvable". Staff of the Approvals Branch will not recommend issuance of a certificate of approval unless the proposal complies with all applicable regulations as well as Ministry's policies and guidelines.

The requirements under various regulations are not, however, set out as conditions of approval because regulations are enforceable without the existence of a certificate of approval. On the other hand, requirements of the various Ministry policies and guidelines are imposed on applicants through conditions of approval. Therefore, if the Ministry develops new policy requirements for $PM_{2.5}/PM_{10}$, these requirements will be considered during the approval process and appropriate conditions may be placed on certificates of approval. All conditions of approval are enforceable unless they have been successfully appealed.

The following outlines the most relevant regulations, policies and guidelines of concern with respect to the $PM_{2.5}/PM_{10}$ issue either because they havea direct impact on emissions of particulate matter or because they place limitations that affect discharge of $PM_{2.5}/PM_{10}$ precursors, such as sulphur dioxide and oxides of nitrogen.

### II.2.4 Regulations, Policies and Guidelines

#### *II.2.4.1 Regulation 338*

Regulation 338 (under review) prohibits anyperson from using in a boiler, to which the regulation applies (see box below), fuel oil or coal that has a sulphur content (average concentration of sulphur in fuel in any ninety day period) in excess of 1 percent. Fuel with a higher sulphur content may only be used if an approval has been obtained for methods or devices that reduce the emissions to the same level as what they would be if the fuel sulphur content was not more than 1 percent.

This Regulation applies to every boiler that uses fuel oil or coal as fuel and

- was first put into operation after 1986 when the Regulation came into force;
- undergoes physical modification so that the ability of the boiler to use fuel is changed;
- is put into use after a period of more than twelve months of disuse;
- an increase occurs in the sulphur content of the fuel used therein; or
- that also uses purchased gas as a fuel where the gas purchase arrangements are modified after this Regulation came into force so that increased permissible interruptions in the gas supply or any other modifications increase the potential maximum utilization of fuel oil or coal as fuel for the boiler.

Some exceptions apply, as set out in the Regulation

#### *II.2.4.2 Regulation 361*

Regulation 361 (under review) sets out maximum sulphur contents for various grades of fuel oils as well as bituminous coal used or sold within the Municipality of Metropolitan Toronto. Certificates of Approval will not be issued for combustion equipment proposed to be located in the above noted geographic area, unless the proposed fuel complies with this regulation.

#### *II.2.4.3 Acid Rain Regulations*

Regulations 660/85, 661/85, 355, 663/85 (under review for consolidation) set emission limits for sulphur dioxides from Inco's Sudbury Smelter Complex, Falconbridge's Smelter Complex in Sudbury, Ontario Hydro's fossil fuel fired generating stations (sulphur dioxide and nitrogen oxide emissions), Algoma Steel's Sinter Operation in Wawa.

#### *II.2.4.4 Regulation 346*

Regulation 346 under the Act is the general air pollution regulation, which, among other things, sets out maximum allowable half-hour average concentrations for a number of pollutants including suspended particulate matter, sulphur dioxide, nitrogen oxides, ammonia and some volatile organic chemicals (VOCs) that are important from the point of view of the $PM_{2.5}/PM_{10}$ issue. The limits in Regulation 346 are generally referred to as "regulatory limits" or "standards". In addition to the regulatory limits, the Ministry has set, and may set in the future, maximum half-hour average guidelines for contaminants other than the ones listed in Regulation 346. These guidelines have previously been referred to as "interim standards" (IS) or Approvals Screening Levels (ASL). The Ministry has used both of ISs and ASLs during the approval process. In the future ISs and ASLs will be referred to as guidelines.

In order to verify compliance with standards, ISs and ASLs, total emissions of each contaminant from a facility are usually considered. Emission rates for each contaminant from a source can be estimated for approval purposes using a variety of methods, such as mass balance calculations, emission factors available from other jurisdictions, source testing data for a similar source, manufacturer's guarantees for control equipment etc. Estimated emission rates are then used in dispersion modelling which will predict contaminant concentrations at a point in the natural environment, referred to as the Point of Impingement (POI). Approval process normally considers worst case emissions and half-hour average POI concentrations, since all standards are maximum allowable half-hour average concentrations.

In cases where no standard, interim standard or ASL is available, staff of the Approvals Branch will use available information and judgement in the review of the application to determine if an approval should be granted. Considerations will include the magnitude of the predicted POI concentration, duration and frequency of discharge, literature data on the contaminant and land use practices. If staff of the Approvals Branch are not sure whether or not there is a potential for an adverse effect with respect to a particular contaminant or a combination of several contaminants, they will forward a request for a site specific evaluation to the Standards Development Branch of the Ministry with respect to the potential for environmental impact that may result from discharge of the contaminants.

### *II.2.4.5 Combustion Turbines*

Ministry Guideline A-5 "Atmospheric Emissions from Stationary Combustion Turbines" together with "Guideline for Emission Limits For Stationary Combustion Turbines, March 1994" place limitations on discharge of nitrogen oxides, sulphur dioxide and carbon monoxide. The requirements of the guideline can be placed as conditions of approval.

This guideline applies to all new and modified combustion turbines as defined in the Guideline; except standby combustion turbines, or combustion turbines used for emergency, research, development, field demonstration or testing purposes, temporary or small (<3 MW) combustion turbines.

### *II.2.4.6 Wood Fired Combustors*

"Interim Design and Review Guide for Wood Fired Combustors, August 1990" (under review) sets out combustion and emission control requirements, including a maximum discharge rate for suspended particulate matter, from wood fired devices. Requirements of the Guide can be placed as conditions of approval.

### *II.2.4.7 Municipal Waste Incinerators*

Guideline A-7 "Combustion and Air Pollution Control Requirements for New Municipal Waste Incinerators" sets out stack concentration limits for particulate matter, hydrochloric acid, sulphur dioxide, nitrogen oxides and organic matter, which canall have an impact on the $PM_{2.5}/PM_{10}$ issue. Requirements of the Guideline can be placed as conditions of approval.

#### *II.2.4.8 Cremators*

Guideline A-9 "Combustion and Air Pollution Control Requirements for Crematoria" (under review) sets out requirements for cremators in a similar way as Guideline A-7 does for Municipal Waste Incinerators. Requirements of the Guideline can be placed as conditions of approval.

#### *II.2.4.9 Other Opportunities to Address Inhalable and Respirable Particulate Matter*

While the approval process generally relies on established regulatory requirements and formal Ministry policies and guidelines, there are also opportunities to negotiate emission reductions beyond regulatory requirements. For instance, if a new facility or an expansion is proposed at a location where the existing airshed is already burdened, it would be appropriate to impose stringent emission limitations on the new or expanded facility even if compliance with the bare regulatory requirements can be established without the extra measures. In general, emission reductions are always encouraged during the approval process.

### II.2.5 Public Involvement

Staff of the Ministry have always considered any input that the general public may have provided with respect to an application for a certificate of approval. The EBR was promulgated in 1994 in order to formalize the role of the public and to allow any interested party the opportunity to review all non-confidential documentation submitted with an application for a certificate of approval and to provide written comments within a given time period for consideration before an approval is issued. Staff of the Ministry are responsible for ensuring that all provisions of the EBR are complied with, including posting of the application in the Environmental Registry, consideration of all written comments and posting of the decision complete with impact of public comments, if any.

### II.2.6 Conditions on Certificates of Approval

Once the detailed technical review has been completed and any EBR comments considered a certificate of approval can be issued with conditions that relate to operation, maintenance and performance among other things. Conditions of approval do not usually specify which of the standards were considered during the review of the application for a certificate of approval, instead the onus is on the discharger to ensure that the facility complies with all regulatory requirements regardless of whether or not approval has been applied for and obtained. On the other hand, interim standards, ASLs and any policy/ guideline requirements can be placed as conditions of approval in order to make them enforceable, provided there are sufficient reasons to include such conditions in a given situation.

It is noted that recommendations set out in Codes of Practice that may have been developed with or by industry can also be placed as conditions of approval either selectively or in their entirety.

### II.2.7 Appeal of Certificates of Approval

The Act allows the person to whom a certificate of approval has been issued to appeal the terms and conditions of the certificate as specified in the Act. In addition, if the proposal for a certificate of approval was posted under s. 22 of the EBR for public review, a third party can seek leave to appeal the certificate.

### II.2.8 Environmental Compliance

The person to whom a certificate of approval is issued has the responsibility to ensure that the installed equipment is the kind of equipment for which the approval was granted and that the approved and installed equipment is operated in compliance with all terms and conditions of the certificate of approval at all times. In addition, any person carrying out a business that may have an environmental impact has the responsibility to be aware of all requirements under the environmental legislation, including the general prohibition for causing an adverse effect, and to comply with all applicable provisions of that legislation. A person carrying out a business will have to be in position to prove due diligence at all times and must not wait for staff of the Ministry to notify him or her of any potential environmental issues, regardless of whether or not the person is required to obtain and has obtained a certificate of approval.

Regardless of the above, staff of the Ministry's District Offices may carry out post-installation inspections to verify whether or not the facility/equipment is installed and operated in compliance with the Act, regulations and the certificate of approval. In some cases staff of the Ministry may select certain facilities for routine inspections. In most cases post-installation inspections are, however, carried out as part of an abatement program or when there is concern about a particular process or facility.

More information on the approval process is provided in a "Guide for Applying (Air)", Approvals Branch, November 1994 and "General Information, Certificates of Approval (Air)", Approvals Branch, August 1992. Procedures outlined above as well as in the Approvals Branch documents are subject to change as new regulations may be passed.

# II.3 LINKAGE OF THE INHALABLE AND RESPIRABLE PARTICULATE MATTER ISSUE TO OTHER AIR QUALITY ISSUES AND INITIATIVES

## II.3.1 Introduction

Inhalable and respirable particulate matter loadings present a difficult air management challenge, because of the wide range of processes which emit or give rise to airborne fine particles (see also Section III.3). However, some knowledge and capability exists already, because these complexities also constitute links between particulate matter and other air issues. For example, a substantial portion of the secondary particulate matter formed in the atmosphere results from atmospheric transformations which produce sulphuric and nitric acids. Thus there is a very direct link between these particles and the problem of acid rain, and control of one will assist in ameliorating the other. Much of the chemistry of particle formation is also common to the chemistry of ozone as formed in the troposphere, thus this link is also well established. However, it must be remembered that the VOC most heavily involved in ozone production tend to be of lower molecular weight (having 6 or fewer carbon atoms), while organic aerosols are generally formed from the heavier VOC. Nevertheless, the chemistry is very similar, and a number of the emission sources are common.

Links also exist between secondary aerosols (and acid rain and ozone) on the one hand and climate change on the other. This is because the aerosol precursors ($NO_x$, and to some extent VOC) are emitted as a result of combustion processes, which also lead to emission of carbon dioxide, which is the major anthropogenic greenhouse gas.

It is also possible to link these air quality problems with a number of airborne toxic pollutants, since many sources of $NO_x$ and VOC are also emitters of metals and other toxic chemicals (e.g., smelting processes, including coking, and diesel vehicles).

Although the main thrust of current concerns regarding atmospheric fine particulate matter relate to impacts on human health, sight must not be lost of aesthetic concerns. These include both soiling and degradation of visibility. Soiling generally underlies many of the citizen complaints received by regional offices. It is important to remember also that visible pollution is one of the few forms of pollution which can be directly perceived by the general public, and therefore receives a great deal of public attention.

Visibility degradation is discussed in more detail in Section II.1. It is most often a concern in areas with natural vistas; however, loss of tourist income can potentially occur also in urban areas. For example, visits to the CN Tower are considerably reduced during periods of poor visibility.

Thus, it can be stated with considerable justification that the issue of inhalable and respirable particulate matter encompasses or includes most, if not all, of the other main air quality issues that face us at present. Abatement measures designed to ameliorate the particulate matter problem will also assist materially with addressing the problems of acid rain and ground-level ozone. If introduction of energy efficiency measures is included as an abatement measure, benefits will also be realized with respect to climate change.

The following table illustrates these relationships:

**Table II.3.1: Links between environmental issues**

| Primary Pollutant | Environmental Issue | | | | |
|---|---|---|---|---|---|
| | Inhalable/ Respirable Particulate Matter | Ground-Level Ozone | Acid Precipitation | Climate Change | Stratospheric Ozone Layer Depletion |
| Nitrogen Oxides | X | X | X | x[1] | |
| Sulphur Dioxide | X | | X | | |
| Inhalable/ Respirable Particulate Matter | X | | | x | |
| Volatile Organics | X | X | | x[2] | x[2] |
| Carbon Dioxide | | | | X | |
| Chlorofluoro-carbons | | | | x | X |

| | |
|---|---|
| X | significant contributor in Ontario airshed |
| x | less significant contributor in Ontario airshed |
| x[1] | Nitrous oxide ($N_2O$) only |
| x[2] | Only certain VOC are active in climate change and stratospheric ozone depletion. |

However, situations do exist where controlling one pollutant may result in increased emission of another. An example is the injection of ammonia in the catalytic reduction of $NO_x$, where the $NO_x$ emissions are indeed reduced, but at the expense of increasing the emissions of ammonia. In other words, it is important that each case be assessed on its own merits. This caution should, in fact, be generalised to include all pollution control commitments. For example, care must be taken to ensure that control measures adopted for PM do not lead to increased emission of pollutants responsible for climate change.

### II.3.2 Links to Current and Proposed Measures

A successful air management strategy for ambient particulate matter loadings will have to take into consideration both primary and secondary particulate matter. It will propose new measures to supplement current regulatory requirements.

#### *II.3.2.1 Application of Existing Regulations*

Under Ontario Regulation 346, sources are required to limit their emissions of suspended particulate matter, such that the concentration mathematically predicted at a point-of-impingement does not exceed 100 $\mu g/m^3$ in any half hour period. Note that this standard is for total suspended particulate matter, which includes all particles less than 44 µm in diameter. It is noted that the point of impingement standard for total suspended particulate matter is not scaled up from the 24 hour Ambient Air Quality Criterion of 120 $\mu g/m^3$ (e.g., by using the usual factor of three) as other air quality criteria are to create the half hour point of impingement, because it recognizes the normal presence of background particulate levels in urban areas.

#### *II.3.2.2 Fine Particulate Matter Reductions as Collateral Benefit of Other Recent Program Initiatives*

As was noted in the introduction to this section, the IP/RP issue is strongly linked to a number of other air pollution issues. It therefore follows that measures introduced, or proposed, to ameliorate those problems can also produce benefits for IP/RP.

<u>Ontario Smog Plan</u>

Since June 1996, when the Smog Plan process was first launched, a partnership of industry, environmental and health members (Smog Plan Steering Committee) has been developing an Ontario Smog Plan to reduce $NO_x$ and VOC emissions. In addition, 33 Sector/Issue Work Groups were formed to develop sector specific emission reduction action plans. One of these Work Groups deals specifically with the issue of inhalable/respirable particulate matter.

By June 1997, the Smog Plan Steering Committee identified voluntary reductions of about 200 kilotonnes each of $NO_x$ and VOCs from various emitters. These values represent approximately a 30% reduction of 1990 $NO_x$ emissions and a 20% reduction of VOC emissions.

"Ontario's Smog Plan: A Partnership for Collective Action" summarizes the actions and progress of the partnership towards reducing emissions that lead to smog. The Plan, which was released in January 1998, contains Ontario's Smog Accord, which outlines the challenges, principles and intent of the partnership. Forty-four organizations have signed the Accord signifying their commitment to the process and to reductions in emissions that contribute to smog. Four other organizations have provided Letters of Cooperation or Partnership.

The Accord sets an air quality target to reduce the number of exceedance hours of the 80 parts per billion ozone ambient air quality criterion by 75% by the year 2015. A 45% reduction (from 1990 levels) in the total $NO_x$ and VOCs emitted is needed to achieve this target. Participants also intend to reduce particulate matter emissions by developing a better understanding of the nature of the particles, sources and reduction measures. As is described in Section III.3, these reductions will assist in reducing secondary particulate matter formation in the atmosphere.

Key areas of focus for the Smog Plan over the next year include:

- implementation of emission reduction plans through memoranda of understanding, agreements or regulatory measures
- completion of the IP/RP strategy
- development of public acceptance and transportation demand management strategies
- development of a performance evaluation, monitoring, reporting and verification process
- development of alternative approaches to implement the emission reduction plans

### Drive Clean

Drive Clean was announced in August 1997. It is an inspection and maintenance program designed to ensure that Ontario motor vehicles meet current (and future) emission standards, thereby reducing emissions of those in-use vehicles which are not presently in compliance. Drive Clean applies to both light and heavy duty vehicles, and to $NO_x$, VOC, CO and primary particle emissions. The program will be introduced in phases, starting with the Greater Toronto and Hamilton-Wentworth areas in 1998/99, extending to 13 designated south-central and southwest Ontario urban areas by 2000, and to the commuter zones around these urban areas by 2002.

### Sulphur in Gasoline and Diesel

In July 1996, a CCME Task Group on Cleaner Vehicles & Fuels established the multistakeholder Sulphur in Gasoline and Diesel Process to set a lower level of sulphur in gasoline, to reduce inhalable particulate matter in ambient air and to provide fuels that are compatible with low emission vehicle technologies and that are cost effective.

The new regulations, gazetted in October 1998, call for a two-stage phase-in of low sulphur gasoline: starting January 1, 2002, the level of sulphur in gasoline will be limited to an average value of 150 ppm, with a never-to-be-exceeded maximum of 200 ppm; starting January 1, 2005, the level of sulphur in gasoline will be limited to an average value of 30 ppm, with a never-to-be-exceeded maximum of 80 ppm.

Combustion of sulphur in gasoline causes tailpipe emissions of $SO_2$, which are converted in the atmosphere into sulphuric acid and sulphates, which are components of fine particulate matter ($PM_{2.5}$). Sulphur in gasoline also contaminates vehicle emission control systems, leading to increased emissions of carbon monoxide (CO), nitrogen oxides ($NO_x$), and hydrocarbons (VOC) and thus to the formation of $PM_{2.5}$ and ground level ozone from these pollutants.

### Canada-Wide Acid Rain Strategy for Post 2000

Energy and Environment Ministers, at their October 19 meeting in Halifax, signed the *Canada-wide Acid Rain Strategy for Post 2000,* as part of national efforts to reduce harmful air emissions. The Strategy is an agreement with the long term goal of meeting the environmental threshold of critical loads for acid deposition across Canada. Among other steps towards the goal, two key items are:

1) the federal government, with support from provinces and territories, will aggressively pursue further $SO_2$ emission reduction commitments from the U.S.
2) Ontario and other eastern provinces will establish targets and schedules for further $SO_2$ emission reductions.

### Canada-US Air Quality Agreement (1990)

This agreement describes reductions in emissions of $SO_2$ and $NO_x$ which will be achieved in stages to 2010. The total $SO_2$ reduction by 2010 (i.e., Canada plus US) will be 40% relative to 1980 emissions, and 22% relative to 1994 emissions. As is discussed in Section III.3, these reductions will lead to reductions in ambient concentrations of sulphate in the particle phase. The planned reductions in $NO_x$ emissions, although smaller, will also provide benefits in terms of IP/RP concentrations.

### US $NO_x$ emission reductions

Following detailed analysis carried out by OTAG (Ozone Transport Assessment Group) for the northeastern US, new SIP (State Implementation Plan) calls in the United States will require reductions in $NO_x$ emissions in the region, ranging up to about 35%. Although primarily aimed at controlling ground level ozone, these reductions will again provide a benefit in terms of IP/RP reductions in downwind areas, including Ontario.

# II.4 STANDARDS AND IMPLEMENTATION ISSUES IN OTHER JURISDICTIONS

This section summarizes how particulate matter (i.e., $PM_{10}$ and $PM_{2.5}$) standard/objective and implementation strategy issues have been handled in other jurisdictions. Please see Table II.4.1 for a summary.

## II.4.1 Status of $PM_{10}$ /$PM_{2.5}$ Standards/Criteria/Objectives in the Canada-wide Context

The establishment of Canadian National Ambient Air Quality Objectives (AAQOs) and Canada-Wide Standards (CWS) for $PM_{10}$ and $PM_{2.5}$ is in transition. The status is described in detail in Section III.5.3, Health Effects.

### *II.4.1.1 Other Canadian Provinces*

British Columbia

A number of initiatives have been introduced over the past five years as part of the province's clean air strategy. These measures include: controls on open burning for land clearing; a requirement that new stoves in B.C. be designed and certified to meet low emission levels; the mandatory phase out since 1995 of 42 wood residue burners located in populated areas; and new vehicle emission and gasoline standards to lower harmful tailpipe pollutants.

The province's Environment Ministry (BC Environment) has also assisted many municipalities in developing local bylaws to restrict backyard burning and curb the use of wood stoves during inversion periods.

BC Environment operates 75 particle monitors throughout BC that measure $PM_{10}$ averaged over a 24 hour period. The province has also prepared an air quality report on fine particulate ($PM_{10}$) levels for the years 1990-95. The report summarizes for each community the daily $PM_{10}$ data, provides annual and monthly mean and maximum levels, and the frequency of exceedence of the BC Environment. air quality objective. In addition, the report also evaluates air quality through the use of the total number of $PM_{10}$ increments per year. From each day's data, increments of 10 μg/m$^3$ above 20 μg/m$^3$ (i.e., above 30 μg/m$^3$ is one increment; above 40 μg/m$^3$ is two increments and so on), which is below the provincial air quality objective, is summed for the year. These increments, based on the recent epidemiological studies, are associated with a linear increase in health effects. Hence, the number of increments provides an estimate of the increased risk that an individual may experience due to ambient $PM_{10}$ levels in their community. The greater the number of increments the greater the risk.

## II.4.2 Particulate Matter Implementation Strategies in Other Jurisdictions

### *II.4.2.1 United States*

Prior to the 1990 Amendments to the Clean Air Act, US EPA promulgated national primary and secondary ambient air quality standards for six "criteria" pollutants: particulate matter, nitrogen oxides, lead, ozone and carbon monoxide. "Primary"air quality standards were those which, in the judgement of the Administrator, if attained and maintained, provided an adequate margin of safety to protect public health. States were required to submit "State Implementation Plans" (SIPs) through which they are to impose control measures which will allow them to meet established ambient air quality standards. As part of the SIP, states must submit lists of non-attainment areas, i.e. those areas that would not meet primary or secondary ambient air quality standards by deadlines set forth in the Act.

In 1990, Congress changed the Clean Air Act requirements for non-attainment areas. The amendments regulate areas not meeting the ozone standard, and contain new provisions directed at attaining other air quality standards as well. The changes focused on ozone, but particulate matter was not considered a problem at the time.

Scientific studies undertaken in the early 1990's pointed out the adverse public health effects associated with exposure to particle levels well below the existing standard. Pressed by legal action initiated by the American Lung Association, US EPA finalized ozone and particulate matter standards by mid June 1997. Similar health effects associated both with exposure to ozone and to particulate matter prompted US EPA to promulgate both standards simultaneously.

US EPA's work was undertaken in association with the Ozone Transport Assessment Group (OTAG) - a partnership between US EPA, the Environmental Council of the States (ECOS), state and federal government officials, industry organizations, and environmental groups. The goal of this partnership was to develop a thoughtful assessment and a consensus agreement for reducing ozone and its precursors in the area east of the Mississippi River.

This work resulted in US EPA's proposed air quality standard for ozone at 80 parts per billion over an 8-hour average. The previous standard was 120 parts per billion over one hour. Any county exceeding the standard more than three times a year will be declared in "non-attainment". US EPA states that the new standard is more accurate because it will discount temporary ozone spikes.

US EPA is requiring control of $PM_{2.5}$. This is a new standard in addition to the existing and proposed control requirements on $PM_{10}$. US EPA claims that 150 counties will not meet the additional particulate matter standard. Only 41 counties meet the current $PM_{10}$ standards.

US EPA has estimated compliance costs at $8.6 billion a year for particulate matter and $1.1 billion a year for ozone.

<u>Presidential Memo to Administrator Browner</u>

After the new $PM_{10}$ and $PM_{2.5}$ standards were announced in July, 1997, (as listed in Table II.4.1) by US EPA, President Clinton sent a memorandum to US EPA Administrator C. Browner which outlined the following views on the implementation plan for the proposed new standards.

It advised the US EPA to develop a common sense, flexible and cost-effective implementation strategy for the new ozone and particulate matter standards. The policy should ensure strong science for implementation, allow time to establish the program, provide a reasonable timetable for compliance, and give credit for reductions under 1990 Clean Air Act Amendments. The following principles were also to be taken into consideration:

1. Maintain the progress currently being madetoward cleaner air, and respect the agreements already made by communities and businesses to clean up the air;
2. Reward state and local governments and businesses that take early action to reduce air pollution levels;
3. Respond to the fact that pollution travels hundreds of miles and crosses many state boundaries;
4. Work with the states to develop control programs that employ regulatory flexibility to reduce economic impacts on large and small businesses to the greatest possible degree consistent with public health protection;
5. Minimize planning and regulatory burdens for local governments and local businesses where air quality problems are regional, not local, in nature;
6. Ensure that air quality planning and related federal, state and local planning are coordinated; and
7. Recognize the substantial lead time necessary for state and local governments and businesses to plan for and meet standards for a new indicator of particulate matter.

In the following months US EPA adhered to the advice given by the President's Office on development of the program - despite the concerns of several states and utilities in the US Midwest.

## Strategy for Meeting the Revised Air Quality Standards for Particulate Matter

### 1) *Implementing the New* $PM_{2.5}$ *Standards - general overview*

For the new $PM_{2.5}$ standards, several years of monitoring and planning will be required before US EPA will require local control measures to be put into effect.

As required under the Clean Air Act, within the next five years US EPA will complete the next periodic review of the PM air quality standards, including review by the Clean Air Scientific Advisory Committee. US EPA will have completed its statutory determination before any designations of nonattainment are made for the $PM_{2.5}$ standards and before imposition of any control strategies directed at $PM_{2.5}$.

2) *General Timelines for Meeting $PM_{2.5}$ Standards*

(i) The first priority will be to establish a comprehensive monitoring network (comprising 1,500 monitors) to determine ambient fine particle concentrations across the country. The monitoring network will help US EPA and the states determine: (1) which areas meet or do not meet the new air quality standards, (2) the major sources of $PM_{2.5}$ in various regions, and (3) what action is needed to clean up the air.

(ii) US EPA will work with states to deploy the $PM_{2.5}$ monitoring network. Based on the ambient monitoring to date, monitors will generally not be deployed in agricultural areas.

(iii) US EPA will fund the cost of purchasing the monitors, as well as the cost of analyzing particles collected at the monitors to determine their chemical composition.

(iv) The Clean Air Act requires that US EPA make designation determinations (i.e., attainment, nonattainment, or unclassifiable) within two to three years of revising a standard. Since US EPA will not have adequate $PM_{2.5}$ monitoring data for that purpose, in 1999 US EPA will issue "unclassifiable" designations for $PM_{2.5}$. These designations will not trigger the planning or control requirements.

(v) Three years of acceptable monitoring data will be available from the earliest monitors by the spring of 2001, and 3 years of data will be available from all monitors in 2004. Allowing time for data analysis, state governments and US EPA will not be able to make the first determinations about which areas should be redesignated from unclassifiable to nonattainment status until at least 2002.

(vi) States will have three years from date of being designated nonattainment (or until between 2005 and 2008) to develop pollution control plans (SIPs) and submit them to EPA showing how they will meet the new standards.

(vii) Areas will then have up to ten years (2012 to 2017) from their designation as nonattainment to attain the $PM_{2.5}$ standards with the possibility of two 1-year extensions.

3) *EPA Actions to Help Meet the $PM_{2.5}$ Standards in a Common-Sense Manner*

(i) As with ozone, it will be important to focus on measures that decrease emissions that contribute to regional, transported pollution. Available information indicates that, nearly 33% of the areas projected to violate the new $PM_{2.5}$ standards, primarily in the Eastern United States, could come into compliance as a result of the regional $SO_2$ emission reductions already mandated under the Clean Air Act's acid rain program, which will be fully implemented between 2000 and 2010.

(ii)As long as states are doing their part to carry out regional reduction programs, the areas that would attain the $PM_{2.5}$ standards based on full implementation of the acid rain program would not face new local requirements.

(iii) Similarly, the Grand Canyon Visibility Transport Commission, consisting of Western States and tribes, committed to reducing regional emissions of $PM_{2.5}$ precursors (sulfates, nitrates and organics) and organized to improve visibility across the Colorado Plains.

(iv) As detailed $PM_{2.5}$ air quality data and data on the chemical composition of $PM_{2.5}$ in different areas become available, US EPA will work with states to analyze regional strategies that could reduce $PM_{2.5}$ levels. If further cost-effective reductions will help areas meet the new standards, US EPA will encourage States to work together to use a cap-and-trade approach similar to that used to curb acid rain.

(v) US EPA will also encourage states to coordinate their $PM_{2.5}$ control strategy development and efforts to protect regional visibility. Visibility monitoring and data analysis will support both $PM_{2.5}$ implementation and the visibility program.

4) *Implementing the Revised $PM_{10}$ National Air Quality Standard*

(i) Given that health effects from coarse particles are still of concern, the overall goal during this transition period is to ensure that $PM_{10}$ control measures remain in place to maintain the progress that has been achieved toward attainment of the current $PM_{10}$ standards (which provides benefits for $PM_{2.5}$) and protection of public health.

(ii) To ensure that this goal is met, existing $PM_{10}$ standards will continue to apply until certain critical actions by US EPA, and by states and local agencies, have been taken to sustain the progress already made.

(iii) For areas not attaining the existing $PM_{10}$ standards today, those standards remain in effect until US EPA completes a rule to prevent "backsliding," or removal of controls needed to achieve clean air.

(iv) For areas attaining the existing $PM_{10}$ standards, US EPA will retain the existing $PM_{10}$ standards until the state submits and US EPA approves the SIP that are required to be submitted under section 110 within 3 years of an air quality standard revision.

(v) US EPA will take action within 3 years to designate areas for the revised $PM_{10}$ standard.

5) *Cost-Effective Implementation Strategies*

(i) Consistent with states' ultimate responsibility to attain the standards, US EPA will encourage states to design strategies for attaining the PM and ozone standards that focus on getting low cost reductions and providing sources the ability to limit their cost of control to under $10,000 per ton.

(ii) US EPA will encourage the use of concepts such as a Clean Air Investment Fund that would allow sources facing control costs higher than $10,000 a ton for any of these pollutants to pay a set annual amount per ton to fund cost-effective emission reductions from non-traditional and small sources.

(iii) Compliance strategies like this will likely lower costs of attaining the standards through more efficient allocation, minimize the regulatory burden for small and large sources, and serve to stimulate technology innovation.

US EPA's final proposals regarding Section 110 of the Clean Air Act and several other aspects of the Ozone/Particulate Matter package will be released during 1998.

*6) Reactions to proposals:*

**Congress:**

Members of the Senate and House of Representatives have been considering advancing Clean Air Act legislation that would restrict US EPA's actions in implementing its new NAAQS for ozone and particulate matter.

For example, legislation introduced in the Senate in March, 1998, proposes to block US EPA from accelerating implementation of its updated ozone and particulate matter standards. The proposed legislation codifies the scheme that US EPA will follow in implementing the new standards. With particulate matter, the amendment would require US EPA to finance establishment of a national fine particle monitoring network by the end of 1999. When the network is up and running, US EPA would be required to collect three years of monitoring data before determining that an area was in non-attainment with the fine particle standards. Under this legislation, US EPA would also be required to make fine particle non-attainment designations by the end of 2005.

Other legislation, or amendments to this proposed legislation, will likely occur while Congress is in session.

**States:**

There are two groups of states with strong views respectively for and against US EPA's proposals.

In August, 1997, eight Northeastern states filed petitions with US EPA under section 126 of the Clean Air Act to force Midwestern and Southwestern states to address the problem of interstate air pollution. US EPA failed to act on the petition within 60 days, as required by the Clean Air Act.

Officials in these states are concerned that US EPA failed to adequately address transboundary ozone. Each of the Northeast states named power plants in other Midwest and Southern states as contributing to their poor air quality: Pennsylvania named facilities in 19 states as far distant as Louisiana and Missouri.

Later, in the fall of 1997, several states in the Midwest expressed concern that the proposed tightening of National Ambient Air Standards will result in hundreds of counties being designated non-attainment areas.

States, however, are generally less anxious over PM than ozone. Noting that the particulate matter program will not mature until well into the next century, some sources are saying that states and US EPA will have plenty of time "to talk that out". There is concern, nevertheless that US EPA's proposed monitoring program will result in increased staff pressures - even though US EPA has indicated that it will foot the $100 million cost.

The consensus among states in the Midwest is that US EPA is making "a good faith attempt" to provide a high level of public health protection. The advice US EPA is getting is that it should work within the framework of the Clean Air Act and set implementation policies and regulations that attempt to balance the costs of meeting the health standards with the social and economic needs of the country.

By December, 1997, NESCAUM and US EPA had reached an agreement whereby US EPA agreed to take action during the next three years with respect to Section 126 of the Clean Air Act. It was agreed that US EPA: 1) would submit a proposal in September 1998 to define the air transportation problem and what US EPA intends to do about it - which would be essentially the same time as SIP proposals are finalized, and 2) would issue final proposals under Section 126 in 1999.

**Environmental health nonprofit groups:**

Advocates who champion the US EPA's rulingclaim that the potential health benefits far outweigh the costs of implementing the new standards.

**American Lung Association (ALA):** US EPA proposed revising the standards downward in response to an ALA lawsuit and numerous scientific studies that show current standards do not adequately protect public health with the "margin of safety" required under the Clean Air Act. "ALA recommends that US EPA set a NAAQS standard for $PM_{2.5}$ of 18 micrograms/cubic meter averaged over 24 hours, and 10 micrograms/cubic meter annually. EPA should retain and strengthen the current $PM_{10}$ standards. The ALA recommends the current one exceedence per year averaged over three years be retained as the system for enforcing the standards".

**National Resources Defense Fund** praised the ruling as a major step forward in protecting the health of children and seniors.

**American Public Health Association**: is pleased with US EPA's updating of the clean air standards for particulate matter and ozone.

**Industries and Power Utilities**:

These groups argue that US EPA has gone too far, too soon, and that compliance comes with a huge price tag. Major industries joined the Air Quality Standards Coalition (AQSC) to oppose US EPA's effort to strengthen the national ambient air quality standards for ozone and particulate matter. The coalition membership includes a number of large oil auto companies (such as General Motors, Ford, General Electric, U.S. Steel, Exxon, Shell Oil); utilities and industry associations.

The Edison Electric Institute (EEI) accused US EPA of misleading the public with the new rules, saying that "targeting utility companies isn't the answer to the nation's clean air problems. "Electricity plant emissions account for only a portion of the pollutants that form smog and soot: 29% of nitrogen oxides and less than 1% of volatile organic compounds," EEI said. "While electricity emissions are also one of the players in the formation of particulate matter, the science of how soot affects health at the microscopic level that US EPA proposes to regulate is not fully understood."

Since November, 1997, some utility companies suggested counter-proposals to US EPA's approach. For example, Cinergy (Ohio) initially proposed a voluntary curb o 65% in emissions. The same company in conjunction with other Midwestern utilities, called for a reduction in emissions of 55% by 2004: a second round of emission cuts would be triggered if additional modeling confirmed that existing controls were not sufficient. In response, US EPA has indicated that these proposals required nothing more than what the acid rain program currently requires.

### *II.4.2.2 Europe*

European Commission

On October 8,1997, the European Commission (EC) adopted a proposal for a Directive setting new ambient air quality limit values for sulphur dioxide, nitrogen dioxide, particulate matter and lead. The proposal is the first of a series to be brought forward under the *Proposal for a Council directive relating to the establishment of limit values for sulphur dioxide, nitrogen dioxide, particulate matter and lead.* Its goals are to provide a high level of protection for public health throughout the European Union (EU), and to set for the first time ambient air quality limit values designed to protect the environment.

The new limit values are based on the revised Air Quality Guidelines for Europe adopted by the World Health Organization in 1996. The main elements of the proposal are health-based limit values for sulphur dioxide, lead and particulate matter to be met by 2005; health-based limit values for nitrogen dioxide and a tighter set of limit values for particulate matter to be met by 2010; limit values to protect the rural environment against the effects of sulphur dioxide and oxides of nitrogen; details of how levels of the pollutants should be assessed throughout the EU; and a requirement that up to date information on all four pollutants should be easily available to the public. To meet these targets emissions of sulphur dioxide and nitrogen dioxide must be reduced by nearly 10% throughout the EU in addition to the reductions already expected by 2010.

In particular, the proposed air quality limit values for particulate matter ($PM_{10}$) are set up in two stages:

1. In the first stage, the 24-hour limit value for human health protection to be met by 2005 is 50 μg/m$^3$ and is not to be exceeded 25 times a year. The annual limit value for the protection of human health is 30 μg/m$^3$.

2. In the second stage, to be met by 2010, the 24-hour limit value is also 50 μg/m$^3$, but it must not be exceeded more than seven times a year. The annual limit value is 20 μg/m$^3$.

It is estimated that emissions in cities will need to be reduced by some 50% over present levels if the limit values proposed for 2010 are to be met throughout the EU.

The EU proposal does not focus on $PM_{2.5}$ except in an exemption provision. Under this, member states would be allowed to exceed the $PM_{10}$ limit between 2005 and 2010 where there were significant concentrations of particulate matter from natural sources, on the condition that they make best efforts to meet less binding action levels for $PM_{2.5}$.

The EC also addressed the difficult question of setting limit values for particulate matter when there are no thresholds for effects. Although it is not possible on current evidence to determine clear thresholds below which there would be no effects on health, expert advice is that it is possible to set goals which would provide a high degree of protection for public health. And, given the relatively high concentrations of particles in some parts of the EU today and the number of different sources that contribute to those concentrations it is essential to have targets for the challenging task of bringing them down.

On health effects, the EC states that several recent studies on particulate matter, including a study financed by the EC, have found that there are more asthma attacks, more hospital admissions (especially for respiratory problems) and higher death rates from respiratory and cardiac diseases on days when levels of particles are high. The extent of the effect of these short-term changes in particle levels on life-expectancy in particular is hard to interpret. But the results taken together show clearly the large potential adverse effects of particulate matter on public health. Long-term studies suggest that chronic exposure to particles can shorten lifespan significantly.

The 1-hour limit value for sulphur dioxide is 350 μg/m$^3$, not to be exceeded more than 24 times per year and is to be met by 2005. The corresponding 24-hour limit value is 125 μg/m$^3$ not to be exceeded more than 3 times per year.

For nitrogen oxides, the 1-hour limit value for the protection of human health is 200 μg/m$^3$ not to be exceeded more than 8 times per year. The corresponding annual limit value is 40 μg/m$^3$.

The cost of meeting the $PM_{10}$ limit values is estimated to be $260 million to $1.6 billion annually. Emissions in European cities will need to be reduced as much as 50% in order to meet the standards.

The framework Directive sets forth the basic principles for a joint strategy designed to fix objectives relating to ambient air quality.

(i) The member states of the EC will have to prepare specific emission reduction plansfor regions or areas where ambient air quality is currently much worse than required by the new standards.

(ii) Efforts to reduce emissions will concern not only major sources such as road traffic, industry, power plants and domestic heating but other potential pollutants such as SO2, NO2 and ammonia.

(iii) In order to ensure the standards are observed and to ensure regular inspections of air quality, the Directive calls for the use of standard pollution measurement methods and defines minimum requirements for designing monitoring networks.

Environmental groups welcomed most aspects of theproposals, but criticized the EC's decision to allow a less stringent interim standard for $PM_{10}$ between 2005 and 2010.

The European Parliament and the EC Economic and Social Committee have not yet delivered their opinions on the proposal. Furthermore, at the meeting of the EC Council of Environment Ministers on March 23, 1998, ministers noted: broad support for the Commission's approach, that available scientific information needs to be improved - especially as regards particulate matter, the need for flexibility particularly where naturalcauses are involved, and, the importance of correct, timely and exhaustive information to the public. Environment ministers will review the proposaln June 1998.

United Kingdom

On March 12, 1997, the UK Government published the final version of theNational Air Quality Strategy which set out standards and objectives for the control and reduction of the eight main health -threatening pollutants in UK: nitrogen dioxide, particles, ozone, sulfur dioxide, carbon monoxide, lead, benzene and 1,3 butadiene. The Strategy was the first of its kind in Europe.

The Strategy sets out the contribution that key sectors, including industry, transport and local government, will have to make in order to achieve the objectives. Existing systems for controlling pollution will be used together with a new system of local air quality management.

The Department of Environment said: "the improvements we seek will not come without cost. We are committed to achieving our objectives through the application of the principles of BATNEC (Best Available Techniques Not Entailing Excessive Cost) and BPEO (Best Practicable Environmental Option). The costs are likely to fall on industry, business, motorists and consumers alike. The

Government will ensure, therefore, that the right balance is struck and that pollution control measures are proportionate and represent the most cost-effective solutions available".

The Strategy will be backed by a package of measures including the European Commission Auto-Oil agreement.

In November 1997, the Department of Environment, Transport & Regions (successor to the Department of Environment) announced that the existing UK public air quality information system was revised and extended to include hourly information and forecasts for carbon monoxide and airborne particles (such as $PM_{10}$). Local authorities will be required to review air quality in their area and assess it against the objective specified in the regulations. They will be required to designate Air Quality Management Areas where it appears that objectives will not be met my 2005, and will have to establish action plans for those areas in pursuit of the objectives.. The pollutants for which the regulations set objectives are: benzene, 1,3-butadiene, carbon monoxide, lead, nitrogen dioxide, fine particles ($PM_{10}$), and sulphur dioxide.

### *II.4.2.3 Australia*

The current proposed air quality standard in Australia is 50 micrograms per cubic meter 24-hour average for $PM_{10}$, and 25 micrograms per cubic meter for $PM_{2.5}$ . In a report of the National Protection Council it was stated that only the $PM_{2.5}$ standard is relevant for smoky areas, since wood smoke is almost entirely $PM_{2.5}$ , and it is suggested that careful consideration should be given to"a restriction on the use of wood heaters in major airsheds, in 10 years time".
A brief summary of $PM_{10}$ and $PM_{2.5}$ standards/objectives is provided in Table II.4.1. Additional information (if known) on the the level/form, basis and role in implementation strategies is included.

**Table II.4.1 $PM_{10}$ /$PM_{2.5}$ Standards/Objectives in Other Jurisdictions**

| Jurisdiction | Level/Form | Basis/Rationale | Role/Use |
|---|---|---|---|
| | $PM_{10}$ | | |
| Hong Kong | 180 µg/m³ (24 h)<br>55 µg/m³ (1 yr) | NA | Air Quality Assessment |
| Mexico | 150 µg/m³ (24 h) | NA | NA |
| United States | 150 µg/m³ (24 h)[1]<br>50 µg/m³ (1 yr)[2] | Health | Emission reductions within State Implementation Plans (SIPs) |
| Sweden | 100 µg/m³ (24 h) | NA | NA |
| California | 50 µg/m³ (24 h)<br>30 µg/m³ (1 yr) | Health | NA |
| British Columbia | 50 µg/m³ (24 h) | Health | Guidance for environmental protection decisions |
| Greater Vancouver Regional District (GVRD) | 50 µg/m³ (24 h) | California Std.<br>Cost/Benefit Analysis | NA |
| Newfoundland | 50 µg/m³ (24 h) | Health | Guideline |
| United Kingdom (UK) | 50 µg/m³ (24 h)[3] | Health | Objective for a Particle Strategy |
| Australia | 50 µg/m³ (24 h) | NA | NA |
| World Health Organization (WHO) | No Level Established[4] | Health<br>*A level below which no effects would be expected, could not be established.* | Exposure-Effect Information Provided as Guidance to Risk Managers |

| **Jurisdiction** | **Level/Form** | **Basis/Rationale** | **Role/Use** |
|---|---|---|---|
| **$PM_{2.5}$** | | | |
| United States | 65 µg/$m^3$ (24 h)[5]<br>15 µg/$m^3$ (1 yr)[6] | Health | Emission reductions within State Implementation Plans (SIPs) |
| Australia | 25 µg/$m^3$ (24 hr) | NA | Only $PM_{2.5}$ standard is relevant in smoky areas |
| Newfoundland | 25 µg/$m^3$ (24 h) | Health | Guideline |

[1] 3-year average of annual 99th percentile 24-hour $PM_{10}$

[2] 3-year average of annual average $PM_{10}$

[3] 24-hour running average

[4] Epidemiological data did not facilitate the establishment of a level below which no effects would be expected. Exposure-effect information was provided as guidance to risk managers.

[5] 3-year average of annual 98th percentile 24-hour $PM_{2.5}$ at community exposure monitors

[6] 3-year average of annual and spatially averaged $PM_{2.5}$ at community exposure monitors

# III SCIENCE AND TECHNOLOGY

## III.1 IP/RP RELATED EMISSION INVENTORY DEVELOPMENT FOR ONTARIO

### III.1.1 Background

*III.1.1.1 1990 Ontario Emission Inventory*

In late 1995, as part of the Ontario Smog Plan development, a 1990 base year emission inventory for inhalable ($PM_{10}$) and respirable ($PM_{2.5}$) particulate matter for Ontario was compiled. It was a rudimentary emission inventory applicable for the first time to program planning. The $PM_{10}$ and $PM_{2.5}$ emission estimates for stationary point sources, area sources and transportation sources were based on the Criteria Pollutant ($SO_2$, VOC, NOX, CO and particulate matter) emission inventory source information. Development of $PM_{10}$ and $PM_{2.5}$ emission profiles for various source categories was an emerging environmental science in North America. There were little source specific data of known accuracy. Open sources and fugitive emissions were mostly based on rudimentary emission models, although they were considered to be the best available at that time.[1]

Figure III.1.1 shows a 1990 emission apportionment of $PM_{10}$ from major industrial, commercial and residential sectors. Open sources of fugitive emissions such as road dust, construction, agricultural dust and wind erosion are not included due to lack of $PM_{10}$ emission profiles and applicable source statistics, although their contribution is significant. Area sources comprising numerous smaller, individual residential, commercial and smaller industrial sources such as residential fuel wood combustion, fugitive $PM_{10}$ emissions from mining, quarrying and industrial open storage are equally difficult to quantify accurately.

*III.1.1.2 Current Status of North America IP/RP Emission Inventory Developments*

In most cases, the $PM_{10}$ or $PM_{2.5}$ emission profiles were derived from either engineering estimates or generalized particle size characterization, based on limited source sampling. Emissions of $SO_2$, $NO_2$ and VOC are used in atmospheric models to estimate their contributions to $PM_{2.5}$ loadings. However, there are other fine crustal, organic and inorganic aerosol fractions of $PM_{2.5}$ which are dependent on primary sources or source regions. As of today, these particle size fractions still remain poorly characterized with respect to chemical constituents and source specificity, thus making source apportionment among local and long range transported sources of $PM_{10}$ and $PM_{2.5}$ a scientific challenge. As a whole, qualitative and quantitative characterization of $PM_{10}$ and $PM_{2.5}$ from many sources and source categories requires more scientific and engineering assessments.

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[1] Refer to Appendix A for more description of the emission source categories.

With the current interest in developing or revising particulate matter standards (PM, $PM_{10}$, $PM_{2.5}$) in North America, more federal, state/provincial attention is being paid to the development of more complete, accurate and comprehensive inventories which are much needed to support the standard setting process. The major thrust of the research and development on $PM_{10}$ and $PM_{2.5}$ emissions for various source categories comes from the U.S. EPA. Environment Canada has been working in cooperation with the provinces through the Canadian National Emission Inventory and Projections Task Group (NEIPTG) to assess the $PM_{10}$ loading from road dust generated by traffic.

Emission estimation models for many fugitive sources of $PM_{10}$ such as agricultural operations, construction activities, structural fires/open burning and natural fires still require better characterization or further "Canadianization". The development of a comprehensive $PM_{10}$/$PM_{2.5}$ emission inventory to support policy and program development requires meaningful cooperation and participation from industry sources in the characterization of emissions. While it is beneficial to monitor continuously the development of $PM_{10}$ and $PM_{2.5}$ source emission profiles in the U.S., the "Canadianization" of many emission profiles will require considerable in-house/provincial attention.

The purpose of this discussion is to help the reader to understand better the scope of the provincial $PM_{10}$ and $PM_{2.5}$ emission data presented as well as the basic concepts behind how the emissions from various source categories are estimated. The existing uncertainty and information gaps in the $PM_{10}$ and $PM_{2.5}$ emission data should not be considered a serious impediment to initiating the development of workable IP/RP emission reduction strategies. Undoubtedly, improvement in the resolution and accuracy of the provincial emission profiles will improve tracking of emission reductions from various sources or source sectors. As sources are undergoing $PM_{10}$ and $PM_{2.5}$ reduction, the emission control, pollution prevention and operational/management practices can be monitored and technically assessed in terms of emission improvements.

### III.1.2 Near-Term MOE Efforts in IP/RP Emission Inventory Development (1998-99)

#### *III.1.2.1 1995 Ontario IP/RP Emission Inventory*

A 1995 IP/RP emission inventory derived from a voluntary industrial point source survey, past source category information, and available provincial source statistics was completed in March 1998. Table III.1.1 gives a breakdown of the provincial PM, $PM_{10}$ and $PM_{2.5}$ emissions by source categories. *Please note that the number of significant figures quoted in this table, and in subsequent tables and figures, does not reflect the accuracy of the emissions estimates. These significant figures are carried forward exactly as they emerge from the underlying calculations merely to avoid difficulties associated in accumulation of round-off errors in subsequent calculations.* For comparison with the 1990 $PM_{10}$ emission profiles estimated earlier, Figure III.1.2b presents a 1995 $PM_{10}$ emission apportionment for the similar major sectors. There is little change in the relative contribution among the major sectors from one year to the other. Figures III.1.2a,b,c show the 1995 PM, $PM_{10}$ and $PM_{2.5}$ emission profiles for point/mobile/area sources. Figures III.1.3a,b,c also show the 1995 provincial PM, $PM_{10}$ and $PM_{2.5}$ emission profiles for all sources.

The 1995 IP/RP emission inventory has incorporated some improvements in the representativeness, coverage and spatial resolution of the $PM_{10}$ and $PM_{2.5}$ emissions from on-road transportation and area sources. The Ministry has applied the best available provincial emission statistics and emission inventory estimation methodologies on $PM_{10}$ and $PM_{2.5}$ resulting from NEIPTG, Environment Canada and U.S. EPA emission inventory studies.

The majority of the $PM_{10}$ and $PM_{2.5}$ emissions for smaller sources, transportation sources and area sources are "top-down" estimates. This means that the emissions are developed using provincial level activity data and some measure of emission rates that could be applied to these source activity data. Most of these source activity data are obtained from published sources such as government statistical documents and databases (e.g., energy and fuel consumption data, food and agricultural data, vehicle licensing statistics).

The quality, uncertainty and resolution of this updated emission inventory are still limited by the above referenced constraints affecting both the U.S. and Canada. The lack of individual industry source specific $PM_{10}$ and $PM_{2.5}$ emission data requires the application of less accurate generic $PM_{10}$ and $PM_{2.5}$ emission factors and/or activities available to estimate the emissions for a given industrial facility or for the entire industrial sector. These emission factors were obtained by an extensive search of the literature and of environmental agencies, such as EPA's AP-42 document and Factor Information Retrieval System database (FIRE). As a result, the current $PM_{10}$ and $PM_{2.5}$ emission profiles are estimates at best. The primary goal is to provide a sense of the relative apportionment or contribution of various source categories. Quantitative emission profiles require much more in-depth source testing, engineering and scientific assessments on the specific sources of $PM_{10}$ and $PM_{2.5}$ emissions.

There is still a lack of $PM_{2.5}$ profiles for many sources, making it difficult to assess the contribution of $PM_{2.5}$ within the $PM_{10}$ total emissions. Nevertheless, the 1995 provincial emission profiles for $SO_2$, $NO_x$ and VOC will provide some perspective on the relative significance of the source sectors contributing to the eventual formation of $PM_{10}$ and $PM_{2.5}$ (see Tables III.1.2 and Figures III.1.4 to III.1.6). The transformation rates of $SO_2$ and $NO_x$ to ammonium sulphate and ammonium nitrate depend, among other factors, on the availability of ammonia. Table III.1.3 presents a 1985 emission inventory for ammonia in Ontario. An updated ammonia emission inventory will be compiled in the near future by Environment Canada.

### *III.1.2.2 $PM_{10}$ Emissions From the U.S. Transboundary States Affecting Ontario*

The impact of transboundary transport of $PM_{10}$ and $PM_{2.5}$ from the U.S. into Ontario can be significant. The contribution depends on the source region and emission loading into the environment. Table III.1.4 and Figures III.1.6 to III.1.10 illustrate the relative magnitude of $SO_2$, $NO_x$, $PM_{10}$ and VOC emissions from the U.S. states affecting Ontario. Some of the $SO_2$ and $NO_x$ emissions will eventually be transformed into sulphates and nitrates susceptible to long range transport and deposit in Ontario. The impact of $PM_{10}$ and $PM_{2.5}$ from these U.S. sources on Ontario is strongly influenced by the distance of the sources from Ontario, and the frequency of the air parcel trajectories which can transport fine particles into Ontario. More in depth discussion of the impact of long range transported $PM_{10}$ and $PM_{2.5}$ into Ontario and the secondary formation of aerosols including sulphates and nitrates is found in Sections III.3 and III.4.

### III.1.3 Longer Term Efforts in IP/RP Emission Inventory Development

The current Ontario $PM_{10}$ inventory has large emissions from open sources. The uncertainty in these emissions requires further characterization and refinement. Collaborative development with NEIPTG in the characterization of selected industry sources, transportation sources, various kinds of open sources and fugitive emissions will improve the comparability of $PM_{10}$ emissions among provinces and territories in Canada. In most cases, source assessment and characterization will involve field studies and analysis of source samples. Additional research and development studies of the $PM_{2.5}$ size fraction and composition within the $PM_{10}$ loading for each source will be needed to understand better the origin and characteristics of the fine particles. Refinement in the $PM_{10}$ and $PM_{2.5}$ emission profiles is needed to develop, track and assess the effectiveness of IP/RP reduction strategies.

Backcast and forecast IP/RP emissions (1990-2015) using available projection models and industrial source data will be required to improve the IP/RP program 1990 base case emission inventory. Active participation of Ontario industries in the development of future $PM_{10}$ and $PM_{2.5}$ emission inventories to track the progressive reduction of IP/RP is strongly recommended.

Comprehensive community based emission inventories for $PM_{10}$ and $PM_{2.5}$ are essential to the assessment of the impact of the IP/RP standards to be established in Ontario. Improvement in the reliability of the IP/RP emission inventory profiles will require closer cooperation among MOE, local communities and industries in the development and selection of proper emission profiles for $PM_{10}$ and $PM_{2.5}$ emissions.

Improvement in environmental quality with respect to ambient $PM_{10}$ and $PM_{2.5}$ concentrations can only be realized through the reduction of emissions of $PM_{10}$ and $PM_{2.5}$ and their precursors from various local and transboundary sources. The development of a good quality emission inventory is an essential component of the IP/RP reduction program.

## TABLE III.1.1 ONTARIO PARTICULATE EMISSIONS
## (1995 Estimates)

| CATEGORY / SECTOR | PM tonnes | $PM_{10}$ tonnes | $PM_{2.5}$ tonnes |
|---|---|---|---|
| **INDUSTRIAL PROCESS** | | | |
| Abrasives Manufacture | 46 | 25 | 18 |
| Aluminum Industry | 206 | 120 | 89 |
| Asphalt Paving Industry | 9,279 | 1,664 | 647 |
| Bakeries | 0 | 0 | 0 |
| Cement Industry | 7,188 | 3,451 | 2,027 |
| Concrete Industry | 1,222 | 607 | 187 |
| Chemicals Industry | 2,512 | 1,104 | 645 |
| Clay Products Industry | 147 | 14 | 2 |
| Coal Mining Industry | 420 | 420 | 386 |
| Ferrous Foundries | 30 | 27 | 26 |
| Grain Industries | 15,746 | 3,087 | 476 |
| Iron and Steel Industries | 16,234 | 7,971 | 5,241 |
| Iron Ore Mining Industry | 929 | 168 | 58 |
| Mining and Rock Quarrying | 37,476 | 6,037 | 1,656 |
| Non-Ferrous Mining & Smelting (Lead and Zinc) | 56 | 40 | 20 |
| Non-Ferrous Mining & Smelting (Copper and Nickel) | 9,308 | 7,951 | 6,453 |
| Other Petroleum and Coal Products | | | |
| Paint & Varnish Manufacturing | 109 | 93 | 33 |
| Petrochemical Industry | 1,080 | 434 | 211 |
| Petroleum Refining | 2,894 | 2,176 | 1,314 |
| Plastics & Synthetic Resins Fabrication | 113 | 60 | 39 |
| Pulp and Paper Industry | 19,277 | 9,438 | 6,430 |
| Upstream Oil and Gas Industry | | | |
| Wood Industry | 12,381 | 7,219 | 2,482 |
| Other Industries | 26,095 | 15,138 | 9,844 |
| **CATEGORY TOTAL:** | **162,748** | **67,204** | **38,284** |

# TABLE III.1.1 ONTARIO PARTICULATE EMISSIONS - cont'd
## (1995 Estimates)

| CATEGORY / SECTOR | PM tonnes | $PM_{10}$ tonnes | $PM_{2.5}$ tonnes |
|---|---|---|---|
| **FUEL COMBUSTION** | | | |
| Commercial Fuel Combustion | 1,050 | 961 | 910 |
| Electric Power Generation (Utilities) | 5,797 | 1,680 | 719 |
| Residential Fuel Combustion | 1,886 | 1,754 | 1,704 |
| Residential Fuelwood Combustion | 28,597 | 28,025 | 28,025 |
| **CATEGORY TOTAL:** | **37,330** | **32,419** | **31,358** |
| **TRANSPORTATION** | | | |
| Air Transportation | 832 | 460 | 325 |
| Heavy Duty Diesel Vehicles | 9,358 | 9,358 | 8,624 |
| Heavy Duty Gasoline Trucks | 132 | 128 | 101 |
| Light Duty Diesel Trucks | 312 | 312 | 289 |
| Light Duty Diesel Vehicles | 110 | 110 | 102 |
| Light Duty Gasoline Trucks | 900 | 873 | 706 |
| Light Duty Gasoline Vehicles | 1,802 | 1,747 | 1,223 |
| Marine Transportation | 1,923 | 1,712 | 1,505 |
| Motorcycles | 5 | 5 | 4 |
| Off-road Use of Diesel | 3,236 | 3,236 | 2,977 |
| Off-road Use of Gasoline | 2,307 | 2,031 | 1,785 |
| Propane Powered Vehicles | 109 | 105 | 94 |
| Rail Transportation | 733 | 733 | 675 |
| Tire Wear & Brake Lining | 1,738 | 1,718 | 563 |
| **CATEGORY TOTAL:** | **23,497** | **22,528** | **18,972** |
| **INCINERATION** | | | |
| Cremation | 3 | 2 | 1 |
| Industrial & Commercial Incineration | 16 | 14 | 13 |
| Municipal Incineration | 3 | 1 | 0 |
| Wood Waste Incineration | 766 | 421 | 306 |
| Other Incineration & Utilities | 141 | 34 | 15 |
| **Category Total:** | **929** | **472** | **335** |

## TABLE III.1.1 ONTARIO PARTICULATE EMISSIONS - cont'd
## (1995 Estimates)

| CATEGORY / SECTOR | PM tonnes | $PM_{10}$ tonnes | $PM_{2.5}$ tonnes |
|---|---|---|---|
| **MISCELLANEOUS** | | | |
| Cigarette Smoking | 230 | 230 | 230 |
| Dry Cleaning | 0 | 0 | 0 |
| Fuel Marketing | | | |
| General Solvent Use | | | |
| Meat Cooking | 442 | 442 | 442 |
| Pesticides and Fertilizer Application | 1,701 | 833 | 238 |
| Printing | | | |
| Structural Fires | 2,108 | 2,087 | 1,897 |
| Surface Coatings | | | |
| **CATEGORY TOTAL:** | **4,481** | **3,592** | **2,807** |
| **OPEN SOURCES** | | | |
| Agricultural (Animal Waste) | 40,037 | 20,651 | 3,293 |
| Agricultural Tilling Operations | 6,801 | 1,428 | 68 |
| Construction | 610,481 | 134,306 | 2,718 |
| Dust from Paved Roads ** | 927,547 | 177,780 | 42,513 |
| Dust from Unpaved Roads ** | 1,477,317 | 454,815 | 66,897 |
| Landfill Sites | 1,555 | 124 | 31 |
| Mine Tailing Piles - Erosion | 10,082 | 807 | 202 |
| Prescribed Burning | 4,356 | 3,630 | 2,541 |
| **CATEGORY TOTAL:** | **3,078,176** | **793,541** | **118,264** |
| **OPEN SOURCES** - NATURAL SOURCES | | | |
| Agricultural Wind Erosion | 131,274 | 65,637 | 1,313 |
| Forest Fires | 69,555 | 59,121 | 48,688 |
| **CATEGORY TOTAL:** | **200,829** | **124,759** | **50,001** |
| **ONTARIO TOTAL (Excluding Natural Sources)** | **3,307,160** | **919,756** | **210,020** |
| **ONTARIO TOTAL (Including Natural Sources)** | **3,507,989** | **1,044,515** | **260,021** |

** The estimates for these sectors have been updated with the National Criteria Air Contaminant Emission Inventory Version 1, December 1998.

## TABLE III.1.2 ONTARIO $SO_2$, $NO_X$ and VOC EMISSIONS (1995 Estimates)

| CATEGORY / SECTOR | $SO_2$ tonnes | $NO_X$ tonnes | VOC tonnes |
|---|---|---|---|
| INDUSTRIAL PROCESS | | | |
| Abrasives Manufacture | 20 | 8 | 82 |
| Aluminum Industry | 1 | 42 | 3 |
| Asphalt Paving Industry | 150 | 74 | 2,039 |
| Bakeries | 0 | 5 | 3,892 |
| Cement and Concrete Industry | 20,838 | 11,152 | 363 |
| Chemicals Industry | 3,794 | 6,647 | 6,957 |
| Clay Products Industry | 3 | 85 | 2 |
| Coal Mining Industry | 0 | 33 | 1 |
| Ferrous Foundries | 50 | 19 | 724 |
| Grain Industries | | | |
| Iron and Steel Industries | 47,645 | 20,946 | 26,986 |
| Iron Ore Mining Industry | 44,000 | 175 | 665 |
| Mining and Rock Quarrying | 1,680 | 2,119 | 41 |
| Non-Ferrous Mining & Smelting (Lead and Zinc) | 469 | 13 | 7 |
| Non-Ferrous Mining & Smelting (Copper and Nickel) | 287,298 | 2,234 | 20 |
| Other Petroleum and Coal Products | 96 | 221 | |
| Paint & Varnish Manufacturing | 0 | 18 | 1,756 |
| Petrochemical Industry | 706 | 3,026 | 6,094 |
| Petroleum Refining | 61,595 | 12,822 | 23,783 |
| Plastics & Synthetic Resins Fabrication | 109 | 273 | 6,302 |
| Pulp and Paper Industry | 11,647 | 9,959 | 9,477 |
| Upstream Oil and Gas Industry | | | 3,729 |
| Wood Industry | 310 | 2,199 | 1,024 |
| Other Industries | 17,809 | 25,732 | 42,998 |
| CATEGORY TOTAL: | 498,221 | 97,802 | 136,946 |

## TABLE III.1.2 ONTARIO $SO_2$, $NO_X$ and VOC EMISSIONS - cont'd
## (1995 Estimates)

| CATEGORY / SECTOR | $SO_2$ tonnes | $NO_X$ tonnes | VOC tonnes |
|---|---|---|---|
| FUEL COMBUSTION | | | |
| Commercial Fuel Combustion | 2,734 | 11,655 | 918 |
| Electric Power Generation (Utilities) | 74,730 | 59,399 | 311 |
| Residential Fuel Combustion | 4,502 | 15,905 | 1,086 |
| Residential Fuelwood Combustion | 346 | 2,327 | 113,938 |
| CATEGORY TOTAL: | 82,312 | 89,285 | 116,254 |
| TRANSPORTATION | | | |
| Air Transportation | 372 | 5,024 | 1,954 |
| Heavy Duty Diesel Vehicles | 14,646 | 91,179 | 12,032 |
| Heavy Duty Gasoline Trucks | 139 | 2,239 | 1,671 |
| Light Duty Diesel Trucks | 557 | 818 | 372 |
| Light Duty Diesel Vehicles | 340 | 613 | 232 |
| Light Duty Gasoline Trucks | 1,980 | 31,568 | 37,971 |
| Light Duty Gasoline Vehicles | 5,582 | 91,668 | 112,152 |
| Marine Transportation | 18,590 | 8,105 | 14,602 |
| Motorcycles | 17 | 219 | 931 |
| Off-road Use of Diesel | 7,016 | 74,295 | 6,998 |
| Off-road Use of Gasoline | 524 | 10,751 | 38,715 |
| Propane Powered Vehicles | 7 | 2,803 | 1,674 |
| Rail Transportation | 2,008 | 30,229 | 1,419 |
| Tire Wear & Brake Lining | | | |
| CATEGORY TOTAL: | 51,777 | 349,511 | 230,723 |
| INCINERATION | | | |
| Cremation | 2 | 9 | 0 |
| Industrial & Commercial Incineration | 188 | 231 | 234 |
| Municipal Incineration | 57 | 56 | 92 |
| Wood Waste Incineration | 13 | 132 | 1,452 |
| Other Incineration & Utilities | 142 | 158 | 292 |
| Category Total: | 402 | 586 | 2,070 |

## TABLE III.1.2 ONTARIO $SO_2$, $NO_X$ and VOC EMISSIONS - cont'd (1995 Estimates)

| CATEGORY / SECTOR | $SO_2$ tonnes | $NO_X$ tonnes | VOC tonnes |
|---|---|---|---|
| MISCELLANEOUS | | | |
| Cigarette Smoking | | | 4 |
| Dry Cleaning | 0 | 1 | 3,039 |
| Fuel Marketing | | | 36,156 |
| General Solvent Use | | | 137,729 |
| Meat Cooking | | | |
| Pesticides and Fertilizer Application | | | |
| Printing | | | 12,714 |
| Structural Fires | | | 2,045 |
| Surface Coatings | | | 63,688 |
| CATEGORY TOTAL: | 0 | 1 | 255,374 |
| ONTARIO TOTAL | 632,712 | 537,185 | 741,368 |

## TABLE III.1.3 ONTARIO AMMONIA EMISSIONS BY SOURCES (1985 Estimates)

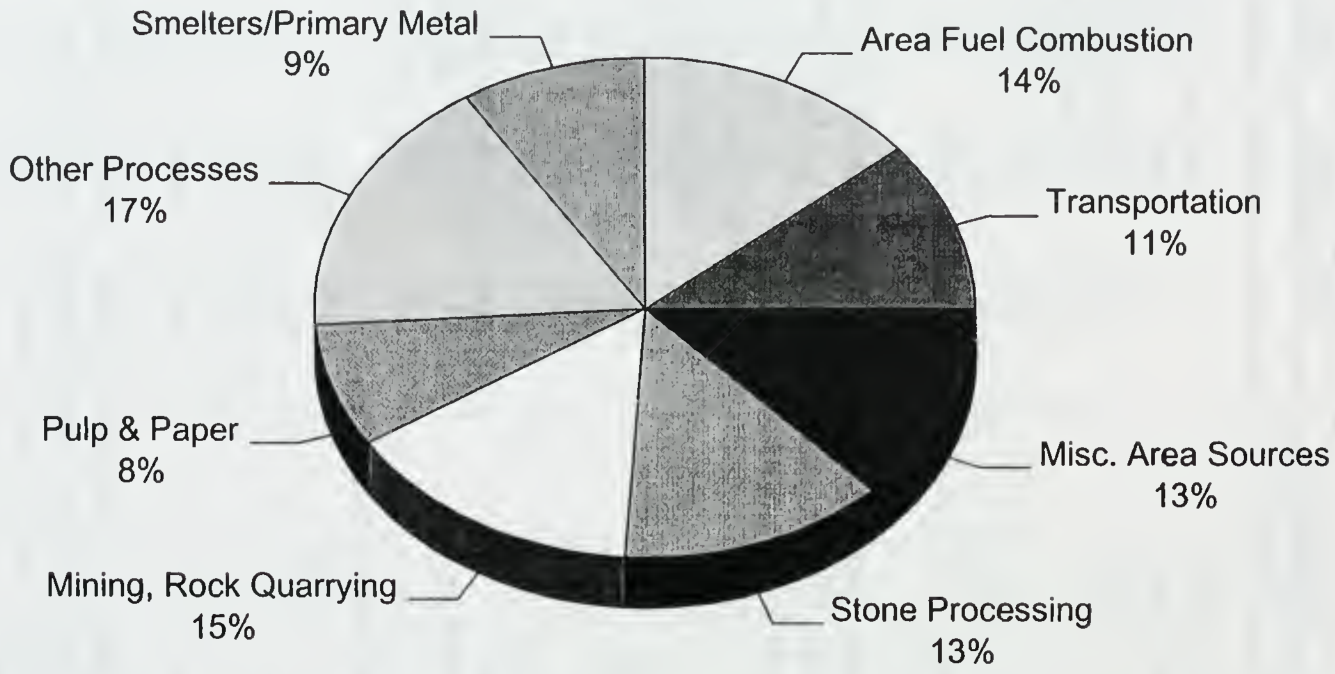
| SOURCE | EMISSIONS (Tonnes) | % OF ONTARIO |
|---|---|---|
| **Natural Sources:** | | |
| Soils | 52,954 | 46.5 |
| Animal Waste | 10,418 | 9.2 |
| Forest Fires | 3 | 0.0 |
| Human Breath | 50 | 0.0 |
| | ---------- | ---------- |
| Subtotal: | 63,425 | 55.7 |
| **Anthropogenic Area Sources:** | | |
| Combustion | 537 | 0.5 |
| Incineration | 37 | 0.0 |
| Livestock Management | 33,208 | 29.2 |
| Fertilizer Application. | 1,705 | 1.5 |
| Cigarette Smoking | 2 | 0.0 |
| | ---------- | ---------- |
| Subtotal: | 35,489 | 31.2 |
| **Anthropogenic Point Sources:** | | |
| Industrial | 14,781 | 13.0 |
| Incineration | 78 | 0.1 |
| | ---------- | ---------- |
| Subtotal: | 14,859 | 13.1 |
| ONTARIO TOTAL: | 113,773 | 100.0% |

Source: Report by The Environmental Applications Group Limited, "Alkaline Dust and Ammonia Emissions Inventory for Ontario", March 1988.

## TABLE III.1.4. CRITERIA POLLUTANT EMISSIONS FROM ONTARIO AND SELECT U.S. STATES (1995 ESTIMATES)

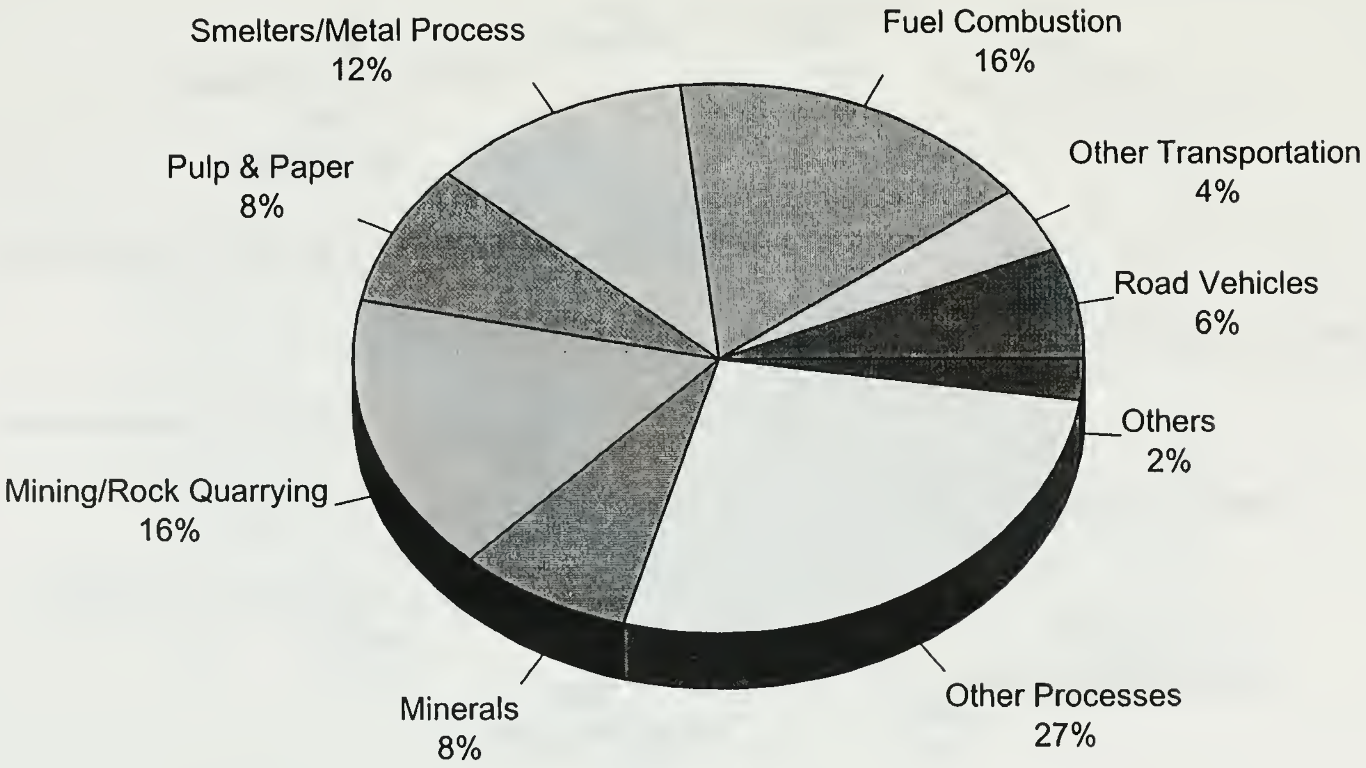
| | EMISSIONS (kilotonnes) | | | |
|---|---|---|---|---|
| | $SO_2$ | $NO_X$ | VOC | PM-10 |
| **Ontario** | 633 | 537 | 741 | 1,045 |
| **Great Lakes States** | | | | |
| Minnesota | 128 | 308 | 372 | 1,131 |
| Wisconsin | 302 | 359 | 405 | 690 |
| Illinois | 878 | 798 | 827 | 1,487 |
| Indiana | 1,296 | 774 | 570 | 730 |
| Michigan | 459 | 669 | 686 | 747 |
| Ohio | 1,422 | 1,010 | 794 | 880 |
| Pennsylvania | 1,154 | 739 | 816 | 877 |
| New York | 448 | 601 | 877 | 1,066 |
| **States Further Out** | | | | |
| North Dakota | 253 | 165 | 75 | 688 |
| South Dakota | 36 | 53 | 71 | 489 |
| Iowa | 233 | 228 | 217 | 936 |
| Missouri | 495 | 464 | 448 | 1,521 |
| Kentucky | 710 | 619 | 328 | 497 |
| West Virginia | 655 | 398 | 539 | 189 |
| Maryland | 292 | 291 | 248 | 368 |
| Delaware | 84 | 51 | 104 | 56 |
| New Jersey | 132 | 328 | 513 | 430 |
| Connecticut | 49 | 122 | 166 | 184 |
| Massachusetts | 177 | 245 | 347 | 361 |
| Vermont | 5 | 26 | 42 | 93 |
| **States Even Further Out** | | | | |
| Montana | 85 | 113 | 79 | 1,296 |
| Wyoming | 140 | 223 | 57 | 654 |
| Nebraska | 74 | 150 | 130 | 799 |
| Kansas | 135 | 351 | 230 | 1,118 |
| Oklahoma | 145 | 378 | 271 | 2,396 |
| Arkansas | 114 | 205 | 237 | 589 |
| Tennessee | 609 | 624 | 550 | 562 |
| Virginia | 358 | 458 | 524 | 566 |
| Dist. Columbia | 5 | 17 | 21 | 21 |
| Rhode Island | 6 | 29 | 60 | 39 |
| New Hampshire | 59 | 67 | 69 | 77 |

**Figure III.1.1 ONTARIO $PM_{10}$ EMISSIONS BY MAJOR SECTORS**
**(Emissions From Point/Mobile/Area Sources, 1990 Estimates)**



[1] Emissions from road dusts, construction, agricultural, etc. are not included.
[2] Emissions from open sources from the smelters are not available.

**Figure III.1.2a ONTARIO TOTAL PARTICULATE EMISSIONS BY MAJOR SECTORS**
**(Emissions From Point/Mobile/Area Sources, 1995 Estimates)**



Total Particulate (229 kilotonnes)

**Figure III.1.2b ONTARIO $PM_{10}$ EMISSIONS BY MAJOR SECTORS (Emissions From Point/Mobile/Area Sources, 1995 Estimates)**

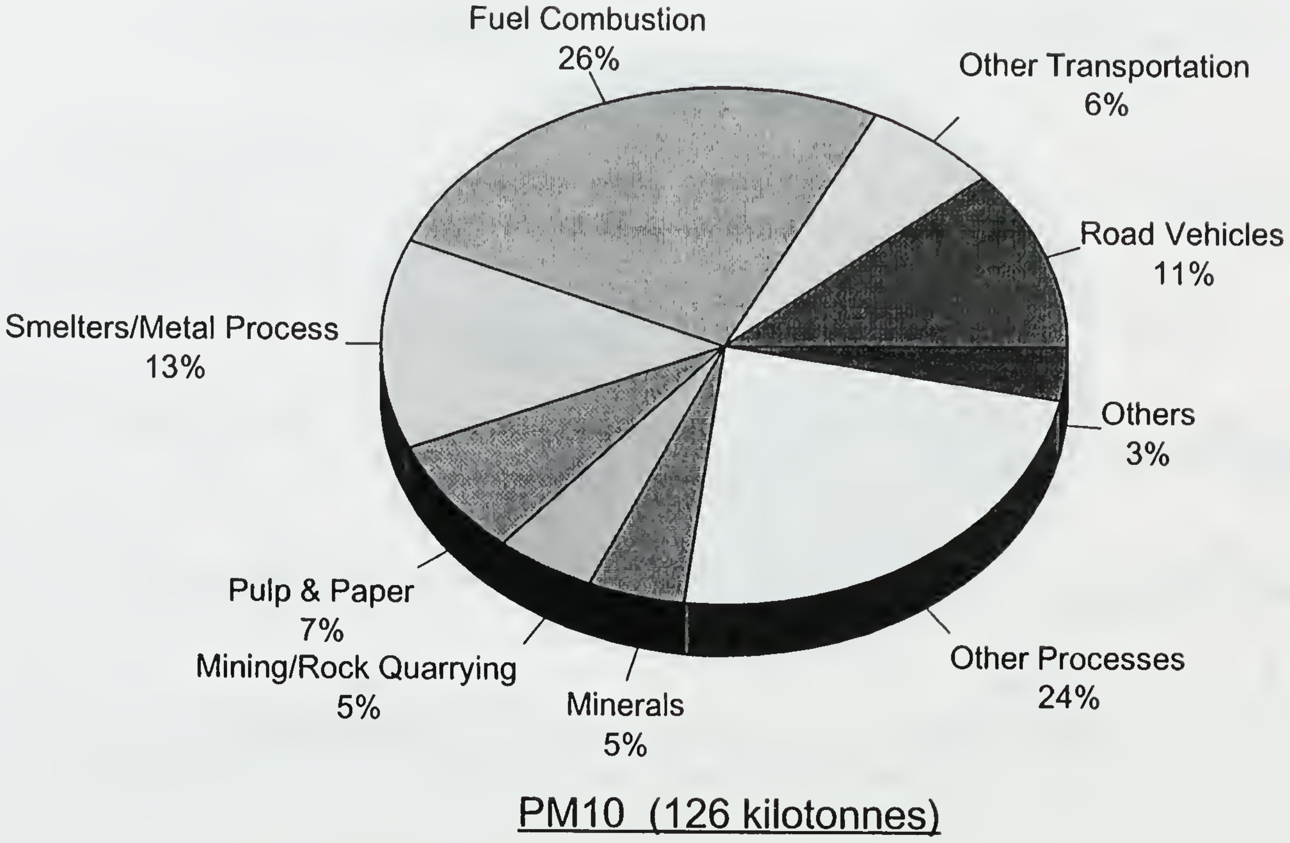
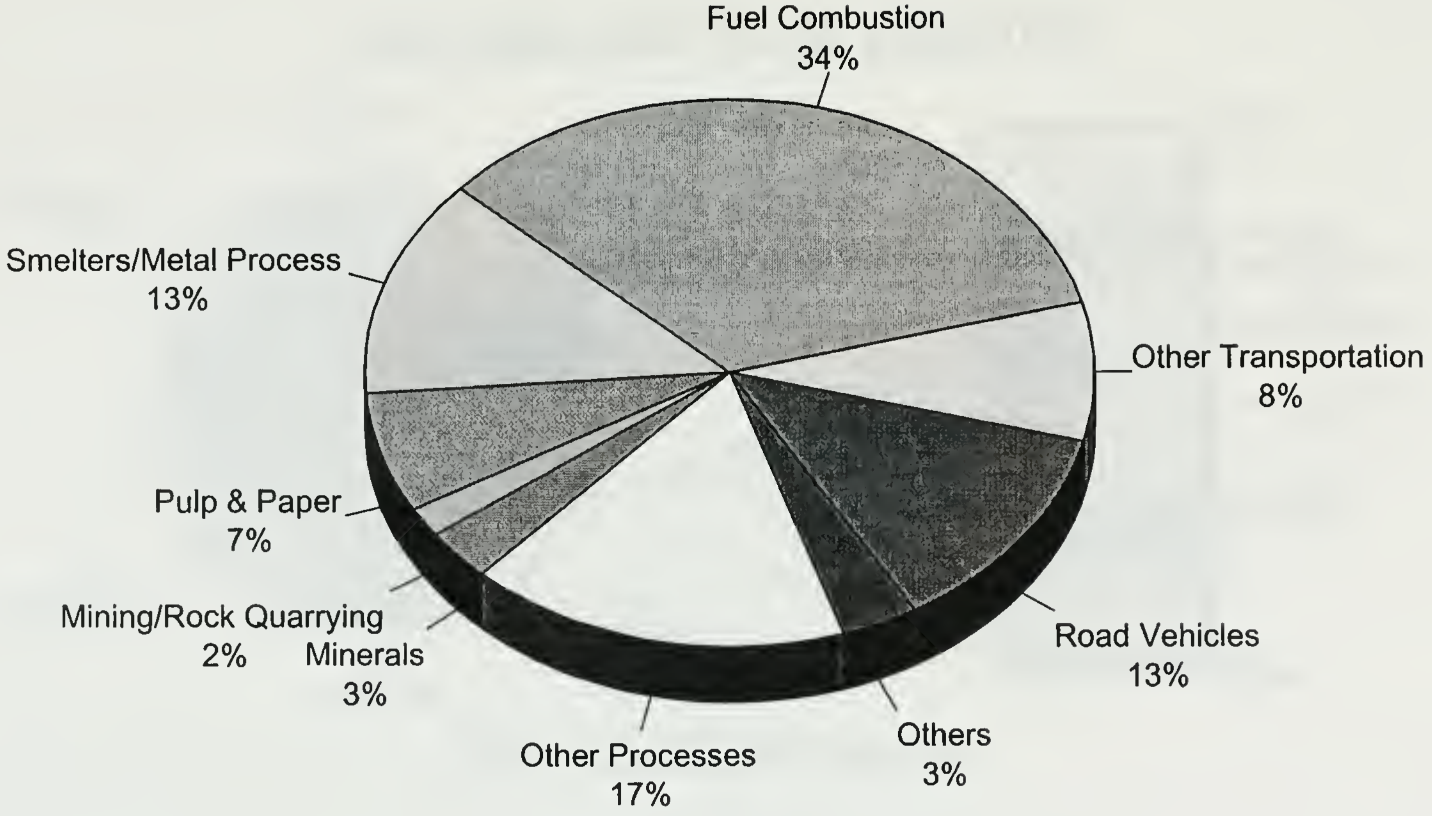


Figure III.1.2c ONTARIO $PM_{2.5}$ EMISSIONS BY MAJOR SECTORS
(Emissions From Point/Mobile/Area Sources, 1995 Estimates)



PM2.5 (92 kilotonnes)

Figure III.1.3a ONTARIO TOTAL PARTICULATE EMISSIONS BY SECTORS
(Emissions From All Sources, 1995 Estimates)

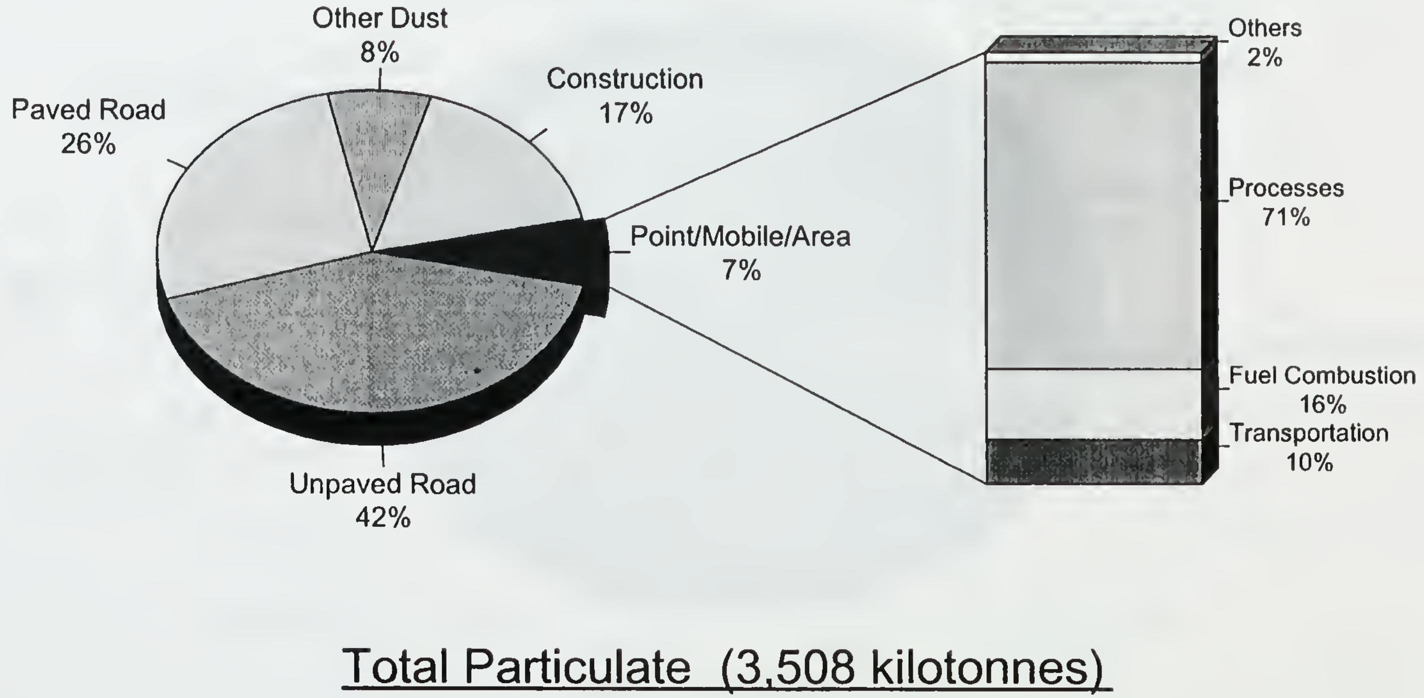
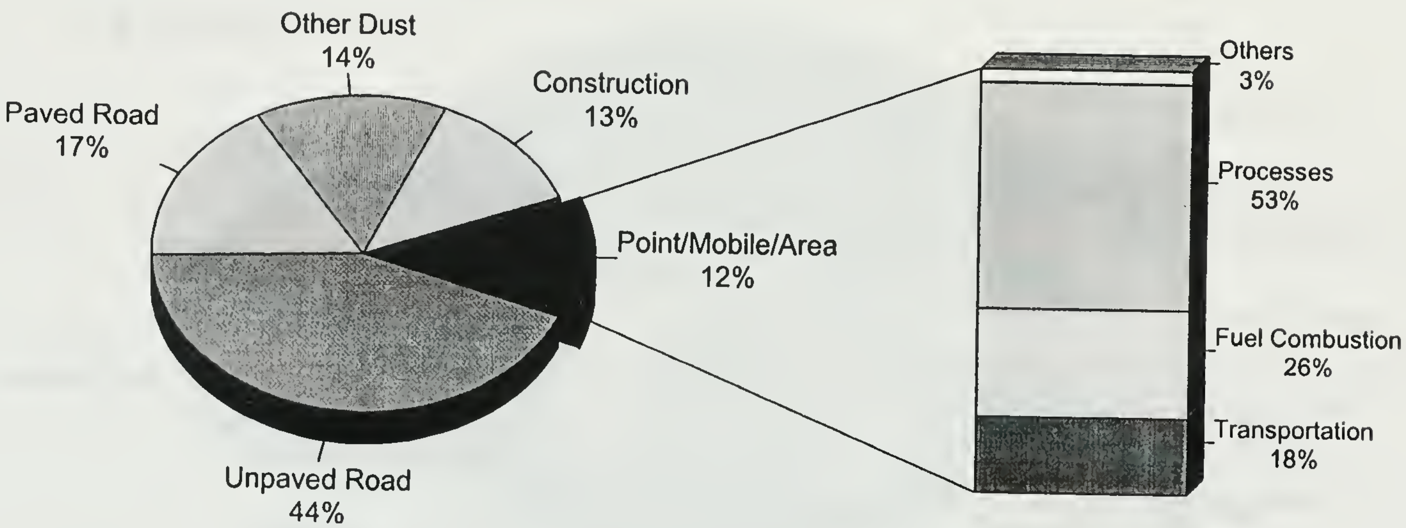
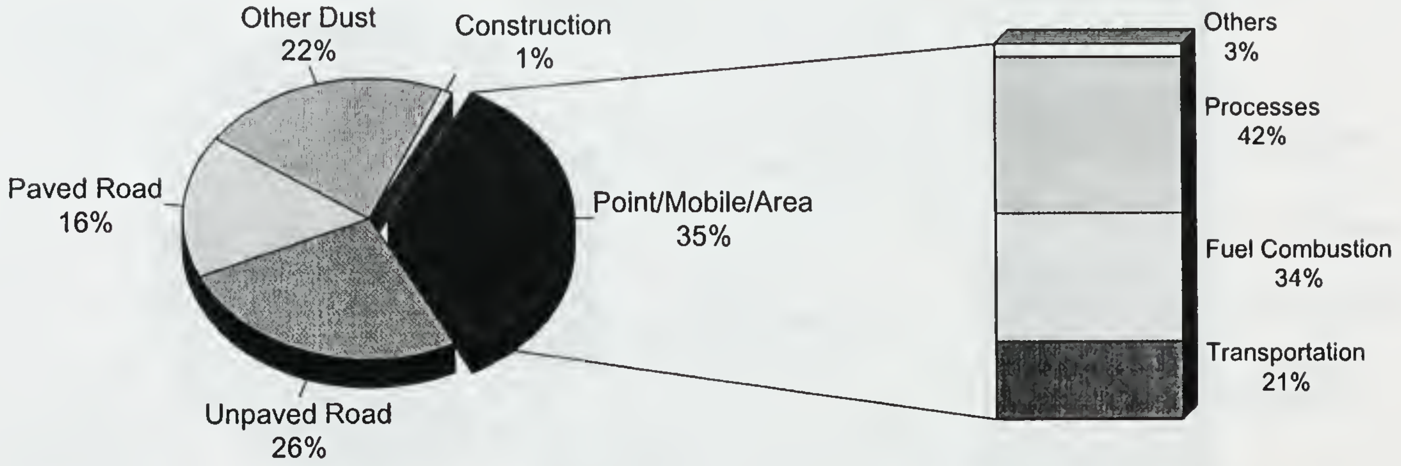


Figure III.1.3b ONTARIO $PM_{10}$ EMISSIONS BY SECTORS
(Emissions From All Sources, 1995 Estimates)



PM10 (1,045 kilotonnes)

## Figure III.1.3c ONTARIO $PM_{2.5}$ EMISSIONS BY SECTORS
(Emissions From All Sources, 1995 Estimates)



PM2.5 (260 kilotonnes)

**Figure III.1.4 ONTARIO $SO_2$ EMISSIONS BY SECTORS**
**(Emissions From Point/Mobile/Area Sources, 1995 Estimates)**

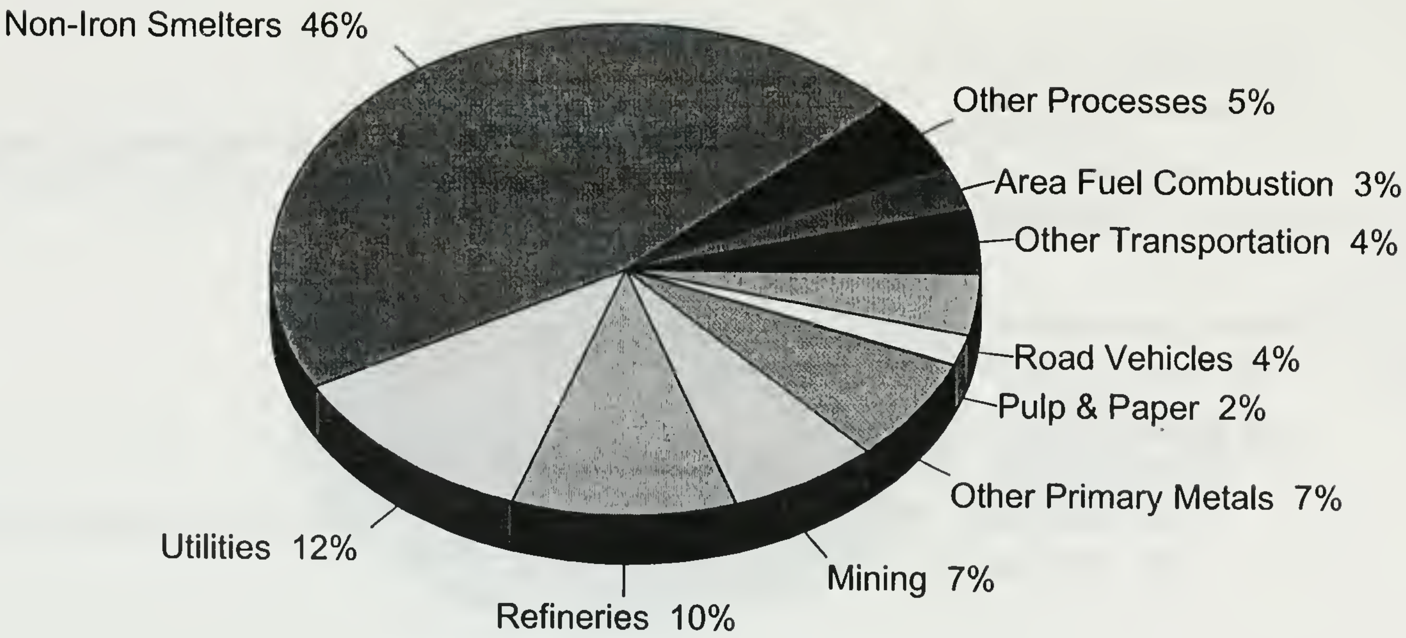


**Figure III.1.5 ONTARIO $NO_x$ EMISSIONS BY SECTORS**
**(Emissions From Point/Mobile/Area Sources, 1995 Estimates)**

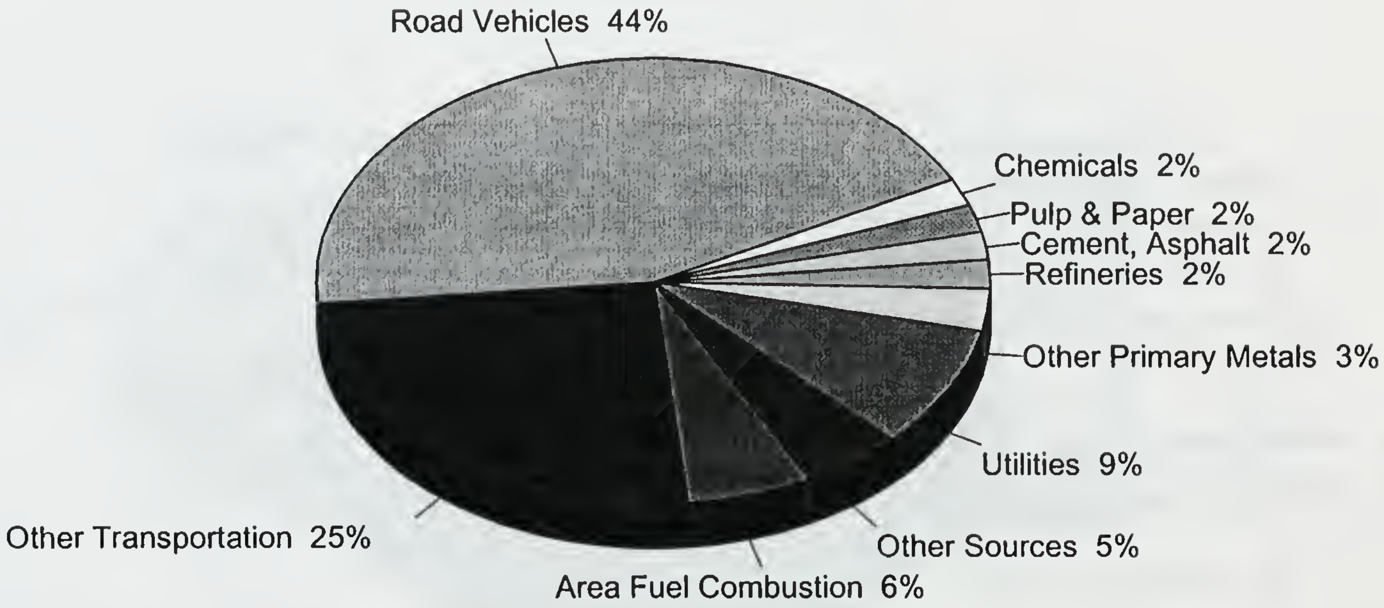
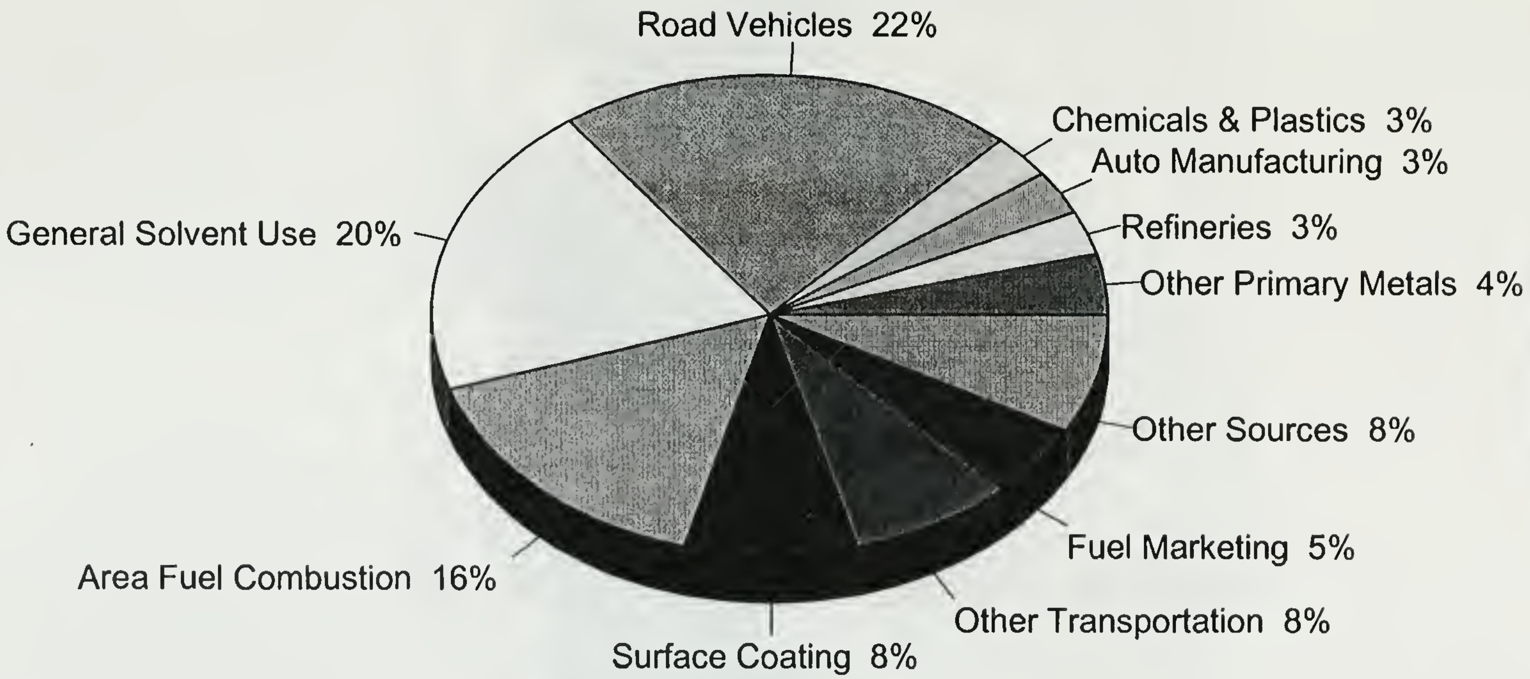


**Figure III.1.6 ONTARIO VOC EMISSIONS BY SECTORS**
**(Emissions From Point/Mobile/Area Sources, 1995 Estimates)**



## FIGURE III.1.7 1995 $SO_2$ Emissions for US States Affecting Ontario (kilotonnes)

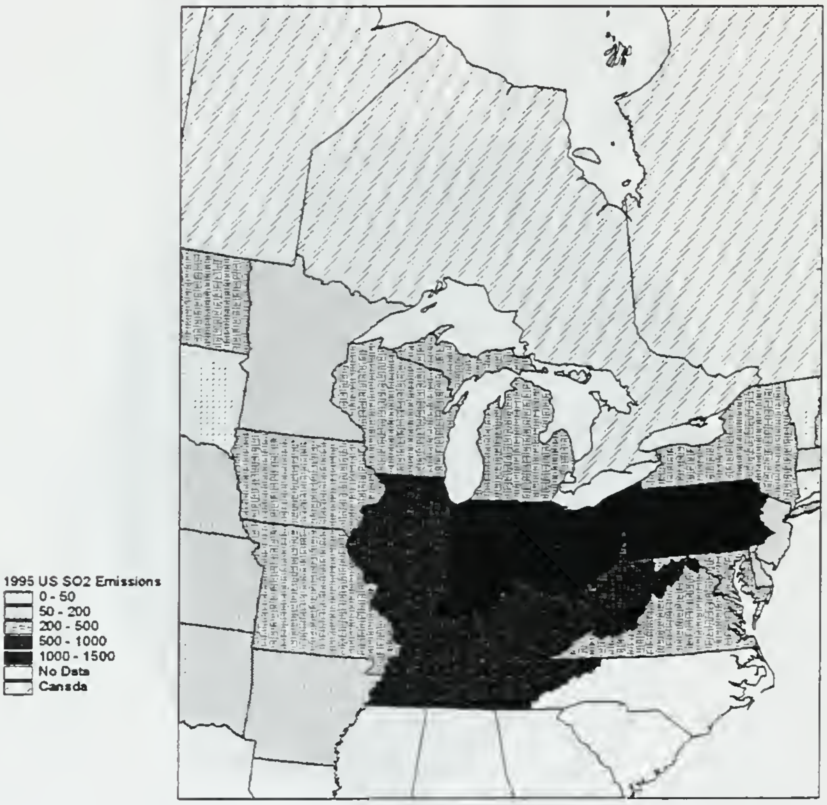
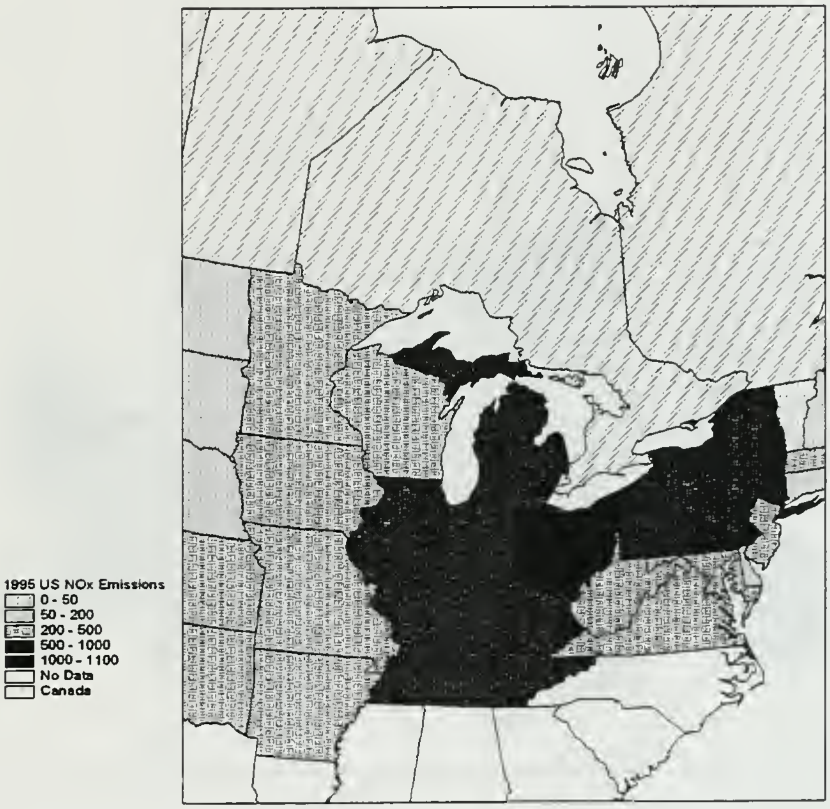


**FIGURE III.1.8 1995 $NO_x$ Emissions for US States Affecting Ontario (kilotonnes)**



## FIGURE III.1.9 1995 $PM_{10}$ Emissions for US States Affecting Ontario (kilotonnes)

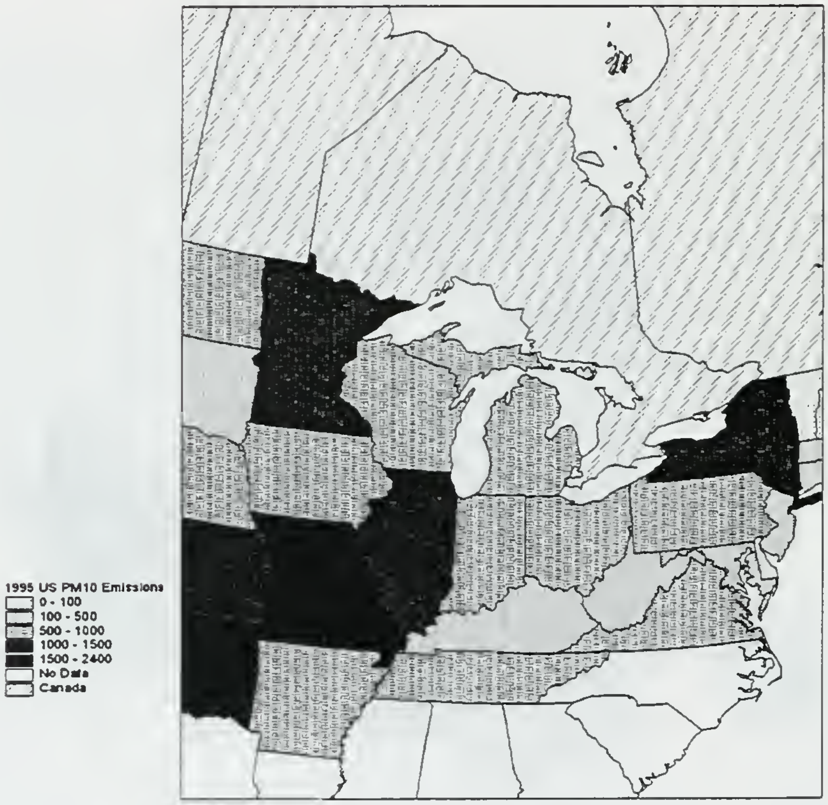
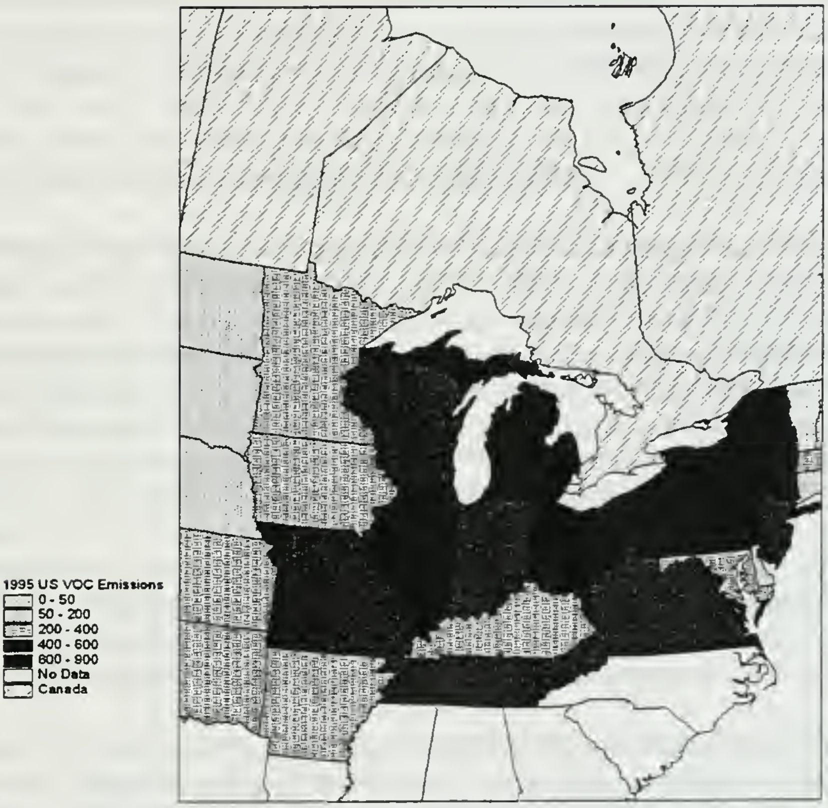


**FIGURE III.1.10 1995 VOC Emissions for US States Affecting Ontario (kilotonnes)**



## III.2 PARTICULATE MATTER ( $PM_{10}/PM_{2.5}$ ) MEASUREMENTS

The chemical composition of the fine fraction of $PM_{10}$ (i.e., $PM_{2.5}$) is very different from that found in the coarse fraction (size between 2.5 and 10μm). $PM_{2.5}$ is typically comprised of a combination of elemental carbon, organic carbons, sulphate, nitrate and ammonium with small amounts of crustal/soil elements. Both primary emissions and secondary aerosol formation account for the fine particle mass. The elemental carbon particles arethe result of primary emissions from combustion processes such as diesel exhaust and wood burning. Organic carbon particles are due to a combinationof secondary aerosol formation and primary emissions mainly from combustion sources. The coarse fraction of $PM_{10}$ is usually dominated by crustal elements such as silicon, aluminum, iron and calcium with sea salt being a significant component near oceans. The chemical constituents of the fine and coarse fractions of $PM_{10}$ provide strong indications of the sources from which the particle mass originates.

### III.2.1 Observed $PM_{10}/PM_{2.5}$ Concentrations and Compositions in the United States

There are several recent reports which include information on the chemical composition of $PM_{10}$ and $PM_{2.5}$ at sites in the eastern U.S.. In 1996, US EPA released a document entitled "Air Quality Criteria for Particulate Matter" which includes information across the U.S. on air concentrations of $PM_{10}/PM_{2.5}$ and their trends as well as providing the available data on the chemical composition of the fine and coarse fractions of $PM_{10}$. A more recent document was prepared by US EPA for the Federal Advisory Committee Act (FACA) National and Regional Strategies Workgroup entitled "$PM_{2.5}$ Composition and Sources; June 1997". Information on the chemical composition of $PM_{2.5}$ at some additional eastern U.S. sites has been presented by Pace (1998).

The rural monitoring networks used in these analyses were the Interagency Monitoring of Protected Visual Environments (IMPROVE) andthe Northeast States for Coordinated Air Use Management (NESCAUM). Urban and suburban monitoring is provided primarily from the Aerometric Information Retrieval System (AIRS) network along with some NESCAUM sites.

Over most of the eastern half of the United States rural $PM_{2.5}$ concentrations are in the 8 to 12 $\mu g/m^3$ range with the lower concentrations found in the New England subregion. The annual average concentrations of the rural coarse fraction of $PM_{10}$ are in the 4 to 7 $\mu g/m^3$ range. $PM_{2.5}$ accounts for about 60 to 70% of $PM_{10}$ mass at rural sites in the eastern U.S.. For both the fine and coarse fractions of $PM_{10}$, higher concentrations are found in the summer than the winter.

U.S. urban and suburban $PM_{10}$ concentrations measured in the AIRS network have shown a reduction of about 40% between 1986 and 1993. The U.S. average for $PM_{10}$ was 26 $\mu g/m^3$ in 1993 with a large variability across the country.

For the eastern U.S., the 1993 average urban $PM_{10}$ concentration was about 25 $\mu g/m^3$; however, there were many locations where annual average $PM_{10}$ concentrations exceeded 35 $\mu g/m^3$. As was found at rural sites, $PM_{2.5}$ accounted for about 60% of the $PM_{10}$ mass.

Although the chemical composition of $PM_{2.5}$ and the coarse fraction of $PM_{10}$ are described in the 1996 US EPA report, speciation data for the eastern U.S. were limited at the time of that study. Subsequent documents by US EPA (US EPA, 1997, Pace, 1998) have summarized the analyses of chemical composition data from the IMPROVE and NESCAUM networks. The data for the eastern U.S. include Washington, DC, Boston and Rochester as urban sites.

Figure III-2.1 gives pie charts developed by US EPA showing the percentages of the $PM_{2.5}$ mass which are sulphate, nitrate, organic and elemental carbon and crustal/soil material. The chemical composition data for the eastern U.S. show sulphates contributing about 50% of the $PM_{2.5}$ mass at rural sites. The next largest component was elemental and organic carbon at 30 to 35% of the mass with ammonium nitrate and crustal/soil material each contributing 4 to 8% on average. The percentage contributions to the chemical composition for Washington D.C. were similar to the rural data with a slightly smaller percentage of sulphates and a larger percentage of ammonium nitrate. Pace (1998) has discussed the above data along with speciated $PM_{2.5}$ data for Boston and Rochester where 40-60% of the mass was elemental and organic carbon.

Over the western U.S., rural sites show higher contributions for elemental and organic carbon and ammonium nitrate with the sulphate percentage lower than that in the east.

Figure III-2.2, from US EPA (1997), presents the composition observed in Washington D.C. for $PM_{10}$ and $PM_{2.5}$. The coarse fraction of $PM_{10}$ was comprised largely of material from crustal/soil sources.

### III.2.2 Observed $PM_{10}$/$PM_{2.5}$ Concentrations and Compositions in Canada ( including Ontario)

Canada wide data on $PM_{10}$ and $PM_{2.5}$ from the NAPS (National Air Pollution Surveillance) particulate matter monitoring network has been summarized in a paper by Brook et. al. (1997a). Of the 19 dichotomous sampler sites in the network, 4 are located in rural areas.

Figure III-2.3 gives box plots from Brook et. al. (1997a) of the concentrations of total suspended particulate matter (TSP), $PM_{10}$, $PM_{2.5}$ and sulphate measured in 10 urban centres across Canada between 1986 and 1993. $PM_{10}$ concentrations ranged from about 17 to 33 μg/m$^3$. Urban areas over the prairie provinces had lower $PM_{2.5}$ concentrations than those found in most eastern urban areas but $PM_{10}$ concentrations were similar because the coarse fraction of $PM_{10}$ was larger in these prairie cities. $PM_{2.5}$ accounted for 50 to 60% of the $PM_{10}$ mass at most of the urban sites with the prairie cities having only 35 to 40% of the $PM_{10}$ mass as fine particles. Section III.2.3 provides additional details of studies on Ontario $PM_{10}$ and $PM_{2.5}$ measurements from various networks.

A partial chemical composition analysis was performed on this data set. Elemental and organic carbon were not measured while ammoniumand sodium were only measured for the 1993 data. In addition, the nitrate concentrations measured in this dichotomous sampler network are likely underestimated due to volatilization losses from the filter.

Within these limitations,Brook et. al. (1997a) have used the available chemical composition data to estimate contributions to the fine and coarse fractions of $PM_{10}$. The chemical composition analysis of the fine fraction, $PM_{2.5}$, only accounted for 40 to 60% of the mass. Part of the missing mass would be elemental carbon and organic carbon compounds. The Ontario sites analyzed were in Ottawa, Toronto, Windsor, Walpole Island and Egbert. The soil/crustal contribution to $PM_{2.5}$ ranged from 5 to 10% of the mass at these sites. Ammonium sulphate and ammonium nitrate represented 30-40% and about 3-6% of the fine mass, respectively. Similarly at other eastern Canadian sites, the ammonium sulphate/ammonium nitrate component of $PM_{2.5}$ was usually 4 to 6 times larger than the crustal/soil component. In western Canadian cities crustal/soil material accounted for 10 to 15% of the $PM_{2.5}$ mass while ammonium sulphate/ammonium nitrate contributed 25 to 30% of the fine mass.

The analysis of the coarse fraction of $PM_{10}$ showed missing mass as 25 to 45% of the total for sites across Canada. On average the crustal/soil component accounted for 50% of the coarse mass with the Ontario sites ranging from 45% to 55% crustal/soil material. At Ontario sites, ammonium sulphate/ammoniumnitrate provided about 10% of the coarse fraction mass. All urban sites had some NaCl during the winter (due in part to road salt) while sites on the east and west coasts had a sea salt contribution throughout the year (about 10% of the coarse fraction mass was NaCl at coastal sites). Figure III-2.4 from Brook et. al. (1997a) is a bar chart giving the chemical composition of the fine and coarse fractions measured at 17 sites across Canada.

While the above inorganic chemical composition analysis provides data for a large number of sites across Canada, the data are limited by the lack of elemental and organic carbon analyses and uncertainties in the nitrate concentrations. An earlier study by Environmental Applications Group (1984), using dichotomous sampler data from August 1983 to January 1984 at seven sites across Canada, included only a limited number of samples at each site (two to six samples per site) for which elemental carbon was analyzed in addition to the elements and ions. Use of this data set for chemical composition analyses is limited by uncertainties in the nitrate measurements and the lack of organic carbon measurements.

Two recent Canadian chemical composition analyses are a study of $PM_{2.5}$ in the Lower Fraser Valley during the summer of 1993 (REVEAL; REgional Visibility Experimental Assessment in the Lower Fraser Valley) and a study of $PM_{2.5}$ and the coarse fraction of $PM_{10}$ at a site in Toronto (August to October, 1995). For both of these studies elemental and organic carbon were measured and the nitrate measurements were more reliable than those taken with dichotomous samplers. A third study on visibility at 4 sites across Canada included elemental and organic carbon analyses but nitrate was not measured (Hoff et. al., 1997).

The REVEAL study in the Greater Vancouver area found ammonium sulphate and ammonium nitrate contributed about 25% and 20% of the $PM_{2.5}$ mass, respectively (Sakayama, 1994, Lowenthal et.al., 1996). The ratio of elemental to organic carbon was only about 25% in this data set, which is lower than that usually found in U.S. studies. Elemental and organic carbons represented 40 to 50% of the $PM_{2.5}$ mass during the REVEAL study. Crustal/soil related elements indicate that fugitive dust sources account for 3 to 10% of the fine particle mass. A smaller marine contribution of NaCl to

$PM_{2.5}$ was also identified in this study (about 3%).

Hoff et. al. (1997) reported on visibility and the chemical composition of $PM_{2.5}$ at 4 sites across Canada including Egbert which is located about 60 km north of Toronto. The measurements were made with the monitor type used in the IMPROVE network but including only part of the IMPROVE measurement protocol. Elemental and total organic carbon were measured but nitrate was not. Analyzing data at Egbert from 1990 to 1996, they found an average $PM_{2.5}$ concentration of about 10 $\mu g/m^3$ comprised of 38% sulphates, 30% organic carbon compounds, 6.5% elemental carbon, 4% crustal/soil material with the remaining concentration (about 22%) presumed to be ammonium nitrate.

The chemical composition analysis at Evans Avenue in Toronto was undertaken as part of Canadian Council of Ministers of the Environment (CCME) mandated Sulphur in Gasoline Study. The results are presented in "Atmospheric Science Expert Panel Report, Sulphur in Gasoline and Diesel Fuels, 1997". Analyses of 23 samples collected from late August to early October 1995 were performed. For $PM_{2.5}$, the percentage contributions of ammonium sulphate, ammonium nitrate, elemental carbon and organic carbon were 33%, 6%, 33% and 25%, respectively. Most of the remaining 3-4% was related to crustal/soil sources. The high ratio of elemental to organic carbon found in this study might have resulted from the close proximity of the site to a highway as well as diesel truck activity in the industrial area around the site. Also, on an annual basis the ammonium sulphate percentage of the $PM_{2.5}$ mass is likely larger than that found in this limited study since the annual average sulphate concentration at the Evans Avenue site is more than 50% higher than the sulphate concentrations for the samples analyzed in the fall 1995 period.

For the coarse fraction of $PM_{10}$, ammonium sulphate and ammonium nitrate respectively accounted for only 3% and 5% of the mass at Evans Avenue. Crustal/soil related sources were estimated to contribute about 55% of the coarse fraction mass. Elemental and organic carbon represented about 35% of the mass of coarse particles. Pie charts of the chemical composition of $PM_{2.5}$, coarse particles and $PM_{10}$ for the Evans Avenue data are presented in Figure III-2.5.

Brook et. al. (1997b) and Brook and Dann (1997) have presented nitrate and nitric acid concentration data at urban and rural sites across Canada. The sites in Ontario; Windsor, Hamilton, Toronto and Egbert (a rural site); had annual average nitrate concentrations of about 2.4, 2.2, >1.4 and 1.5 $\mu g/m^3$ respectively which represents about 10 to 15% of the $PM_{2.5}$ mass. The nitrate concentrations in the warm season were found to be 25 to 50% smaller than cold season averages at the Ontario sites. On the other hand, nitric acid concentrations were larger in the warm season and represented half or more of the total-$NO_3$ (nitrate plus nitric acid) mass on an annual basis. That means there would be more nitric acid available for conversion to ammonium nitrate if sufficient ammonia gas were present.

### III.2.3 $PM_{10}/PM_{2.5}$ Measurements in Ontario

#### *III.2.3.1 $PM_{10}/PM_{2.5}$ Monitoring Networks in Ontario*

As indicated in Section II.1, particulate matter has been measured in Ontario for over 25 years, mostly by high volume samplers, dustfall jars, and soiling index tape samplers. Overall, particulate matter levels have improved since the 1970s and in particular, for the period prior to the early 1980s (for example, total suspended particulate matter has declined by 54 per cent over the past 25 years). Munro (1998) overview report on Sarnia area particulate matter for the period 1968 to 1998 also shows this decreasing trend for total suspended particulate matter. The report also includes long-term data of inhalable particluate matter ($PM_{15}$) for Lambton Country for the period 1980 to 1993 and this also show some decline in the early 1980s. These long term measurement programs contain valuable information and provide an important perspective to the more recent programs underway to monitor $PM_{10}$ and $PM_{2.5}$ across Ontario.

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Since 1984 Environment Canada, in cooperation with provincial and municipal agencies, has been operating a measurement program for $PM_{10}$ and $PM_{2.5}$ across Canada. Both dichotomous (Dichot) samplers and size selective inlet (SSI) hi-vol samplers are used in the program. The Dichot sampler fractionates particles according to their aerodynamic characteristics and hence allows two size fractions of particulate matter ($PM_{10}$ and $PM_{2.5}$) to be measured simultaneously. As part of this network, there are data from urban locations in Ontario, namely Windsor, Toronto, Hamilton and Ottawa and from 2 rural sites, Walpole Island and Egbert.

The Ontario Ministry of the Environment commenced in 1989 to monitor daily $PM_{10}$ on a six day cycle. Inhalable particulate matter is monitored by modified Hi-vol sampler outfitted with a size selective inlet to restrict particle size to no greater than 10 um. Quartz fibre filters are used as the filter medium for collection. The daily concentration of inhalable particulate matter is computed from the mass of collected particles and the volume of air sampled. The filters are also analyzed for various trace metals and sulphate. There are currently 23 such monitors in the province (Figure III-2.6). Only six of these daily $PM_{10}$ monitors have measured ambient urban data continuously throughout the period 1991 to 1996 and these data are used to produce yearly and monthly trends.

Since June 1995, the Ministry has installed a state-of-the-art continuous (inhalable and respirable) particulate matter monitoring network of 23 real-time instruments across the province (Figure III-2.7). Continuous hourly measurements of either $PM_{10}$ or $PM_{2.5}$ are obtained by the Tapered Element Oscillating Microbalance (TEOM) method. The TEOM measures the accumulation of mass on a heated filter attached to a hollow, tapered, oscillating glass rod. From change in the oscillation frequency, direct measurement of mass accumulation over time is obtained. The $PM_{10}/PM_{2.5}$ monitoring is intended to allow the capture of immediate changes in fine particulate matter levels in urban communities, near local industries, and in areas impacted by transboundary sources. Fairly complete $PM_{10}$ data from this network are available in 1996 for 5 urban sites, namely, Windsor, London, Hamilton, Kingston and Sault-Ste-Marie and for one $PM_{2.5}$ site, Toronto.

Complementing the continuous PM provincial network are networks operated by the Lambton Industrial Society in the Sarnia area (2 TEOM instruments, one $PM_{10}$ and one $PM_{2.5}$) and by Ontario Hydro in the Nanticoke area (4 TEOM instruments, two $PM_{10}$ and two $PM_{2.5}$). These have been in operation since 1997.

Comparisons of 24-hour average $PM_{10}$ concentrations determined with the TEOM versus the 24-hour average $PM_{10}$ concentrations determined with the size-selective $PM_{10}$ (six day cycle data) at co-located sites in Hamilton and Sault-Ste-Marie for 1996 show good agreement between the two methods used to obtain daily averages ($r^2$=0.96 in the case of Hamilton and 0.91 in the case of the Sault-Ste-Marie data). Daily average ratios for the two methods (TEOM/Hi-Vol) were 1.04 for Hamilton and 0.89 for Sault-Ste-Marie (Yap et. al., 1998).

### *III.2.3.2 Environment Canada Studies*

Based on studies of the period 1984-1995 (Dann, 1994, SAD, 1997), mean $PM_{10}$ concentrations at the urban (downtown) sites in Ontario range from 21 $\mu g/m^3$ in Ottawa, 26-28 $\mu g/m^3$ in Toronto to 31 $\mu g/m^3$ in both Hamilton and Windsor. The rural site, Egbert, recorded a mean concentration of 17 $\mu g/m^3$. Walpole Island, the other rural site, recorded relatively high $PM_{10}$ values (a mean of 30 $\mu g/m^3$) due partly to the effect of windblown dust from nearby agricultural operations and also to its proximity to Metropolitan Detroit.

Annual mean $PM_{2.5}$ concentrations at the urban sites in Ontario range from 12 $\mu g/m^3$ in Ottawa, and 16 $\mu g/m^3$ in Toronto, to 18 $\mu g/m^3$ in both Hamilton and Windsor . The rural site , Egbert, recorded 11 $\mu g/m^3$ and Walpole Island, 18 $\mu g/m^3$. These results indicate that $PM_{2.5}$ generally accounted for about sixty percent of $PM_{10}$.

On a seasonal basis, the highest concentrations were recorded in the summer months with a peak median value in August. At all sites the seasonal variation in $PM_{2.5}$ was similar to that of $PM_{10}$. Day of the week variation showed minimum $PM_{10}$ concentrations on Sunday and typical maximum concentrations during the middle of the week. A substantial contribution to $PM_{10}$ from transportation sources was suggested. Such observations are noteworthy and offer potential reality check on the various source sector contribution estimates (e.g. emissions from road dust) to the emission inventory of $PM_{10}$ in Ontario.

Unlike other sites in Canada, the Ontario sites have not shown a decreasing trend in $PM_{10}$ and $PM_{2.5}$ concentrations, rather there were no significant changes during the study period 1984-1993.

Sulphate was the most dominant compound associated with the collected $PM_{10}$ samples in Ontario, ranging from a mean concentration of 3 $\mu g/m^3$ in Ottawa, 3 to 5 $\mu g/m^3$ in Toronto, 5 µg/m3 in Windsor, to 6 $\mu g/m^3$ in Hamilton. The rural sites also ranged from 3 to 6 $\mu g/m^3$. Maximum 24 hour sulphate concentrations of over 30 $\mu g/m^3$ were measured at most of the Ontario sites. Also, there was no statistically significant change in fine sulphate concentrations during the study period. The sulphate/$PM_{2.5}$ ratios in Ontario were about 0.30.

Examination of other species in $PM_{10}$ samples (nitrate, chromium, iron, lead, manganese, nickel, vanadium and zinc) revealed overall decreasing trends in Ontario cities.

In terms of distribution, SAD (1997) indicates that $PM_{10}/PM_{2.5}$ data were found to be strongly skewed, and to be best fitted by a Weibull distribution rather than a log-normal distribution. The large number of low values would tend to mask trends in PM concentrations or the frequency or magnitude of extreme events. With the normal frequency of sampling every six days, the upper portion of the frequency distribution may not be well represented. It is noted, nevertheless, that average $PM_{10}$ and $PM_{2.5}$ concentrations are commonly calculated using the arithmetic mean.

### *III.2.3.3 Environment Ontario Studies*

A study undertaken to analyse the daily (six day cycle) $PM_{10}$ data of the Environment Ontario network (22 monitoring sites) for the five year period 1990 to 1994 (Debosz, 1996) showed the following:

Mean $PM_{10}$ concentrations (all available data) ranged from 16 to 38 $\mu g/m^3$ with most sites in the range 20 to 30 $\mu g/m^3$. The highest concentrations of $PM_{10}$ (in terms of means and 90th percentiles) were recorded at the Sault Ste Marie site. These results are consistent with those reported in the Environment Canada studies and with recent provincial data for the 5 year period 1992 to 1996 (Figure III-2.8 and Table III-2.1).

Mean sulphate concentrations measured in $PM_{10}$ ranged from 2.1 $\mu g/m^3$ in Thunder Bay to 6.7 $\mu g/m^3$ in Hamilton for the period 1990 to 1993 (Debosz, 1996). For the 1992 to 1996 period, the range was from 2.0 $\mu g/m^3$ in Thunder Bay to 5.9 $\mu g/m^3$ in Hamilton (Figure III-2.9 and Table III-2.2). These sulphate results are consistent with that found in the Acid Precipitation in Ontario Study (APIOS) data (based on 18 sites across the province) for the period 1990 to 1995 which show a north-south gradient with mean rural sulphate concentrations ranging from4.1 $\mu g/m^3$ in southwest Ontario (Merlin) and 3.6 $\mu g/m^3$ in southeast Ontario (Point Petrie) to 2.1 $\mu g/m^3$ at Dorset in northeast Ontario.

The frequency distributions of 24-hour $PM_{10}$ concentrations were almost the same for sites located in the Metropolitan Toronto: Etobicoke, Toronto and Scarborough.

The ratios of iron to total $PM_{10}$ ranged from 0.06 at the Sault Ste Marie to 0.009 in Cornwall and London. There was a strong relationship between the measured concentration of iron and the location of the monitoring sites due to the impact of emissions from the nearby industrial sources.

The mean ratio of manganese to $PM_{10}$ ranged from 0.003 in Sault Ste Marie to 0.0004 in Fort Frances. These results also reflected strong industrial influences.

The mean ratio of copper to $PM_{10}$ ranged from 0.003 at the Sudbury site to 0.0003 at the London site. The ratio of copper to $PM_{10}$ was very high at the Sudbury site due to smelting operations.

Detailed analyses of the Hamilton area particulate matter (HAQI Env. WG Report, 1997) have revealed the following:

Annual average $PM_{10}$ concentrations were approximately 21 μg/m$^3$ over the suburban area (70% due to background sources, 10 % due to industrial sources and 20% due to urban sources), 27 μg/m$^3$ over urban areas (55% due to background, 15% due to industry and 30% due to urban sources), and $PM_{10}$ was greater than 30 μg/m$^3$ over industrial areas. Rural "background" concentrations were estimated to be 15 μg/m$^3$.

Both local and long-range transport sources contributed significantly to the annual $PM_{10}$, $PM_{2.5}$ to $PM_{10}$, $PM_{2.5}$ and nitrates levels. For sulphates and ammonium compounds, long-range transport sources were found to be the dominant contributor to the average annually observed concentrations.

Analyses of $PM_{10}$ and $PM_{2.5}$ data in Ontario (Fraser et. al.,1997) from both daily and continuous monitors show the following:

Based on the data collected at the six urban $PM_{10}$ monitoring sites, annual averages during the period 1991 to 1996 varied across the province and were governed to some extent by prevailing meteorological conditions (Figure III-2.10). A comparison with the California annual standard of 30 μg/m$^3$ show no exceedences at any of the sites during this period. The percentage of days on which $PM_{10}$ exceeded the interim Ontario daily criterion of 50 μg/m$^3$ is shown in Figure III-2.11. Windsor and Hamilton show the highest percentage of exceedence during this period. The majority of exceedences at Windsor is recorded during the summer months and this further points to the influence of transport of particulate matter into the province from nearby industrial sources. Hamilton, with its escarpment, is influenced by the emissions from the industries located around Hamilton harbour, as well as long-range transport, and has exceedence days during both spring and summer months.

Daily $PM_{10}$ levels from the continuous network, along with the data from the 6-day daily sampling network for 1995 showed that the highest percentage of days on which $PM_{10}$ exceeded the Ontario interim criterion of 50 μg/m$^3$ was approximately 5%, and this occurred in both Windsor and Hamilton. In 1996, the continuous data showed 40 days (11% of the year) of exceedences of the interim Ontario criterion in Hamilton and 17 such days (5% of the year) in Windsor. Comparable statistics were also noted for the daily 6-day $PM_{10}$ samples for Hamilton and Windsor.

The 1996 mean $PM_{2.5}$ level in Toronto, based on continuous measurements, was found to be 14 μg/m$^3$.

Dichotomous sampling of $PM_{10}$ and $PM_{2.5}$ in Windsor, Ontario for the period 1988-1994 during high event days (days with $PM_{10}$ concentrations above 50 μg/m$^3$ and sulphate above 20 μg/m$^3$) showed that $PM_{2.5}$ was approximately 73% of the $PM_{10}$ fraction and that sulphate accounted for approximately 50% of $PM_{2.5}$.

Trajectory analyses suggest that air pollutants transported over medium and long-range distances arrive mainly from several emission source regions in the U.S. and contribute to elevated sulphate and fine particulate matter pollution recorded in southern Ontario. A south to southwesterly flow on the rear side of a high pressure cellprovides favourable condition for transport of pollution and is conducive to episodes of sulphate and fine particulate matter pollution in southern Ontario.

Based on the measurements of $PM_{10}$ and $PM_{2.5}$ at Etobicoke in Metropolitan Toronto, $PM_{2.5}$ measurementsaccounted for about 80% of$PM_{10}$ during "episode" conditions (see for example, Figure III-2.12). It has been found that during ozone "episodes", $PM_{10}$ concentrations are also elevated (Figure III-2.13).

Data analysis strongly implicates neighbouring U.S. states as being significant contributors to the high levels of sulphate and fine particulate matter recorded in southern Ontario during “episode” conditions.

### *III.2.3.4 Future Efforts*

An expanded network of continuous $PM_{10}$ and $PM_{2.5}$ monitors is required for improved spatial representation of levels in Ontario. This would assist in the development of real-time forecasting techniques to augment the existing Air Quality Advisory Program and to allow improvement/modification to the existing Air Quality Index System in the province. It is also important to enhance the existing network with chemical speciation of fine particulate matter.

Such measurements would also be very useful for further assessment of and insight into the important relationshipof air pollution mixtures (carbon monoxide, nitrogen dioxide, sulphur dioxide, coefficient of haze, total suspended particulate matter, sulphates, $PM_{10}$ and $PM_{2.5)}$ and mortality as indicated by the recent study of Burnett et. al. (1998).

## III.2.4 References

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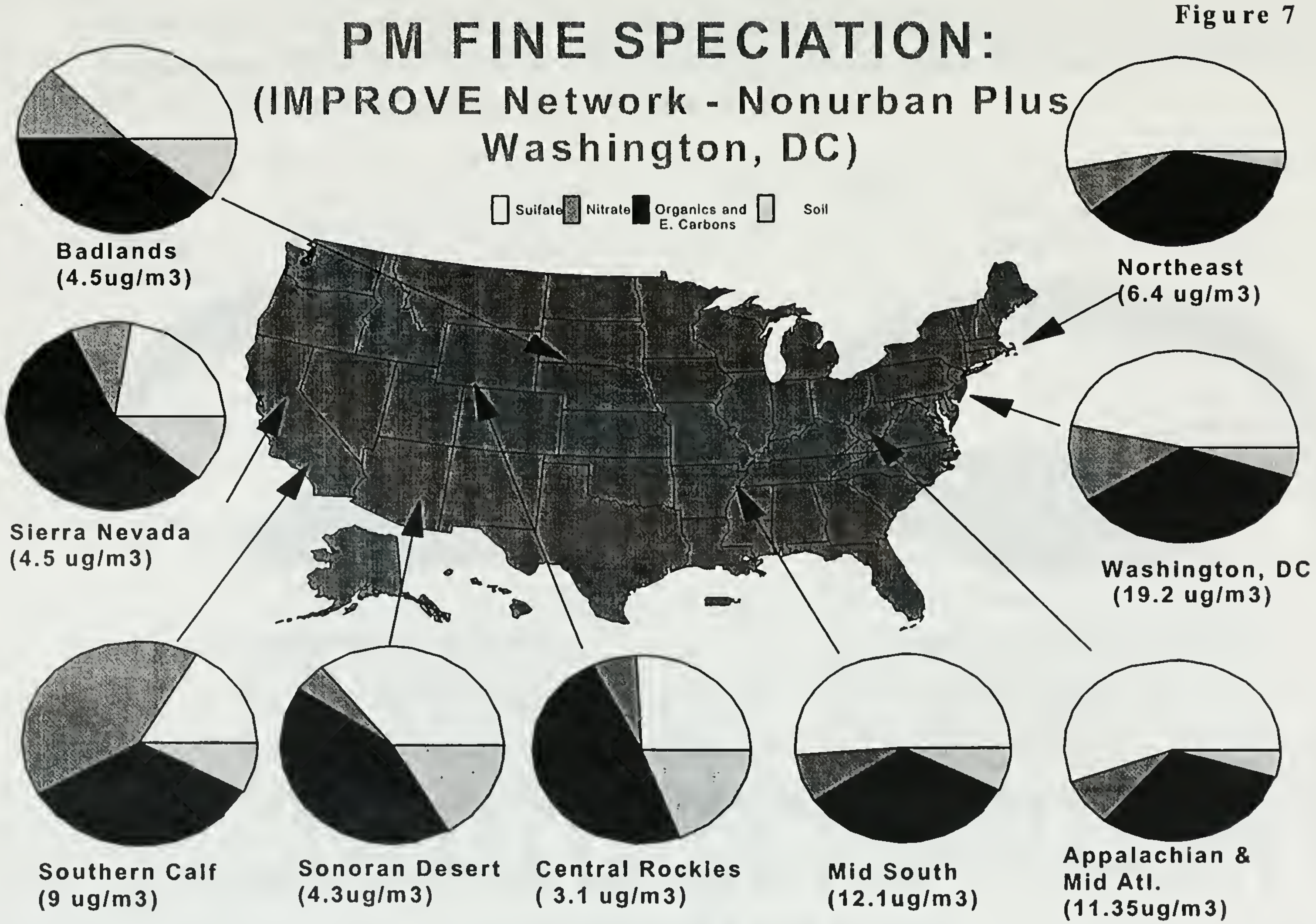
**Figure III.2.1**



Data from the IMPROVE network (July 1996, ISSN:0737-5352-32), (US- EPA, 1997)

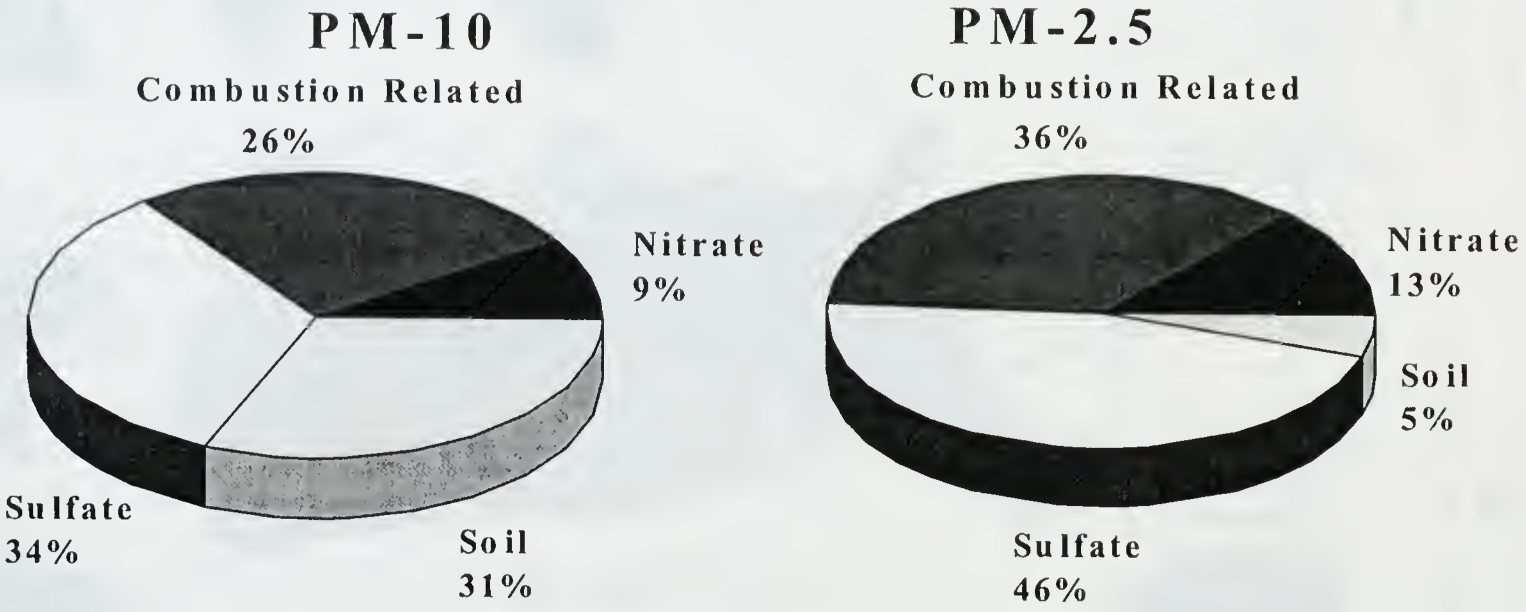
Figure III.2.2

Figure 4

# Washington, DC

## Comparison of PM-10 and PM-2.5 Sources

## (Based on Ambient Measurements)



Ref: Adapted from IMPROVE, Cooperative Center for Research in the Atmosphere CSU, Ft. Collins, CO, July 1996

6/5/97
DRAFT

Figure III.2.3: Comparison of the distributions of the TSP, $PM_{10}$, $PM_{2.5}$ and $SO_4^{=}$ at 11 urban sites (1984 to 1993). The box plots indicate the mean 24-hour concentration and the 5th, 25th, 75th and 95th percentiles. (Brook et. al. 1997a)

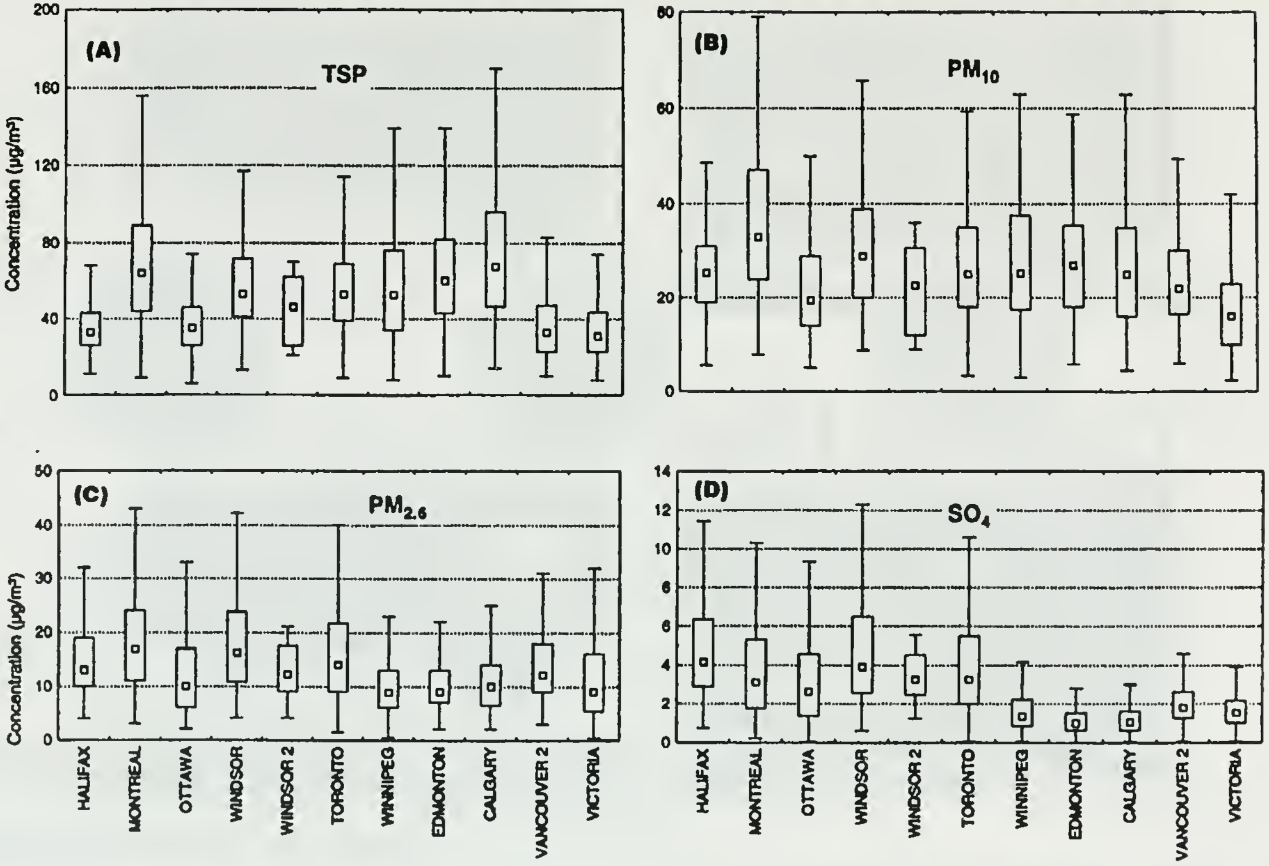


Figure III.2.4: Mean fractional contributions to the total fine and coarse mass from the chemical species attributed to soil (crustal material) $SO_4^=$, $NO_3^-$ (includes $NH_4^+$), NaCl and other elements. (Brook et. al. 1997a)

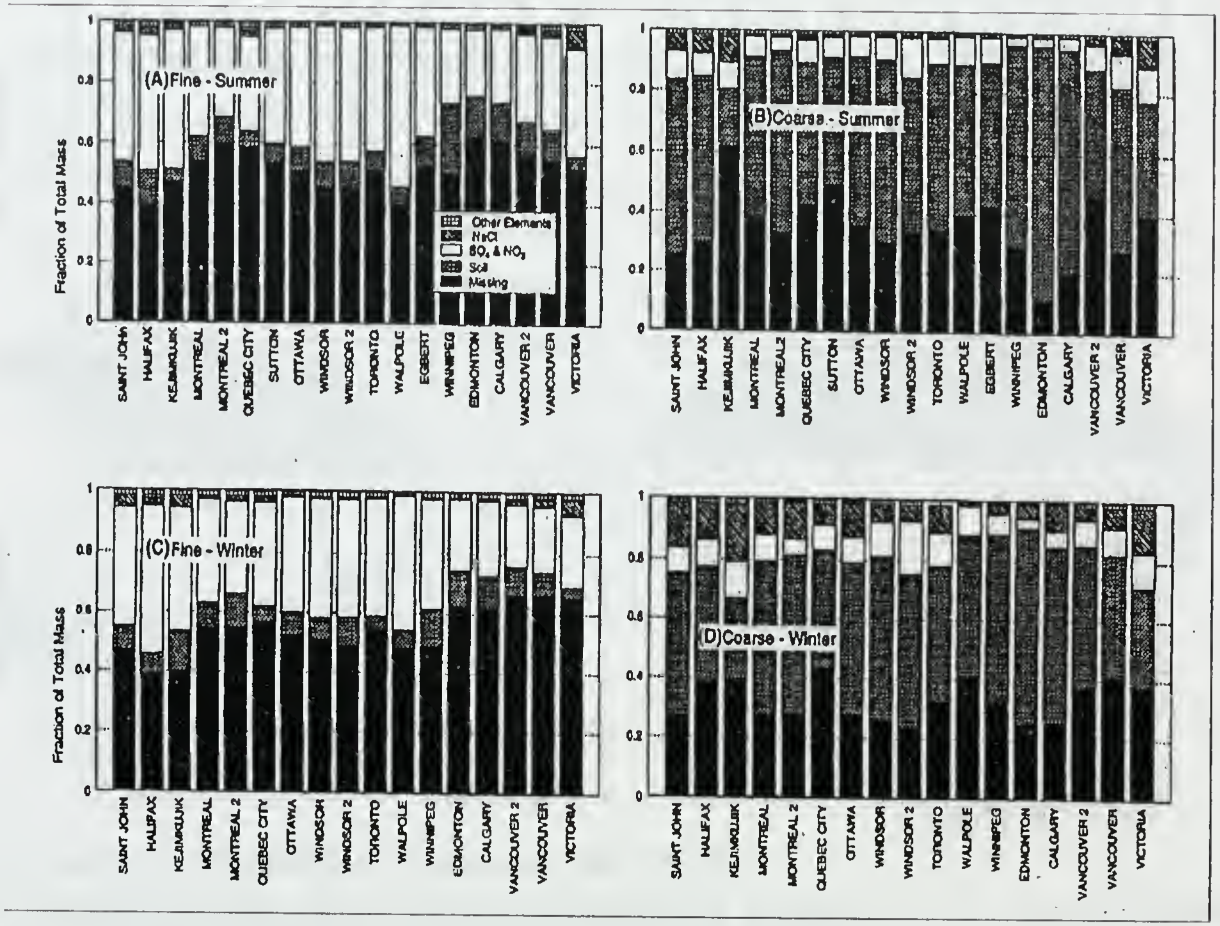
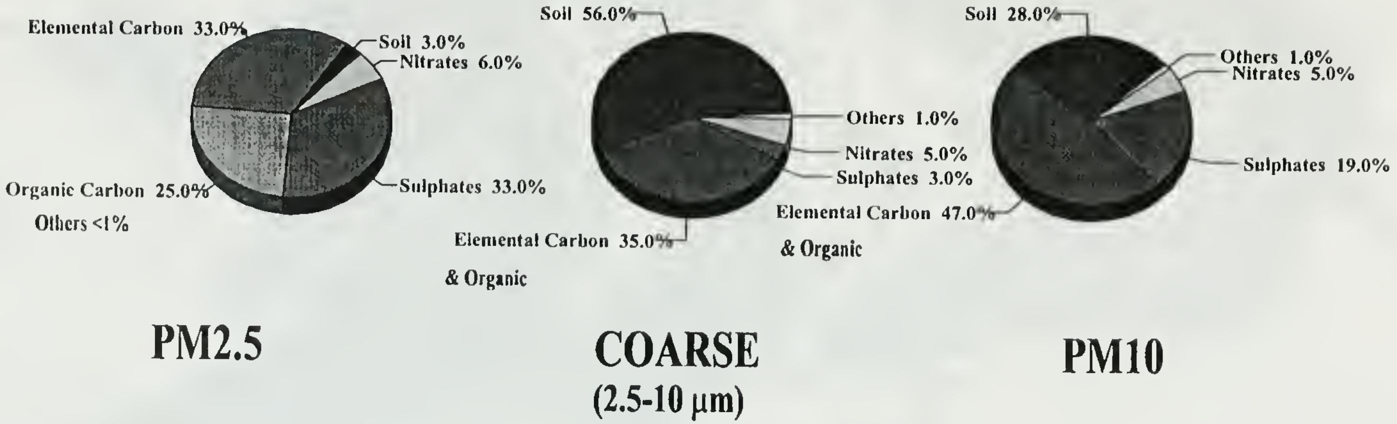
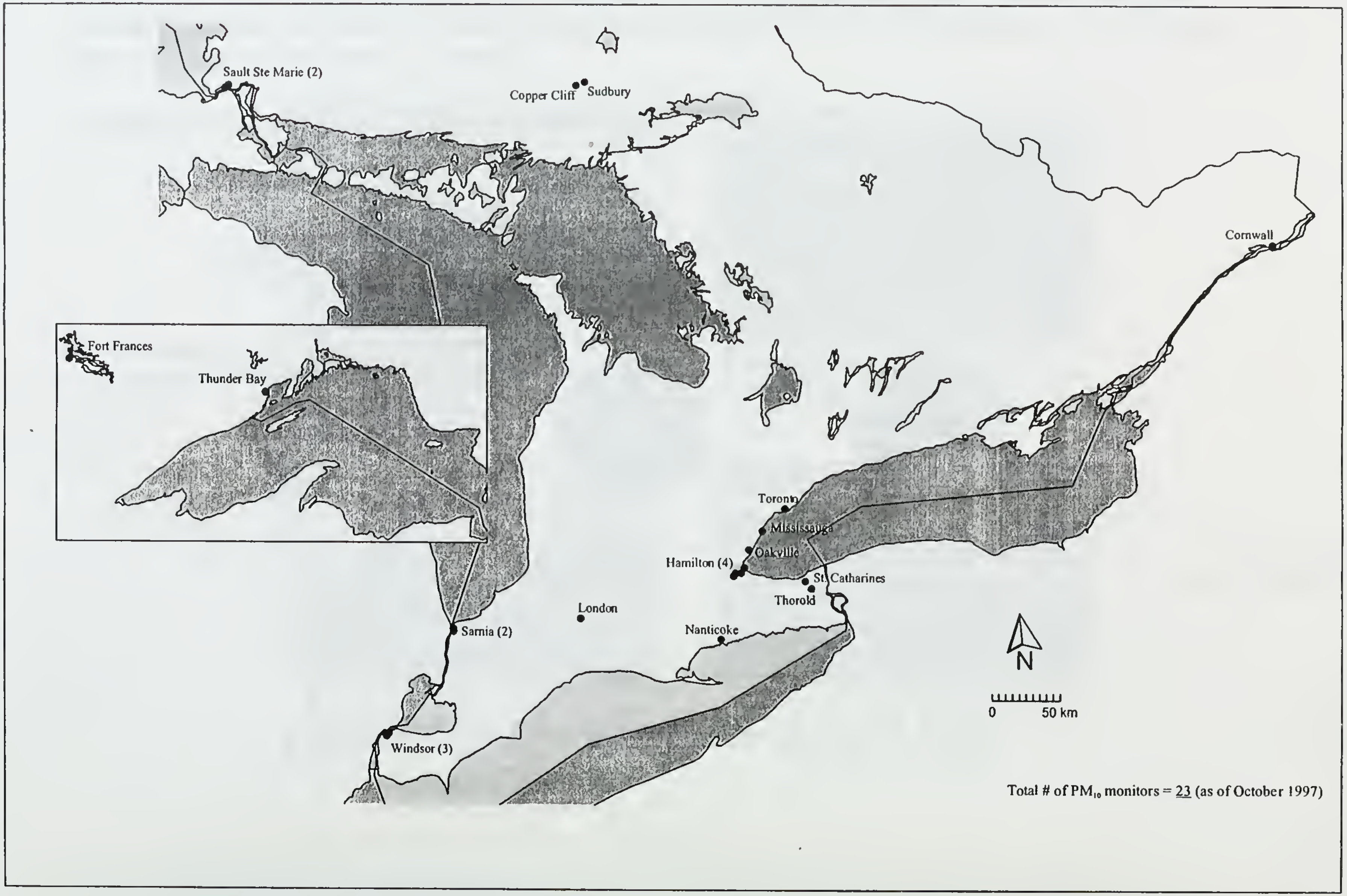


Figure III.2.5: Toronto: Evans Ave Fall 1995



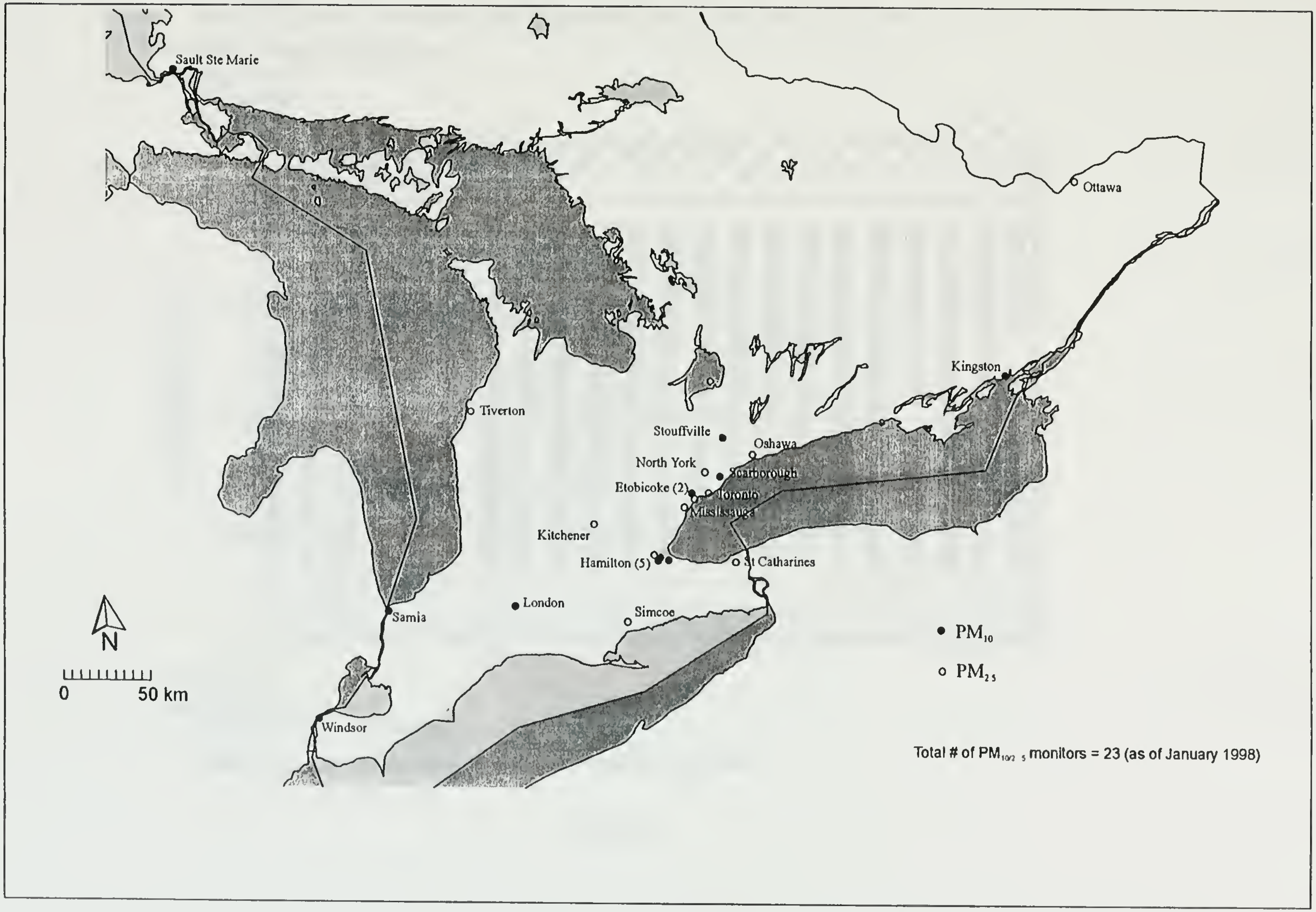
(Adapted from Sulphur In Gasoline Study, 1997)

Figure III.2.6 Location of MOE 24-Hour Hi-Vol $PM_{10}$ Stations



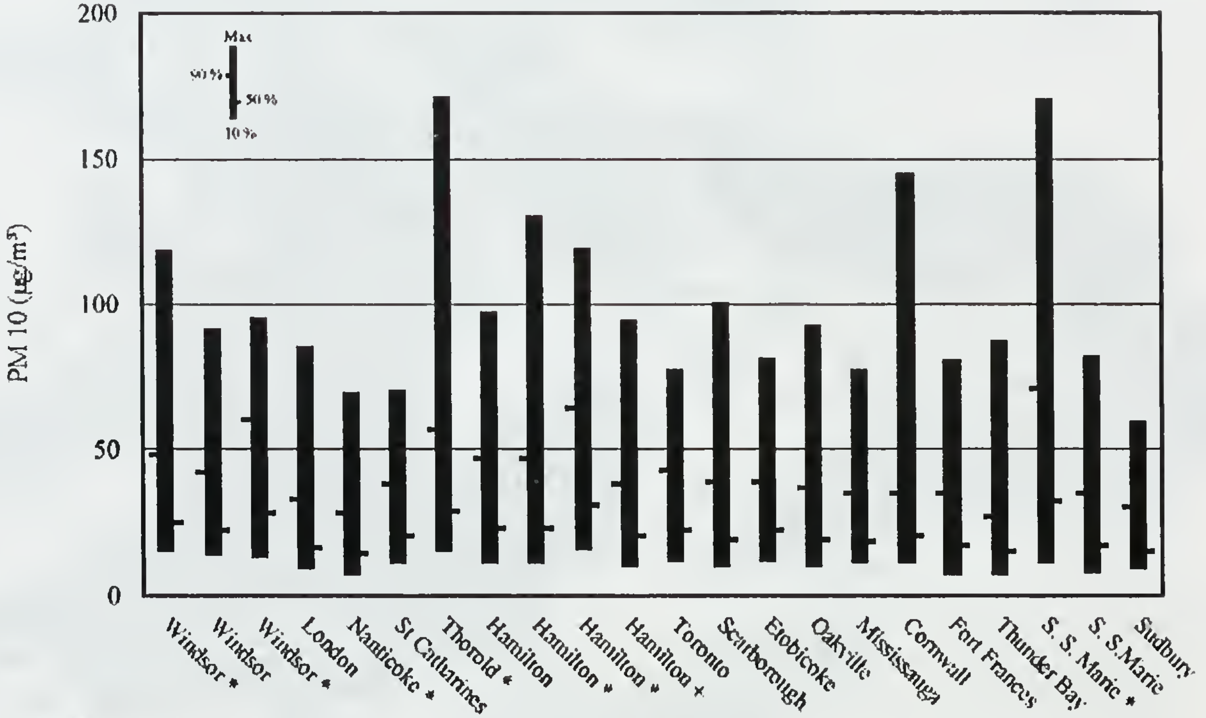
Total # of $PM_{10}$ monitors = 23 (as of October 1997)

**Figure III.2.7** Location of MOE Continuous $PM_{10/2.5}$ Air Monitoring Stations



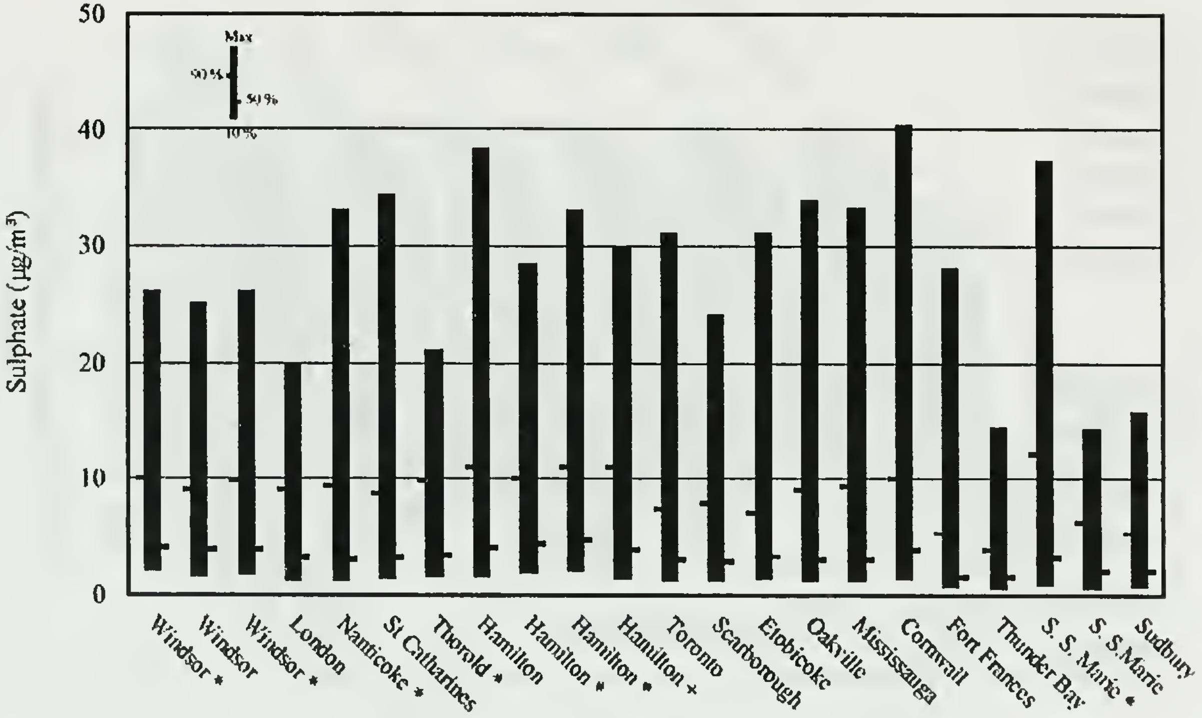
Total # of $PM_{10/2.5}$ monitors = 23 (as of January 1998)

Figure III.2.8 PM10 Concentrations Distribution Across Ontario in 1992 - 1996



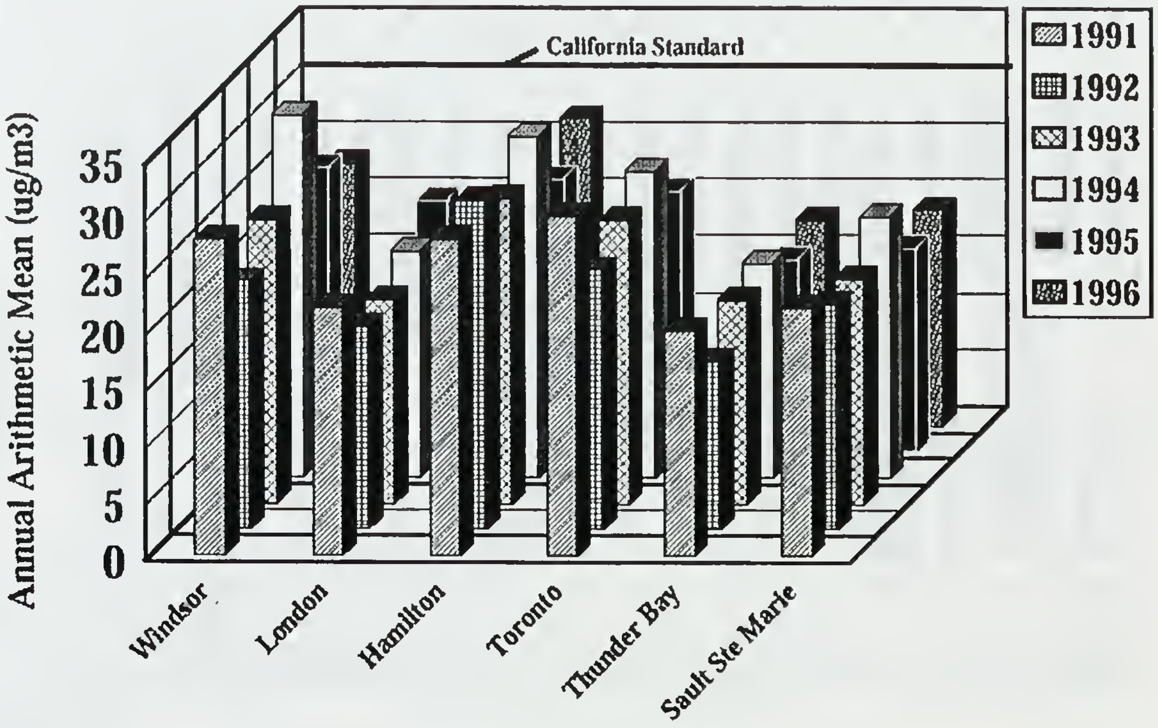
* industrial sites
+ suburban site
unlabelled sites are ambient urban

Figure III.2.9 Sulphate Concentrations Distribution From $PM_{10}$ Filters Across Ontario in 1992 - 1996



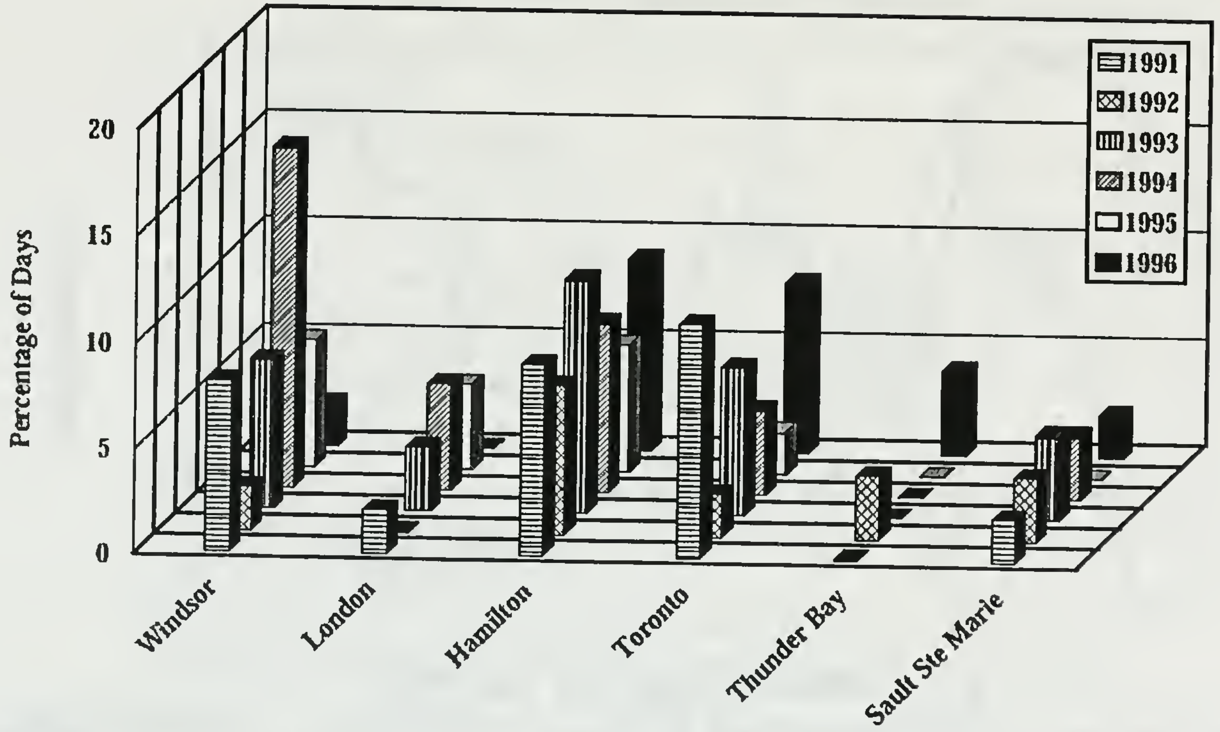
* industrial sites
+suburban site
unlabelled sites are ambient urban

**Figure III.2.10 Annual Mean $PM_{10}$ Levels at Selected Sites Across Ontario (1991 - 1996)**



Note: Data for 6 Urban Sites

Figure III.2.11 Percentage of Days $PM_{10}$ > 50 µg/m³ at Selected Sites Across Ontario (1991 - 1996)



Note: Data for 6 Urban Sites

Figure III.2.12 $PM_{10}/PM_{2.5}$ Levels at Etobicoke South During the June 29 - 30, 1996 Episode

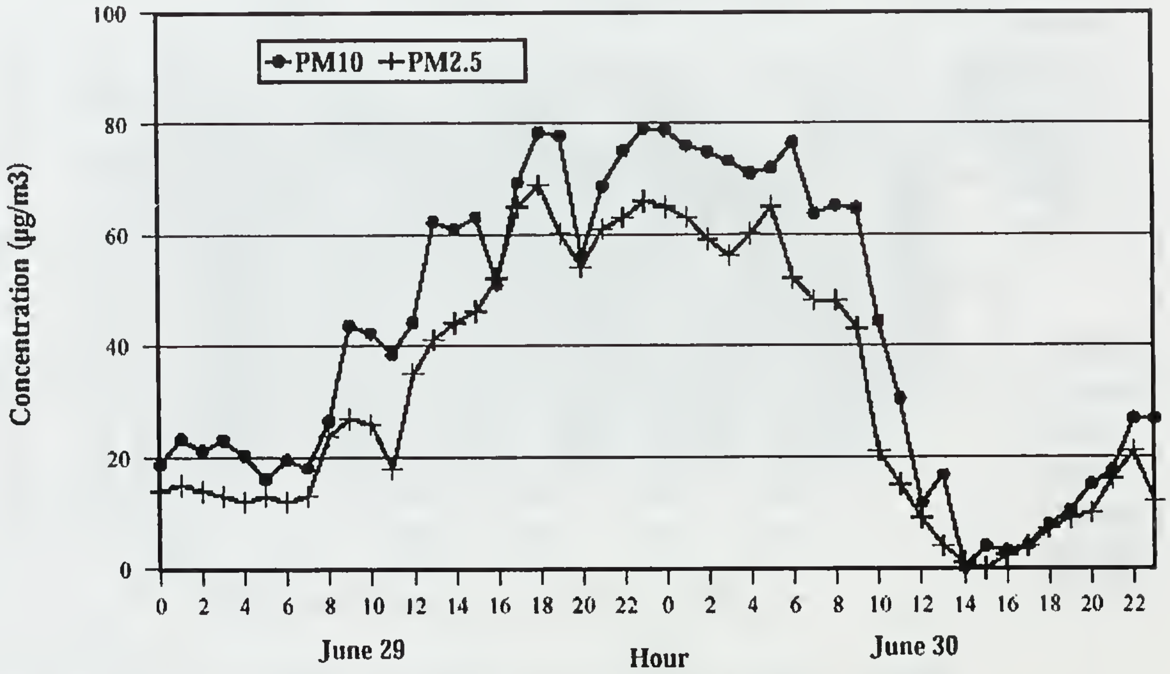
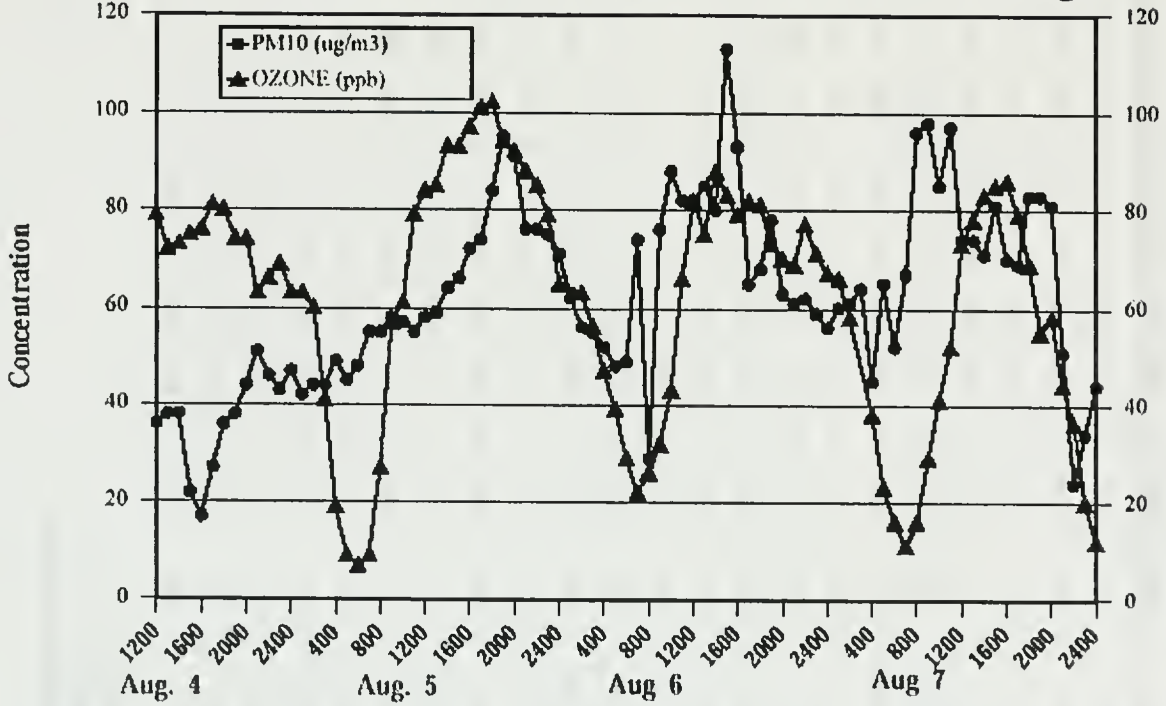


Figure III.2.13 $PM_{10}$ & Ozone Concentrations for the Aug. 4 - 7, 1996 Episode at Windsor College



## Table III.2.1 Inhalable Particulate ($PM_{10}$) 24-Hour Statistics (1992 - 1996)

Unit= $\mu g/m^3$

| Station | Number of Samples | PERCENTILES | | | | | | Max. | Arith Mean | Geom Mean |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 10% | 30% | 50% | 70% | 90% | 99% | | | |
| Windsor * | 250 | 15 | 21 | 25 | 31 | 48 | 74 | 118 | 28.8 | 25.9 |
| Windsor | 274 | 14 | 18 | 22 | 27 | 42 | 65 | 91 | 25.3 | 22.8 |
| Windsor * | 254 | 13 | 20 | 28 | 38 | 60 | 88 | 95 | 32.7 | 28.1 |
| London | 247 | 9 | 13 | 16 | 21 | 33 | 54 | 85 | 19.0 | 16.4 |
| Nanticoke * | 243 | 7 | 10 | 14 | 17 | 28 | 61 | 69 | 16.4 | 13.9 |
| St Catharines | 251 | 11 | 16 | 20 | 26 | 38 | 62 | 70 | 22.8 | 20.3 |
| Thorold * | 223 | 15 | 23 | 29 | 37 | 57 | 92 | 171 | 33.7 | 29.1 |
| Hamilton | 272 | 11 | 18 | 23 | 30 | 47 | 89 | 97 | 27.1 | 23.1 |
| Hamilton * | 269 | 11 | 17 | 23 | 34 | 47 | 72 | 130 | 27.5 | 23.3 |
| Hamilton * | 261 | 16 | 23 | 31 | 44 | 64 | 97 | 119 | 36.8 | 31.9 |
| Hamilton + | 222 | 10 | 15 | 20 | 27 | 38 | 72 | 94 | 23.1 | 19.9 |
| Toronto | 256 | 12 | 17 | 22 | 28 | 43 | 74 | 77 | 25.0 | 22.0 |
| Scarborough | 192 | 10 | 14 | 19 | 25 | 39 | 74 | 100 | 22.6 | 19.4 |
| Etobicoke | 257 | 12 | 18 | 22 | 26 | 39 | 60 | 81 | 24.0 | 21.8 |
| Oakville | 214 | 10 | 15 | 19 | 25 | 37 | 77 | 92 | 22.4 | 19.6 |
| Mississauga | 182 | 11 | 14 | 18 | 23 | 35 | 62 | 77 | 20.8 | 18.4 |
| Cornwall | 246 | 11 | 16 | 20 | 25 | 35 | 65 | 145 | 22.6 | 20.0 |
| Fort Frances | 237 | 7 | 12 | 17 | 23 | 35 | 64 | 80 | 19.8 | 16.7 |
| Thunder Bay | 279 | 7 | 12 | 15 | 20 | 27 | 51 | 87 | 17.1 | 14.7 |
| S. S. Marie * | 267 | 11 | 20 | 32 | 48 | 71 | 137 | 170 | 37.8 | 29.6 |
| S. S.Marie | 283 | 8 | 13 | 17 | 23 | 35 | 57 | 82 | 19.9 | 16.9 |
| Sudbury | 272 | 9 | 12 | 15 | 20 | 30 | 47 | 59 | 17.7 | 15.6 |

* industrial sites
+ suburban site
unlabelled sites are ambient urban

## Table III.2.2 Sulphate in Inhalable Particulate ($PM_{10}$) 24-Hour Statistics (1992- 1996)

Unit= $\mu g/m^3$

| | Number of | PERCENTILES | | | | | | | Arith | Geom |
|---|---|---|---|---|---|---|---|---|---|---|
| Station | Samples | 10% | 30% | 50% | 70% | 90% | 99% | Max. | Mean | Mean |
| Windsor * | 234 | 2.1 | 3.0 | 4.0 | 5.6 | 10.0 | 19.4 | 26.0 | 5.1 | 4.2 |
| Windsor | 258 | 1.7 | 2.7 | 3.8 | 5.3 | 9.0 | 21.3 | 25.0 | 4.9 | 3.9 |
| Windsor * | 238 | 1.8 | 2.8 | 3.8 | 5.6 | 9.8 | 17.5 | 26.0 | 5.1 | 4.0 |
| London | 230 | 1.3 | 2.2 | 3.2 | 4.2 | 9.0 | 17.5 | 19.9 | 4.3 | 3.2 |
| Nanticoke * | 242 | 1.3 | 2.3 | 3.1 | 4.5 | 9.3 | 24.5 | 33.1 | 4.6 | 3.3 |
| St Catharines | 253 | 1.4 | 2.3 | 3.2 | 4.8 | 8.7 | 22.4 | 34.3 | 4.6 | 3.4 |
| Thorold * | 215 | 1.6 | 2.5 | 3.4 | 5.0 | 9.9 | 18.9 | 21.0 | 4.8 | 3.7 |
| Hamilton | 262 | 1.6 | 2.6 | 4.1 | 6.1 | 11.0 | 20.5 | 38.3 | 5.4 | 4.1 |
| Hamilton * | 263 | 1.9 | 3.1 | 4.4 | 6.0 | 10.0 | 22.2 | 28.4 | 5.4 | 4.4 |
| Hamilton * | 256 | 2.1 | 3.2 | 4.6 | 6.4 | 11.0 | 22.4 | 33.1 | 5.9 | 4.7 |
| Hamilton + | 219 | 1.4 | 2.4 | 3.9 | 5.8 | 11.0 | 22.8 | 29.7 | 5.3 | 3.9 |
| Toronto | 251 | 1.3 | 2.0 | 3.0 | 4.5 | 7.4 | 17.7 | 31.0 | 4.0 | 3.1 |
| Scarborough | 188 | 1.2 | 1.8 | 2.8 | 4.3 | 7.8 | 19.1 | 24.0 | 3.9 | 2.9 |
| Etobicoke | 253 | 1.5 | 2.3 | 3.3 | 4.5 | 7.1 | 16.0 | 31.1 | 4.1 | 3.2 |
| Oakville | 205 | 1.3 | 2.2 | 3.1 | 4.9 | 9.0 | 19.0 | 33.9 | 4.5 | 3.3 |
| Mississauga | 170 | 1.2 | 2.1 | 3.0 | 4.4 | 9.4 | 17.6 | 33.2 | 4.3 | 3.1 |
| Cornwall | 226 | 1.5 | 2.6 | 3.8 | 6.0 | 10.0 | 22.0 | 40.4 | 5.3 | 3.9 |
| Fort Frances | 225 | 0.8 | 1.2 | 1.6 | 2.3 | 5.3 | 16.8 | 28.1 | 2.5 | 1.8 |
| Thunder Bay | 266 | 0.6 | 1.1 | 1.6 | 2.2 | 3.9 | 7.3 | 14.4 | 2.0 | 1.6 |
| S. S. Marie * | 249 | 0.9 | 2.0 | 3.2 | 5.7 | 12.1 | 24.2 | 37.4 | 5.2 | 3.4 |
| S. S.Marie | 266 | 0.7 | 1.4 | 2.1 | 3.4 | 6.2 | 10.0 | 14.2 | 2.9 | 2.1 |
| Sudbury | 250 | 0.8 | 1.5 | 2.1 | 3.0 | 5.3 | 11.0 | 15.7 | 2.7 | 2.1 |

* industrial sites

\+ suburban site

unlabelled sites are ambient urban

## III.3 THE ATMOSPHERIC CHEMISTRY OF FINE PARTICLE FORMATION

The formation of secondary particulate matter will be discussed in this section. The important emitted chemical species involved are sulphur dioxide ($SO_2$), oxides of nitrogen ($NO_X$), ammonia ($NH_3$) and volatile organic compounds (VOC). The chemistry involving all of these species will be discussed below. In addition, the role of atmospheric water will also be considered.

### III.3.1 Free Radicals in the Atmosphere

Much of the atmospheric chemistry leading to the production of secondary particulate matter involves free radicals, particularly including the hydroxyl radical (OH), the hydroperoxy radical ($HO_2$) and organic peroxy radicals of general formula $RO_2$, where R denotes an organic chain. The chemistry of these free radicals has been extensively discussed in a number of places (e.g., Finlayson-Pitts and Pitts, 1986; Seinfeld and Pandis, 1997). Only a very brief overview will therefore be given here.

#### *III.3.1.1 Formation*

The major source of hydroxyl radicals in the atmosphere is the photolysis of ozone by sunlight, producing an oxygen molecule and an excited oxygen atom ($O^{\bullet}$). This excited atom reacts with water to form two hydroxyl radicals

$$O_3 + h\nu \rightarrow O_2 + O^{\bullet} \quad \ldots\ldots\ldots\ldots \quad (1)$$

$$O^{\bullet} + H_2O \rightarrow 2\,OH \quad \ldots\ldots\ldots\ldots \quad (2)$$

Hydroperoxy radicals are formed following the photolysis of formaldehyde

$$HCHO + h\nu \rightarrow H + HCO \quad \ldots\ldots\ldots\ldots \quad (3)$$

since both of the products of this reaction are rapidly converted to $HO_2$

$$H + O_2 \rightarrow HO_2 \quad \ldots\ldots\ldots\ldots \quad (4)$$

$$HCO + O_2 \rightarrow HO_2 + CO \quad \ldots\ldots\ldots\ldots \quad (5)$$

Clearly, any process which leads to formation of H or HCO will also contribute to formation of hydroperoxy radicals. Examples include the photolysis of acetaldehyde and higher aldehydes.

$$RCHO + h\nu \rightarrow R + CHO \quad \ldots\ldots\ldots\ldots \quad (6)$$

The organic free radical, R, will react rapidly with an oxygen molecule, to produce an organic peroxy radical

$$R + O_2 \rightarrow RO_2 \quad \ldots\ldots\ldots\ldots \quad (7)$$

### *III.3.1.2 Cycling*

A number of reactions occur in the atmosphere, which involve consumption of a free radical, with simultaneous formation of another, different free radical. This amounts to a cycling of reactive species, without net consumption. Examples include

$$HO_2 + NO \rightarrow NO_2 + OH \quad \ldots\ldots\ldots\ldots \quad (8)$$

and reaction of the hydroxyl radical with an organic molecule (denoted by RH)

$$RH + OH \rightarrow R + H_2O \quad \ldots\ldots\ldots\ldots \quad (9)$$

followed by organic peroxy radical formation by reaction (7). This rapid interconversion of free radicals means that a source of OH is a source of $HO_2$, and vice versa. It also means that the introduction of just one free radical into a polluted air parcel will lead to the formation of a considerable amount of $NO_2$ and other secondary pollutants.

### *III.3.1.3 Removal*

Offsetting the cycling processes discussed briefly above, are those processes which remove free radicals without forming replacements. These include physical processes, such as deposition to the surface of the earth, and attachment to particulate matter, as well as a number of chemical processes, e.g.,

$$HO_2 + HO_2 \rightarrow H_2O_2 + O_2 \quad \ldots\ldots\ldots\ldots \quad (10)$$

The concentrations of reactive species in any air parcel will depend on their relative rates of formation and removal, and thus on the concentrations of other chemical species involved in these processes (noting that sunlight is also to be considered as a reactant in this context). Typically, in moderately polluted air, one might expect to find about $10^6$ OH radicals per cubic centimetre, and about $10^8$ $HO_2$ radicals per cubic centimetre. These are very small concentrations; $10^6$ per cubic centimetre is equivalent to less than 0.1 ppt (parts per trillion). However, the effect of these free radicals is very important, because they react very rapidly, and because of the cycling effect referred to in Section 1.2.

## III.3.2 Reactions of Sulphur Dioxide

In the gas phase sulphur dioxide reacts with the hydroxyl radical as follows

$$SO_2 + OH \rightarrow HSO_3 \quad \ldots\ldots\ldots\ldots \quad (11)$$

The intermediate species $HSO_3$ reacts rapidly with water vapour to produce sulphuric acid ($H_2SO_4$). Although all details of this reaction are not clear, it is believed that a further free radical is produced.

Sulphuric acid has low volatility. Thus, it will form as an aerosol, even in the absence of other material in the atmosphere. If other materials are present, the newly formed sulphuric acid will often react or combine very rapidly with trace components of the atmosphere, such as water droplets, dust particles, ammonia, etc., producing aerosols of varying composition.

Sulphur dioxide may also be oxidised to sulphuric acid in the aqueous phase, e.g., in cloud droplets. The oxidising agent may be hydrogen peroxide or ozone, or atmospheric oxygen in the presence of iron or manganese acting as catalysts. Under typical conditions the reaction with hydrogen peroxide is the most important one, though for pH values above about 6 the reaction with ozone may be dominant. Typically, however, the production of sulphuric acid by this reaction leads to reduction of the pH, which reduces the importance of the ozone reaction relative to that with hydrogen peroxide.

The conversion rates for sulphur dioxide to sulphuric acid obviously depend on the concentrations of the various reactants present in the atmosphere. Typically the gas phase reaction (1) will convert $SO_2$ to sulphuric acid at up to about 1 per cent per hour (with the highest rates being found only within plumes), while the aqueous phase reactions will be about an order of magnitude faster at 10 per cent per hour.

### III.3.3 Reactions of Oxides of Nitrogen

The oxides of nitrogen are emitted to the atmosphere mainly in the form of nitric oxide (NO). This species is readily converted to nitrogen dioxide ($NO_2$) by reaction with ozone or with the hydroperoxy radical ($HO_2$) or various organic peroxy radicals of the general formula $RO_2$

$$NO + O_3 \rightarrow NO_2 + O_2 \qquad \text{.......} (12)$$

$$NO + HO_2, RO_2 \rightarrow NO_2 + OH, RO \qquad \text{.......} (13)$$

As is well known, nitrogen dioxide may be photolysed during daylight hours, resulting in the production of ozone and reformation of nitric oxide

$$NO_2 + h\nu \rightarrow NO + O \qquad \text{.......} (14)$$

$$O + O_2 \rightarrow O_3 \qquad \text{.......} (15)$$

The reactions (12), (14) and (15) constitute a stationary state, producing essentially no change.

Some of the $NO_2$ may react with hydroxyl radicals to produce nitric acid

$$NO_2 + OH \rightarrow HNO_3 \quad \ldots\ldots. (16)$$

Nitric acid has a relatively high vapour pressure, and unlike sulphuric acid will remain in the gas phase. However, it will react readily with other trace components of the atmosphere, such as ammonia, dust particles, etc. to form aerosols.

At night $NO_X$ may be converted to nitric acid by processes involving the nitrate radical ($NO_3$). This pathway is not available during the day because $NO_3$ is photolysed very rapidly, and is therefore unable to exist in sunlight.

The gas phase conversion of $NO_X$ to nitric acid is substantially more rapid than the corresponding conversion of $SO_2$ to sulphuric acid, and may occur at a rate of several per cent per hour, to as high as about 10 per cent per hour. On the other hand, it is accepted that there is no significant aqueous phase pathway for the conversion of $NO_X$ to nitric acid.

### III.3.4 Reactions of Volatile Organic Compounds

Although considerable work is still required to unravel the details of the rates and mechanisms of the reactions, it is well established that some organic compounds in the atmosphere can react to produce fine particles. The alkenes and aromatics are particularly important in this regard. The amount of starting material that is converted to aerosol increases significantly with the molecular mass.

Thus, it has been shown that only hydrocarbons containing at least seven carbon atoms are able to contribute to aerosol formation. Further, it has been established that aerosol production from gasoline vapour may be completely accounted for by the aromatic components of the vapour. These aerosols are believed to be produced from the ring-opening products resulting mainly from initial attack by hydroxyl radicals. These results may also be considered to be largely representative of the VOC found in urban atmospheres, since the urban mix generally looks (qualitatively at least) very much like gasoline.

As far as alkenes are concerned, isoprene is converted to particles to an insignificant extent, and 1-octene and 1-decene to only a few per cent, whereas β-pinene and limonene were found to have yields of 30 to 40 %, and heavier alkenes such as *trans*-caryophyllene produce particles with yields of essentially 100 % (realising that these yields depend to some extent on the concentrations of reactive species in the atmosphere). The major reaction leading to formation of aerosols from alkenes is that with ozone, and it is noteworthy that it is the biogenic alkenes that are the major contributors. The absence of a significant contribution to aerosol production by light alkenes (6 carbon atoms or less) explains why it is only the aromatics which are converted in the case of gasoline.

The rates of production of fine particles by the atmospheric reaction of VOC are not well established. However, it is not unreasonable to expect that they should be at least as fast as the rate of conversion of $SO_2$ to aerosol, i.e., a few per cent per hour. Depending on the conditions, and the exact structure of the VOC involved, the rates may be even higher.

### III.3.5 The Role of Other Species

#### *III.3.5.1 Ammonia*

Ammonia is the predominant basic, gaseous species in the atmosphere. It reacts rapidly with sulphuric acid to produce ammonium sulphate or ammonium bisulphate, depending on the relative amounts of ammonia and sulphuric acid that are present

$$NH_3 + H_2SO_4 \rightarrow NH_4HSO_4 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (17)$$

$$2NH_3 + H_2SO_4 \rightarrow (NH_4)_2SO_4 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (18)$$

These sulphates exist as solid particles, unless the relative humidity is very high. In this case, they may have a liquid phase surface layer. Since they are very soluble they will readily be incorporated into water droplets if any are present.

Ammonia will also react rapidly with nitric acid

$$NH_3 + HNO_3 \rightarrow NH_4NO_3 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (19)$$

to form ammonium nitrate, which will also tend to form solid particles. However, unlike the formation of sulphates, this reaction is reversible, and the ammonium nitrate can dissociate, giving back ammonia and nitric acid

$$NH_4NO_3 \rightarrow NH_3 + HNO_3 \quad \ldots\ldots\ldots\ldots \quad (20)$$

An equilibrium state is achieved, in which formation of ammonium nitrate is favoured by low temperatures and/or high concentrations of ammonia and nitric acid, with the opposite conditions (high temperatures or low concentrations of nitric acid and ammonia) favouring the dissociation of ammonium nitrate.

#### *III.3.5.2 Other Chemical Species*

Both sulphuric acid and nitric acid will react with other basic chemical species in the atmosphere. Beside ammonia, the most important of these are basic soil derived dusts, composed mainly of oxides or carbonates of magnesium and calcium. Reaction with these dust particles is irreversible, and leads to the incorporation of the acid with formation of sulphate or nitrate salts.

Near the ocean it is also possible for sulphuric and nitric acids to react on the surface of sea salt particles. The result of this reaction is liberation of volatile chlorides (especially hydrochloric acid) with formation again of sulphate or nitrate salts.

### III.3.6 The Role of Water

Water vapour is present in the atmosphere at concentrations ranging from a few tenths of a per cent at low temperatures to as much as 4 % at 30 °C and relative humidities approaching saturation. Liquid water can also be present in the form of cloud, fog or mist droplets, or as rain drops.

Many of the fine particles in the atmosphere are able to take up watervapour from the atmosphere if they move to a regime of increased water concentration. The effect of this is to increase the size of the particles, which, in turn affects all of the properties which depend on the particle size, including dry deposition, respiratory system uptake and visibility of the particulate matter. Conversely, if the particles move to a regime of lower water vapour concentration, as a result of transport, or temperature change, they will tend to lose water, and become smaller.

In addition, if liquid water droplets are present, they may take up gas phase species, especially the more soluble ones like nitric acid, thus effecting a gas to particle conversion. They can also incorporate already formed particles. If the droplet is part of a cloud which subsequently produces precipitation, the result is wet deposition of the original pollutant. The direct interactions of particulate matter and falling precipitation are less important because the fall times of precipitation are quite short. However, a certain amount of scavenging by rain, with wet deposition to the surface of the earth, can occur.

### III.3.7 Discussion

#### *III.3.7.1 Uncertainties*

In the scientific assessment of inhalable and respirable particulate matter, uncertainties exist in both the state of scientific knowledge and in the data required to support that knowledge.

Much of the science of fine particles is common to the study of acid rain and to tropospheric ozone. The formation of sulphates and nitrates are exactly the processes that are of concern in acid deposition, while the atmospheric oxidants which are required toform these sulphates and nitrates from the precursor compounds are intimately involved in the reaction sequences which lead to ozone. The uncertainties in knowledge are therefore common to all of these areas. In particular, considerable work is still required to improve our understanding of the reactions of the volatile organic compounds. This is a huge task. Literally hundreds of VOC species are present in the urban atmosphere, and each of these can produce other VOC species after the initial reaction step.

Understanding the rates and mechanisms of VOC reactions is of direct importance in understanding the formation of organic aerosol. The situation is actually worse for these reactions, since it is the higher molecular weight compounds (generally those containing at least seven carbon atoms) which are important in the production of aerosols. However, these VOC react more slowly in the production of ozone than do the lighter compounds, and have therefore been less studied to date.

Major data uncertainties exist in our knowledge of the emissions of aerosol precursors. Emissions data for $SO_2$ are considered to be the most reliable (perhaps within 25%), followed by $NO_x$ (50%), and VOC (factor of two). Emissions data for ammonia are currently very uncertain.

### *III.3.7.2 Non-linearity*

In developing control strategies for fine particles, it is very important to understand the linearity, or lack thereof, of the chemical systems involved. In other words, if the system is linear, a 50% reduction in $SO_2$ will lead to a 50% reduction in ambient sulphate concentrations. However, if the system is non-linear, the sulphate reduction will be less (or more) than 50%. Most of these systems are actually non-linear, often to a substantial extent, and the benefit realised from emission reductions is less than the amount of the reduction. This non-linearity can arise for a number of reasons all related to the complexity of the chemical process involved, as will be summarised briefly below.

The gas phase production of sulphuric acid is inherently linear in sulphur dioxide, because it is dominated by reaction with the hydroxyl radical, as shown in Reaction xx. However, if there are concurrent changes in $NO_X$ or VOC emissions, the situation is complicated by the fact that the concentration of the hydroxyl radical will be changed, thus introducing non-linearity.

If clouds or fog are present, the oxidation of sulphur dioxide to sulphates will usually be dominated by reactions taking place in the aqueous phase. The most important reactant is hydrogen peroxide, which is often present in lower concentrations than the sulphur dioxide. This leads to non-linearity of response to emission reductions, as may be illustrated by the following example.

Assume that the $SO_2$ emissions are such that a concentration of $SO_2$ of 2 ppb enters a cloud, which contains 0.5 ppb of hydrogen peroxide. All of the hydrogen peroxide will be consumed in reacting with 0.5 ppb of the $SO_2$, and about 2 µg $m^{-3}$ of sulphuric acid will be produced. If the emissions are halved, the concentration of $SO_2$ entering the cloud will be halved, to 1 ppb. However, the hydrogen peroxide concentration will be essentially unchanged at 0.5 ppb, so that only 0.5 ppb of the $SO_2$ will be reacted. Again, about 2 µg $m^{-3}$ of sulphuric acid will be produced. In this slightly simplified example the response to emission changes is highly non-linear, to the extent that the final concentration of aerosol sulphate is not reduced at all by a halving of emissions.

The important difference between the gas- and aqueous-phase processes is that the hydroxyl radical in the gas phase is replenished at a very rapid rate by the reactions of $NO_x$ and VOC (during daylight hours, anyway), and is therefore essentially unchanged by reaction with $SO_2$. Hydrogen peroxide, on the other hand, is formed and transported into cloud water at a much slower rate, and is thus consumed by reaction with $SO_2$.

The non-linearity of the atmospheric reaction sequences leading to production of ozone and nitric acid is well known. The situation is further complicated by the fact that other products than aerosols are possible, including PAN and organic nitrate. In addition, some of the reactions are reversible, with a substantial temperature dependence, including the very important reaction between nitric acid and ammonia, which results in the formation of nitrate particles.

Other non-linearities result from the coupling of the sulphate and nitrate systems through ammonia. In an ammonia rich regime, additional sulphuric acid will be converted to ammonium sulphate. Ammonium nitrate will also be present. In this regime addition of 1 $\mu g\ m^{3}$ of sulphuric acid will lead to the production of about 1.4 $\mu g\ m^{-3}$ of aerosol mass. Conversely, a similar reduction would be realised for a 1 $\mu g\ m^{-3}$ reduction in sulphuric acid, and the system is essentially linear.

However, the situation is more complicated in an ammonia poor regime. In this case, because the reaction of ammonia with sulphuric acid is preferred over that with nitric acid, the atmospheric mixture will contain ammonium sulphate or bisulphate, ammonium nitrate and nitric acid (since there is not enough ammonia present to react with all of the acid, and it reacts first with the sulphuric acid). If the amount of sulphuric acid is reduced, by reducing $SO_2$ emissions, some ammonia will be freed up. This will react with the nitric acid to form more ammonium nitrate. Thus the reduction in sulphate aerosol mass will be somewhat offset by an increase in nitrate aerosol, leading to a smaller than expected reduction, constituting non-linearity.

### III.3.8 References

Finlayson-Pitts, Barbara J. and Pitts, James N., Jr. (1986), "Atmospheric Chemistry: Fundamentals and Experimental Techniques". New York: Wiley.

Seinfeld, John H. and Pandis, Spyros N. (1997), "Atmospheric Chemistry and Physics: From Air Pollution to Climate Change". New York: Wiley.

## III.4 SOURCE APPORTIONMENT: DATA ANALYSIS AND MODELLING

### III.4.1 Section Overview

As described in the introduction, $PM_{10}$ and $PM_{2.5}$ concentrations result from both primary emissions from sources and secondary chemical and photochemical formation of particles from precursor gases. Since secondary aerosols can be produced over a period of several days and fine particles have low dry deposition velocities, emissions of precursor gases and primary emissions must be considered over regional scales and, to a lesser degree, over continental scales to understand the contributions to regional particulate matter concentrations. Over an urban area, particulate matter concentrations are elevated above regional levels due toprimary emissions and precursor gas emissions over the area. Individual sources and groups of sources with high emission rates can add to the regional and urban particulate matter concentrations resulting in very high local concentrations.

Emission sources on continental, regional, urban and, in some cases, local neighbourhood scales must be considered to understand the contributions to $PM_{10}$ and $PM_{2.5}$. There are a number of assessment methodologies ranging from comprehensive mathematical modelling to source specific monitoring which can be used to assess the contribution of sources to observed particulate matter concentrations.

A detailed source apportionment would involve the determination of the contributions of all large individual emission sources and all area source sectors to air concentrations of a contaminant at a specific location or over a region. A comprehensive mathematical model with detailed and accurate emission inventories would be required to perform such a source apportionment. Due to the complex interactions between sulphate, nitrate and ammonia described in Section III.3, emission reductions of individual precursor gases can result in non-linear reductions in $PM_{2.5}$ concentrations. Mathematical modelling is the only effective way of predicting non-linear responses to precursor gas emission reductions.

The comprehensive aerosol models required to perform detailed evaluations of emission reduction scenarios are only now becoming available. To this time, comprehensive aerosol models have not been applied in Canada, however several agencies are in the process of developing the capacity to perform aerosol modelling. For eastern North America, the input emission inventories of a number of species including ammonia, primary fugitive dust and to a lesser extent VOCs are currently too poorly known to give reliable results in model simulations. Additionally, a gridded, temporally resolved inventory of primary particle emissions needs to be developed for input to an aerosol model.

Once the aerosol models and all input emission inventories are available, the models must be tested for their sensitivity to emission input data and evaluated against monitoring data which include chemically speciated particulate matter concentrations.

Although an evaluated aerosol model is not yet available, there are other modelling/data analysis approaches which can be used to provide some assessments of the contributions of sources of primary particle emissions as well as secondary precursor gas emissions to observed $PM_{2.5}$ and $PM_{10}$

concentrations. These approaches include the use of chemical composition data on $PM_{2.5}$ and $PM_{10}$ in source-receptor modelling assessments and chemical composition data in combination with emission inventories for each chemical component. Other analysis methods include using paired urban/rural data to assess urban contributions to particulate matter concentrations. Source specific monitoring studies are also used in assessing contributions from large sources or groups of sources.

The differing compositions and general source types for $PM_{2.5}$ and the coarse fraction of $PM_{10}$ were discussed in Section III.2. The chemical constituents of fine and coarse fractions of $PM_{10}$ provide strong indications of the sources from which the particle mass originates. Figure III.4.1 shows an idealized atmospheric aerosol size distribution for the fine and coarse size fractions of particulate matter.

This source apportionment section begins with a description of comprehensive modelling of aerosols along with the information limitations which have restricted the application of these models. The available information on the chemical composition and the concentrations of the fine and coarse fractions of $PM_{10}$ have been presented in the Particulate Matter ($PM_{10}$/$PM_{2.5}$) Measurements section; Section III.2. The chemical composition data are used in several data analysis/modelling approaches to apportion the contributions of source sectors. These analyses are described Section III.4.3. Other analysis approaches described in Section III.4.3 are the use of urban and rural data to estimate urban contributions to concentrations and source oriented monitoring to determine impacts near large emission sources. The conclusion to this section is a summary of the estimates and uncertainties in source apportionment of particulate matter concentrations.

### III.4.2 Comprehensive Modelling

#### *III.4.2.1 Components of a Comprehensive Model*

A comprehensive linking of sources of emissions with the resulting air concentrations of the many chemical constituents comprising $PM_{2.5}$ and the coarse fraction of $PM_{10}$, requires detailed understanding of all of the chemical and physical processes which occur simultaneously in the atmosphere. Mathematical models provide the framework in which we can incorporate our understanding of the transport/mixing, chemical and physical processes occurring in the atmosphere along with the interactions between these individual processes.

Comprehensive modelling of the interaction of emissions with atmospheric processes can be done in a Lagrangian framework where air parcels are tracked as they are advected over emission regions or in an Eulerian framework (fixed in space) where the changes in pollutant concentrations over time are determined for locations in a model grid domain. For modelling situations where many sources are contributing to the final air concentrations, an Eulerian framework is usually used.

The basic processes that must be incorporated into a comprehensive 3 dimensional (3-D) Eulerian model are:

1) transport and diffusion;
2) gas phase chemistry;
3) cloud mixing and scavenging;
4) aqueous phase chemistry and
5) dry deposition.

In addition to the above processes, comprehensive modelling for atmospheric aerosols requires knowledge of heterogeneous reactions at particle surfaces and the physical processes involved in particle aggregation and the breakup of larger particles. Regional and urban scale Eulerian models are usually run with a model time step of one hour with the chemical mechanisms and some of the physical processes using much shorter internal time steps.

The input data requirements of a large 3-D Eulerian model are enormous. Gridded hour by hour information for the meteorological fields and for the speciated emissions are needed along with initial and domain boundary concentrations of modelled pollutants and surface geophysical data.

### *III.4.2.2 Aerosol Modelling*

As indicated schematically in Figure III.4.2, both primary emissions of particles and secondary aerosol formation from precursor gases contribute to $PM_{10}$ and $PM_{2.5}$ in the atmosphere. Correspondingly, an atmospheric aerosol model requires particle size (and additionally composition) data for the primary emissions as well as all of the precursor gas emission rates.

The main modules which need to be added or modified to incorporate aerosols into a comprehensive model are: (1) secondary aerosol formation through gas phase reactions and heterogeneous reactions on particles; (2) aqueous phase aerosol formation in cloud or fog droplets; (3) the evolution of particle size distributions through nucleation, coagulation and condensation; (4) the scavenging, wet deposition and dry deposition of size distributed aerosols; and (5) the influence of cloud droplet evaporation on aerosol size distributions.

The secondary formation of aerosols in the atmosphere is described in Section III.3. Emissions of $SO_2$, $NO_X$ and ammonia are required to model the partitioning of sulphate between sulphuric acid, ammonium bisulphate and ammonium sulphate and the partitioning of nitrate between the gas phase nitric acid and particle phase ammonium nitrate. Ammonium sulphate is preferentially formed over ammonium nitrate. Other factors which critically affect ammonium nitrate formation rates are air temperature and relative humidity. Sodium nitrate can be formed by surface reactions on salt particles.

As indicated in the discussions of the composition of $PM_{2.5}$ and the coarse fraction of $PM_{10}$, primary emissions from both combustion related sources and crustal/soil related sources affect the observed air concentrations. To validate aerosol models against both air concentration and aerosol composition data, primary particle emissions should be identified at least as sooty/carbon versus crustal/soil related sources. In addition, the primary particle emissions must be allocated to the particle size groupings used in the model.

The size distribution of atmospheric aerosols can be modelled by either a detailed sectional approach or by separating the size distribution into several modes (i.e., a bimodal example is shown in Figure III.4.1). In a detailed sectional approach, the particles are grouped into a large number of size bins with the bin widths varying logarithmically to provide sufficient resolution across the full distribution. This method provides high resolution of particle size distributions but it can result in large computation times if many sections are used in the model.

In a modal approach, the main atmospheric particle size modes are first identified. This could include a nucleation size mode, an accumulation size mode and one or more coarse size modes depending on the types of primary emission sources expected to contribute significantly to the atmospheric aerosol concentrations. This method requires less computation time than resolving a large number of size sections and it can resolve the main features of the observed atmospheric size distributions. Since size resolution data for most primary particulate matter emission sources are currently limited, the input size distribution of emission data needed for detailed sectional models would only be estimates or guesses.

### *III.4.2.3 Information Requirements for Model Development/Validation*

Starting from an existing comprehensive 3-D Eulerian model, there are two main areas where information is required to develop and evaluate an atmospheric aerosol model. The emissions required to run a model include both primary particles and the precursor gases resulting in secondary aerosol formation. Extensive air monitoring data on $PM_{2.5}/PM_{10}$ concentrations and composition are required to evaluate how well the model/emission inventory can represent the relative contributions of primary versus secondary particulate matter and of different source types (i.e., combustion versus crustal/soil related sources). Monitoring data in urban areas, at rural sites across a region and, in some cases near large sources, are needed to evaluate the model determinations of the relative contributions of urban, regional and local emission sources.

Emission inventories forprimary emissions of $PM_{2.5}$ and $PM_{10}$ as well as emissions of the precursor gaseous species $SO_2$, $NO_X$, VOC and ammonia are presented in Section III.1. There are large uncertainties in the primary particle emissions, especially fugitive/open source emissions of $PM_{2.5}$, and in the ammonia emissions. Also, the primary particle emissions have to be spatially allocated. Modelling the contributions of sources to regional particulate matter concentrations requires emissions gridded to a resolution of about 20 km or better. Modelling the impacts of urban areas on air concentrations would require emissions gridded to a resolution of 5 km or less.

The descriptions presented earlier on the chemical composition of $PM_{2.5}$ and the coarse fraction of $PM_{10}$ show how little information is currently available for Ontario or any of the surrounding jurisdictions. Section III.2 has described the $PM_{10}$ and $PM_{2.5}$ concentration measurements currently available in Ontario. There are very few rural measurements of even the masses of $PM_{10}/PM_{2.5}$. Rural data are needed to evaluate a model's predictions of regional contributions to the fine and coarse fractions of $PM_{10}$. When rural data are paired with urban data, the concentration differences can be used to evaluate how well an urban scale model simulation predicts the urban contributions to particulate matter. Sulphate is the only constituent of $PM_{10}/PM_{2.5}$ for which there are currently sufficient urban data (from the MOE $PM_{10}$ network, the federal NAPS network and the federal Acid Aerosol Network) and rural data (from acid deposition networks plus some MOE $PM_{10}$ and federal data) to adequately assess a model's predictions.

The major information and scientific limitations in developing and validating a regional/urban aerosol model are:

1. There are very large uncertainties in the primary particle emissions from open/fugitive sources; especially for $PM_{2.5}$.

2. The uncertainties in primary particle emissions and their size distribution from other point and area sources are significant.

3. For each of the area source sectors, the emissions need to be spatially and temporally allocated.

4. Emissions of ammonia are critical to the formation of ammonium nitrate. These emissions have a large uncertainty factor.

5. There is currently little complete and accurate data on the elemental carbon, organic carbon and nitrate components of $PM_{10}/PM_{2.5}$ in or near Ontario (See Section III.2).

6. Except for sulphate, rural data to evaluate regional particulate matter concentrations are limited.

7. In addition to limitations in emission and monitoring data, there are uncertainties in a number of the chemical and physical processes involved in secondary aerosol production and in the growth and breakup of particles.

### *III.4.2.4 Current Status of Comprehensive Modelling of Aerosols*

To this time, most of the comprehensive 3-D model simulations of atmospheric aerosols has been performed for episodes in California (Pilinis and Seinfeld, 1988; Pandis et. al., 1992; Pandis et. al., 1993; Wexler et. al., 1994; Meng et. al., 1997; Lurmann et. al., 1997). Braverman and Dennis (1998) have presented some preliminary results of secondary aerosol simulations for eastern North America.

There are currently a number of model development exercises going on in the U.S. to upgrade existing 3-D Eulerian models to model atmospheric aerosols. Seigneur et. al. (1997) and Seigneur (1998) provided reviews of the comprehensive aerosol models developed or under development in the U.S.. The seven models listed below have been developed to model episodes. The same 3-D Eulerian models were used as the starting point for several of these aerosol model development exercises.

| | |
|---|---|
| UAM-AERO: | Carnegie-Mellon University (Urban Airshed Model; UAM) |
| UAM-AIM: | University of Delaware (AIM: Aerosol Inorganic Model) |
| RPM: | Regional Particulate Model; US-EPA |
| CIT: | California Institute of Technology |
| DAQM: | Denver Air Quality Model: Aerosol version of Regional Acid Deposition Model (RADM) |
| SAQM-AERO: | Aerosol version of SARMAP Air Quality Model developed for California Air Resources Branch |
| GATOR: | Gas, Aerosol, Transport and Radiation model: Developed at University of California; Los Angeles now at Stanford University |

In addition to the comprehensive episodic models, several simplified models have been developed to estimate annual average concentrations of particulate matter. An alternative method of estimating annual averages is to run episodic models for a number of representative meteorological conditions and use climatology to extrapolate long term averages.

US EPA has developed a prototype particulate matter model, the Regional Particulate Model (Binkowski and Shankar, 1995), which uses a modal approach to treat aerosol size distributions and includes both gas phase and cloud processing of atmospheric aerosols. The aerosol modules in this model are currently being combined with elements of the RADM to produce a more complete model which is called the Community Multi-Scale Air Quality Model (CMAQM).

US EPA is also funding the upgrade of the Urban Airshed Model (UAM) to include state-of-the-art atmospheric aerosol modules (UAM-AERO). The aerosol modules for UAM-AERO are being developed as a set of models starting with a very comprehensive sectional model including all known chemical pathways with subsequent models using various simplifying assumptions. The most comprehensive version of the aerosol modules would be the most computer intensive and would require the most input information.

In Canada there are several efforts either starting or under way to upgrade existing 3-D Eulerian models to include aerosols. The Atmospheric Environment Service (AES) of Environment Canada has begun work on upgrading the Chemical Tracer Model (CTM) to include aerosol modules. Aqueous chemistry and wet scavenging modules will first be added to the current version of CTM. To model aerosols, AES intends to use a sectional treatment for the particle size distribution. The chemical mechanisms would likely be a combination of those available from RPM or UAM-AERO with the inclusion of a new secondary organic aerosol module being developed by the Canadian National Research Council (NRC).

NRC is planning on incorporating aerosol modules including their secondary organic aerosol module into CALGRID which is a comprehensive 3-D Eulerian model originally developed by the California Air Resources Board. The Ontario Ministry of the Environment (MOE) in a project with Ontario Hydro and in cooperation with AES, is proposing to update the Acid Deposition and Oxidant Model (ADOM) to include aerosol modules. A modal approach to aerosol sizes will likely be used. Chemical and physical algorithms currently employed in RPM would be the starting point for this model development with improvements such as the new secondary organic aerosol module being developed by NRC.

The proposal for comprehensive modelling of aerosols for Vancouver and the Lower Fraser Valley is to adopt an aerosol version of the UAM-V model.

Although comprehensive aerosol models and sufficiently accurate emission inventories for primary particles and some of the precursor gases have not been available to perform simulations over Canada, model simulations for acid deposition studies have been performed. These model studies include changes in regional sulphate concentrations corresponding to various $SO_2$ emission reduction strategies. These acid deposition model simulations have been performed with a grid resolution of 127 km which resolves the regional pattern of sulphate concentrations.

"*Towards a National Acid Rain Strategy*" (1997) provides analyses of the impacts of $SO_2$ reduction scenarios on acid deposition and on regional sulphate concentrations. The model was run for more than 100 simulation days with climatological data used to extend the results to a yearly average. Since that report included a scenario with reductions of Canadian emissions only in addition to scenarios with combined U.S. and Canadian $SO_2$ reductions it is possible to estimate relative contributions of Canadian and transboundary sources to regional sulphate levels in Ontario. Sulphate concentrations in an urban area such as the Greater Toronto Area would have an urban contribution added to the regional sulphate concentrations simulated in '*Towards a National Acid Rain Strategy*" (1997).

The simulations indicate that Ontario sources are responsible for about 25% of the regional component of sulphate concentrations transported into the Greater Toronto Area. For southwestern Ontario, the percentage contribution of transboundary sources to regional sulphate levels is higher than that over the Greater Toronto Area while the transboundary percentage contribution in southeastern Ontario is lower. Emissions of $SO_2$ from the U.S. sources dominate the transboundary component of sulphate concentrations in Ontario. U.S. $SO_2$ sources account for 60% to 70% of the regional sulphate concentrations transported into the Greater Toronto Area with global sources contributing 5% to 15% of the regional sulphate.

Although initial efforts at comprehensive modelling of aerosols for the eastern U.S. have begun, considerable time and effort are still required to evaluate and develop the models and emission inventories to the point that they can be reliably used to evaluate emission control strategies. As an initial effort at assessing the source-receptor relationships between emissions (primary particles and precursor gas emissions) and $PM_{10}/PM_{2.5}$ concentrations across the United States, US EPA has used a greatly simplified air quality model along with currently available emission data (US EPA, 1996). The model used was the Climatological Regional Dispersion Model (CRDM). CRDM is a simple Gaussian dispersion model incorporating wet and dry removal rates as annual average deposition velocities and linear conversion rates from precursor gases to aerosols. In the case of secondary organic aerosols (SOAs), a fixed percentage of the VOC emissions were used as anSOA emission rate. Statistical data on the frequency of occurrence of wind directions and speeds and annual average mixing heights were used to transport and disperse the contaminants.

The annual average aerosol concentrations produced by these model simulations were then calibrated using observed $PM_{10}/PM_{2.5}$ concentration data. A major adjustment to the modelled results was to reduce fugitive dust emissions by 75%to more nearly correspond to the observed contributions of soil/crustal material to $PM_{2.5}$. The modelled source-receptor matrix was then modified to improve the agreement with observed concentrations. The modified source receptor matrix was then used to evaluate compliance with the proposed U.S. particulate matter standards (i.e., the study was done in 1996). The report (US EPA, 1996) described these model simulations with CRDM as being a placeholder until comprehensive evaluated aerosol models are available for emission change applications.

Although Canadian emissions were included in the modelling, the emissions were only province totals which were assumed to come from the largest urban area in each province. Environment Canada is currently having the model simulations of Canadian emissions redone using emissions spatially allocated to 290 subdivisions across Canada. The work is being performed by the same U.S. consulting company that did the CRDM model simulations for US EPA.

### III.4.3 Data Analysis/Modelling Approaches

#### *III.4.3.1 Chemical Composition*

Source-Receptor Modelling

Chemical Mass Balance (CMB) source-receptor modelling for particles makes use of information on the chemical composition of primary particle emissions from different source sectors. The chemical species usually included in emission source profiles are individual elements, the major ions; $SO_4^{2-}$, $NO_3^-$, $NH_4^+$, $Na^+$ and $Cl^-$; elemental carbon and total organic carbon. The chemical compositionof particles collected at an individual receptor site is compared with emission source profiles to estimate the relative contributions of each source sector to the observed particle mass.

The source contributions are determined by regression analysis usually weighted by the uncertainty estimates for the source profiles and/or the measurements. The result gives each chemical concentration ($C_k$) measured at a receptor as a linear sum of the contributions from over all source sectors.

$$C_k = \Sigma_{i=1}^{p} S_{ik}F_i + \text{error}$$

where $S_{ik}$ is the percentage contribution of species k to source sector i emissions
and $F_i$ is the contribution of source sector i to the $PM_{2.5}$ or $PM_{10}$ mass.

Secondary sulphate and secondary nitrate are usually included as separate 'source' categories in the analysis.

Since the source profiles are usually obtained from previous studies in other cities or areas, the representativeness of the source profiles is one of the main uncertainties in this modelling approach. A second assumption is that the source sectors considered in the analysis are comprehensive and account for all of the observed aerosol mass. A third uncertainty occurs when two or more source sectors have similar chemical compositions. In these cases, the CMB analysis can only provide an attribution for the group of collinear sources. Problems with separating the contributions from similar or collinear source profiles might be overcome by more detailed speciation. Detailed organic compound analyses might allow better differentiation of various combustion sources. Appendix 7 of the Atmospheric Science Report on Sulphur in Gasoline and Diesel Fuels (Lowenthal, 1997) provides a more detailed description of CMB modelling and its limitations.

Many CMB analyses have been performed for locations in the western U.S. with a much smaller number of studies in the eastern U.S. and Canada. Lowenthal (1995,1997) has provided summaries of source-receptor modelling studies in the U.S. and Canada (including some studies which used factor analysis as the apportionment technique). There were a wide range of source distributions found in these studies with median percentages ofcrustal/soil, vehicular exhaust, vegetative/wood burning, secondary ammonium sulphate, secondary ammonium nitrate and other sources in $PM_{10}$ being about 40%, 20%, 10%, 10%, 10% and 10%, respectively.

A CMB analysis by Environmental Applications Group (1984) at seven cities across Canada, including Ottawa and Toronto, identified secondary sulphate, vehicular exhaust and wood burning as the largest contributors to $PM_{2.5}$ concentrations. For the coarse fraction above 2.5 µm in diameter, road dust and construction activities were usually the largest source sectors from the CMB analyses. The utility of this data set for assessing current source contributions is limited. The masses of $PM_{2.5}$ and the coarse fraction of $PM_{10}$ were higher than current concentrations. In addition, there were no data on organic carbon mass, nitrate concentrations were not used in the analyses and only a limited amount of data on elemental carbon concentrations was available.

CMB analyses have been performed for two of the recent Canadian data sets giving chemical composition information. The Lower Fraser Valley study took place during the summer of 1993 and a study at Evans Avenue in Toronto analyzed data from the fall of 1995. The chemical compositions found in these studies have been described in Section III.2.

In the Lower Fraser Valley Study, CMB analyses were performed for two sites along the valley; Chilliwack and Pitt Meadows (Sakiyama, 1994, Lowenthal et. al. 1997). Species concentrations were similar at the two site with the notable exception of nitrate which was much higher at Chilliwack, the site further inland. Sulphate concentrations were also higher at Chilliwack. The percentage contributions to $PM_{2.5}$ from vehicular exhaust, ammoniumsulphate, ammonium nitrate, vegetative/wood burning, crustal/soil and marine sources were (34%,43%), (25%,27%), (27%,12%), (8%,9%), (3%,5%) and (3%,5%) for Chilliwack and Pitt Meadows, respectively.

The Evans Avenue data were analyzed for the source contributions to both $PM_{2.5}$ and the coarse fraction of $PM_{10}$. For $PM_{2.5}$, the CMB analysis gave percentage contributions from vehicle exhaust, ammonium sulphate, ammonium nitrate, crustal/soil, vegetative/wood combustion, incineration and salt as 52%, 33%, 5.6%, 3.6%, 2.7%, 2.8% and 0.6%, respectively (*Sulphur in Gasoline and Diesel Fuels, Atmospheric Science Expert Panel Report*, 1997). The analysis for the coarse fraction of $PM_{10}$ showed crustal/soil sources dominating with 56% of the mass but the vehicle exhaust contribution was also large at 32%. As discussed earlier, the Evans Avenue site is influenced by nearby diesel sources. Other analyzed contributions to the coarse mass were ammonium nitrate, ammonium sulphate, industrial, incineration and salt at 5%, 3.3%, 2.8%, 0.8% and 0.6%, respectively.

### Chemical Composition Combined with Emission Data

US EPA (1997) has combined information on the percentages of the main chemical components of $PM_{2.5}$ found at urban locations with emission inventory data corresponding to each chemical component. The combined use of monitoring and emission data puts the primary and precursor gas emissions in context with the chemical component of $PM_{2.5}$ to which they contribute.

Using the limited amount of chemical composition data available for Ontario (Lowenthal, 1997; Brook et. al., 1997; Hoff et. al., 1997) along with data from eastern U.S. cities (US EPA, 1997; Pace, 1998), Figure III.4.3 provides a graphical estimation of the source contributions to $PM_{2.5}$ in Ontario. Separating crustal/soil emission sources from combustion related sources of primary particles greatly reduces the influence of large uncertainties in emissions of open/fugitive dust sources on the source attribution. The contributions of fugitive dust sources are limited to the analyzed crustal/soil component. For urban areas, the fugitive dust sources would be mainly paved road dust and dust from construction activities with industries affecting local areas.

The elemental and organic carbon mass, referred to as combustion related on the pie chart (Figure III-4.3), would include a secondary organic aerosol (SOA) contribution as well as emissions of primary particles from combustion sources. There is limited information available on the contributions of biogenic and anthropogenic VOC emissions to secondary organic aerosol concentrations. Analyses in California suggest that SOA concentrations could be large during high ozone smog episodes but that on an annual basis only 10-40% of the organic aerosol is due to secondary formation (Sulphur in Gasoline and Diesel Fuels, Atmospheric Science Expert Panel Report, 1997). Lower oxidant levels and less ultraviolet radiation in Ontario compared to California would likely result in significantly less SOA production in Ontario. Elemental carbon concentrations are entirely due to primary emissions from combustion sources. Note that CMB analyses tend to attribute a larger portion of the elemental and organic carbon mass to vehicular emissions than indicated by province wide emission inventory estimates for combustion sources.

Figure III.4.4 provides a similar breakdown of source contributions to the coarse fraction of $PM_{10}$. The data available for Ontario and the eastern U.S. on the chemical composition of the coarse fraction of $PM_{10}$ are even more limited than for $PM_{2.5}$ (Lowenthal, 1997; Brook et. al. 1997, US EPA, 1997). Crustal/soil related sources are the major contributors to the coarse particle mass. In urban areas, fugitive dust from paved roads and construction activities would likely dominate the crustal/soil component but industrial processes and fugitive emissions can be large contributors to local concentrations.

### *III.4.3.2 Urban-Rural Analyses*

Estimates of the urban contributions to $PM_{2.5}$ and $PM_{10}$ concentrations can be determined by comparing data at urban and rural sites. Ideally the rural site(s) would be located to provide estimates of the air concentrations transported into the urban area and possibly at sites downwind of the urban area. The most complete information would be obtained if chemically speciated data were available at both the urban and rural sites. The differences in the urban concentrations compared to the rural values represent the impacts of both primary particle emissions and secondary aerosol chemistry occurring over the urban area.

In the *Atmospheric Science Expert Panel Report* (1997), data for $PM_{2.5}$ and sulphate collected at Egbert, a rural site north of Toronto, were compared with paired samples collected at sites in the Toronto area. Trajectory analyses were used to identify days when the urbanplume from Toronto could have affected concentrations at Egbert. These days were excluded from the comparisons of the paired data. The paired urban-rural analyses indicated that about 26% of the sulphate observed in Toronto was due to a combination of primary sulphate emissions and photochemical production of sulphate across the urban complex. For $PM_{2.5}$, the data gave an urban contribution of about 28% which indicates emissions from the urban area affected other chemical constituents of $PM_{2.5}$ in addition to sulphate.

The majority of the data used in this study was taken during the May to September period. Seasonal analyses of the urban contributions to $PM_{2.5}$ and sulphate were not done in the study. An assessment of the spatial variabilityof sulphate concentrations for the sites in the Toronto area gave a range of about 9%. Spatial variability can arise from localized emission sources and from variations in the amount of $SO_2$ which has been converted to $SO_4$ at sites across the urban area. Taking into account both the spatial variability and an estimate of the instrument precision, the Toronto area contribution to sulphate was estimated as 26±3%.

Since the Greater Toronto Area is quite large which allows a significant time for sulphate formation, the percentage urban contribution to sulphate in Toronto is likely larger than for most other major urban areas in Ontario. Exceptions would be locations near sources and localities such as downtown Hamilton where local meteorological conditions allow significant residence times and more pollution buildup. The contribution of primary emissions from combustion sources to $PM_{2.5}$ concentrations would be more comparable between Greater Toronto and other major urban areas in Ontario since residence time is not as important as it is for secondary aerosol formation.

### *III.4.3.3 Ratios with Other Compounds*

There are several data analysis approaches where comparisons with emissions and concentrations of other compounds can be used to estimate concentrations due to primary particulate matter emissions from sources distributed over an urban area. In the Atmospheric Science Expert Panel Report (1997), the ratio of (air concentrations)/(emissions) of CO was used along with primary sulphate emissions from vehicles to estimate the contribution of those sources to sulphate concentrations in seven urban centres across Canada. Carbon Monoxide was used because it is comparatively unreactive and the emissions are dominated by combustion sources which are well distributed across the urban areas (i.e., vehicle and fuel combustion sources). The air concentrations used in the ratios have subtracted off the background inflow CO concentrations to correspond to the impact of only the urban emissions.

The study estimated primary sulphate emissions from gasoline vehicles, on-road and off-road diesel in the Greater Toronto Area in 1990. Using the CO (air concentration)/(emission) ratio for Toronto, a vehicular primary emission contribution of about 0.2 $\mu g/m^3$ for sulphate can be calculated. Similar estimates of air concentrations can be made for species where chemical changes and dry deposition losses are expected to be small for the residence time over the urban area. Concentration estimates could only be made for source sectors that are well distributed over the urban area similar to the CO emission sources. Emissions of $PM_{2.5}$ from combustion sources such as gasoline and diesel vehicles, vegetative/wood burning, meat cooking and fuel burning could be used to estimate their contributions to air concentrations. However part of the fugitive dust emissions, which are mainly in the coarse fraction of $PM_{10}$, would be removed by dry deposition during the residence time over the urban area. Correspondingly, an emission estimate for fugitive dust applied to the CO (air concentration)/(emission) ratio would result in an overestimate of air concentrations due to these source sectors.

Estimates of the urban contribution to the concentrations of a chemical component such as elemental carbon can be made using paired urban-rural data. Comparing the urban contribution for the chemical component with the urban contribution to CO concentrations, an estimate of the overall urban emissions of that chemical component can be made using estimates of the CO emissions. This approach to estimating urban emissions can be used for slowly depositing and nonreactive compounds with widespread emissions across the urban area. Other compounds such as $_{NOX}$ or $SO_2$ could be used in these comparisons but CO is better because widespread emission sources are the dominant contributors to CO concentrations and CO is not very chemically reactive.

### *III.4.3.4 Source or Source Group Assessments*

Analyses of source oriented monitoring data can be used to estimate the contributions of sources or groups of sources to $PM_{2.5}$ and $PM_{10}$. For cases where the monitors can be identified as being upwind or downwind of the source area, differences in the concentrations can be used to back estimate emissions from the sources. The pattern of annual average concentrations around a source area could also be used to back estimate emissions from the sources. For primary emissions, dispersion model simulations for hour averages, 24 hour averages or annual averages can be compared with the observed concentration differences across the source area or the concentration patterns to perform a back estimate of emission rates.

For the Hamilton Air Quality Initiative (HAQI), extensive monitoring was available around the Hamilton Harbour industrial complex. A number of 24 hour average events where monitors could be identified as upwind or downwind were used to backcalculate emissions of $PM_{10}$ from the main industrial source areas (Hamilton-Wentworth Air Quality Initiative: Environmental Workgroup Report, 1997). A similar back calculation of emission rates was performed using the annual average concentrations observed around the area. Large volume sources were used in the dispersion modelling to represent the industrial emissions. If some of the $PM_{10}$ emissions were in fact from taller stacks, the back calculation using a volume source would underestimate the overall emissions. Also, some deposition of the coarser portions of $PM_{10}$ would have occurred over the industrial sites before reaching the monitors. Again this would result in some underestimate of emission rates.

Figure III.4.5, taken from the HAQI Environmental Workgroup Report (1997), was produced using $PM_{10}$ monitoring across Hamilton, estimates of $PM_{10}$ transported into Hamilton from data at a rural site and dispersion modelling of the industrial emissions. The result is an apportionment of $PM_{10}$ concentrations into components from outside the region, from widespread urban sources and from industrial sources. The urban contributions were determined by subtracting the rural concentration and the calculated industrial concentrations from the measured annual average concentrations at locations across the city.

Although the analyses in the HAQI study give an attribution for the overall $PM_{10}$ concentrations, information on the distribution of the chemical constituents would provide a more complete starting point for developing an emission reduction strategy. A study which included chemical speciation of $PM_{2.5}$ and the coarse fraction of $PM_{10}$ for a combination of rural, residential, urban core and source oriented monitoring sites such as used in the HAQI study, would be ideal. In addition to the type of analysis in Figure III.4.5, the speciated particulate matter concentrations could be analyzed by the Chemical Mass Balance method. Combining CMB results at various sites with wind trajectory/sector data would provide additional data on the emission sources contributingto the regional, urban and industrial loadings of particulate matter.

Source oriented monitoring can also be used to back estimate emissions from specific sources such as a highway, an arterial roadway, an industry or a landfill.

### III.4.4 Summary of Estimates and Uncertainties in Source Apportionment

Section III.4.3.1 has described the use of a combination of chemical composition data for $PM_{2.5}$ and the coarse fraction of $PM_{10}$, source-receptor modelling and emission inventories for each chemical component to provide overall source sector contributions to particulate matter concentrations. Figure III.4.3 indicates the emission source sectors which contribute to the combustion related, ammonium sulphate, ammonium nitrate and soil related components of $PM_{2.5}$. Figure III.4.4 provides a similar apportionment for the coarse fraction of $PM_{10}$. The pie charts indicate ranges for the percentage of particulate matter in each chemical component. The range in the percentages represents both spatial variability and uncertainty estimated from the limited amount of analyzed data available for Ontario and sites in the northeastern U.S..

Section III.1 provides information on the emission estimates for $SO_2$, $_{NOX}$ and primary particle emissions for Ontario and for the surrounding U.S. states. Note that chemical mass balance studies tend to attribute a large portion of the combustion related elemental and organic carbon component of $PM_{2.5}$ to vehicular emissions. While emission inventories of combustion sources do have vehicle exhaust as a significant source, a number of other combustion sources contribute to the province wide emission totals. Recent work with detailed organic compound analyses of combustion sources have started to identify tracer compounds for combustion sources such as vehicle exhaust, hard and soft wood burning and cooking. These source characterizations coupled with speciated ambient organic carbon measurements could give better source attributions in the future.

While the information in Figures III.4.3 and III.4.4 provides guidance on the source sectors that contribute to $PM_{2.5}$ and the coarse fraction of $PM_{10}$, they do not show the relative importance of urban scale emissions versus other Canadian emission sources and transboundary transport of particulate matter. Analyses of paired rural data and urban data for the Greater Toronto Area has shown that, on average, urban emission sources contribute 25% to 30% of the $PM_{2.5}$ concentrations in the urban area (*Atmospheric Science Expert Panel Report*, 1997). The contributions of local urban emissions to $PM_{2.5}$ concentrations in other Ontario urban centres can be estimated by comparing urban averages given in Section III.2 with the average at Egbert; a rural site north of Toronto. These urban-rural comparisons show variations from city to city and within an urban area. The data indicate urban contributions ranging from about 10% to 15% in Ottawa (for the 1990-1995 period) to about 35% at a site in Hamilton where industrial emissions also affect the observed concentrations.

Similar urban-rural comparisons can be made for $PM_{10}$ concentrations. Section III.2 gives the $PM_{10}$ concentrations observed at sites across Ontario. Although the site at Nanticoke would have some local impacts on $PM_{10}$ from fugitive dust sources and industries, it is the closest to a rural remote site in the Ontario network. $PM_{10}$ at most urban sites indicates urban contributions of 15% to 40%. At sites near local sources, the urban/industrial contribution can be 60% or more. Figure III.4.5 shows a breakdown of urban and industrial contributions to $PM_{10}$ in the suburban, urban core and industrial areas of Hamilton.

Approximate estimates of the transboundary transport of $PM_{2.5}$ and the coarse fraction of $PM_{10}$ into Ontario could be made using monitoring data at clean rural sites near the Canada-U.S. border. Using data at Sutton near the Quebec-U.S. border, Brook and Dann (1998) reported average $PM_{2.5}$ concentrations of about 12 $\mu g/m^3$ when the air flow was into Canada while an average of about 6.6 $\mu g/m^3$ was observed with northerly flows. Data at non-urban monitoring sites in the U.S. were used to estimate that $PM_{2.5}$ concentrations of 9 to 13 $\mu g/m^3$ would be transported into southern Ontario with westerly or southerly air flows (*Towards a National Particulates Strategy for Canada*, 1997).

The contribution of transboundary $PM_{2.5}$ to Ontario urban centres depends on the frequency of air flows from the U.S. and on the physical/chemical processes (dry deposition, wet scavenging, mixing, chemical production etc.) occurring as the air mass is transported from the border to the urban area. A comprehensive aerosol model with complete and reliable emission inputs is required to quantify the contributions of sources from various regions to urban air concentrations. Qualitatively, the fine particles, $PM_{2.5}$, would have impacts over longer distances than the coarse fraction of $PM_{10}$ because they have lower dry deposition velocities and the secondary aerosols formed during transport are mostly in the $PM_{2.5}$ fraction.

One component of $PM_{2.5}$ for which comprehensive model simulations have been performed is sulphate. Using various $SO_2$ emission reduction scenarios described in '*Towards a National Acid Rain Strategy*" (1997), estimates of the relative contributions of Canadian and U.S. sources to regional sulphate concentrations in Ontario can be made. For the Greater Toronto Area, a paired urban-rural analysis showed that urban emissions contributed about 25% of the observed sulphate (Atmospheric Science Expert Panel Report, 1997). Figure III.4.6 has used the results from these two studies to apportion the sulphate component of $PM_{2.5}$ for the Greater Toronto Area. For the Greater Toronto Area, the contribution of transboundary transport was estimated to be 60-65% of the observed sulphate levels with Canadian sources outside the area contributing 10-20%. Emissions of $SO_2$ from U.S. sources dominate the transboundary contribution to sulphate in Ontario.

The *Atmospheric Science Expert Panel Report* (1997) has estimated that about half of the urban contribution to sulphate in the Greater Toronto Area was due to emissions from on and off-road vehicles (i.e., about 13% of total). Other sources of $SO_2/SO_4^{2-}$ emissions in the Greater Toronto Area are marine, railroad, airports, industrial, power generation and other fuel combustion. These sources would then be responsible for the remainder of theurban contribution to sulphate (i.e., about 13% of total).

Since the $SO_2$ emission reduction scenarios described in "*Towards a National Acid Rain Strategy*" (1997) were uniform percentage reductions in either Canada or Canada and the U.S., the contributions of individual sources or source sectors to the regional sulphate concentrations were not quantified. Qualitatively, $SO_2$ emission sources usually upwind of the Greater Toronto Area (southwestern Ontario and Hamilton) would have more impact on the Greater Toronto Area per tonne of emissions than sources in central or northern Ontario. Emissions from sources in central and northern Ontario would have a larger impact on regional sulphate concentrations in eastern Ontario than in the Greater Toronto area.

For the transboundary contribution to sulphate, emissions of $SO_2$ from the Great Lakes States bordering Ontario would have the largest impacts on Ontario with significant impacts from states further away such as Missouri, Kentucky and West Virginia. Section III.1 provides state total emissions of $SO_2$ with the states grouped by their location relative to Ontario (e.g., Great Lakes states).

Although the information currently available to apportion the relative contributions of various emission sources sectors and emissions from different regions (i.e., urban, other Ontario/Canadian, U.S., global) to measured $PM_{2.5}$ and $PM_{10}$ concentrations in Ontario leaves many gaps in our knowledge, some source apportionment estimates can be made for some of the chemical components of fine and coarse particulate matter. The relative contributions of the precursor gases, primary emissions from combustion relatedsources and primary emissions from soil/crustal related sources to particulate matter concentrations are illustrated in Figures III.4.3 and II.4.4. A number of the other analysis approaches described earlier, especially urban-rural analyses, can be used to provide estimates of the extent to which communities in Ontario are contributing to observed particulate matter concentrations within the community.

To illustrate the extent to which local communities contribute to their own $PM_{10}$, $PM_{2.5}$ and secondary aerosol concentrations, assessments of ambient pollutant levels in some Ontario communities have been done. The communities used to illustrate the impacts of local urban/industrial sources were selected to include the major population centres and some communities with major local sources including several northern Ontario cities where woodsmoke might be a concern. Monitoring data for at least $PM_{10}$ and sulphate had to be available for the communities used in the assessment. The communitiesselected are: Hamilton, Toronto, Windsor, London, Ottawa, Cornwall, Sault Ste. Marie, Thorold, and Thunder Bay.

Table III.4.1 summarizes the available information on average $PM_{10}$ and $PM_{2.5}$ concentrations in the nine Ontario communities examined. The table also includes average concentrations of the secondary aerosols; sulphate, nitrate and ammonium; where data are available. For nitrate and ammonium, observed concentrations are only available for Windsor, Toronto and an urban Hamilton site. There are no measurements which give information on secondary organic aerosol concentrations.

Using the observed concentrations in Table III.4.1 along with the limited data available at rural sites (see Section III.2) and the modelling/data analyses described earlier in this section, some estimates can be made of the relative contributions of source regions (local community emission sources versus other Ontario, Canadian, US and global emission sources) to the observed particulate matter concentrations. Estimates of the contributions of local community sources to observed concentrations can be combined with the community emission information given in Section III.1 to estimate the improvements in air quality that can be expected by reducing these emissions. Near large emission sources and in urban areas the local/urban contributions to particulate matter concentrations can be significant and in some cases the major portion of the problem.

However, for many communities a major portion of the observed concentrations is the result of emissions from other Ontario/Canadian sources and US and global emission sources. Actions to reduce primary particulate emissions as well as emissions of precursor gases on Ontario-wide and international scales are required to address this portion of the IP/RP problem.

As a result of the work performed in the Hamilton-Wentworth Air Quality Initiative and for the Greater Toronto Area in the Sulphur in Diesel and Gasoline Fuels Study, there is more information on the contributions of source regions for these communities than is available for many of the other communities in Ontario. Also, the extensive modelling analyses and rural monitoring which has been performed for acid deposition studies provides more complete information on the source contributions to sulphate concentrations than is available for the other components of particulate matter.

Table III.4.2 summarizes the apportionment results in percentage of observed concentration levels due to local sources (area, transportation, and point sources). Contributions due to outside sources (US transboundary, and other Ontario and Canadian sources) can be calculated by subtracting the local source percentage from 100%. Details are provided below.

### *III.4.4.1 Greater Toronto Area*

Comparisons of urban $PM_{10}$ concentrations in the Greater Toronto Area (GTA) with rural data indicate that emission sources within that community contribute 25% to 40% of the observed values. For the fine fraction of particulate concentrations, $PM_{2.5}$, analyses indicate that the urban area contributes 25% to 30% of the concentrations. A large portion of the concentrations of particles in the coarse fraction of $PM_{10}$ is likely due to emissions within the GTA.

As indicated in Figure III.4.3, area-wide transportation and fuel combustion sources are the largest emitters of primary $PM_{2.5}$ particles in the community. For the coarse fraction of $PM_{10}$, fugitive dust from paved roads and construction activities would be the main sources over the urban area with more localized impacts occurring near some industries or industrial neighbourhoods.

For the portion of $PM_{10}$ and $PM_{2.5}$ concentrations transported into the GTA or any of the other communities examined, information to quantify the relative contributions of US and global sources from other Ontario/Canadian sources is currently not available. Qualitatively, transboundary emissions would be most important for the $PM_{2.5}$ because this material can be transported over longer distances than particulates in the coarse fraction of $PM_{10}$.

Comparisons of urban and rural sulphate concentrations indicate that GTA emissions were responsible for about 25% of the observed sulphate concentrations. The source regions for the remaining 75% of the sulphate can be estimated from model simulations for acid rain studies. These studies estimate that US and global sources contribute 55% to 65% of GTA sulphate concentrations with other Canadian sources contributing the remaining 10% to 20%.

As described earlier in this section, about half of the urban contribution to sulphate in the GTA was due to emissions from on and off road vehicles (i.e., about 13% of total). The other sources of $SO_2/SO_4$ emissions in the GTA are other transportation sources (marine, railroad, airports), fuel combustion, power generation and industries. These sources combined contribute about 13% of the total sulphate over the GTA.

For nitrate and ammonium concentrations, there are limited urban and rural data available to estimate the impact of urban emissions. Since the nitrate data available for Toronto are only a lower limit for the average concentration, an urban contribution to nitrate in the GTA can not be estimated. An urban contribution to ammonium concentrations (ammonium occurs as ammonium nitrate, ammonium sulphate or ammonium bisulphate) can be estimated to be about 30% of the Toronto observed value in Table III.4.1. The sources of the urban ammonia emissions are not well known.

### *III.4.4.2 Hamilton*

Since there are large variations in the observed concentrations of $PM_{10}$ from sites near the industrial area on Hamilton Harbour to the downtown urban site and then to the suburban site on the mountain, these three areas are discussed individually.

*Hamilton: Near Industry*

$PM_{10}$ concentrations near the industries on Hamilton Harbour are much higher than those observed in other parts of Hamilton. Comparing the near industry $PM_{10}$ concentrations with rural data indicates that the industrial and urban sources combine to contribute 50% to 60% of the observed values. Section III.1 gives the estimates of primary $PM_{10}$ emissions for Hamilton that show significant emissions from the iron and steel industry in addition to the emissions from area wide fugitive sources (paved roads, construction, unpaved roads), transportation and fuel combustion.

A combined data and dispersion modelling analysis performed for the Hamilton-Wentworth Air Quality Initiative (HAQI) found that the industrial emissions contributed significantly to the observed $PM_{10}$ levels near the industry sites (about 45%), with additional contributions from widespread area sources in Hamilton (about 15%) and sources outside of Hamilton (about 40%).

A sub-component of $PM_{10}$ measured at the industrial sites was sulphate which was a little higher than values measured at other Hamilton sites. Comparing the sulphate concentrations in Table III.4.1 with rural data given in Section III.2 indicates that emission sources in Hamilton contribute 20% to 30% of the observed concentrations at sites near the industries. Since Section III.1 indicates that more than 90% of the $SO_2$ emissions in the Hamilton area are from industrial sources, these sources are likely the main contributors to increased sulphate values in Hamilton.

*Hamilton: Urban Core*

Comparing the $PM_{10}$ concentration at the urban Hamilton site given in Table III.4.1 with rural data indicates that about 40% of the observed concentrations are due to emission sources within the Hamilton area. The combined data and dispersion modelling analysis in the HAQI study suggests that widespread area sources are responsible for about 2/3 of the enhancement in $PM_{10}$ concentrations with industrial emissions contributing the other 1/3.

Environment Canada data at this site show that $PM_{2.5}$ concentrations are about 60% of the $PM_{10}$ concentrations. Comparing estimated $PM_{2.5}$ concentrations at this site with rural data (from Egbert) indicates that 30% to 40% of the urban concentrations are due to sources in the Hamilton area, i.e., similar to $PM_{10}$.

Sulphate measurements at the urban site are 15% to 25% higher than rural data reported in Section III.2. Again, the large $SO_2$ emissions from industrial sources are likely the main reason for the increased sulphate concentrations. For the sulphate transported into the Hamilton area, US and global sources would contribute much more than other Canadian sources (model simulation indicates that US and global sources contribute about 3/4 of the sulphate transported into Hamilton).

Since nitrate and ammonium concentrations are available at this site, estimates of the urban contributions to these secondary aerosols can be made by comparing rural (Egbert) and urban concentrations. It is estimated that local urban sources contribute about 30% of the nitrate and about 40% of the ammonium observed in downtown Hamilton. The $NO_x$ emission estimates given in Section III.1 indicate that transportation and industrial emissions would be the main sources of the precursor gases leading to nitrate formation. The sources of urban ammonia emissions are not well known.

*Hamilton: Suburban*

The urban/rural comparison of $PM_{10}$ concentrations at the site on the mountain indicates about 30% of the $PM_{10}$ results from emissions in the Hamilton area. Analyses in the HAQI study suggest that widespread area source emissions account for the majority of the increase in $PM_{10}$ with additional contributions from industrial sources.

Comparisons of sulphate concentrations at this site with rural data in Section III.2 indicate that 15% to 20% of the observed values are due to local urban sources.

### *III.4.4.3 Windsor*

Table III.4.1 gives the average $PM_{10}$ concentrations for 3 monitoring sites in Windsor. As shown in Section III.2, two of the Windsor sites are influenced by industrial emissions and the $PM_{10}$ concentrations are higher at those locations. Comparing the individual site data with data at a rural site gives a range from about 35% to 50% as the contribution of Detroit/Windsor emission sources to the observed concentrations of $PM_{10}$. For $PM_{2.5}$, urban/rural comparisons indicate that 30% to 40% of the observed values are due to Detroit/Windsor emission sources.

The urban enhancement of concentrations in Windsor would be due to emissions from both Windsor and Detroit with emissions from Detroit having the larger impact. The Windsor Air Quality Study gave estimates of the contribution of Windsor emissions for a number of contaminants as 20% to 40% of Windsor air concentrations while emissions from the Detroit area accounted for 60% to 80% of the urban impact. Although widespread urban sources of primary $PM_{10}/PM_{2.5}$ emissions are more important for most of the Windsor area, primary particulate matter emissions from industrial sources are responsible for the higher $PM_{10}$ values at two of the Windsor sites.

The sulphate concentrations in Windsor are about 10% to 20% higher than rural concentrations transported into the Detroit/Windsor area. Emissions of $SO_2$ from sources in Detroit likely contribute more to the urban enhancement of sulphate in Windsor than the Windsor $SO_2$ sources themselves. The sulphate transported into the Detroit/Windsor area would be predominantly the result of $SO_2$ emissions from US and global sources (about 85% to 90% of the regional sulphate).

Nitrate and ammonium concentrations were measured at a site in downtown Windsor. Since the only available rural data are at Egbert (located about 350 km northeast of Windsor) estimates of the urban contributions to these contaminants have large uncertainties. Doing these comparisons, the nitrate measurements in Windsor indicate a 35% to 40% urban contribution while the ammonium concentrations given in Table III.4.1 are a third higher than the Egbert measurements.

### *III.4.4.4 London*

$PM_{10}$ concentrations in London are lower than in other large urban centres in southern Ontario. Compared with rural data, the $PM_{10}$ concentration in London is only about 15% higher. The primary $PM_{10}$ emissions given in Section III.1 indicate that widespread area sources are the main contributors to elevated particulate matter concentrations in London.

The sulphate concentrations measured in London are similar to or slightly higher than rural sulphate concentrations. These urban sulphate concentrations are about 5% (0% to 10%) higher than rural values. $SO_2$ emissions from the US and global sources would be responsible for 75% to 85% of the sulphate transported into London.

### *III.4.4.5 Ottawa*

Although there are no rural sites very close to Ottawa which measure either $PM_{10}$ or $PM_{2.5}$ concentrations, an Environment Canada site at Sutton south of Montreal measures concentrations which should be similar to the rural concentrations transported into Ottawa. An additional uncertainty in assessing an urban contribution to $PM_{10}$ and $PM_{2.5}$ concentrations in Ottawa is that the urban data given in Table III.4.1 are for the period from 1984 to 1995. Particulate matter concentrations measured in the 1980s were generally a little higher than those measured in the 1990s.

Including an uncertainty factor for the different averaging times for the urban and rural data, Ottawa's $PM_{10}$ concentrations show a 25% contribution from local sources while the $PM_{2.5}$ concentrations indicate a 10% to 15% local contribution. Table V.10 indicates that widespread area sources dominate the primary emissions of $PM_{10}$ and $PM_{2.5}$ in Ottawa.

Comparisons of urban and rural sulphate data show concentrations in Ottawa to be elevated by 10% to 20%. Again, area wide $SO_2$ emission sources would be responsible for the large majority of the urban impact on sulphate concentrations. The sulphate transported into the Ottawa area would be the result of $SO_2$ emissions from both other Canadian sources and US and global sources. The contribution of US and global sources to the sulphate transported into Ottawa is in the 50% to 70%

range.

### *III.4.4.6 Cornwall*

When the observed $PM_{10}$ concentration in Cornwall is compared with the data from Sutton, a large local contribution is indicated. About 40% to 45% of the observed $PM_{10}$ concentrations would be due to emissions in the Cornwall area. The emissions given in Section III.1 show that both industries and widespread area sources are contributing to the primary particulate matter emissions.

The sulphate concentrations in Cornwall are significantly higher than at rural sites in southeastern Ontario. Comparing the urban and rural sulphate concentrations indicates that emissions in Cornwall are responsible for 40% to 50% of the observed concentrations. Industries dominate the $SO_2$ emissions given in Section III.1.

### *III.4.4.7 Sault Ste. Marie*

Concentrations of $PM_{10}$ and sulphate at a monitoring site near an iron & steel industry in Sault Ste. Marie are much higher than those at a site in the urban area. There are no rural $PM_{10}$ monitors near Sault Ste. Marie to use in estimating the overall impact of industrial and urban emissions on observed concentrations. However, a minimum estimate of the contribution of industrial emissions to $PM_{10}$ concentrations near the industry can be made by comparing the measured values at the industrial and urban sites. Since the near industry site has nearly double the concentration of $PM_{10}$ observed at the urban site, industrial emissions account for at least half of the observed concentrations near the industry. There would also be some contribution of the industrial emissions at the urban site but there is insufficient information to estimate that impact.

During the winter woodsmoke could be a significant contributor to $PM_{2.5}$ concentrations in this northern Ontario community; however, there is currently insufficient information to quantify that impact.

Sulphate concentrations at the urban site in Sault Ste. Marie are higher than those at a rural site in the region. Comparing the urban and rural concentrations indicates that local sources (possibly including some impacts from U.S. Sault Ste Marie) account for 40% to 45% of the observed concentrations at the urban site. Sulphate concentrations at the industrial site are much higher. Local industrial and urban sources contribute about 70% of the observed sulphate concentrations at the industrial site. Section III.1 shows that the very large majority of local $SO_2$ emissions come from industrial sources.

For the sulphate transported into Sault Ste. Marie, model simulations indicate that more than 60% is the result of $SO_2$ emissions from US and global sources.

### *III.4.4.8 Thorold*

The monitoring results in Thorold are taken very close to an industrial area and are mainly influenced by a single industry. However, no emission data from this industry are available. Comparing $PM_{10}$ concentrations with rural data shows that about 50% of the observed values are due to emissions from the industrial sources.

Sulphate concentrations at the Thorold site are a little higher than values observed at Nanticoke and St. Catharines; both of which would have some local contribution to their observed concentrations. The enhancement in sulphate at the Thorold monitor is estimated to be in the 5% to 10% range, although the monitor is located so close to the industry that secondary particulate formation due to the industrial emissions may not have sufficient time to develop to impact this monitor. As was found for Hamilton and the Greater Toronto Area, model simulations show that about 3/4 of the sulphate transported into the area is due to emissions from the US and global sources.

### *III.4.4.9 Thunder Bay*

Since there are no rural $PM_{10}$/$PM_{2.5}$ monitors near Thunder Bay, estimates of the urban contributions to these concentrations are currently not available. The emission data in Section III.1 show that local industries emit significant amounts of primary $PM_{10}$ and $PM_{2.5}$. In addition, woodsmoke could be contributing to concentrations of $PM_{2.5}$ during the winter.

Comparing sulphate concentrations in Thunder Bay with rural data in the region indicates that urban/industrial sources are responsible for 30% to 50% of the observed concentrations. The $SO_2$ emission data given in Section III.1 indicate several significant industrial sources and also show that transportation sources (including marine sources) contribute to precursor gas emissions. For the portion of the sulphate transported into Thunder Bay, model simulations indicate that other Canadian sources of $SO_2$ emissions contribute 20% to 40% of the regional sulphate while global and US sources contribute 60% to 80%.

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## TABLE III.4.1: IP/RP AND PRECURSOR LEVELS IN ONTARIO COMMUNITIES

| COMMUNITY | AVERAGE AMBIENT 24 H. LEVEL[1] (µg/m$^3$) | | | | |
|---|---|---|---|---|---|
| | $PM_{10}$ | $PM_{2.5}$ | $SO_4^{-2}$ | $NO_3^-$ | $NH_4^+$ |
| **Major Populated Communities** | | | | | |
| ***With major local point sources*** | | | | | |
| Hamilton-near industry | 32.2 | | 5.7 | | |
| Hamilton-urban | 27.1 (31) | (18.1) | 5.4 (6.1) | (2.2) | (2.5) |
| Hamilton-suburban | 23.1 | | 5.3 | | |
| Toronto (GTA) | 23.0 (27) | (16.5) | 4.2 (3.9) | (>1.4) | (2.2) |
| Windsor | 28.9 (30.8) | (17.5) | 5.0 | (2.4) | (2.0) |
| ***Without major local point sources*** | | | | | |
| London | 19.0 | | 4.3 | | |
| Ottawa | 16.4[2] (22.6) | 10.3[2] (12.5) | (3.4) | | |
| **Communities with Local Sources and/or Significant Woodsmoke Sources** | | | | | |
| Cornwall | 22.6 | | 5.3 | | |
| Sault Ste. Marie-near industry | 37.8 | | 5.2 | | |
| Sault Ste. Marie-urban | 19.9 | | 2.9 | | |
| Thorold | 33.7 | | 4.8 | | |
| Thunder Bay | 17.1 | | 2.0 | | |

[1] Data in brackets are from various Environment Canada sources covering the period 1984-1995; other data are from MOE, averaged over the period 1992-1996, except noted.

[2] Data are from Environment Canada for the 1990-1995 period.

## TABLE III.4.2: CONTRIBUTIONS OF LOCAL URBAN/INDUSTRIAL SOURCES TO IP/RP AND AEROSOL LEVELS IN ONTARIO COMMUNITIES

| COMMUNITY | PERCENTAGE (%) DUE TO LOCAL SOURCES | | | | |
|---|---|---|---|---|---|
| | $PM_{10}$ | $PM_{2.5}$ | $SO_4^{-2}$ | $NO_3^-$ | $NH_4^+$ |
| **Major Populated Communities** | | | | | |
| ***With major local point sources*** | | | | | |
| Hamilton-near industry | 50-60 | | 20-30 | | |
| Hamilton-urban | 40 | 30-40 | 15-25 | 30 | 40 |
| Hamilton-suburban | 30 | | 15-20 | | |
| Toronto (GTA) | 25-40[1] | 25-30 | 25 | | 30 |
| Windsor[2] | 35-50 | 30-40 | 10-20 | 35-40 | 25 |
| ***Without major local point sources*** | | | | | |
| London | 15 | | 0-10 | | |
| Ottawa | 25 | 10-15 | 10-20 | | |
| **Communities with Local Sources and/or Significant Woodsmoke Sources** | | | | | |
| Cornwall | 45 | | 40-50 | | |
| Sault Ste. Marie-near industry[3] | 50 | | 65-75 | | |
| Sault Ste. Marie-urban | | | 40-50 | | |
| Thorold | 50 | | 5-10 | | |
| Thunder Bay | | | 30-50 | | |

1 For $PM_{10}$ the range represents the variations in observed concentrations across the 5 sites in the GTA.

2 There are 3 sites in Windsor with $PM_{10}$ measurements. The urban contribution to concentrations is due to emissions from both Detroit and Windsor with emissions from Detroit having the larger impact. The estimates of the urban contributions to nitrate and ammonium are uncertain because the rural site is not close to Windsor.

3 Since $PM_{10}$ measurements near an industrial site in Sault Ste. Marie are about double the values at an urban site, the impacts of local industrial and urban emissions on $PM_{10}$ are at least 50% at this site.

**Figure III.4.1: Idealized Aerosol Mass Distribution Showing the Fine and Coarse Size Fractions**

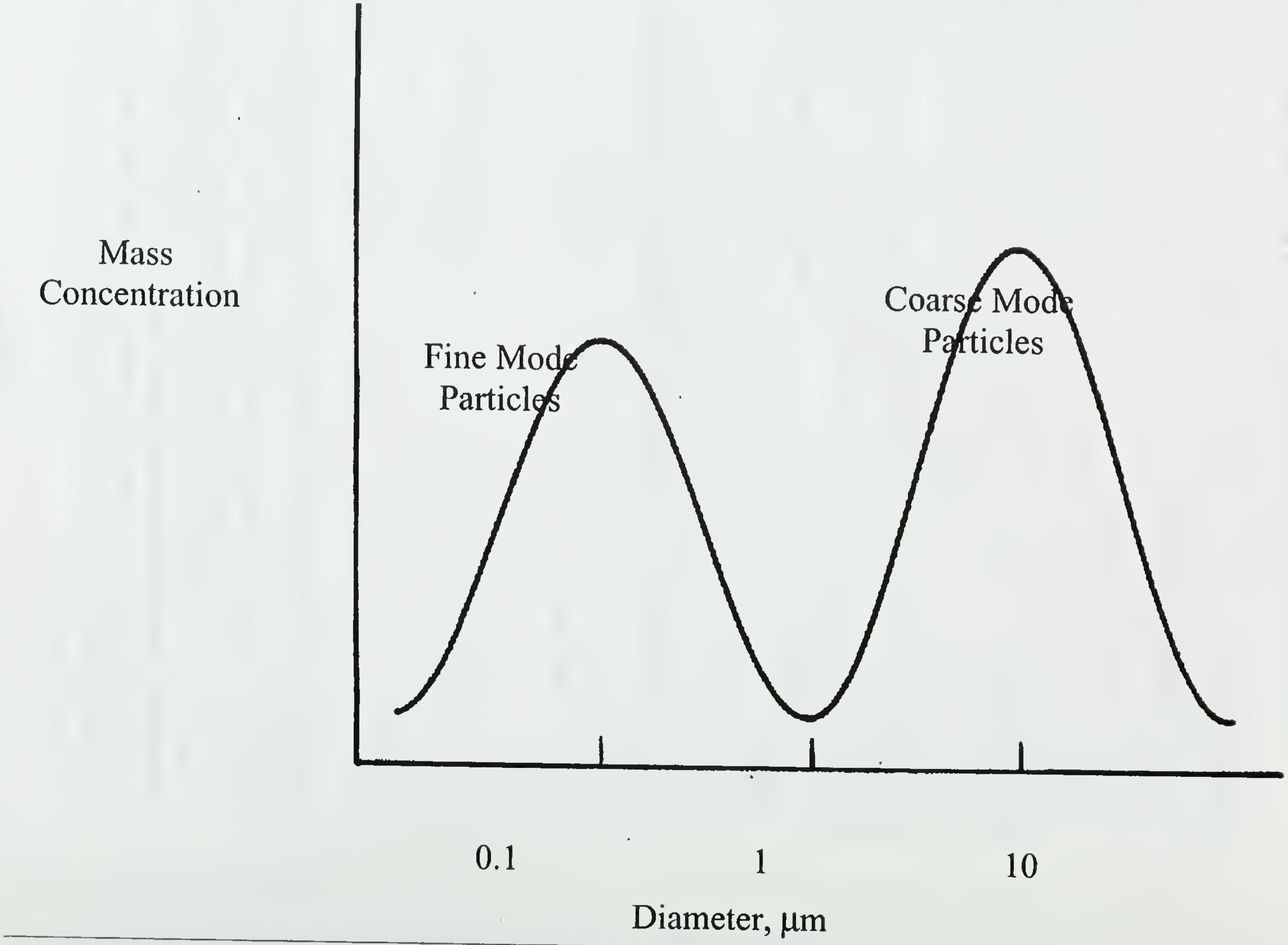
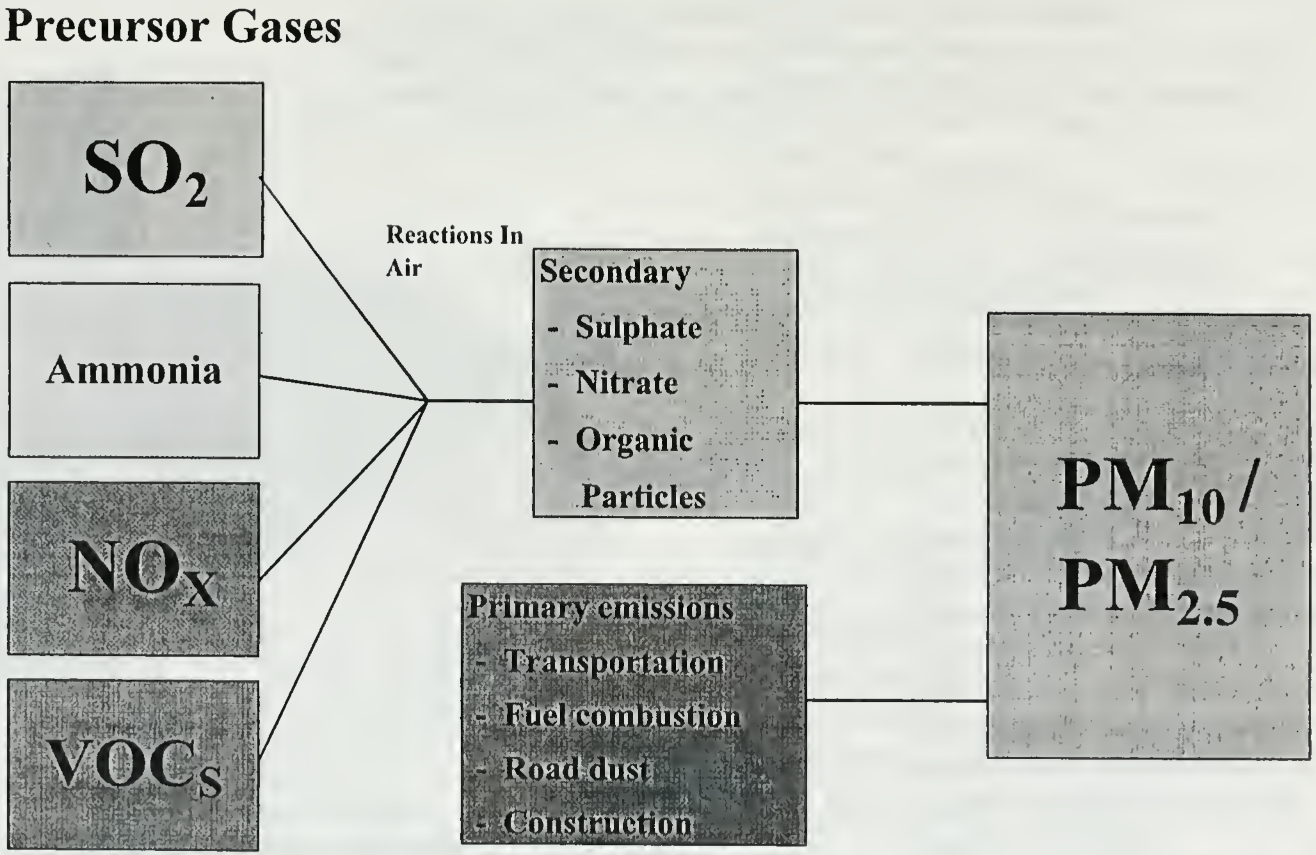
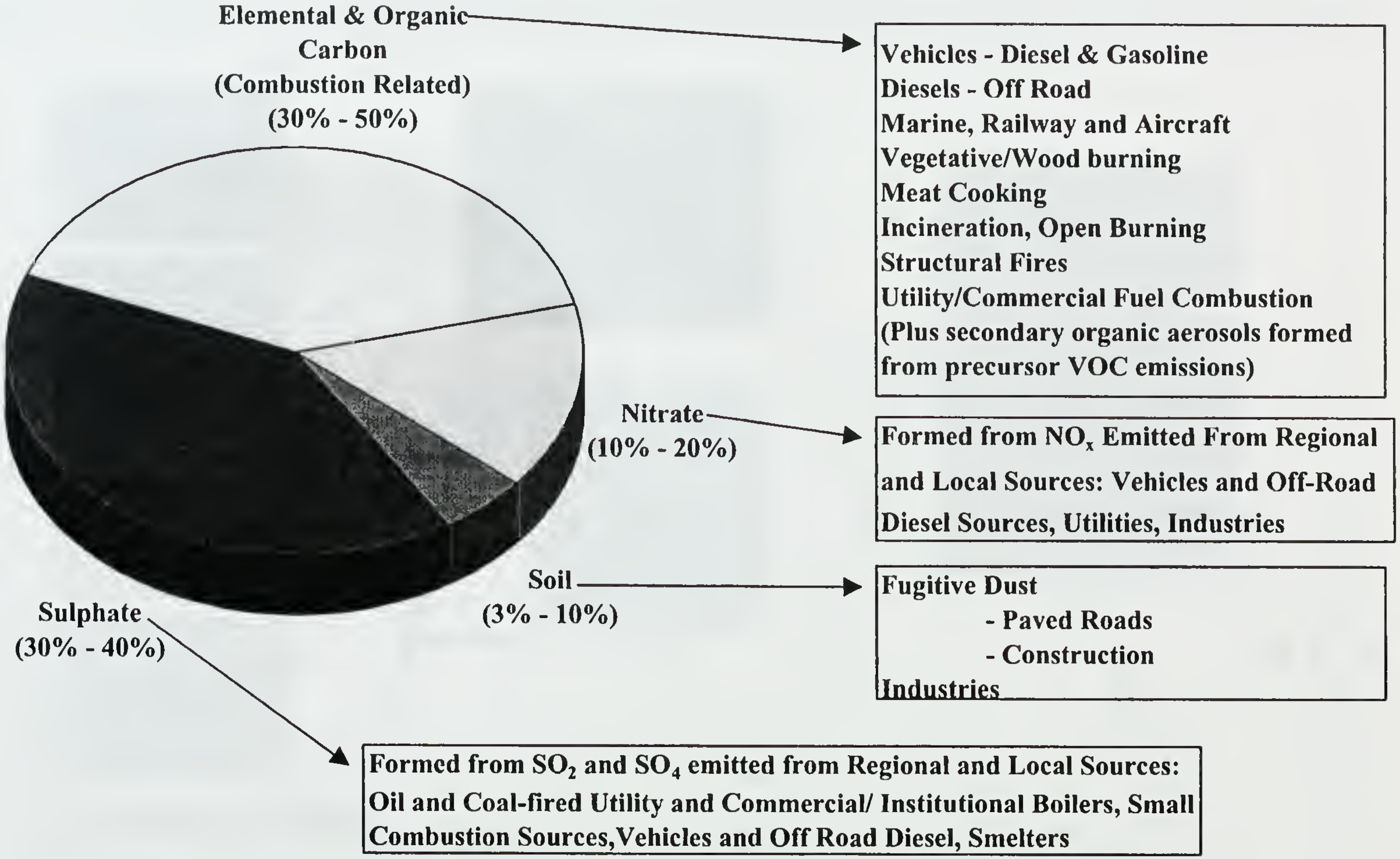


Figure III.4.2 Both Primary Emissions of Particles and Secondary Aerosol Formation Contribute to $PM_{10}/PM_{2.5}$ Concentrations



# Figure III.4.3 : $PM_{2.5}$ Composition/Emissions



Vehicles - Diesel & Gasoline
Diesels - Off Road
Marine, Railway and Aircraft
Vegetative/Wood burning
Meat Cooking
Incineration, Open Burning
Structural Fires
Utility/Commercial Fuel Combustion
(Plus secondary organic aerosols formed from precursor VOC emissions)

Formed from $NO_x$ Emitted From Regional and Local Sources: Vehicles and Off-Road Diesel Sources, Utilities, Industries

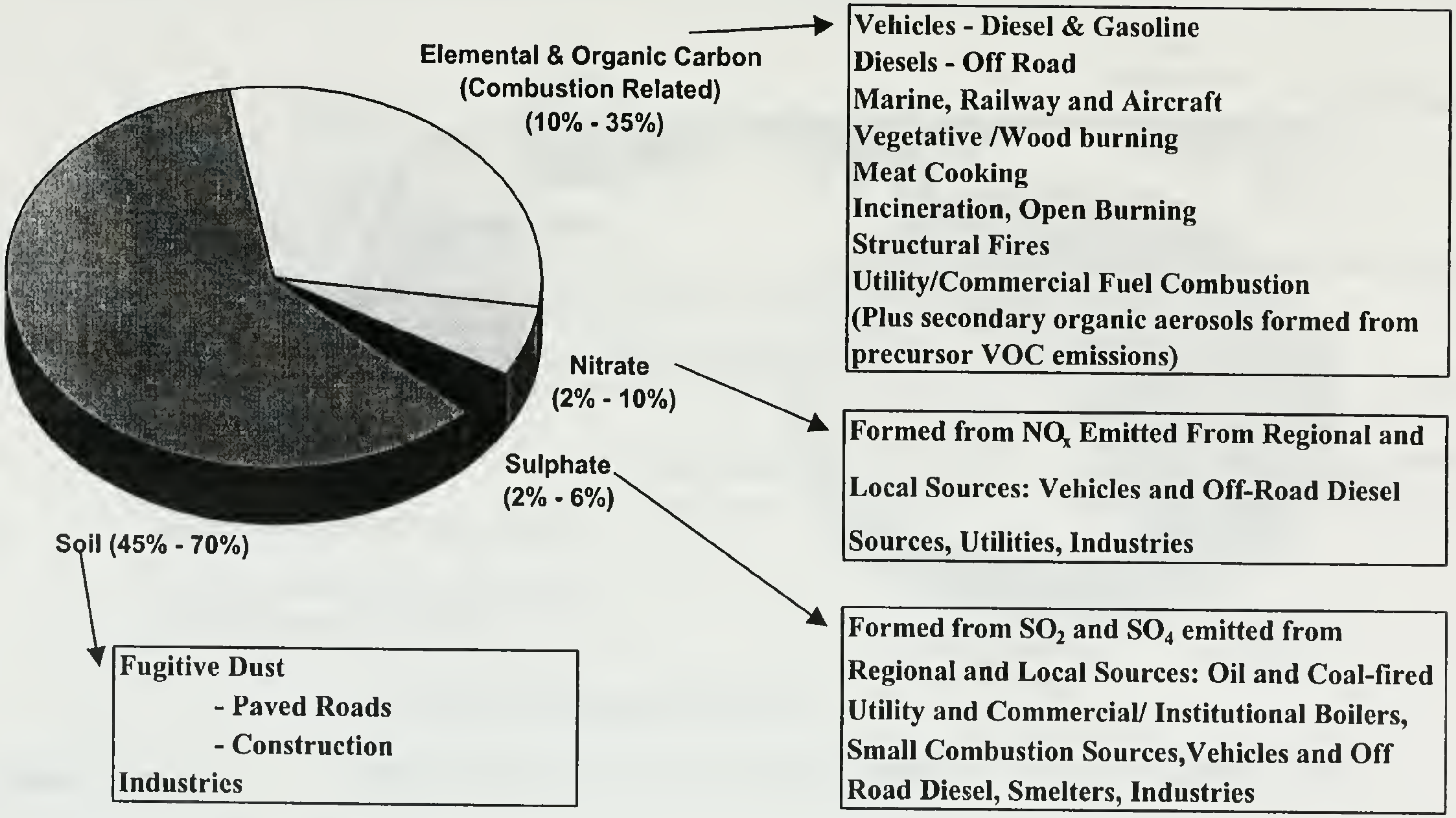
Fugitive Dust
- Paved Roads
- Construction

Industries

Formed from $SO_2$ and $SO_4$ emitted from Regional and Local Sources: Oil and Coal-fired Utility and Commercial/ Institutional Boilers, Small Combustion Sources,Vehicles and Off Road Diesel, Smelters

Section III-4.1 provides information on emission estimates of $SO_2$, $NO_x$ and primary particulates for Ontario and the surrounding U.S. states.

## Figure III.4.4 : Coarse Fraction of $PM_{10}$ Composition/Emissions



Vehicles - Diesel & Gasoline
Diesels - Off Road
Marine, Railway and Aircraft
Vegetative /Wood burning
Meat Cooking
Incineration, Open Burning
Structural Fires
Utility/Commercial Fuel Combustion
(Plus secondary organic aerosols formed from precursor VOC emissions)

Formed from $NO_x$ Emitted From Regional and Local Sources: Vehicles and Off-Road Diesel Sources, Utilities, Industries

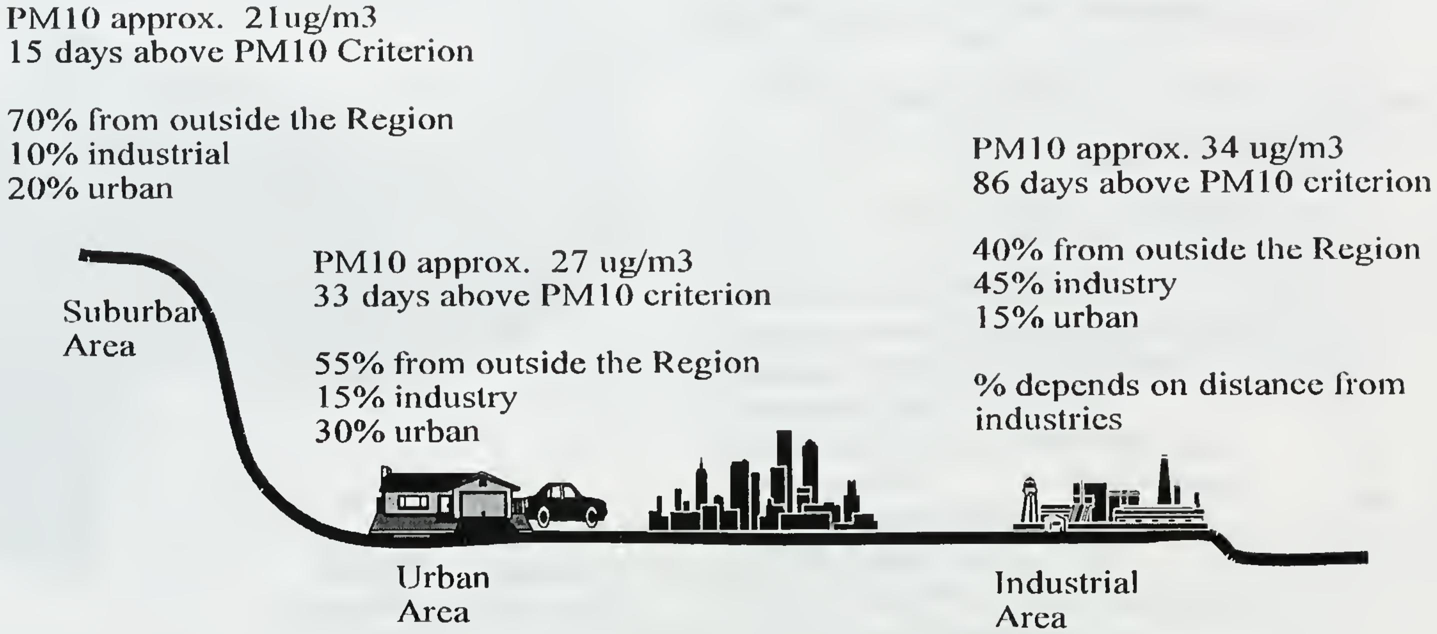
Formed from $SO_2$ and $SO_4$ emitted from Regional and Local Sources: Oil and Coal-fired Utility and Commercial/ Institutional Boilers, Small Combustion Sources,Vehicles and Off Road Diesel, Smelters, Industries

Fugitive Dust
- Paved Roads
- Construction

Industries

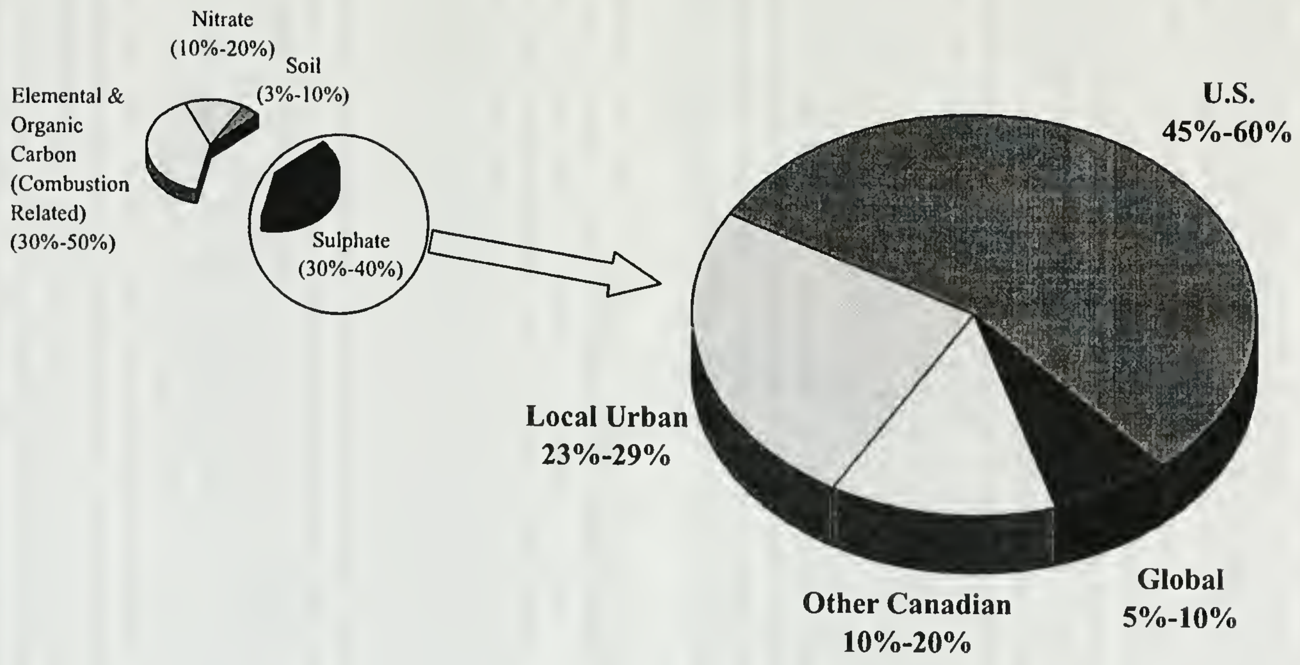
Section III-4.1 provides information on emission estimates of $SO_2$, $NO_x$ and primary particulates for Ontario and the surrounding U.S.states.

**Figure III.4.5:** CONTRIBUTION TO AVERAGE ANNUAL CONCENTRATIONS IN HAMILTON-WENTWORTH



(Hamilton -Wentworth Air Quality Initiative: Environmental Workgroup Report, 1997)

Figure III.4.6: Sulphate Portion of $PM_{2.5}$ For Greater Toronto Area



# III.5 HEALTH EFFECTS ($PM_{10}$/$PM_{2.5}$) AND HEALTH BENEFITS ON ACHIEVING POTENTIAL GOALS

## III.5.1 Health Effects of Inhalable ($PM_{10}$) and Respirable ($PM_{2.5}$) Particulate Matter

This section on PM health effects (i.e., Section III.5.1) is based primarily on highlights from the following Federal-Provincial reports. These are the Science Assessment Document on Particulate Matter (PM SAD, 1998), the Executive Summary of the Science Assessment Document (PM SAD E/S, 1998) and the Rationale Document on Particulate Matter (PM R/D, 1998). The Science Assessment Document and the Executive Summary contain extensive coverage of the toxicological, clinical and epidemiological studies reported in the literature. They also include extensive discussion of the uncertainties, confounding factors, various views of different investigators on addressing the uncertainties and the attributes used by investigators to build a causal link between an agent and its health effects. A weight of evidence approach is used whereby multiple lines of evidence are brought together and duly considered to build a case for the health effects of fine particulate matter. The Science Assessment Document has been extensively peer reviewed. All the documents noted above were developed by the Federal-Provincial Working Group on Air Quality Objectives and Guidelines. In this short compendium, although entitled a 'compendium of current knowledge...' it will not be possible to reproduce and discuss **all** the studies, points-of-view, and weight of evidence. Although highlights have been selected in an attempt to portray a balanced view, to fully appreciate allviews in this very complex area, the interested and concerned readeris encouraged to consult the Science Assessment Document on Particulate Matter (PM SAD, 1998) and its Executive Summary (PM SAD E/S, 1998).

### *III.5.1.1 Linkage: Particle Size and Cardiorespiratory Effects*

The adverse health effects that result from exposure to fine particulate matter (PM) are specific to the cardiorespiratory system. The smaller the particle, the deeper into the lungs it can penetrate, increasing the risk of inducing a negative reaction. Mechanisms by which particles are cleared from each region of the airway and the residence time of the inhaled particles in the various regions are quite different. Most particles greater than about 10 µm will be caught in the nose and throat, never reaching the lungs. Inhalable particulate ($PM_{0}$) may reach the upper respiratory tract. The larger size fraction of these particles (2.5 µm to 10 µm; the coarse fraction of $PM_{10}$) will be caught by cilia lining the walls of the bronchial tubes, which will move the particles up and out. Respirable particulate matter ($PM_{2.5}$) can penetrate deeper into the lungs, into regions where there are no cilia. Some removal mechanisms (e.g., phagocytosis by alveolar macrophages, thoughit has been shown that this can be inhibited by urban air particles) operate in the pulmonary region but retention times are between one to two years.. The ways in which air pollutants such as PM affect the heart are not yet fully understood, but the lung and heart are closely connected which means that a disturbance in one organ can affect the functioning of the other. The types of cardiorespiratory problems examined in studies of the effects of PM on human health include lung function problems, lung infections, asthma, chronic bronchitis and emphysema (the latter two are known as chronic obstructive lung disease) and various forms of heart disease.

### *III.5.1.2 Highlights from Health Effect Evaluations*

#### ***Approaches to PM Health Effect Evaluations - A Brief Overview***

The general approaches to PM health effect evaluations are summarized in Box III.5.1.

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Box III.5.1: Approaches to PM Health Effect Evaluations (PM SAD E/S, 1998).

There are three major approaches used to study the relationships between human health effects and PM:

1) epidemiological studies;
2) controlled human exposure studies (also called "clinical studies"); and
3) toxicological studies.

A brief definition/description of each of these approaches with their strengths and weaknesses are as follows:

**Epidemiological studies** explore correlations/statistical associations between changes in ambient levels of PM in the real world and changes in the prevalence of cardiorespiratory health problems in the general population, including susceptible individuals. The analysis and interpretation of epidemiological data can be challenging given that other "*confounding factors*" (e.g., temperature, seasons, day-to-day variations, *other pollutants*, health status of individuals) may contribute to the observed health effects or bias the interpretation of the association. Epidemiology relies on attributes/criteria (including consistency, coherence, strength of the association, biological plausibility) to judge whether statistically significant relationships exist between an observed effect and a postulated cause. Epidemiological studies do not themselves provide data on biological mechanisms that would explain the observed associations.

**Clinical studies** seek to investigate further the relationships uncovered by epidemiological studies, by exposing human test subjects to controlled amounts of pollutants in a laboratory setting. Clearly, for ethical reasons, only short term, reversible health effects can be studied in the healthy population.

**Toxicology studies** involve exposing animals, or tissue samples (human or animal) as surrogates for human responses to exposure, to known amounts of pollutants. In toxicology studies, since animals can be autopsied to look for lung damage, a much wider range of pollutants and concentrations can be tested. However, these types of experiments are highly artificial and it is difficult to extrapolate the results from test animals to humans.

Results from all three types of studies need to be considered in a weight of evidence approach whereby multiple lines of evidence are brought together and duly considered in order to build a case for causality. From a public health perspective, epidemiological studies provide the best means of examining population-wide effects resulting from exposure to real world levels and mixes of atmospheric pollutants. Clinical and toxicological studies are largely used to support the epidemiological evidence if possible and to help elucidate the mechanisms by which exposures to PM can induce diseases.

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#### III.5.1.2.1 Epidemiological Evidence

Recent epidemiological studies of the effects of PM on human health explored statistical associations between changes in airborne PM at levels that are currently experienced and changes in the occurrence of cardiorespiratory health problems in the general population. These studies, conducted under a broad range of environmental conditions, in many different cities on three continents, and by a number of different investigators, have shown that the following health impacts are linked to ambient PM levels (Table III.5.1):

- increases in mortality due to cardiorespiratory diseases
- increases in hospitalization due to cardiorespiratory diseases
- decreases in lung function (e.g., decline in peak expiratory flow rates) in children and in asthmatic adults

**Table III.5.1: Mean Fine Particle Levels and Health Effects (PM SAD, 1998)**

| Health Endpoints Examined in Epidemiological Studies | Range of Mean 24 h PM Levels over Study Period for Individual Studies (μg/m³) | Range of Maximum 24 h PM Levels Reported in Individual Studies (μg/m³) |
|---|---|---|
| School Absenteeism | $PM_{10}$ 40.9 - 50.9 | $PM_{10}$ 234.0 - 251.0 |
| Respiratory Health / Pulmonary Function | $PM_{2.5}$ 0.5 - 11.0 | $PM_{2.5}$ 73.1 - 250.0<br>$PM_{10}$ 174.0 - 251.0 |
| Hospital Admissions | $PM_{2.5}$ 15.0 - 22.3<br>$PM_{10}$ 29.6 - 50.0 | $PM_{2.5}$ 57.0 - 63.0<br>$PM_{10}$ 77.0 - 385.0 |
| Mortality | $PM_{2.5}$ 11.0 - 20.6<br>$PM_{10}$ 18.2 - 47.9 | $PM_{2.5}$ 75.0 - 158.0<br>$PM_{10}$ 67.0 - 365.0 |

- increases in respiratory stress which can lead to absenteeism from work or school, and to activity restrictions
- long term or chronic effects including reduced survival, reduced lung function and capacity in children and increases in development of chronic bronchitis and asthma in some adults.

All of the epidemiological studies are observational in nature; that is, the investigator has no control over the exposure or treatment of the subjects in the study, which differentiates them from the controlled human exposure studies discussed below.

*Mortality*

Daily or short-term variations in particulate matter, as $PM_{10}$, BS ('British Smoke' or 'Black Smoke' - a particle metric commonly used in Britain and Europe), $PM_{2.5}$, or sulphate ($SO_4^{2-}$), were significantly associated with increases in all-cause mortality (i.e., mortality from all causes except accidents) in 43 regressions (PM SAD, 1998) carried out in 20 cities across North and South America, England, and Europe (18 studies). These associations could not be explained by the influence of weather (temperature and humidity were most commonly found to have independent associations with mortality), season, yearly trends, day-to-day variations and variations due to holidays, epidemics, or other non-pollutant factors, since all the analyses looked for some or all of these potential biases and accounted for them in various ways in the analysis.Most of the studies also examined one or more gaseous pollutants in addition to PM (PM SAD E/S, 1998). The increases in mortality observed per 10 µg/m$^3$ rise in $PM_{10}$ are on the order of 0.4% to 1.7% , with a mean of 0.8% and a median also of 0.8%, for concentrations averaging 28 to 115 µg/m$^3$. The results were highly consistent under differing $PM_{10}$ exposure conditions (PM SAD E/S, 1998).

The magnitude of the increase was about the same for BS as for $PM_{10}$ (i.e., a 1% increase in daily deaths per 10 µg/m$^3$ increase in BS).

For $PM_{2.5}$, a 1.5% increase in mortality per 10 µg/m$^3$ was observed (range 0.80 to 2.2% per 10 µg/m$^3$) for six U.S. cities at average $PM_{2.5}$ concentrations that ranged from 11-30 µg/m$^3$. The increase in $PM_{2.5}$ risk of mortality was thus about twice that for $PM_{10}$. Although the magnitude of the mortality risk was greater in the six city study for sulphate compared to $PM_{2.5}$ (2.2 % vs. 1.5% per 10 µg/m$^3$), the strength of the association was greater for $PM_{2.5}$ than sulphate (PM SAD E/S, 1998).
While the increases in mortality risks associated with different particles metrics are small, they nonetheless signify substantial numbers of avoidable deaths due to the very large size of populations impacted by air pollution (PM SAD E/S, 1998). These increases in relative risk due to air pollution have been observed at particulate matter concentrations well within the range of normal ambient concentrations and substantially below current standards (both the current Ontario Ambient Air Quality Criterion and the Canadian 24hour acceptable TSP objective are approximately equivalent to a $PM_{10}$ level of 60-80 µg/m$^3$ and to a $PM_{2.5}$ level of about 30-50 µg/m$^3$). Furthermore, there was little evidence in the $PM_{10}$ and $PM_{2.5}$ data that the dose-response curve included a threshold; instead the response was observed to increase monotonically with increasing concentration, in the $PM_{10}$ concentration range *below* 80-100 µg/m$^3$and average $PM_{2.5}$ concentrations 14.7-21 µg/m$^3$. The lack of a threshold down to low concentrations suggests that it will be difficult to identify a level at which no adverse effects would be expected to occur as a result of exposure to particulate matter (PM SAD E/S, 1998).

On a population basis, the hypothesis is that what we are seeing is exacerbation of pre-existing disease, or enhanced response of a subpopulation of sensitive individuals. Suggestions that the elderly are a susceptible population, more so than young adults, remain unsolved in the absence of pathology. However, overall the results suggested a surprisingly modest increase in relative risk for the elderly compared to the whole population. This does not support the suggestion that it is only the elderly who are being affected and dying from air pollution and that their lives are being shortened by air pollution episodes by only a few days or weeks before they would have died anyway (PM SAD E/S, 1998).

In all of the analyses that examined one or more air pollutants together in the same statistical model with particulate matter, the association of particulate matter with daily mortality was remarkably robust, despite the problems of disentangling the effects of PM from other air pollutants. This was the case for all four of the normally considered gaseous pollutants, $SO_2$, $NO_2$, CO and ozone. Moreover, in most locations, the magnitude of the PM associations was greater than any other air pollutant considered, the exception being ozone, in a few cases (for discussion of most recent studies see new section '*Recent Developments*' later). The magnitude, robustness and consistency of this association across so many locations with differing air pollutant mixtures indicates that PM is the best indicator of the air pollution effect on mortality, and is considered to give some support to PM of some kind, possibly acting together with other air pollutant(s), as a causal agent (PM SAD E/S, 1998).

*Hospitalizations and Emergency Department Visits*

Particulate matter of some kind has been shown to have significant associations with increased hospitalizations in most or all of the 26 studies (i.e., studies, independent of the mortality studies) examined. All of the sixteen studies that examined $PM_{10}$ and one or more respiratory endpoints requiring hospitalization showed significant associations, varying between 0.45% and 4.7% per 10 $\mu g/m^3$ increase in $PM_{10}$ at mean concentrations varying between 25 and 53 $\mu g/m^3$ (PM SAD E/S, 1998).

Only three hospitalization studies, two in Toronto and one in Montreal, directly examined the association between $PM_{2.5}$ and respiratory and cardiac effects, with an increase in respiratory effects observed in all three studies. At mean $PM_{2.5}$ concentrations 12.2-18.6 $\mu g/m^3$, respiratory hospitalization and emergency room visits increased 2.5 - 9.6% per 10 $\mu g/m^3$ $PM_{2.5}$ increase. Five different pollutants were considered in addition to PM in single, bivariate and multiple analyses in various locations. Particulate matter was the air pollutant with the most consistent and stable association with increases in hospitalization. Ozone and carbon monoxide were judged to have independent associations as well as PM (PM SAD E/S, 1998).

The strongest and most consistent association of particulate matter with respiratory hospitalizations is considered to be with sulphate (PM SAD E/S, 1998). In the best conducted study of the series of eight examined (Burnett et. al.,1994, 1995), a 2.0-2.7 % increase per 10 $\mu g/m^3$ increase in sulphate (co-regressed with ozone) was indicated in southern Ontario. This was calculated to be equivalent to a 1.1 % increase per 10 $\mu g/m^3$ increase in $PM_{2.5}$, based on site-specific monitoring and conversion factors. The correlations between ozone and sulphate were high (0.5-0.8) in all eight studies, which causes difficulties in separating out the effects of one from the other. Overall, there is good evidence for an association between sulphate and respiratory hospitalizations and sulphate is considered to be a good surrogate for fine particles from combustion sources (PM SAD E/S, 1998). This does not mean that the sulphate is itself directly toxic however. Results for acidity ($H^+$) were inconsistent, with strong associations and high significance in some studies and none in others.

No evidence for a threshold of effects for respiratory hospitalizations associated with particulate matter or other air pollutants was found at the low (10 to 100 $\mu g/m^3$ $PM_{10}$) concentration ranges examined. Curves appear to increase monotonically, with steep slopes at low concentrations and some suggestion of curvilinear responses (lower slope) at higher concentrations. The effect of age on hospitalizations or emergency department visits was examined in several locations, since historical data from episodes of high air pollution had strongly suggested that it was the elderly, the young and those with pre-existing respiratory and/or cardiovascular conditions who were responding to air pollution. While some studies found that the elderly were at increased risk compared to other age groups in the population, the increases observed in cardiorespiratory hospitalizations were by no means predominantly due to effects on the elderly (PM SAD E/S, 1998). Children were also shown to be a high risk group for increased respiratory diseases in a few , but not all, studies. Those with preexisting COPD were also identified as a susceptible subgroup.

*Effects on Lung Function, Symptoms, Restricted Activity and Days Absent from Work or School*

In addition to its effects on mortality and hospitalizations, increases in particulate matter have been shown to cause other health effects. In both normal and symptomatic and/or asthmatic children, recent epidemiology studies have shown that short-term particle exposure is associated with increased respiratory symptoms, such as cough and wheeze, and/or small reductions in lung function (PM SAD, 1998). Asthmatic adults also are affected by increases in the daily or short-term particle levels, mostly the fine fraction, reporting decreases in lung function and increases in respiratory symptoms. These lung function changes were were often accompanied, especially in adults, by increases in symptoms such as chronic bronchitis or cough.

A particularly informative series of studies was conducted in the Utah Valley where the closing and reopening of a steel mill was paralleled by marked changes in population health (Pope, 1989). Pope found that respiratory admissions of children to nearby hospitals were two- to three-fold higher during the winters when the steel mill was in operation in comparison with the winter during which it was closed. The number of days absent from school and the number of respiratory-related activity restrictions in adults has been found to increase during periods with high particulate matter concentrations. Ten microgram per cubic metreincreases in fine particles or $SO_4^{2-}$ were associated with 2.8% to 16% reductions in activity (i.e., alterations from normal activity as defined by respondent's responses to questionnaires).

Effects on respiratory health (lung function symptoms, absenteeism, etc.), although much less serious than hospitalizations, and most certainly than mortality, nonetheless have the potential ti impact much more of the population (PM SAD E/S, 1998).

*Longer Term and Chronic Effects*

In contrast to the larger number of studies on daily variations in pollution associated with mortality and morbidity, relatively few studies are available that examine the effects of long term or chronic exposure on health endpoints. The effect of such exposure, varying between one and 16 to 20 years duration, is associated with increases in mortality, lung function decrements, respiratory disease symptoms and, possibly, with increases in lung cancer in both cross-sectional and the more powerful prospective cohort studies. The probability of survival over a seven to 16 years period was reduced for people living in the most polluted cities compared to the least polluted, by an average of two years (i.e., the range was four years between the most and least polluted city). In the six-cities study (Dockery et. al., 1993), average mortality was increased by 9%, 14% and 35% for each $10\mu g/m^3$ increase in $PM_{10}$, $PM_{2.5}$, and $SO_4$, respectively. Several cross-sectional studies(e.g., Pope et. al., 1995) have reported increases in mortality, per $10\mu g/m^3$ increase in PM, ranging from 4.3% to 9.8% for $PM_{2.5}$, and 8.2% to 12.4% for $SO_4$.

The effects on mortality cannot with certainty be ascribed to a true chronic effect, since they could

equally be the result of cumulative effects of daily variations in particulate matter. However, the increases in incidence of chronic bronchitis and decreases in lung function capacity, growth and development that were shown in cohorts of children across North America after chronic or lifetime exposure to acidity, sulphate and fine particle air pollution, must be considered to be true chronic effects (PM SAD E/S, 1998). The evidence, however, associating chronic exposure to PM with these endpoints is still inconclusive. Some studies have shown no association between exposure to PM and these chronic health endpoints. Recent evidence shows increases in the development of bronchitis and airway obstructive disease following chronic exposure to acid, sulphate, $PM_{2.5}$, coarse particles ($PM_{2.5-10}$), $PM_{10}$, and TSP (Abbey et. al., 1995 and Dockery et.al., 1996). There were indications from a long-term (20 to 25 years) cohort study in older adults that this increased incidence of disease, and probably also the reduced lung capacity that accompanies it, is carried over into adulthood as increased susceptibility to adverse effects of air pollutants (PM SAD E/S, 1998).
Another important point illustrated by the two large studies (Dockery et. al., 1993 and Pope et. al., 1995) is that mortality is not only a matter of "harvesting" or shortening by a few days or weeks the lives of those who are already ill, but that the lifespan is significantly shortened by several years.

The development of lung cancer was associated with fine particle air pollution (Dockery et. al., 1993 and Pope et. al., 1995); results are not yet available for $PM_{10}$ or coarse particles. The association was weak by comparison with other lifestyle factors, particularly smoking, and the possibility of residual confounding cannot be dismissed (PM SAD E/S, 1998).

### III.5.1.2.2 Evidence from Controlled Human Exposure Studies

Carefully controlled, quantitative studies of exposed humans in laboratory settings offer a complementary approach to epidemiological investigations. Advantage is taken of the highly controlled environment to identify responses to individual pollutants or sometimes to pollutant mixtures and to characterize exposure response relationships where possible. In addition, such a controlled environment provides the opportunity to examine interactions with other environmental variables, such as exercise, humidity or temperature. Insofar as individuals with acute and chronic respiratory diseases can participate in exposure protocols, potentially susceptible populations may also be studied, although those with more severe preexisting disease and hence those most likely to be affected by air pollutants, are naturally excluded. Clinical studies also have other limitations: for practical and ethical reasons, studies must be limited to small groups, which may not be representative of larger populations; exposure must also be limited to short durations and to concentrations of pollutants that are expected to produce mild and transient responses; and exposures are often limited to a single pollutant, or to a very limited pollutant mix, which never replicates the complex mixture to which populations are actually exposed. Furthermore, transient responses in clinical studies have never been validated as predictors of more chronic and persistent effects (PM SAD E/S, 1998).

Controlled human exposures to acidic and inert particles at relatively high levels compared to those generally experienced in the environment have not caused significant alterations in pulmonary function in healthy individuals. However, acidity has been shown to affect the slowing of mucociliary clearance at concentrations of 100 $\mu g/m^3$.

The controlled human exposure studies identify asthmatics as a susceptible population, but not persons with chronic obstructive pulmonary disease (COPD), or the elderly, at least not for acidic particles. Asthmatics, especially children and adolescents, may experience adverse effects on pulmonary function at aerosol concentrations experienced on occasion in ambient air [about 35 µg/m³ of $H_2SO_4$ (sulphuric acid) for 40 min].

None of the human clinical studies has usedparticle generation systems that reflect the complexity of ambient particles. Based on the extremely limited clinical database available on various species of particles, acidic aerosols produce the most significant bronchoconstriction, while the toxicity of sulfate is related to acidity*per se*.

Although very fine particle diesel exhaust affected neutrophil production and macrophage clearance of microorganisms from the lung, the effects cannot be ascribed with certainty to particles, since formaldehyde and other combustion gases were also present in the inhaled mixture.

A newly published study by Peters et. al. demonstrates that symptoms and decrements of peak expiratory flow in asthmatic subjects (n = 27) were significantly associated with the 5-day mean of the number of ultrafine particles (mass median aerodynamic diameter-MMAD: 0.01 to 2.5 µm) (Peters *et. al.,* 1997).

Overall, at this stage, the clinical data do not lend much support to the observations seen in the epidemiology studies, particularly to the observations that high ambient particulate matter concentrations are associated with mortality within hours or a few days at most (PM SAD E/S, 1998). It does indicate one susceptible subpopulation, asthmatics, who currently comprise 5 to 8 percent of the population, a percentage that has been rising in thepast decade in Canada as well as in other western countries. The discrepancy between clinical and epidemiological data may be related to a number of factors, many of which are related to the general limitations of clinical studies described above (PM SAD E/S, 1998). Possible explanations for the discrepancy are summarized in Box III.5.2.

### III.5.1.2.3 Animal Toxicology Evidence

Studies on experimental animals (or tissue samples) have many of the same advantages and disadvantages of controlled human studies. A wide range of pollutants and concentrations can be tested under controlled laboratory conditions, and autopsies of study animals can be performed to investigate tissue damage from exposure to pollutants. However, for the most part, experimental studies involve well-defined particle species and do not by any means reflect the full range of complex ambient particle mixtures to which humans are exposed, a problem noted before with respect to clinical studies also. There is considerable uncertainty also in extrapolating results from animal inhalation studies and applying these results to humans for the purpose of risk assessment. Therefore, such studies are most appropriately used to explore mechanistic aspects of the toxicity of particles.

Box III.5.2. Possible explanations for the discrepancy between clinical and epidemiological data (PM SAD E/S, 1998):

(1) the experimental subjects can only be exposed to the tested air pollutants for short duration for practical and ethical reasons, while an urban pollution episode usually lasts a few days for general population exposure; a clinical study has shown that doubling the length of exposure to $H_2SO_4$ exerted greater effect on bronchial mucociliary clearance than did an order of magnitude increase in the concentration of $H_2SO_4$;
(2) ethically it is almost impossible to investigate responses in those people most likely to be affected by air pollutants;
(3) the pulmonary function parameters that are most often used in clinical studies may not be sensitive enough to indicate particle-induced adverse health effects;
(4) artificial particles used in exposure chambers may not reflect the potential synergistic effects of particulate matter and aerosol mixtures;
(5) in most human studies, the sizes of aerosols used are above 0.5 µm. Since nanometre-sized ultrafine particles have been found in animal studies to induce acute pulmonary inflammation and death at very low concentrations, and they are present in ambient air, ultrafine particles may be a good candidate to provoke acute alveolar inflammation with release of mediators capable, in susceptible individuals, of causing cardiorespiratory responses

Studies using experimental animals have not provided convincing evidence of particle toxicity at ambient levels (PM SAD E/S, 1998). Studies using experimental animals have been restricted to well-defined particle species. Although not comparable with the complex ambient particle mixture, acute exposures (4-6 hour single exposures), almost always at concentrations well above those occurring in the environment, have been shown to cause:

- decreases in ventilatory function;
- changes in mucociliary clearance of particles from the lower respiratory tract (front line of defence in the conducting airways);
- increased number of alveolar macrophages and polymorphonuclear leukocytes in the alveoli (primary line of defence of the alveolar region against inhaled particles);
- alterations in immunologic responses (particle composition a factor, since particles with known cytotoxic properties e.g., metals, affect the immune system to a significantly greater degree);
- changes in airway defense mechanisms against microbial infections (appears to be related to composition and not the particle effect);
- increase or decrease of the ability of macrophages to phagocytize (engulf and digest) particles (related to composition);
- a range of histologic, cellular, and biochemical disturbances, including the production of proinflammatory cytokines and other mediators by the lung's alveolar macrophages, (may be related to particle size, with greater effects occurring with ultrafine particles);
- increased electrocardiographic abnormalities;
- increased mortality.

As expected, bronchial hypersensitivity to non-specific stimuli and increased morbidity from cardiorespiratory symptoms and mortality occur with the greatest probability in animals with pre-existing cardiorespiratory diseases.

The epidemiological finding of an association between 24 hour ambient particle levels below 100 $\mu g/m^3$ and mortality has not been substantiated by animal studies as far as $PM_{10}$ and $PM_{2.5}$ are concerned. With the exception of ultrafine particles ($\leq$ 0.1 μm), none of the other particle types and sizes used in animal inhalation studies cause such acute dramatic effects, including high mortality at ambient concentrations. The lowest concentration of $PM_{2.5}$ reported that caused acute death of rats with acute pulmonary inflammation or chronic bronchitis was about 250 $\mu g/m^3$ (3 days, 6 h/day), using exposure to concentrated ambient particles (Godleski et al., 1996).

The particle types most likely to induce acute adverse effects include metals, organics, acids, and acidic sulphates of the fine particle mode, possibly occurring as coatings on fine or even ultrafine carrier particles. It appears that the ultrafine particle mode ($\leq$0.1 μm in size) may be of significant toxicological importance due to its large number and slow clearance rate from pulmonary interstitium.

Subchronic and chronic exposures to some types of particles at mass concentrations greater than 1 $mg/m^3$ result in significant compromises in various lung functions similar to those seen in the acute studies, and in addition cause:

- reductions in lung clearance;
- induction of histopathologic and cytologic changes (regardless of particle type, mass concentration, duration of exposure or species examined);
- production of chronic alveolitis and fibrosis;
- production of lung cancer.

The interpretation of results from experimental inhalation studies in animals with particles and their significance for human exposures involves considerable uncertainties (PM SAD E/S, 1998). This uncertainty relates to the dosimetry of the respiratory tract, differences in the sensitivities of specific target cells, difference in cell populations in the individual airway generations of animal species, differences in metabolic activity of lung cells, and differences in the lifespan between laboratory animals and humans. A recent comparative dosimetric analysis conducted by Miller *et. al.* (Miller *et. al.,* 1995) has yielded some interesting results, namely that, based on the calculations per ventilatory unit or per alveolus, humans receive much greater *numbers* of particles than do rats when exposed to the same concentration of PM (while the deposition of particles on *mass* per unit alveolar surface area is the same). This trend of differences between humans and rats is even more pronounced for the individuals with compromised lungs (smokers, asthmatics and patients with chronic obstructive pulmonary disease) compared with normal subjects. Therefore, rats exposed to 1000 to 1500 $\mu g/m^3$ of particles may actually have received the levels of particles equivalent to 120-150 $\mu g/m^3$ in humans. Given the caution which must be exercised in extrapolating risks from animals to humans, animal studies are best used to help elucidate the mechanism(s) of particle toxicity (PM SAD E/S, 1998).

Most recent studies (Godleski et. al., 1998) of exposure of dogs with chronic bronchitis to Boston air (in which particles were concentrated to a level of 200 $\mu g/m^3$ ) showed the following effects, which appear to be accumulating mechanistic evidence underlying the particle-induced cardiovascular effects (i.e., rapid mortality) observed in the epidemiological studies:

- a 37 % increase in mortality in the exposed dogs;
- evidence of cytokines and particulate matter itself in the heart macrophage; and
- evidence of inversions in parts of the electrocardiogram signal of the exposed dogs for extended periods, reflecting a blood flow constriction condition generally preceding ventricular fibrillation and sudden death

### III.5.1.2.4 Weight of Evidence-Causality, Multiple Pollutant Issues and Recent Developments

In evaluating the epidemiological studies as a whole, a number ofissues arise, key among them the issue of causality.

Some uncertainties in the evidence of a causal relationship in the observed association between adverse health impacts and increases in airborne particles include (PM SAD, 1998):

- lack of an accepted biologically demonstrated mechanism
- lack of quantitative support from experimental animal and/or human clinical studies
- difficulty in discerning what exactly is the toxic moiety
- confounding, and difficulty of separating out the effects of other co-occurring pollutants
- problems of misclassification of personal exposure to ambient particles
- dependence on ecological or community-based exposures, including analytical studies
- uncertainty regarding the appropriate pollutants to include in statistical modelling

These uncertainties are in various stages of being resolved. Space considerations allow only a limited discussion. More details can be found elsewhere (PM SAD, 1998; PM SAD E/S, 1998).

Epidemiologicalstudies do not themselves provide data on biological mechanisms that would explain the observed associations. Associations found in epidemiological studies between PM and health effects may reflect chance, bias orcause. A weight of evidence approach is used whereby multiple lines of evidence are brought together and duly considered in order to build a case for causality. On the basis of accepted criteria, the weight of evidence from the epidemiological literature that supports a causal link between particulate matter and adverse health effects is summarized in Table III.5.3.

These criteria (i.e., bolded in Table III.5.3), cited by Bradford Hill (Hill, 1965) and others are useful in helping to gauge the strength of evidence that exists at a given point in time, upon which judgements are made regarding the likelihood that epidemiologically-demonstrated associations reflect actual cause-effect relationships –judgements that often serve as the basis for taking preventive measures to protect the public health of human populations. However, as noted in the US EPA Criteria Document on PM (US EPA, 1996), neither Hill's criteria nor other lists of criteria should be used as an absolute checklist for establishing a cause-effect relationship, since any given criterion must be judged in context. Hill himself stated (Hill, 1965), "What I do not believe –and this has been suggested– is that we can usefully lay down some hard-and-fast rules of evidence that *must* be obeyed before we accept cause and effect. None of my nine viewpoints can bring indisputable evidence for or against the cause-and-effect hypothesis and non can be required as a *sin qua non.*" [Bradford Hill's italics]. In fact each criterion is discussed at length by Hill (1965) and exceptions and qualifications are given for each of them. For example on plausibility, Hill states "It will be helpful if the causation we suspect is biologically plausible. But this is a feature I am convinced we cannot demand. What is biologically plausible depends upon the biological knowledge of the day".

A recent critical review (Vedal, 1997) states that the association between particle pollution and mortality seems to satisfy many, although not all, of the Bradford Hill criteria. Although this view is also the one reflected in the Science Assessment Document on PM (PM SAD E/S, 1998 and as in Box III.5.3), agreement is not consistent on this issue (Moolgavkar, 1996; Vostal, 1997). One investigator (Vostal, 1997) referring to Bradford Hill's paper (Hill, 1965) believes that the criteria points *must* be verified before a judgement is passed from observed associations to a verdict of a documented causation and finds that only two have been fulfilled.

Box III.5.3. Weight of evidence from the epidemiological literature that supports a causal link between particulate matter and adverse health effects (PM SAD E/S,1998).

*the* ***probability*** *of a relationship between PM and cardio-respiratory health has been ably established;*

*the* ***strength of the association*** *between exposure to PM and health outcomes can be considered relatively strong, since although the magnitude of the estimates of increased risk are generally small, they are remarkably stable among different studies and are often highly statistically significant;*

*a monotonically increasing (no threshold)* ***concentration-response curve*** *was observed from very low ambient levels up to much higher levels with remarkable consistency in many of the studies on acute and chronic mortality and hospitalization;*

*the evidence is considered to be strong with respect to the* ***specificity of the effect*** *to respiratory and cardiac outcomes; non-respiratory effects are not associated with exposure to particulate pollution;*

*the* ***specificity of cause*** *is considered to be strong enough to conclude that particulate matter per se, rather than other pollutants or environmental variables, is associated with adverse health effects;*

*a logical* ***temporal relationship*** *exists, with exposure (e.g., daily peaks in PM), followed by effects (e.g., increased mortality and hospitalizations), although the rapidity with which mortality has been observed following incidents of high exposure remains a puzzle in terms of the mechanism of action of particles;*

*positive associations between particulate air pollution and cardio-respiratory related mortality and hospitalizations, and respiratory related health effects, have been* ***consistently*** *reported in numerous studies conducted under a broad range of environmental conditions in many cities on three continents, by a number of different investigators, providing a strongly* ***coherent*** *picture of the nature of particle-induced effects.*

One of the most difficult questions has been, and continues to be, the role played by other gaseous pollutants (particularly $SO_2$, $NO_2$, CO and $O_3$) in the toxicity of particulate matter. The brief section on 'Multiple Pollutants' below highlights the underlying issues and the various approaches different investigators have taken to address them.

## Multiple Pollutants

Airborne pollution always occurs as a mixture of agents, of which particulate matter is only one. Perhaps the most difficult issue to deal with in drawing any conclusions about the relationship of particulate matter to adverse health outcomes is the presence of other covariate air pollutants and the methods used to disentangle the influence of particulate matter from these other gaseous air pollutants.

Particulate matter, especially in the smaller size fraction, is a primary air pollutant, along with $SO_2$, $NO_x$, and CO; these are produced directly from combustion processes (see section III.4). Sources are mostly vehicular traffic, industrial activity and some coal- or oil-fired power generation. Moreover, $SO_2$ and $NO_2$ can be transformed secondarily by photochemical processes into acid and neutral sulphates and nitrates which become part of the fine particle fraction. These four air pollutants are often (but not always) highly correlated with each other. If variables that are not independent, i.e., are moderately or highly correlated, are entered into a multipollutant model as independent variables, the basic assumptions of the model regarding independence will be violated and the results will be uncertain and indeed, could be altogether invalid. Therefore, on the basis of common sources and high correlations between them, it would not seem reasonable a priori to treat them together in a multipollutant model and expect to obtain accurate estimates of their independent effects on health outcomes. Ozone has a much lower correlation with particulate matter and the other primary pollutants (with the possible exception of $NO_2$), since it is a secondary air pollutant formed by photo oxidation with $NO_x$ and volatile organic compounds in the atmosphere. Therefore there is some a priori reason to expect that models including both ozone and PM would give reasonable estimates of the independent effects of each.

Some investigators (Lipfert 1994; Moolgavkar et al. 1996; Moolgavkar & Luebeck 1996) have been concerned that the association which has been ascribed to particles is actually reflecting the association of one or more of these other air pollutants that may not have been considered in the analysis or even measured in the study location. These and other investigators have preferred to include several or multiple pollutants together in multipollutant models, despite the attendant problems of collinearity, in order to allay the suspicion that something has been overlooked.

Other groups of investigators have examined each pollutant alone in models in which the other major non-pollutant variable (weather, season, day-to-day effects) have been accounted for (Pope et al.. 1992; Pope et al.. 1995; Dockery et al.. 1992; Schwartz 1993; Schwartz et al. 1996b). They have preferred to rely on the association noted in various locations with differing climates, weather patterns, sources and mixtures of air pollutants. However, univariate analyses are considered likely to give biased estimates of effects because of the possibility of more than one causal agent, and because of the high correlations between pollutant.

A modification of this approach has been the extension of the analyses to include bivariate regressions with all pollutants that showed associations with adverse health outcomes in the univariate models, accompanied by correlation analyses showing that the correlations between the two are not excessively high (correlations greater than 0.5 would cast doubt on the validity of the results).

Pollutants which were not associated in the original univariate analysis wereconsidered unlikely to show associations in pairwise models. This approach is considered to be useful in helping to disentangle the effects of one pollutant from another and in establishing their independent effects within the same locality.

One problem that could occur is modification of the effects of one pollutant by the co-occurring pollutant included in the model. Interaction terms could be developed for the model (Schwartz et al. 1996b), or the effect of high and low levels of one pollutant on the other could be separately analysed as was done for several of the APHEA studies in Europe (Touloumi et al. 1996; Ballester et al. 1996; Sunyer et al. 1996). Another more intractable problem is that of the effect of differential measurement error on the outcome when several pollutants are included together. Lipfert and Wyzga (1995) have shown that this differential measurement error can bias the interpretation of bivariate or multipollutant analyses,because the pollutant with the least measurement will have the tightest confidence limits and the effect estimate for the pollutant with the larger measurement error may include zero. This type of error is difficult to recognize or to quantify if suspected, but the possibility should be considered when evaluating the results of bivariate or multipollutant analyses.

While careful analysis and consideration of the results from bivariate analysis in each location are useful in establishing which of several air pollutants have an independent effect on health outcomes in that location, they do not tell us whether particulate matter is really the causal agent, or is acting instead as the best surrogate of the pollutants examined in that location for the air pollution effect.

For the overall evaluation of the role of particulate matter versus other air pollutants in exacerbation of adverse health effects, reliance in the Science Assessment Document on PM (PM SAD, 1998) has been placed on the results from a large number of locations on three continents: locations differing in pollutant levels, mixtures of co-occurring air pollutants, climate, and sources. It would be unlikely that co-pollutants could confound the particulate matter-adverse health association in all of these disparate settings (PM SAD, 1998).

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The brief section above illustratedthe various ways in which investigators have dealt with the issue of multiple pollutants. However, many of the available studies could not or did not consider several of these co-occurring gaseous pollutants. In analyses designed to help separate out the effects of one pollutant from another, the association of particulate matter with adverse health outcomes reported in the epidemiology literature was remarkably robust to inclusion (one at a time) of all four of the normally present gaseous air pollutants $SO_2$, $NO_2$, CO and $O_3$ (PM SAD E/S, 1998). Moreover, the magnitude of this association was often (but not always) greater than any of these other air pollutants individually or combined. The magnitude, robustness, and consistency of this association across so many locations with differing air pollutant mixtures supports the position that particulate matter of some kind is the best indicator for the effects of air pollution on adverse health outcomes (PM SAD E/S, 1998). The question of which particle metric is the best indicator of toxicity remains unsettled, but current evidence suggests that some form of fine particulate matter is the most appropriate measure of particle toxicity, although in some locations, and with respect to some endpoints, coarse particles remain important and cannot yet be entirely dismissed.

The second critical outstanding issue with respect to causality relates to biological plausibility of the effects of particulate matter on human health. When evaluating the effects of low levels of ambient particulates, we need to clearly separate acute adverse effects from chronic effects that reflect long term levels of air pollution. The association of mortality with daily variations in particulate air pollution presents difficulties in establishing a plausible mechanism that could explain these associations, particularly the very short lag period, or in some cases no lag, between the recording of elevated particle concentrations and the occurrence of increased mortality. Several hypotheses have been put forth to explain acute particle related mortality, and although the puzzle is by no means resolved, neither is it beyond explanation. The answer may likely involve exacerbation of preexisting disease conditions and evidence is mounting for a critical role for ultrafine particles on the strength of some recent toxicological evidence that has shown that mortality in rats can be induced after exposure to relatively low concentrations of these tiny particles (PM SAD E/S, 1998).

These suggested biological mechanisms still require much more research and confirmation. However, they help close a major gap in our understanding, thus providing some support for the idea of causality. Precise mechanisms of action have yet to be established. It should be noted, however, that biological plausibility is not an absolute requirement for a conclusion of causality. Epidemiological observations have often preceded the biologic knowledge of the day, as evidenced by the example of smoking and lung cancer. A fundamental purpose of epidemiology is to establish a cause with enough certainty that it will be justifiable and highly appropriate to take action to mitigate effects on public health. This point has clearly been reached with respect to particulate matter (PM SAD E/S, 1998).

Recent Developments

Based on recent evidence in 11 Canadian cities (Burnett et al. 1998a), it appears that statistically significant associations also exist between daily levels of each of the following gaseous ambient air pollutants, sulphur dioxide, nitrogen dioxide, carbon monoxide and ozone and, daily variations in premature non-accidental mortality rates. The specific contribution to the overall risk of each of these pollutants varies by location due to differing pollutant sources and climatic factors.

In the Toronto study (Burnett et al., 1998b) the investigators were looking for a PM effect. They found a premature mortality association with PM$_{10}$ and PM$_{2.5}$ which was similar to the results of the six U.S. cities study (Schwartz et al., 1996). However, they also found a carbo monoxide (CO) effect which was larger than the effect of PM, which may reflect the effects due to vehicular emissions.

These recent studies, although preliminary in nature, imply (Burnett, 1998c) that the effects due to gaseous pollutants (i.e., $SO_2$, $NO_x$, CO and $O_3$) are in addition and larger that the effects attributed to PM alone. Estimates using PM alone does not capture the impact of the total mix of pollutants. In fact these studies imply that the estimates of health effects due to air pollution have increased by a factor of 3, with the total attributed to PM being in the order of 30%. Thus from a broad public health perspective, in managing the health effects of air pollution it is important to consider both the gaseous and particulate fractions (see points # 5 and #6 in section III.5.1.3 and also section III.5.1.4). Burnett also noted (Burnett, 1998c) that one should recognize that information on health impacts is still being developed and more research is needed to refine the understanding of the impacts. Burnett concluded that the mixture of urban air pollution is a risk factor for mortality and there are additional risks due to gases which are beyond those predicted by PM alone.

The Ontario Medical Association (OMA, 1998) released a position paper in May 1998 on the 'Health Effects of Ground-Level Ozone, Acid Aerosols, and Particulate Matter'. They have reviewed the research related to the health effects of air pollution and noted the strong evidence that increases in these air pollutants are linked to increases in subclinical effects, to hospitalization for cardio-respiratory disease and to premature mortality. Recommendations pertaining to combustion sources, sources emitting $SO_2$ and $NO_x$, transportaion sources and physician activities were also included.

The David Suzuki Foundation (Suzuki Foundation, 1998) also released a report reviewing the health effects of PM and the gaseous air pollutants and the linkages to fossil fuel emissions and global warming.

Recent research presented at conferences of the American Thoracic Society and the Health Effects Institute (Cooney, C.M., 1998; Forum, 1998) revealed preliminary links to PM exposure and effects on heart rates in humans and canines. A pilot study in Baltimore on elderly individuals indicated that those with underlying cardiopulmonary disease exposed tofairly moderate levels of PM had lower heart rate variability than those exposed to the same PM concentration but had no heart disease. The difference in heart rate variability, a well-established factor in sudden death from cardiac arrest, provides a tentative explanation for how PM causes negative health effects. A healthy newborn has highly variable heart rate but as an individual ages heart rate variability normally decreases. Similar work, being conducted on dogs breathing ambient particles concentrated from Boston air, found a significant increase in breathing rate and a change in heart rate variability. A number of mechanisms by which PM could lead to cardiac effects are currently being explored. The effect could be part of a generalized inflammatory response since inflammatory mediators such as tumor necrosis factor, interleukin-8, and other cytokines are able to induce arrhytmia in cultured heart cells. Other mechanisms may involve toxic effects of transitional metals, as well as the effects of acidic aerosols and allergic reactions to organic chemicals inthe PM. J. Bachmann of the US EPA described these exciting times (events) as [epidemiology] - inspired toxicology, and [toxicology]-inspired epidemiology.

### *III.5.1.3 Important Conclusions - Highlights*

Although the epidemiology studies are observational rather than experimental, they are nonetheless considered more relevant to a characterization of health risks associated with particulate air pollution than either animal toxicology or controlled human chamber studies for several reasons (PM SAD E/S, 1998). These reasons are summarized in Box III.5.4. These studies were conducted under a broad range of environmental conditions in many cities on three continents, by a number of different investigators.

According to the weight of evidence presented in the Science Assessment Document for PM (PM SAD 1998) "the strength and consistency of the epidemiological evidence for mortality and morbidity effects at current levels of particulate matter air pollution is remarkable, robust, consistent and compelling" (PM SAD E/S, 1998). Although the magnitudes of the estimates of increased risk are seemingly small, the estimates were often highly statistically significant. Moreover, the adverse health effects represent a large impact on the general population, since most of the population is exposed.

Box III.5.4. Reasons for epidemiology studies being considered more relevant to a characterization of health risks associated with particulate air pollution than either animal toxicology or controlled human studies:

- they are the most direct way of assessing the adverse health outcomes of "real world" complex mixtures of pollutants to which people are exposed;
- human populations, unlike laboratory animals, are highly heterogeneous, including individuals who encompass a large range of susceptibilities, disease status and exposures, and whose responses cannot be predicted from animal toxicology studies or are not available from controlled human exposure studies for ethical reasons;
- population studies based on large administrative databases (such as the hospital admissions study in southern Ontario based on a population of 8.7 million people) are able to demonstrate the impacts of pollution on public health, and even to allow some partial estimate of the costs to society;
- no extrapolation is necessary when assessing the effects on public health of a particular concentration of air pollutant or of an ambient air objective, as measured by the ambient compliance monitoring network, despite our lack of knowledge about the exposures of each individual in the population. We need only know that the correlation is reasonable between the ambient monitor and the personal exposure.

The evidence is considered to be strong regarding the specificity of the effect for respiratory and cardiovascular outcomes. The evidence is harder to judge, but on balance, is considered to be sufficient to conclude that particulate matter of some kind is associated with adverse health effects. A strong pattern of coherence between endpoints is provided both qualitatively and quantitatively by the associations shown between particulate matter and a broad range of endpoints from the least to the most serious (i.e., mortality). The time pattern of exposure and effect adds to the coherence of the picture, with the exception of the rapidity of the effects on mortality (preliminary mechanistic research may soon provide an explanation for this observation). It should be noted that biologic plausibility is not an absolute requirement for a conclusion of causality.

It can be acknowledged that there are difficult questions regarding the role played by other gaseous pollutants (particularly $SO_2$, $NO_2$, CO and $O_3$). However, the magnitude, robustness, and consistency of the association across so many locations with differing air pollutant mixtures supports the position that particulate matter of some kind, possibly acting together with other air pollutant(s), is the most appropriate indicator for the effects of air pollution on adverse health outcomes. Although the biological mechanism is not clearly elucidated, the epidemiological data support a causal hypothesis between ambient particle exposure and adverse health effects and provide a reasonable basis for preventive and public health action. Measures to reduce ambient $PM_{10}$ and $PM_{2.5}$ concentrations will lead to improvements in the health of Canadians.

Controlled human exposure studies have shown that normal individuals experience few or no adverse effects on airway function or on defense or immunological mechanisms at relatively high concentrations of soluble particles compared to ambient levels. Asthmatic individuals may experience adverse effects on airway function at concentrations equivalent to relatively high ambient levels. Effects are more pronounced in adolescents and children; they are also responsive to acidic aerosols at concentrations close to ambient levels. There is no conclusive evidence, however, of enhanced responsiveness in the elderly, or in individuals with chronic obstructive pulmonary disease (COPD).

On a population basis, the hypothesis is that what we are seeing is exacerbation of pre-existing disease, or enhanced response of a subpopulation of sensitive individuals. Suggestions that the elderly are a susceptible population, more so than young adults, remain unsolved in the absence of pathology. However, overall the results suggested a surprisingly modest increase in relative risk for the elderly compared to the whole population. This does not support the suggestion that it is only the elderly who are being affected and dying from air pollution and that their lives are being shortened by air pollution episodes by only a few days or weeks before they would have died anyway

Several aspects of the findings need highlighting.

1) Unlike the situation with many other toxins, a **monotonically increasing (no threshold) concentration-response curve** was observed from very low ambient levels up to much higher levels with remarkable consistency in many of the studies on acute and chronic mortality and hospitalization. (see Box III.5.5). This lack of an observed threshold means that any increase in ambient particulate matter concentration is associated with a statistical increase in mortality and hospitalization rates. Human populations are highly “heterogeneous” (non-uniform) including individuals who have a wide range of susceptibilities to pollutants due to differences in health status, activity levels and exposures. Therefore, even at very low levels of ambient PM, susceptible individuals such as the elderly, children and people with pre-existing respiratory or cardiovascular disease may respond adversely. At higher exposure levels, healthy individuals are also at risk of developing symptoms in response to exposure to atmospheric PM..

Box III.5.5: Lack of an Observed Health Effects Threshold

Current health effects research has found no concentration threshold below which PM does not affect cardiorespiratory health. Increasing effects have been observed with increasing concentration down to very low levels, indicating that it is not possible to define a safe level that will protect all of the population all of the time. This lack of an observed effect threshold for human health and environmental air quality impacts is observed for other air pollutants as well, such as ground-level ozone.

2) Although the magnitudes of the estimates of increased risk are seemingly low, the risk estimates represent large numbers of people when extrapolated to the general population. While the endpoints captured by epidemiological studies have been emphasized because of their ability to provide some measure of quantifiability, they are only the “tip of the iceberg” (see Figure III.5.2, in section III.5.2) with respect to other adverse health effects including exacerbation of respiratory symptoms, such as bronchitis, reduced lung function, restricted activity due to illness, loss of work-days or school absences, and increased costs for medication. Thus **the more serious effects of mortality and**

**hospital admissions straddle a much greater number of illness cases (e.g., bronchitis, respiratory symptoms, asthma exacerbation, school absenteeism) in the general population which, although less critical, is nonetheless impairing quality of life.** These particulate matter - adverse health associations are observed at concentrations currently occurring in Ontario and Canada, which are low by comparison with international air standards or with the concentrations observed in former pollution episodes as a result of which thousands died.

3) **Mass concentrations for both $PM_{2.5}$ and $PM_{10}$ are recommended** (PM SAD, 1998; PM SAD E/S, 1998) as the **metrics of choice**. Within the past several years, several large well-conducted studies have been published that support the hypothesis that some form of fine particulate matter is generally more closely associated with respiratory illnesses than the larger particle sizes. Although most of the epidemiology studies measured $PM_{10}$ or $PM_{15}$ ($PM \leq 15$ µm), the evidence indicated that the fine fraction of particulate matter ($PM_{2.5}$) was consistently associated with adverse health effects, and that the association was usually of greater magnitude than the associations with other particle metrics, including $PM_{10}$, acid, and sulphates, in studies which included both or several.

4) While sulphate was an excellent surrogate for $PM_{2.5}$ in locations where $PM_{2.5}$ measurements were not available, the strength of the sulphate association was not as great as the total $PM_{2.5}$ association when both were available in the same location. In addition, there was evidence from one study that the non-sulphate portion of $PM_{2.5}$ had at least as great an association as the sulphate fraction. It is important to note that in humans approximately 25% to 60% of inhaled particles with a size $\leq 2.5$ µm (MMAD) can be deposited in the alveolar gas exchange region, as opposed to less than 5% of larger particles (~10 µm) deposited in this region, which may render $PM_{2.5}$ more harmful in causing lung injury. Thus, based on biological deposition and available, albeit limited data, **$PM_{2.5}$ is the metric of choice for the *fine* fraction at this time.**

5) Recent evidence in 11 Canadian cities indicates that statistical **associations also exist between** each of the following gaseous ambient air pollutants, **sulphur dioxide, nitrogen dioxide, carbon monoxide and ozone and, daily variations in mortality**.

6) The above implies that **in a broad-based particulate matter strategy fine particulate matter would be the most appropriate index of the air pollution mix. If focus is directed at fine particulate matter, along with the accompanying combustion-related pollutant gases (i.e., $SO_2$, $NO_X$, VOCs, and CO), then all components of the air pollution mix can be addressed. The critical components of the air pollution mix would then be addressed either because they are precursors of fine particulate matter and/or are emitted by combustion sources and/or have been associated with daily variations in mortality (see also section III.5.1.4).**

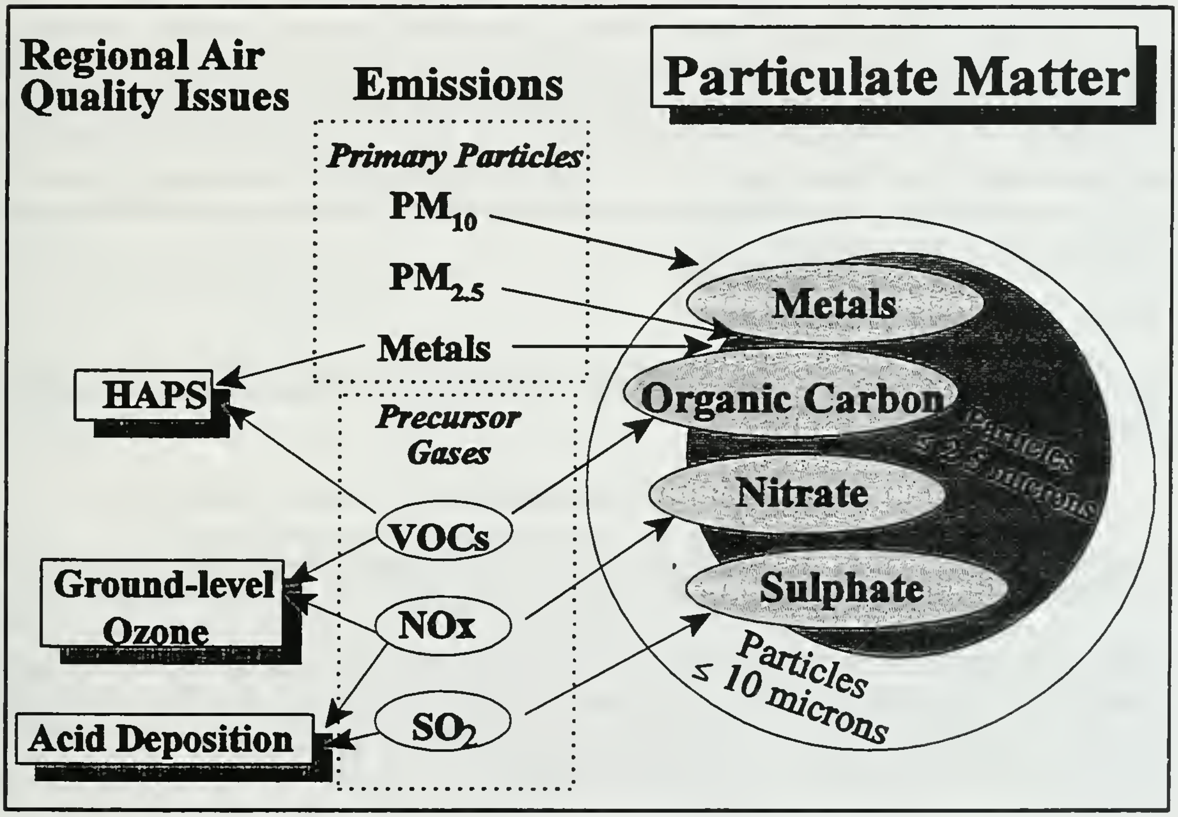
7) A few studies which have specifically examined the coarser fraction of $PM_{10}$, between 5 and 10 $\mu$m in aerodynamic diameter, in addition to $PM_{10}$ and/or $PM_{2.5}$, found that the coarse fraction was not associated with adverse health outcomes while the fine fraction, and often the total $PM_{10}$ fraction as well, displayed such an association. On the other hand, other studies have shown an association between the coarse fraction ($PM_{2.5-10}$) and adverse health outcomes. The **larger particles, therefore, have not been eliminated from consideration.**

### *III.5.1.4 $PM_{2.5}$/$PM_{10}$/Air Pollution Mix Causal Chain - Health Effects Point of View*

It is appropriate at this stage to revisit and recap the linkages of PM to precursors and to other air issues, even though this was discussed in some detail in other sections (e.g., Section II.3) and to view this from the health perspective.

An understanding of secondary particle formation from precursor gases reveals that there are direct links between the PM issue and a number of other critical environmental issues (Figure III.5.1). Emissions of $SO_x$ and $NO_X$ link the PM issue to acid deposition, since these are the primary gases involved in the formation of acidic compounds such as sulphuric acid and nitric acid.

**Figure III.5.1: Links of $PM_{2.5}$ and $PM_{10}$ to Precursor Emissions and Other Air Quality Issues**



Emissions of $NO_X$ and VOCs are an integral part of the chemistry of ground level ozone - a major component of smog. PM is connected also to the issue of hazardous air pollutants (HAPs) through organic carbon particles and metals, many of which are themselves toxic, and by the adsorption and absorption of other contaminants (such as semi-volatile organic compounds like PAHs , chlorinated organics) onto existing particles. Generally the amount of the toxic organics and metals is highest in the fine particles in emissions.

As exemplified in Figure III.5.1, the emissions of primary particles and precursor gases which impact on ambient levels of $PM_{10}$ and $PM_{2.5}$ also impact on a number of other significant air pollution problems.

Figure III.5.1 also indicates that $PM_{2.5}$ (small shaded circle), which stands out as the metric of choice for the fine fraction at this time (i.e., section III.5.1.3), contains most of the atmospherically formed sulphate, nitrate, organic carbon (i.e., shaded ellipses are mainly in the $PM_{2.5}$ fraction) and the primary $PM_{2.5}$ emitted.

Recent studies also show associations of respiratory and/or cardiac mortality or hospitalization effects with lower concentrations of $SO_2$ , $NO_X$ and CO , as has already been shown for PM and ozone. Carbon monoxide is linked to the precursor gases ($SO_2$ and $NO_X$) through their common sources of emission (i.e., combustion).

From the public health protection point of view, of paramount importance is that of lowering the levels of any of these pollutants in the causal chain (i.e., in the causal chain, from the health impact, emission and atmospheric chemistry points of view), that is, disrupting the causal chain leading to the air pollution mix. This overlap of pollutants, precursors, their sources and health impacts and an understanding of these linkages gives rise to an unprecedented opportunity for a comprehensive ‘fine particulate matter and precursor’ air pollution management, and points towards an IP/RP strategy to address multiple issues simultaneously.

## III.5.2 Estimates of Health Impacts

### *III.5.2.1 Estimates of Health Impacts Based on Current Levels of Inhalable Particulate Matter ($PM_{10}$).*

***Impacts of $PM_{10}$ Above zero $\mu g/m^3$ - No Threshold Approach***

Health impacts, based on current knowledge, associated with Ontario's existing $PM_{10}$ levels have been estimated. This was prepared in order to examine the full impact of IP down to 0 $\mu g/m^3$ and also down to natural background and, to facilitate the preparation of a reduction strategy. A previous estimate of this type (IP/RP Progress Note # 1, November/1996 - disseminated by the IP/RP Strategy Group to all Ontario Smog Plan Working Groups) was prepared based on $PM_{10}$ concentration data spanning the years 1990-94. The present estimate has been updated with the inclusion of 1995 $PM_{10}$ data . Box III.5.6 summarizes the approach to estimating current impacts.

***Insights from this Analysis***

The *current* range (i.e., *low, central and high*) of health effects estimated to result from Ontario's

Box III.5.6: Approach to Estimating Current Impacts

Epidemiology-baseddose-response functions relate an increment in mortality, as well as, cardiac and respiratory illness effects with the 24 hour average PM$_{10}$ concentration. To estimate the health effects due to exposure to PM$_{0}$ over a year, monitoring data must be summed over all samples in the year. Since the sampling frequency is usually 1 day out of every 6 days, the sum of the PM$_{0}$ concentrations must be normalized to account for exposure over all of the days in the year [i.e., multiply by (365 days/# of samples)].

Existing levels of PM$_{10}$ were extracted from monitoring data (1990-1995) and assembled from 24 Ontario stations. Daily (24-hour average) concentrations were summed for each station (in each year) and then normalized to a full year. Within each year, the individual station sums were population-weighted to yield an Ontario-average sum. The 'population weighting' involves the assignment of different weighting factors to the various monitoring stations across Ontario, reflecting the representativeness of those stations to potential population exposures. The individual year population-weighted Ontario sums were averaged over the 6 years of monitoring to yield an overall population-weighted average concentration sum of existing ambient levels above negligible health effect levels.

*Negligible health effects levels* in this analysis were assumed to be zero µg/m$^3$ based on the fact (i.e., as per Section III.5.1.3) that there is no known threshold concentration above which effects begin to be observed or below which exposures are deemed safe.

Using these population-weighted concentration sums, Ontario population data (e.g., adults, children) and epidemiology-based dose-response functions summarized in two recent reports[1,2], mortality and other cardiac and respiratory illness effects associated with current levels of inhalable particulate matter (PM$_{10}$) were estimated. These Ontario-wide estimates are summarized in Table III.5.2.

The epidemiology-based dose-response functions summarized in the two recent reports included 'high', 'central' and 'low' values for each health effect category, which have been used to obtain the Ontario-wide estimates.

This estimation approach is consistent with the approach used recently in the Ministry's June 1996 Smog Plan discussion documents (i.e., *"Towards a Smog Plan for Ontario"*).

[1] Hagler-Bailly, 'Health Benefits of Cleaner Vehicles and Fuels' prepared by a Task Force for the CCME, October 1995.

[2] Air Quality Valuation Model (AQVM), Draft Final Report, prepared for Environment Canada and Health Canada by Hagler-Bailly, June 1996.

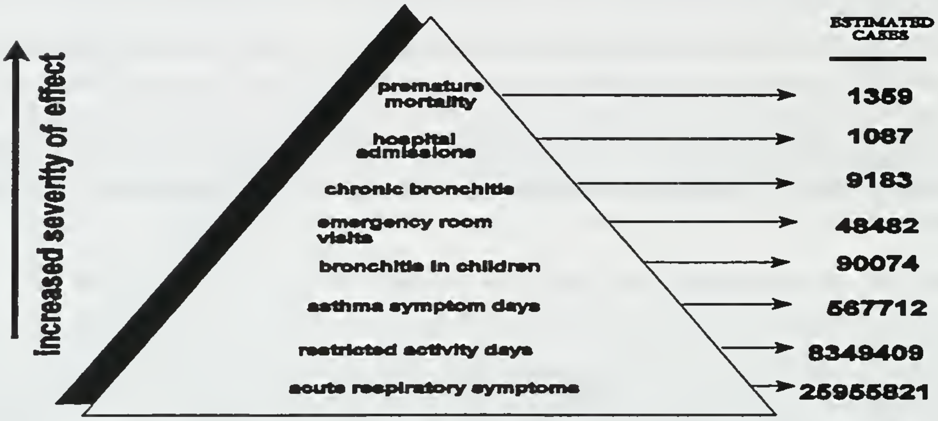
## Table III.5.2: Estimated Health Effects (Mortality and Illness) Associated with Current Levels of Inhalable Particulate Matter (PM$_{10}$) in Ontario

***(Units for All Endpoints: Number of Cases or Events per Year <u>to be multiplied by 1000</u>)***

**NOTE: 21% of these impacts is attributable to natural, non-anthropogenic background levels (See Figure III.5.2)**

| Estimate | Mortality | Adult Chronic Bronchitis | Hospital Admissions | Emergency Room Visits | Symptom Days | Restricted Activity Days | Bronchitis In Children |
|---|---|---|---|---|---|---|---|
| Low | 0.9 | 6 | 1.1 | 30 | 10300 | 5300 | 57 |
| Central | **1.7** | **12** | **1.4** | **62** | **33600** | **10600** | **114** |
| High | 6.3 | 18 | 4 | 90 | 58300 | 15600 | 171 |
|  | Hospital Admissions: Sum of Respiratory and Cardiac Admissions<br>Symptom Days: Sum of Asthma and Acute Respiratory Days |  |  |  |  |  |  |

**Figure III.5.2. Pyramid of effects for estimated impacts of PM10 due to human activity in Ontario (Based on 1990-95 PM10 concentrations)**



current $PM_{10}$ levels are presented in Table III.5.2. These results indicate that the current impact (looking at the *central* estimates) on the health of Ontarians due to inhalable particulate matter is significant. It can be noted that significanteffects like premature mortality and hospital admissions straddle a much greater number of cases of illness in the general population. This pyramid of estimated impacts, excluding impacts due to natural background levels, is illustrated in Figure III.5.2

Another small point of general clarification can be noted here. There is a slight difference between the present central estimates of premature mortality (i.e., ≈ 1725) due to inhalable particulate matter, and the recently widely quoted estimates of 'up to ≈ 1800 premature mortalities in Ontario are due to smog'. The main reason for this difference is that this estimate includes inhalable particulate matter only, while the estimates due to smog included mortalities relate to inhalable particulate matter and ozone. It is clear though that the contribution of ozone to premature mortality is relatively small. Another reason is that the present estimates include an extra year (1995) of $PM_{10}$ monitoring data.

It can also be noted here that if premature mortality, associated with the whole air pollution mix (i.e., PM and the gaseous pollutants $SO_2$, $NO_X$, CO and $O_3$) were estimated based on recent evidence (Burnett et al., 1998a), the total premature mortality estimates would increase by approximately 3-fold and the estimate due to PM would be slightly reduced.

### *Impacts of $PM_{10}$ Above 5, 25, 40, 50 and 60 $\mu g/m^3$, respectively*

The previous analysis was extended to estimating current health impacts above concentrations other than 0 $\mu g/m^3$. Such an analysis can help to illustrate which 24 hour average concentrations, in the **distribution** of environmental levels of $PM_{10}$ (e.g., over a year), are associated with the majority of health impacts. Table III.5.3 illustrates the frequency distribution in 5 $\mu g/m^3$ intervals, ranging from less than 15 $\mu g/m^3$ to more than 65 $\mu g/m^3$, of 24 hour average concentrations at various Ontario sites for the years 1993-1995.

The concentration levels selected for estimating current health impacts were 5, 25, 40, 50 and 60 µg/m$^3$. The 50 µg/m$^3$ level corresponds to the Ontario Interim Ambient Air Quality Criterion (AAQC), introduced in November 1997. The 5 µg/m$^3$ is the estimated annual average "natural non-anthropogenic background" concentration (i.e., it is based on analyses of data for remote sites, in combination with emission estimates). The 25 µg/m$^3$ is the Reference Level for $PM_{10}$ identified in the PM Science Assessment Document (PM SAD E/S,1998). Other levels are included for perspective purposes. Box III.5.7 summarizes the approach to estimating current impacts **above** the selected concentrations.

**Table III.5.3. $PM_{10}$ Frequency Distribution of 24-hour Average Concentrations (1993 - 1995)**
**Values Normalized for one Year**

| City | < 15 | 15-<20 | 20-<25 | 25-<30 | 30-<35 | 35-<40 | 40-<45 | 45-<50 | 50-<55 | 55-<60 | 60-<65 | >65 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Windsor | 26 | 53 | 82 | 67 | 34 | 24 | 12 | 24 | 10 | 7 | 12 | 14 |
| Windsor | 53 | 86 | 64 | 42 | 38 | 18 | 13 | 11 | 18 | 9 | 7 | 7 |
| Windsor | 47 | 72 | 25 | 36 | 39 | 29 | 18 | 11 | 25 | 21 | 4 | 39 |
| London | 139 | 90 | 46 | 24 | 24 | 15 | 7 | 5 | 7 | 2 | 2 | 2 |
| Nanticoke | 188 | 69 | 44 | 25 | 16 | 7 | 9 | 0 | 2 | 0 | 2 | 2 |
| St. Catharines | 77 | 85 | 70 | 48 | 12 | 27 | 22 | 15 | 0 | 0 | 7 | 2 |
| Thorold | 28 | 57 | 51 | 39 | 41 | 31 | 21 | 18 | 21 | 18 | 5 | 36 |
| Hamilton | 77 | 54 | 74 | 52 | 20 | 20 | 18 | 18 | 5 | 14 | 2 | 11 |
| Hamilton | 84 | 36 | 57 | 27 | 39 | 32 | 25 | 20 | 18 | 9 | 7 | 11 |
| Hamilton | 29 | 48 | 45 | 36 | 38 | 43 | 19 | 21 | 24 | 19 | 12 | 31 |
| Hamilton | 102 | 77 | 64 | 39 | 33 | 22 | 8 | 3 | 3 | 0 | 6 | 8 |
| Toronto | 84 | 75 | 68 | 33 | 29 | 31 | 24 | 4 | 2 | 0 | 7 | 9 |
| Etobicoke | 78 | 72 | 72 | 36 | 39 | 21 | 33 | 6 | 0 | 3 | 3 | 3 |
| Oakville | 96 | 80 | 56 | 50 | 27 | 20 | 10 | 13 | 7 | 0 | 0 | 7 |
| Mississauga | 124 | 72 | 75 | 33 | 16 | 16 | 10 | 7 | 3 | 0 | 7 | 3 |
| Cornwall | 114 | 71 | 59 | 50 | 34 | 7 | 11 | 9 | 2 | 2 | 0 | 5 |
| Fort Frances | 127 | 82 | 61 | 27 | 27 | 14 | 9 | 9 | 2 | 0 | 2 | 5 |
| Thunder Bay | 150 | 84 | 69 | 35 | 13 | 4 | 4 | 4 | 0 | 0 | 0 | 0 |
| S.S. Marie | 64 | 40 | 31 | 28 | 31 | 40 | 24 | 21 | 12 | 12 | 9 | 52 |
| S.S. Marie | 143 | 73 | 51 | 28 | 26 | 16 | 9 | 9 | 0 | 5 | 2 | 2 |
| Sudbury | 135 | 80 | 67 | 28 | 25 | 14 | 9 | 2 | 2 | 2 | 0 | 0 |

Box III.5.7: Estimating current impacts above 5, 25, 40, 50 and 60 µg/m$^3$

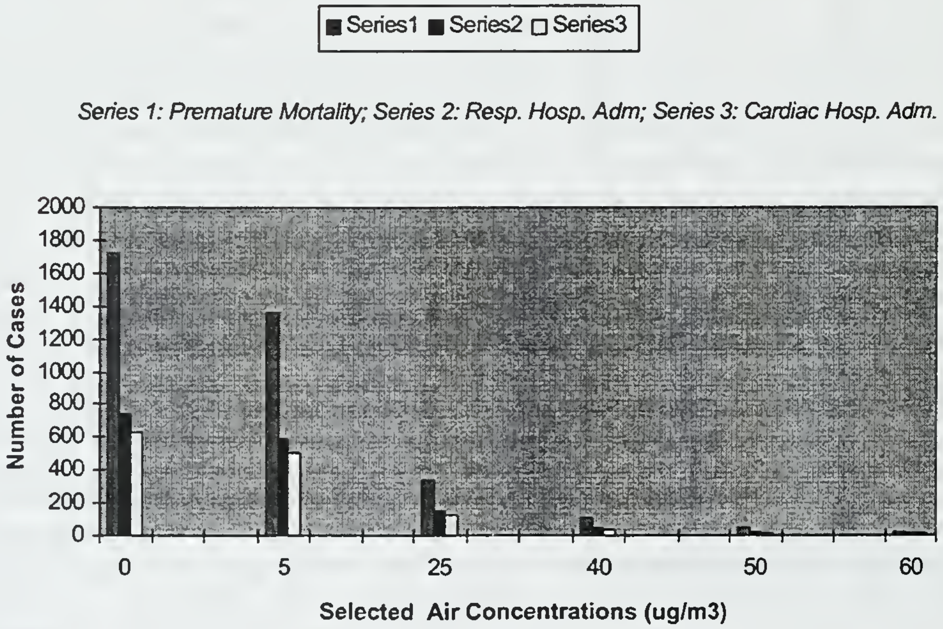
Essentially the general methodology is analogous to that in Box III.5.6 except for the differences noted below.

Monitoring data from 1990-1995, on existing levels of $PM_0$ were extracted and assembled from 24 Ontario stations. As before (i.e., Box III.5.6) an overall population weighted average concentration **sum** from existing ambient levels down to the various selected levels (i.e., 5, 25, 40, 50, 60 µg/m$^3$) was estimated. Essentially, the first and *different* step in this exercise is the subtraction of say 5µg/m$^3$ (and similarly for the other selected concentrations) from every 24-hour average $PM_{10}$ measurement in the distribution. This leaves the sum of the remaining concentrations above, say 5 µg/m$^3$, to be used in the estimation of the health impacts.

**Table III.5.4. Estimated Current Impacts above Selected Concentrations of X µg/m3**

| Scenario (i.e., above X µg/m³) | Annual Sum (µg/m³)xday | Estimated Annual Impacts Above X µg/m3 *(Number of cases/year)* | | | | % of Total Potential Impact Above X µg/m3 |
|---|---|---|---|---|---|---|
| | | Premature Mortality | Respiratory Hospital Admiss. | Cardiac Hospital Admiss. | Chronic Bronchitis | |
| 0 µg/m3<br>*(Zero Thr.)* | 8607 | 1724 | 747 | 632 | 11651 | **100** |
| 5 µg/m3<br>*('Backgrnd')* | 6800 | 1359 | 589 | 498 | 9183 | 79 |
| 25 µg/m3<br>*(Ref. Lev.)* | 1715 | 343 | 149 | 126 | 2320 | 20 |
| 40 µg/m3<br>*(Perspective)* | 535 | 107 | 47 | 39 | 726 | 6.2 |
| 50 µg/m3<br>*( Int. AAQC)* | 245 | 49 | 21 | 18 | 331 | 2.8 |
| 60 µg/m3<br>*(Perspective)* | 125 | 25 | 11 | 9 | 168 | 1.5 |

**Figure III.5.3. Estimated Annual Impacts Above Selected Concentrations of x ug/m3**



*Series 1: Premature Mortality; Series 2: Resp. Hosp. Adm; Series 3: Cardiac Hosp. Adm.*

### *Insights from this Analysis*

Table III.5.4 summarizes the current annual impacts above the selected concentrations. Annual estimated impacts of premature mortality, respiratory and cardiac hospital admissions and chronic bronchitis are included. The table also includes the annual sum leading to impacts [in units of (μg/m$^3$) x days] above the selected concentrations. Figure III.5.3, which also contains impacts above 0 μg/m$^3$ from the previous analysis, illustrates the premature mortality and hospital admission impacts graphically.

It can be seen from this analysis that, on a province-wide basis, most of the impacts are associated with the lower end of the distribution of $PM_{10}$ levels. Impacts above 60 μg/m$^3$ and even 50 μg/m$^3$, in a Province-wide context, are relatively insignificant in light of the overall impacts associated with $PM_{10}$ levels. Thus, it appears from this analysis, that **focusing PM reduction strategies on 'peak' concentrations will not yield the most health benefits**. Rather these **data point in the direction of broad-based strategies whose aim is to reduce the whole distribution of PM levels in general**. However, it should be noted that in a site-specific context, areas with large urban populations and experiencing relatively frequent elevated levels (i.e., above 50 and 60 μg/m$^3$) would still be considered to have significant impacts from these $PM_{10}$ levels.

Another important point needs to be made regarding this analysis. **Approximately 20% (i.e., 21% specifically) of the estimated health effects above 0 μg/m$^3$, as detailed in Table III.5.2 and Figure III.5.2, may be attributable to natural, non-anthropogenic background levels (i.e., assumed to be 5 μg/m$^3$), which is essentially not amenable to health impact reduction**.

Common questions, on seeing these results, are: "What would be the avoided impacts on attaining these selected levels?" "Would the number of avoided impacts be the same as the current impacts above these selected levels?" Analyses in other studies (Abt Associates, 1996) have used an approach called 'peak shaving' to answer such questions. Implicit in the peak shaving analysis, a simplistic technique, is that all concentrations in the *distribution* of PM levels are reduced by 'shaving' back all concentrations *just sufficiently to attain* these selected levels.

In view of the shortcomings of this approach, what is needed is a **realistic** way of projecting what might happen to a $PM_{10}$ distribution when emissions reductions, especially broad-based emissions reduction programs, are effected. It is more likely that when effecting broad-based emission reductions to achieve a certain potential goal (e.g., 40 μg/m$^3$), the $PM_{10}$ distribution will be proportionally reduced, that is, both high and low levels in the distribution will be reduced by the same percentage, rather than all levels just being 'shaved' back to the target. This results in *benefits gained **below** the potential goals*. This more realistic approach is referred to as a 'proportional linear rollback analysis' and will be discussed in detail in sections III.5.4 and III.5.5. The purpose of briefly noting this 'peak shaving' analysis here was to emphasize that a more realistic approach is needed for analysing avoided health effects associated with $PM_{10}$ reductions, aimed at achieving certain potential goals.

### *III.5.2.2 Health Impacts Based on Current Levels of Respirable Particulate Matter ($PM_{2.5}$)*

Presently only one site (Evans Avenue, Toronto) in the Ontario monitoring network has a full year of data for $PM_{2.5}$. Thus an analysis, similar to $PM_{10}$ above, is not possible.

Some limited insights can be gained from a preliminary analysis based on a few Ontario urban sites (i.e., Windsor, Hamilton and Toronto) in the NAPS data base. Both $PM_{10}$ and $PM_{2.5}$ are monitored at these sites and in these cities. Very preliminary estimates (based on Table III.5.11 in section III.5.4.2) of annual mortalities can be obtained in each of these cities due to levels above background (i.e., above 5 and 2.5 ug/m$^3$ for $PM_{10}$ and $PM_{2.5}$ respectively). It should be noted that in some cities several $PM_{10}$ monitors (which were population weighted) were used for the estimated impacts due to $PM_{10}$, in contrast to data being available from only one $PM_{2.5}$ monitor, for $PM_{2.5}$ impacts. These preliminary estimates indicate that over 90% of the premature mortalities and hospital admissions are due to $PM_{2.5}$.

## III.5.3 Status of Standards

This section describes the present state of affairs with regard to the establishment of Ontario Ambient Air Quality Criteria (AAQCs), Canadian National Ambient Air Quality Objectives (AQOs) and Canada-Wide Standards (CWS) for $PM_{10}$ and $PM_{2.5}$.

### *III.5.3.1 Ontario Interim AAQC for $PM_{10}$*

In March, 1997, Ontario made a submission to the US EPA supporting their proposed decision to enact more stringent air quality standards for both particulate matter (inhalable - $PM_{10}$ and respirable - $PM_{2.5}$) and ozone. Ontario also urged the EPA to give more serious consideration to the compelling scientific evidence generated by their own scientists and to enact more stringent standards than those proposed in the November 1996 Federal Register decision.

At the same time, in March 1997, Ontario announced that it was considering the introduction of an interim $PM_{10}$ ambient air quality criterion in Ontario. This was to provide improved human health protection during the period while the Federal/Provincial working group (see section III.5.3.2) on air quality objectives and guidelines was finalizing its efforts to establish National Ambient Air Quality Objectives and possibly also Canada-Wide air standards for both $PM_{10}$ and $PM_{2.5}$. It was also anticipated that ozone and particulate matter would be candidates for development of Canada-Wide Standards when the Environment Ministers signed a proposed sub-agreement to the CCME Harmonization Accord.

Essentially, the interim $PM_{10}$ ambient air quality criterion would provide guidance for environmental protection decisions in Ontario and serve as a goal to many of the ongoing initiatives now under way as part of Ontario's Smog Plan. It would also provide an initial health-based benchmark of air quality by which the effectiveness of these programs can be measured.

The proposed introduction of the Ontario interim $PM_{10}$ ambient air quality criterion was announced and placed on the EBR registry for public consultation on May 21, 1997, and it was finally introduced on November 18,1997. The highlights of the rationale behind the Ontario interim $PM_{10}$ air quality criterion are summarized in Box III.5.8.

Box III.5.8: Highlights of rationale for the Ontario interim $PM_{10}$ ambient air quality criterion. (Appears on Ministry of Environment's web site)

- The nature of inhalable particles ($PM_{10}$) is described, along with their *primary* (emitted directly) and *secondary* (formed by reactions of gaseous pollutants in the atmosphere) origins and the sources of primary and secondary particles.
- Numerous recent epidemiological studies have linked $PM_{10}$ exposures with serious health effects ranging from respiratory and cardiac symptom-related hospital admissions to premature mortality. $PM_{10}$ has also been linked with other morbidity effects like asthma symptoms and chronic bronchitis. The linkage with health effects has been clearly demonstrated when $PM_{10}$ concentrations exceed about 25 µg/m$^3$, with some evidence suggesting the effects can occur at even lower $PM_{10}$ concentrations. Although there is still some scientific uncertainty at the lower end of the range, there is now general consensus that there is no clear threshold for health effects. This was further supported in 1995 when the World Health Organization (WHO) considered the health impacts of $PM_{10}$ and concluded that there was no air concentration that could be judged a threshold and decreased by uncertainty factors to avoid risk.
- MOE is currently working in partnership with Environment Canada, Health Canada and other Canadian provinces to develop both $PM_{10}$ and $PM_{2.5}$ air quality objectives.
- As announced in a March 14, 1997 press release in which Ontario provided its comments on the U.S. EPA's air standard proposals and recognizing the serious threat that $PM_{10}$ poses to human health, MOE has decided to establish an interim ambient air quality criterion (AAQC) for $PM_{10}$ in Ontario.
- The interim AAQC is being set at a level now in effect in several jurisdictions, including the United Kingdom, the State of California. It is also consistent with the interim $PM_{10}$ guidelines in the Provinces of British Columbia and Newfoundland.
- The interim AAQC will serve as Ministry policy to provide guidance for environmental protection decisions in Ontario and as an interim goal for assessing the effectiveness of ongoing and future Inhalable Particulate/Respirable Particulate Matter (IP/RP) initiatives as part of Ontario's Smog Plan.
- The interim $PM_{10}$ AAQC will be evaluated in the context of the national objective once the latter has been finalized.

### *III.5.3.2 National Air Quality Objectives (AQOs) for $PM_{10}$ and $PM_{2.5}$*

The establishment of National Ambient Air Quality Objectives (NAAQOs) is the responsibility of the Working Group on Air Quality Objectives and Guidelines (WGAQOG), a federal-provincial working group. This working group reports to the Federal Provincial Advisory Committee established under the Canadian Environmental Protection Act (CEPA/FPAC) which includes members from Environment Canada, Health Canada and the provincial Environment Ministries. The WGAQOG itself has members from all provincial Environment and Health Ministries, as well as Environment

Canada and Health Canada and is co-chaired by one federal and one provincial member.

National ambient air quality objectives, once developed, may be directly adopted or adopted with modifications, reflecting local conditions, to become provincial ambient air quality guidelines, standards or goals. Once the goals are set, implementation strategies need to be developed.

The existing federal National Ambient Air Quality Objective three-tiered framework, which specifies maximum desirable, acceptable and tolerable levels for critical air pollutants is in a state of transition and it is recommended that it be replaced with a new two-tiered framework. The new framework consists of a Reference Level and an Air Quality Objective and their definitions are as follows.

The **Reference Level (RL)** is a level above which there are demonstrated effects on human health and/or the environment. It provides a scientific basis for establishing goals for air quality management. The **Air Quality Objective (AQO)** represents the air quality management goal for the protection of the general public and the environment in Canada. It is a level selected based upon consideration of scientific, social, economic, and technological factors. It should be noted that in the case of $PM_{10}$ and $PM_{2.5}$, due to the technical difficulty of linking specific primary and precursor emission reductions to reduced ambient PM levels, a robust economic and technological analysis was not possible.

Development of RLs and AQOs for $PM_{10}$ and $PM_{2.5}$ has proceeded within this new framework. The RLs are supported by a peer-reviewed science assessment document (PM SAD, 1998; PM SAD E/S, 1998). A rationale document describes the scientific, social, economic and technical factors that were available and considered in the development of recommendations for AQOs.

The proposed values are as follows:

| | |
|---|---|
| Reference Levels: | $\mathbf{PM_{10}}$ = 25 µg/m$^3$ (24 hour av.)<br>$\mathbf{PM_{2.5}}$ = 15 µg/m$^3$ (24 hour av.) |
| Air Quality Objectives: | $\mathbf{PM_{10}}$ = 40 µg/m$^3$ (24 hour av.)<br>$\mathbf{PM_{2.5}}$ = 20 µg/m$^3$ (24 hour av.) |

A national level stakeholder consultation workshop was held on December 1-2, 1997 in Toronto, by the Federal-Provincial Working Group on Air Quality Objectives and Guidelines. The purpose was to examine and discuss the new framework for establishing National Ambient Air Quality Objectives (NAAQOs), and consult on the proposed NAAQOs for Particulate Matter ($PM_{10}$ and $PM_{2.5}$) as developed under the framework.

The outcome of the workshop and comments subsequently received from stakeholders were evaluated and responded to. Stakeholders at the workshop expressed their desire to be more involved, in the future, in the development of AQOs and even in some parts of the RL development. In light of the health impacts associated with existing levels of PM, there is some urgency on the part of the national government to move forward with the proposed AQOs so that there are national goals established to initiate the development of regional/ provincial particulate strategies and implementation plans.

***Canada-Wide Standards (CWS)***

Under the Canada-Wide Accord on Environmental Harmonization, Canadian Ministers of Environment are developing standards (i.e., which could be ambient levels, codes of practice, implementation plans/interim schedules to reach goals) for a number of substances, including particulate matter and ozone, that all Canadian jurisdictions would formally agree to meet and develop implementaion plans for their approach. These standards are being developed under the Environmental Standard Sub-Agreement of the Accord on Environmental Harmonization. This Accord has been signed by Ministers at their January 30, 1998 CCME meeting.

Discussions have been completed under the auspices of CCME to ensure the smooth transfer of the federal-provincial committee work on the NAAQOs tothe CWS process so that there is one clear process for particulate matter and ozone standard development. The EPPC acting chair has proposed to the CEPA/FPAC chair that the scientific work of the WGAQOG be gazetted in the Federal Register, and that it be used as the primary health advice in developing standards under the CWS process. It was also proposed that for substances like PM and Ozone which have been identified as priorities for CWS development, no AQO will be developed. The first CWS workshop on PM and Ozone was held in October, 1998 to discuss possible approaches to setting the CWSs . Benefit-cost analyses of several scenarios, which attempt to capture the full possible range of CWSs, are under way and the next CWS workshop is planned for the spring of 1999.

### III.5.4 Potential Goals for Reduction and Avoided Health Impact Analysis

Section III.5.4.1 will explore the percentage reductions that may be needed in various Ontario airsheds to reach decreasing ambient level goals for $PM_{10}$. In section III.5.4.2, the health benefits of, or avoided health impacts on reaching decreasing goal levels for $PM_{10}$ will be explored. The Ontario interim AAQC (i.e., 50 $\mu g/m^3$) was selected for analysis. Other levels (40 and 60 $\mu g/m^3$) were added for perspective purposes. Thus the levels for analysis in sections III.5.4.1 and III.5.4.2 are 40, 50 and 60 $\mu g/m^3$ for $PM_{10}$.

For $PM_{2.5}$ levels corresponding to half of those chosen for $PM_{10}$ were selected for avoided health impacts assessment. Due to the lack of extensive province-wide $PM_{2.5}$ monitoring data, only limited analysis is feasible at this time.

#### *III.5.4.1 Percentage Reductions That May Be Needed to Achieve Potential Goals.*

***Percentage Reductions to $PM_{10}$ Potential Goals***

This section explores the percentage reductions of the existing $PM_{10}$ distribution levels that may be required in various Ontario airsheds to reach decreasing ambient level potential goals of 40, 50 and 60 $\mu g/m^3$ of $PM_{10}$.

It was noted already in section III.5.2, that the 'peak shaving' approach (i.e.*just attaining* a certain selected level) is not an appropriate way of projecting what might happen to the whole range of $PM_{10}$ levels in the distribution, when emissions reductions, especially broad-based emission reduction programs, are applied in an airshed. Therefore a more realistic 'proportional linear rollback analysis' is applied here. In this analysis the working assumption is that a balanced, broad-based reduction program in an airshed will reduce all levels in the existing concentration distribution in the airshed as it reduces a 'representative maximum' concentration. This approach has been used previously (U.S. EPA Staff Paper, 1996b and Abt Associates, 1996; PM R/D 1998).

There are other approaches (Abt Associates, 1996; contractor to US EPA) such as the previously noted 'peak shaving' or a 'weighted proportional rollback' to adjusting the $PM_{10}$ distribution such that they do not exceed a potential goal level. As already noted, the former method is unlikely to reflect the actual changes in ambient concentration distributions that would occur under various reduction/attainment scenarios. A weighted proportional rollback involves applying one reduction factor to days with higher concentrations and a different reduction factor to days with lower concentrations. The maximum is still reduced to or below the potential target level. Currently there is insufficient information to determine the multiple factors that a weighted proportional rollback technique would require.

Furthermore, in the development of risk estimates the U.S. EPA also reviewed various rollback methodologies, and analysed the extent to which historical changes in particulate matterair quality have been linear (Abt, 1996). Proportional linear rollbacks accounted for the vast majority of the variation between consecutive years of data; however, the relationships become less linear at either extreme, that is at the low and high ends of the concentration distributions. Incorporating background estimates in the rollback calculations improved the predictive power of the linear regressions between consecutive years. Exponential and logarithmic forms of rollbacks performed more poorly than the linear approach.

Based on the above, it can be concluded that the proportional linear rollback methodology, applied to all levels in the existing $PM_{10}$ distribution, is the most suitable method for simulating attainment of various potential goals given the limited source-receptor modelling and understanding of how emissions reductions would actually translate into reductions in ambient PM concentrations. The basic assumption of the 'proportional linear rollback analysis' is as follows. It is assumed (expected) that a balanced, broad-based reduction program in an airshed will affect/reduce the present concentration distribution in the airshed as it affects/reduces a 'representative maximum' concentration.

Briefly the procedures are as follows. First, a 'representative maximum' is determined. Then, the required rollback percentages are calculated. These values can be seen in Table III.5.5 later in this section. These are the percentages needed to roll back the 'representative maximum' to various potential goal levels (i.e., this section). Then, in section III.5.4.2, this calculated percentage is applied to all levels in the existing ambient $PM_{10}$ concentration distribution (i.e., examples of existing, binned concentration distributions can be seen in Table III.5.3) in order to generate a predicted (i.e., rolled back) concentration distribution (i.e., not shown but it would be similar to Table III.5.3 except that only the bins under the potential goals would have values in them), with all concentrations to be under the various potential goal levels and, to estimate the avoided health impacts (i.e., health benefits) associated with achieving these potential goals.

Selecting a 'representative maximum' from a monitoring data set, acquired once every six days, is not straightforward. An all important consideration is to avoid serious outliers which are non-representative of the existing distribution and hence would not appropriately reflect the impact of broad-based emission reduction strategies on the rolled-back distribution. Two approaches have been taken in this analysis which are described in Box III.5.9.

Box III.5.9: Approaches to determining the 'representative maximum' (and % reduction) for % rollback.

***(1) Maximum concentration - as 'representative maximum'***

From the six year, one-in-six-day data set(1990-1995), select the maximum concentration for each site.

Determine the percentage required to roll back this maximum to the various $PM_{10}$ potential goal levels (i.e., 40, 50 and 60 $\mu g/m^3$) at each site.

*Note: An analysis (PM R/D, 1998) comparing one-in-six-day and daily measurements at NAPS sites indicated tha the observed maximum from the one-in-six-day data set approximates the 98th percentile of the daily measurements. This partially ensures that the 'representative maximum' used is not a complete outlier.*

*However, inspection of the one-in-six-day data set and knowledge of certain non-representative activities (e.g., short-term construction near some monitoring sites) indicated that there were still some maximum values at several sites which could be considered non-representative and hence outliers. For this reason another analysis, using the 3rd maximum from the one-in-six-day data set was also performed.*

***(2) 3rd maximum concentration - as 'representative maximum'***

From the six year, one-in-six-day data set(1990-1995), select the 3rd maximum concentration for each site.

Determine the percentage required to roll back this 3rd maximum to the various $PM_{10}$ potential goal levels (i.e., 40, 50 and 60 $\mu g/m^3$) at each site.

Table III.5.5 summarizes the percentage reductions that may be required at Ontario sites to reach the potential goal levels of 40, 50 and 60 $\mu g/m^3$, using the maximum and 3rd maximum values at

## Table III.5.5. Percentage Reductions Required in Various Airsheds in Ontario (to Achieve Potential Goal Levels of 40, 50 and 60 µg/m3, Using Maximum and 3rd Maximum Values)

| Data: 1990-1995 | | Max3 | Max | % Reduction | | % Reduction | | % Reduction | |
|---|---|---|---|---|---|---|---|---|---|
| | | µg/m$^3$ | µg/m$^3$ | to 40 µg/m$^3$ | | to 50 µg/m$^3$ | | to 60 µg/m$^3$ | |
| Site Id | City | | | MaxTo40 | Max3To40 | MaxTo50 | Max3To50 | MaxTo60 | Max3To60 |
| 12056 | Windsor | 47 | 56 | 28.6 | 14.9 | 10.7 | 0.0 | 0.0 | 0.0 |
| 12057 | Windsor | 49 | 52 | 23.1 | 18.4 | 3.9 | 0.0 | 0.0 | 0.0 |
| 12507 | Windsor | 75 | 118 | 66.1 | 46.7 | 57.6 | 33.3 | 49.2 | 20.0 |
| 12508 | Windsor | 81 | 91 | 56 | 50.6 | 45.1 | 38.3 | 34.1 | 25.9 |
| 12513 | Windsor | 86 | 95 | 57.9 | 53.5 | 47.4 | 41.9 | 36.8 | 30.2 |
| 15516 | London | 56 | 85 | 52.9 | 28.6 | 41.2 | 10.7 | 29.4 | 0.0 |
| 22304 | Nanticoke | 60 | 69 | 42 | 33.3 | 27.5 | 16.7 | 13.0 | 0.0 |
| 27308 | St. Catharines | 61 | 70 | 42.9 | 34.4 | 28.6 | 18.0 | 14.3 | 1.6 |
| 27352 | Thorold | 100 | 171 | 76.6 | 60.0 | 70.8 | 50.0 | 64.9 | 40.0 |
| 29300 | Hamilton | 88 | 97 | 58.8 | 54.5 | 48.5 | 43.2 | 38.1 | 31.8 |
| 29302 | Hamilton | 100 | 130 | 69.2 | 60.0 | 61.5 | 50.0 | 53.9 | 40.0 |
| 29313 | Hamilton | 93 | 110 | 63.6 | 57.0 | 54.6 | 46.2 | 45.5 | 35.5 |
| 29324 | Hamilton | 72 | 94 | 57.5 | 44.4 | 46.8 | 30.6 | 36.2 | 16.7 |
| 31127 | Toronto | 77 | 120 | 66.7 | 48.1 | 58.3 | 35.1 | 50.0 | 22.1 |
| 33127 | Scarborough | 75 | 100 | 60 | 46.7 | 50.0 | 33.3 | 40.0 | 20.0 |
| 35127 | Etobicoke | 79 | 81 | 50.6 | 49.4 | 38.3 | 36.7 | 25.9 | 24.1 |
| 44127 | Oakville | 60 | 92 | 56.5 | 33.3 | 45.7 | 16.7 | 34.8 | 0.0 |
| 46127 | Mississauga | 60 | 77 | 48.1 | 33.3 | 35.1 | 16.7 | 22.1 | 0.0 |
| 56051 | Cornwall | 56 | 145 | 72.4 | 28.6 | 65.5 | 10.7 | 58.6 | 0.0 |
| 62135 | Fort Frances | 62 | 69 | 42 | 35.5 | 27.5 | 19.4 | 13.0 | 3.2 |
| 63201 | Thunder Bay | 51 | 62 | 35.5 | 21.6 | 19.4 | 2.0 | 3.2 | 0.0 |
| 71342 | S.S. Marie | 146 | 170 | 76.5 | 72.6 | 70.6 | 65.8 | 64.7 | 58.9 |
| 71368 | S.S. Marie | 63 | 82 | 51.2 | 36.5 | 39.0 | 20.6 | 26.8 | 4.8 |
| 77326 | Sudbury | 48 | 59 | 32.2 | 16.7 | 15.3 | 0.0 | 0.0 | 0.0 |

each site. As implied by the 'note' in Box III.5.9, it is expected that the potentially achievable percentage reductions to various goal levels (i.e., 40, 50 and 60 μg/m$^3$) is most realistically represented by those based on the 3rd maximum values (i.e., 'Max3To40', 'Max3To50' and 'Max3To60' columns in Table III.5.5).

***Percentage Reductions to $PM_{2.5}$ Potential Goals***

In a manner similar to the previous analysis on $PM_{10}$, the percentage reductions of $PM_{2.5}$, required in various airsheds in Ontario, as limited by data availability, was determined. Data were available from the federally operated NAPS sites. Table III.5.6 summarizes the percentage reductions required in four cities to achieve potential goal levels of 20, 25 and 30 μg/m$^3$, using the 3rd maximum values from the monitoring data set.

**Table III.5.6. Percentage Reductions Required in Various Airsheds in Ontario (To Achieve Potential Goal Levels of 20, 25 and 30 μg/m$^3$, Using the 3rd Maximum Values)**

| Site Id | City | 3rd Maximum 24 h. level (μg/m$^3$) | % Reduction to 20 μg/m$^3$ | % Reduction to 25 μg/m$^3$ | % Reduction to 30 μg/m$^3$ |
|---|---|---|---|---|---|
| 60104 | Ottawa | 44 | 55 | 43 | 32 |
| 60204 | Windsor | 46 | 57 | 46 | 35 |
| 60211 | Windsor | 66 | 70 | 62 | 55 |
| 60424 | Toronto | 57 | 65 | 56 | 47 |
| 60403 | Toronto | 37 | 46 | 32 | 19 |
| 60512 | Hamilton | 67 | 70 | 63 | 55 |

Notes: Data from NAPS sites (T. Dann, Environment Canada. Personal communication). Data covers the period from 1990-95 where available. For one site only one year of data were available.

### *III.5.4.2 Avoided Health Impacts (Health Benefits) of Achieving Various Goals.*

#### Ontario-wide *average* analysis - Determining IP/RP Reduction Requirements

The potential number of avoided impacts across Ontario corresponding to a reduction of 24-hour ambient $PM_{10}$ concentrations can be calculated by rolling back all levels in the existing ambient $PM_{10}$ distribution to simulate no exceedences of the various potential goals proposed at the beginning of section III.5.4. Rolling back the current ambient $PM_{10}$ concentrations involves decreasing $PM_{10}$ levels on all days by the same percentage (a proportional linear rollback).

The maximum and 3rd maximum concentrations in the existing data set and the percentage reductions required in various Ontario cities to reach the various potential goals have been determined in section

III.5.4.1 (Table III.5.5).

In this section, the potential number of avoided impacts, on attaining various potential goal levels, are estimated. The results are expressed as a percentage of total current impacts avoided after rollback. Two scenarios were considered.

In the **first** scenario, based on the fact that no threshold has been identified for PM effects, all concentrations, which are above zero µg/m$^3$ after rollback, were considered to contribute to avoided impacts. The difference between the annual sum of concentrations (above 0 µg/m$^3$) before rollback, which define the *current* impacts, and the annual sum of concentrations after rollback (i.e., those that remain above 0 µg/m$^3$) was used to estimate the avoided impacts (i.e., health effect benefits).

In the **second** scenario, based on the assumption that no strategy will be able to reduce $PM_0$ concentrations below background levels due to natural sources, only concentrations which were above 5 µg/m$^3$ after rollback were considered to contribute to avoided impacts. The difference between the annual sum of concentrations (above 5 µg/m$^3$) before rollback, which define the *current* impacts above 5 µg/m$^3$, and the annual sum of concentrations after rollback (i.e., those that remain above 5 µg/m$^3$) was used to estimate the avoided impacts.

It was noted in section III.5.4.1 that the potentially achievable percentage reductions to various goal levels (i.e., 40, 50 and 60 µg/m$^3$) is likely most realistically represented by those based on rollbacks from the 3rd maximum values. Therefore the above noted two scenarios were analysed using the 3rd maximum value in the existing concentration distribution. The methodology is described in more detail in Box III.5.10.

Box III.5.10: Approach to determine percentage of total impacts avoided after rolling back to potential goals of 40, 5 and 60 µg/m$^3$.

The *general* rollback method for the 3rd maximum concentration is as follows: Using the percentage required to roll back the 3rd maximum to the various $PM_{10}$ goal levels (i.e., 40, 50 and 60 µg/m$^3$) at each site, each value in the six year distribution was rolled back (reduced) by the same percentage.

***Scenario 1.*** (All levels above zero µg/m$^3$, after rollback, contribute to avoided impacts)

The remaining sum of concentrations were normalized to one year and population-weighted (i.e., weighting as before, described in Box III.5.6) for Ontario. The **difference** between this *rolled-back* sum and the *current* sum, evaluated as the percentage of the *current* sum of concentrations above zero µg/m$^3$ [calculated in section III.5.2 ,Table III.5.4, 'annual sum as (µg/m$^3$)x.day'] is the percentage of total impacts avoided.

***Scenario 2.*** (Only levels above 5 µg/m$^3$, after rollback, were considered to contribute to avoided impacts)

From each value, after roll-back, 5 µg/m$^3$ (i.e., the annual background $^{\text{Note 1}}$) was subtracted. The remaining sum of concentrations (after excluding the negative values) were normalized to one year and population-weighted (i.e., weighting as for scenario 1) for Ontario. The **difference** between this *rolled-back* sum and the *current* sum, evaluated as the percentage of the *current* sum of concentrations above 5 µg/m$^3$ [calculated in section III.5.2 ,Table III.5.4, 'annual sum as (µg/m$^3$) x day'] is the percentage of total impacts avoided.

Box III.5.10 (continued)

[Note 1] **Annual background of 5 µg/m$^3$**

PM$_{10}$ annual natural backgrounds (concentrations of 5-6 µg/m$^3$ for North American sites) have been estimated using data at remote sites along with emission estimates for natural sources (PM SAD, 1998). Daily 24 hour average background levels could be higher. However, since in these estimates, concentrations are summed annually and impacts are also evaluated annually, it seemed appropriate to subtract the annual representative background from *each daily level* after rollback.

The percentages of total impacts avoided after proportional rollback of all levels in the existing PM$_{10}$ distribution to potential goal levels of 40, 50 and 60 µg/m$^3$ are summarized in Table III.5.7.
It was noted in section III.5.4.1, that the potentially achievable attainment of goal levels (i.e., of 40, 50 and 60 µg/m$^3$) is most realistically represented by those rollback approaches relying on the more representative 3rd maximum values. This can be combined with the fact that levels will not be reducible below background, which in this case was assumed to be 5 µg/m$^3$. This combined scenario is depicted as '**M3(5)**' and is shaded in Table III.5.7.

This scenario indicates that attainment of potential goals of 40, 50 and 60 µg/m$^3$, after application of a broad-based PM emissions reduction strategy, will result in only 53, 34 and 19 %, respectively, of the total impacts (i.e., those impacts which are **above 5 µg/m$^3$ currently)** avoided. This again points to the need for broad-based emission reduction strategies and the importance of aiming and working towards the lower end of potential target levels.

**Table III.5.7. Percentage of Province-wide Avoided Impacts Resulting from Proportional Rollback[Notes 1,2] to Potential Goals of 40, 50, and 60 µg/m3**

| | **Percentage of 'Total' [Note 3] Impact Avoided After Rollback** | |
|---|---|---|
| **Scenario Rollback to Goals:** (µg/m3) | ***(Threshold:0)*** **From: 3rd Max** **M3(0)** | ***(Threshold:5)*** **From: 3rd Max** **M3(5)** |
| **40** | **41** | **53** |
| **50** | **28** | **34** |
| **60** | **16** | **19** |

**Notes :**

1) Table includes rollback from the 3rd maximum concentration (M3) in the existing distribution of PM$_{10}$ levels

2) Two 'thresholds' are considered for including avoided impacts. These are 0 and 5 μg/m$^3$, meaning that levels down to 0, and 5 μg/m3, respectively, contribute to avoided impacts, after rollback. Hence the **two** cases: **M3(0)**, which is rollback from the 3rd maximum with all levels down to 0 μg/m$^3$ contributing to avoided impacts; and **M3(5)**, which is rollback from the 3rd maximum with all levels down to 5 μg/m$^3$ contributing to avoided impacts

(3) For 'threshold' = 0 μg/m$^3$ assumption, '*total*' impact are current impacts above 0 μg/m3 from Table III.5.4
For 'threshold' = 5 μg/m$^3$ assumption, '*total*' impact are current impacts above 5 μg/m3 from Table III.5.4

The other scenario (i.e., '**M3(0)**' in Table III.5.7) shows that attainment of potential goals of 40, 50 and 60 μg/m$^3$ results in 41, 28 and 16 %, respectively, of the total impacts (i.e., those impacts which are **above 0 μg/m$^3$ currently)** avoided.

It was noted in section III.5.2 that a certain percentage (i.e., 21%) of current estimated impacts may be attributable to natural, non-anthropogenic background levels (i.e., assumed to be 5 μg/m$^3$). Thus, when estimating the percentage of province-wide avoided impacts, resulting from proportional rollback to potential goals of 40, 50 and 60 μg/m$^3$, the most realistic baseline to start from are those impacts which are **above 5 μg/m$^3$ currently and, not to include any avoided impacts which would be due to levels below 5 μg/m$^3$ after rollback.** This scenario is thus the most realistic one and is depicted by the shaded column in Table III.5.7.

These percentages of avoided impacts (i.e., 53, 34 and 19%, corresponding to potential goals of 40, 50, and 60 μg/m$^3$ respectively) can be considered as simple surrogates for province-wide average percentage reductions of **anthropogenic** emissions to achieve the potential goals.

Figure III.5.4 depicts the avoided impacts for the two scenarios shown in Table III.5.7 and also includes two extra scenarios in which the rollback was based on the maximum rather than the 3rd maximum concentration. These latter two scenarios result in higher % reduction of avoided impacts, due to the rollback from the less representative maximum (vs 3rd maximum) concentrations. These scenarios are less likely to be representative of the projected reduction of impacts when broad-based emission reduction strategies are undertaken.

### *Community Specific Analysis - Determining IP/RP Reduction Requirements*

In addition to analysing province-wide average percentage reductions of **anthropogenic** emissions that may be required to achieve the potential goals, preliminary community specific analyses of urban areas with known PM problems are also included in this section. Most of Ontario's population resides in urban areas and are thus exposed to PM.

Assessments of ambient pollutant levels in some Ontario communities (chosen based on factors such as air quality levels, population and unique local source) have been done. These communities are: Hamilton, Toronto, Windsor, London, Ottawa, Cornwall, Sault Ste. Marie, Thorold, and Thunder Bay.

Table III.5.8 shows the reduction that would be required as a percentage (based on the 3rd maximum 24 h. concentration) in order to achieve a number of sample desirable goals for $PM_{10}$, i.e., 40, 50, and 60 μg/m$^3$. The lower the desirable level is, the more reduction is necessary. In some cases where

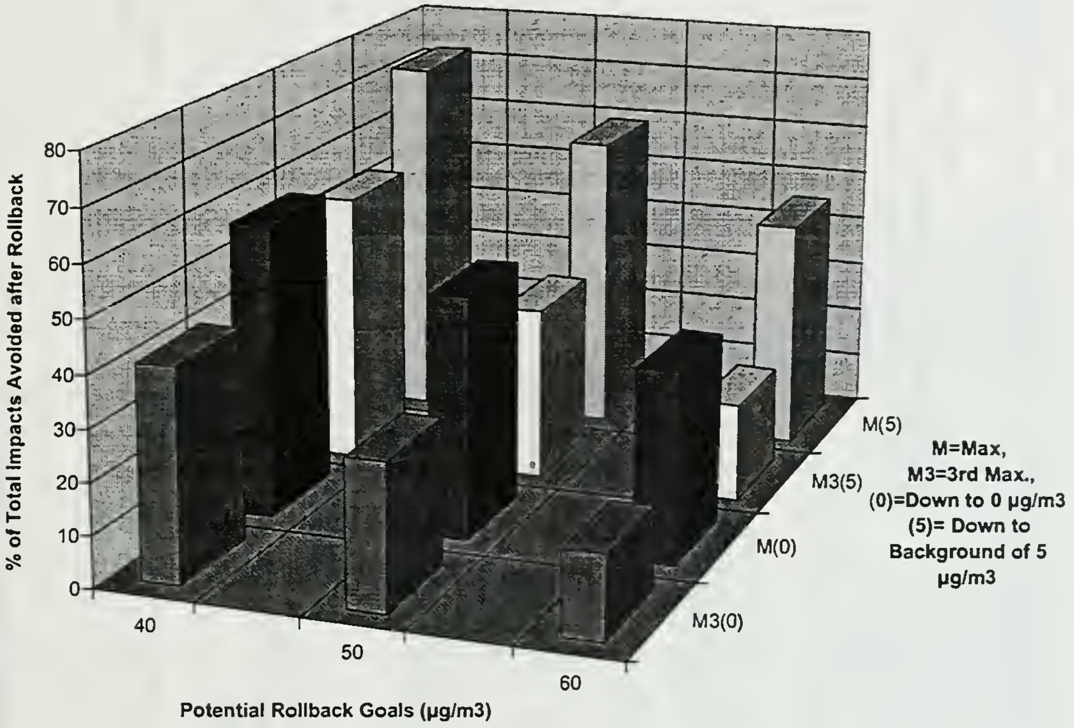


Figure III.5.4. Comparison of Rollbacks Using Max. and 3rd Max. (with avoided impacts included down to 0 µg/m3 and down to background of 5 µg/m3)

existing ambient levels are already at or below the desirable level, no reduction would be necessary.

Table III.5.9 summarizes the reduced health effects expected, compared with the current situation, by achieving the potential $PM_{10}$ goals of 40, 50, and 60 µg/m$^3$. Existing integrated burden, burden after proportional rollback to the desirable level, (all these burdens are directly related to health effects - in unit of µg/m$^3$ x day) and the reduced health effect percentage are shown, using a background level of 5 µg/m$^3$. It should be noted that the number of health incidents reduced (e.g., moralities, hospital admissions, etc.) is dependent onthe size of the population. A smaller rollback percentage in the GTA (53%) will actually result in a larger numberof cases avoided than would a seemingly larger percentage in other communities, e.g., higher rollback percentages in Hamilton (69%), Sault Ste. Marie (83%), because of the smaller populations associated with Hamilton and Sault Ste. Marie.

Corresponding $PM_{2.5}$ data are shown in Tables III.5.10 and III.5.11. Since there is limited $PM_{2.5}$ monitoring in the province to date, only information pertaining to Hamilton, Toronto, Windsor, and Ottawa is shown. Comparison of Tables III.5.11 and III.5.9 indicates that the percentage reduction necessary to attain the specified $PM_{2.5}$ goal is usually higher than that of the $PM_{10}$ goal. Therefore, meeting the $PM_{2.5}$ goal will likely meet the corresponding $PM_{10}$ goal.

**TABLE III.5.8: PROPORTIONAL PERCENTAGE REDUCTION OF ALL AMBIENT $PM_{10}$ LEVELS (Based on 3rd MAXIMUM level) TO ACHIEVE DESIRABLE $PM_{10}$ LEVEL GOALS**

| COMMUNITY | THIRD MAXIMUM 24 H. LEVEL (µg/M$^3$) | PERCENTAGE REDUCTION TO ACHIEVE SPECIFIED $PM_{10}$ LEVEL (Units: %) | | |
|---|---|---|---|---|
| | $PM_{10}$ | 40 µg/M$^3$ | 50 µg/M$^3$ | 60 µg/M$^3$ |
| **Major Populated Communities** | | | | |
| ***With major local point sources*** | | | | |
| Hamilton -near industry | 93/100 (2 sites) | 57-60 | 46-50 | 35-40 |
| Hamilton -urban | 88 | 55 | 43 | 32 |
| Hamilton -suburban | 72 | 44 | 31 | 17 |
| Toronto (GTA) | 79/77/75/60/60 (5 sites) | 33-49 | 17-37 | 0-24 |
| Windsor | 86/81/75/49/47 (5 sites) | 15-54 | 0-42 | 0-30 |
| ***Without major local point sources*** | | | | |
| London | 56 | 29 | 11 | 0 |
| Ottawa | n.a. | n.a. | n.a. | n.a. |
| **Communities with Local Sources and/or Significant Woodsmoke Sources** | | | | |
| Cornwall | 56 | 29 | 11 | 0 |
| Sault Ste. Marie -near industry | 146 | 73 | 66 | 59 |
| Sault Ste. Marie -urban | 63 | 37 | 21 | 5 |
| Thorold | 100 | 60 | 50 | 40 |
| Thunder Bay | 51 | 22 | 2 | 0 |

## TABLE III.5.9: REDUCED INTEGRATED BURDEN BY ACHIEVING SPECIFIED PM $_{10}$ LEVELS BY PROPORTIONAL PERCENTAGE REDUCTION OF ALL AMBIENT PM $_{10}$ LEVELS (Based on 3rd MAXIMUM level) (INTEGRATED BURDEN ABOVE 5 µg/M $^3$)

| COMMUNITY | INTEGRATED BURDEN (B).Units: (µg/m $^3$) x days<br>$B_E$= Existing burden above 5 µg/m $^3$; $B_{PR}$=Burden after proportional rollback to 40, 50 or 60 µg/m $^3$ from 3rd maximum; % $B_E$ RED.= *Percentage* by which existing burden is reduced if specified levels achieved (Corresponds to percentage by which current health impacts are reduced). | | | | | | |
|---|---|---|---|---|---|---|---|
| | $B_E$ | 40 µg/M $^3$ | | 50 µg/M $^3$ | | 60 µg/M $^3$ | |
| | | $B_{PR}$ | % $B_E$ RED. | $B_{PR}$ | % $B_E$ RED. | $B_{PR}$ | % $B_E$ RED. |
| Major Populated Communities | | | | | | | |
| *With major local point sources* | | | | | | | |
| Hamilton -near industry | 10155 | 3210 | 68 | 4435 | 56 | 5672 | 44 |
| Hamilton -urban | 8217 | 2774 | 66 | 3896 | 53 | 5029 | 39 |
| Hamilton -suburban | 6717 | 2946 | 56 | 4122 | 39 | 5301 | 21 |
| Toronto (GTA) | 7040 | 3267 | 54 | 4530 | 36 | 5800 | 18 |
| Windsor | 7743 | 3973 | 49 | 5290 | 32 | 6090 | 21 |
| *Without major local point sources* | | | | | | | |
| London | 5401 | 3358 | 38 | 4634 | 14 | 5401 | 0 |
| Ottawa | 4150 | 2711 | 35 | 3816 | 8 | 4150 | 0 |
| Communities with Local Sources and/or Significant Woodsmoke Sources | | | | | | | |
| Cornwall | 6318 | 3999 | 37 | 5446 | 14 | 6318 | 0 |
| Sault Ste. Marie -near industry | 11870 | 2072 | 83 | 2954 | 75 | 3859 | 67 |
| Sault Ste. Marie -urban | 5746 | 3009 | 48 | 4194 | 27 | 5387 | 6 |
| Thorold | 10964 | 3302 | 70 | 4573 | 58 | 5849 | 47 |
| Thunder Bay | 4674 | 3290 | 30 | 4548 | 3 | 4674 | 0 |

**TABLE III.5.10: PROPORTIONAL PERCENTAGE REDUCTION OF ALL AMBIENT $PM_{2.5}$ LEVELS (Based on 3rd MAXIMUM level) TO ACHIEVE DESIRABLE $PM_{2.5}$ LEVEL GOALS**

| COMMUNITY | THIRD MAXIMUM 24 H. LEVEL (µg/M³) | PERCENTAGE REDUCTION TO ACHIEVE SPECIFIED $PM_{2.5}$ LEVEL (Units: %) | | |
|---|---|---|---|---|
| | $PM_{2.5}$ | 20 µg/M³ | 25 µg/M³ | 30 µg/M³ |
| **Major Populated Communities** (for which $PM_{2.5}$ data were available; for some sites only 1 or 2 years of data were available) | | | | |
| ***With major local point sources*** | | | | |
| Hamilton | 67 | 70 | 63 | 55 |
| Toronto | 37/57 (2 sites) | 46-65 | 32-56 | 19-47 |
| Windsor | 46/66 (2 sites) | 57-70 | 46-62 | 35-55 |
| ***Without major local point sources*** | | | | |
| Ottawa | 44 | 55 | 43 | 32 |

**TABLE III.5.11: REDUCED INTEGRATED BURDEN BY ACHIEVING SPECIFIED PM $_{2.5}$ LEVELS BY PROPORTIONAL PERCENTAGE REDUCTION OF ALL AMBIENT PM $_{2.5}$ LEVELS (Based on 3rd MAXIMUM level) (INTEGRATED BURDEN ABOVE 2.5 µg/M $^3$)**

| COMMUNITY | INTEGRATED BURDEN (B).Units: (µg/m$^3$) x days<br>$B_E$= Existing burden above 2.5 µg/m$^3$; $B_{PR}$=Burden after proportional rollback to 20, 25 or 30 µg/m$^3$ from 3rd maximum; % $B_E$ RED.= *Percentage* by which existing burden is reduced if specified levels achieved (Corresponds to percentage by which current health impacts are reduced). | | | | | | |
|---|---|---|---|---|---|---|---|
| | $B_E$ | 20 µg/M$^3$ | | 25 µg/M$^3$ | | 30 µg/M$^3$ | |
| | | $B_{PR}$ | % $B_E$ RED. | $B_{PR}$ | % $B_E$ RED. | $B_{PR}$ | % $B_E$ RED. |
| Major Populated Communities (for which PM$_{2.5}$ data were available) | | | | | | | |
| *With major local point sources* | | | | | | | |
| Hamilton | 5680 | 1117 | 80 | 1585 | 72 | 2064 | 64 |
| Toronto (Site 1) | 4736 | 1124 | 76 | 1592 | 66 | 2075 | 56 |
| Toronto (Site 2 - based on 1 year of data) | 4885 | 2230 | 54 | 3007 | 38 | 3788 | 22 |
| Windsor (Site 1) | 5055 | 1695 | 66 | 2337 | 54 | 2983 | 41 |
| Windsor (Site 2) | 5430 | 1049 | 81 | 1506 | 72 | 1977 | 64 |
| *Without major local point sources* | | | | | | | |
| Ottawa | 2780 | 861 | 69 | 1243 | 55 | 1639 | 41 |

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# III.6 CONTROL TECHNOLOGIES

## III.6.1 Introduction

Control technologies for inhaleable particulate matter (IP) and respirable particulate matter (RP) will be evaluated in the order suggested by the relative importance of the various fractions that comprise the fine particulate matter considered in this document,as they appear in ambient air samples. The composition of these fractions will lead us to examine several gaseous precursors, important in particular for the formation of the fine particles. Inevitably, the applied use of the technologies surveyed will have to be considered within the context of the inventories of actual (anthropogenic) sources that emit such particles, or gaseous precursors, into the atmosphere. This approach was chosen because there is a great discrepancy between the relative ratio of the components of the aerosol collected in ambient air sampling, compared with what one would expect to find based on emission inventories.

The reader should bear in mind that the nature of this chapter is descriptive. The presentation of one particular type of technology as being suitable to an industry or process should not be interpreted as a recommendation for its actual implementation in all instances. Some industrial sites may have already implemented, in part or fully, the technology described, or other suitable ones. The economics of each specific application, and sometimes the applicability of the technology itself, are highly site specific.

## III.6.2 Removal Technologies

The removal technologies applicable to most of the pollutants discussed herein include process modifications, good engineering practices and emission control devices. As we look at each technology in turn, it will be important to note that some solutions offer the advantage of controlling more than one pollutant. Each practical solution will, therefore, be customized for the application at hand and the generic parameters quoted herein for typical technologies should only be considered as orientative. While some detailed data on the removal efficiency and costs will be addressed by pollutant, in conjunction with specific sectors or individual sources, general comments about the suitability of various approaches are discussed below. To avoid repetitions, it should be noted that each technology will be discussed once only, under the type of source where it may be most widely applied. Some comments applicable to both $SO_2$ and $NO_x$ removal may also appear in only one place.

### *III.6.2.1 Process Modifications*

Process modifications avoid the generation of aerosols by either excluding the offending substances (responsible for the subsequent formation of the aerosols) from the process, or conducting the industrial process in a manner in which the offending substances are not released into the gaseous effluent. In this last aspect, process modifications are related to good engineering practices.

The applicability of process modifications is general but the evaluation and implementation of changes resulting in lowering the emissions are industry and process specific. Process modifications are the most elegant solution for eliminating offending contaminants and quite often they are also the least expensive manner of doing it. Sometimes a process modification involves the addition of a new (secondary) production process that takes as its input a polluted stream (from the primary process) and cleans it, while generating another useful end product. An example of such an application would be the addition of a sulphuric acid plant to a smelting facility (see example in Section III.6.3.1).

A special case of process modification is fuel switching. This solution is common across a wide range of activities and industrial processes. Sulphate is responsible for the lion's part of RPs collected in ambient air samples and since much of the $SO_2$ that eventually generates it comes from combustion processes, where essentially all the sulphur present in the fuel is oxidized to $SO_2$, a reduction of sulphur in fuel may translate into an easily quantifiable reduction in RPs.

### *III.6.2.2 Good Engineering Practices*

This term is used here to cover all the good practices that prevent the fine particles created in an activity (or their gaseous precursors) from being emitted into the air. In industrial applications, this may involve process containment and use of enclosures for all the steps involving the transportation of fine material. Storage in closed bins, transport by enclosed conveyer belts, local ventilation at transfer points and packing stations, are all examples of good containment practices.

In the case of fugitive sources, e.g., coal piles, good engineering practices may involve grading at less than the natural angle of rest and spraying the pile with a liquid promoting the formation of a solid cake.

For diffuse area sources, like roads, regular sweeping and periodic spraying of the (road) surface to keep the dust down are good examples of mitigation steps. Such steps can go a long way to reduce emissions from transportation.

For mobile sources, like diesel powered means of transportation, good engineering practices would include engine rebuilding and the use (and replacement or repair) of exhaust filters and/or catalysts.

In the most general acception of the term, good engineering practices also encourage the achievement of the highest efficiency in all processes. In energy generation, for example, this concept would favour combined cycle generation (using combustion turbines) over the conventional steam condensing power generation. If district heating can be made part of the generating plant, the overall yield in terms of calories used per unit of heat input would increase even more. In transportation, one can aim at increased energy efficiency at different levels. The most all-encompassing evaluation would look at minimizing the heatcontent (fuel) input per unit of useful mass moved. This points to a menu of solutions that includes not only better engine design but also the addition of braking-regenerative motive power and lowering of the overall vehicle weight.

### *III.6.2.3 Emission Control Devices*

Emission control devices are used in end-of-the-pipe type of applications. They are most often an added cost to the industrial process. The recovery of valuable products may occasionally provide some financial benefit to the user, offsetting all or part of the cost of the control equipment.

The basic types of emission control devices for fine particles and their precursors are: mechanical collectors, scrubbers, baghouses, electrostatic precipitators (ESP), combustion systems (incinerators), absorbers, and adsorbers. All these devices are used successfully, alone or in combination, to lower the emissions from a variety of sources, with each application specific to the process it controls.

Some of the relative advantages and disadvantages of each class of emission control devices are highlighted in Table III.6.1. The relative magnitude of each attribute discussed is proportional to the number of check marks. A more detailed discussion of the merits of each device appears under the description of its application at specific sources.

## Table III.6.1: Relative Advantages and Disadvantages of Various Emission Control Devices

| Device<br>Features | Cyclone | Wet scrubber1) | Electrostatic precipitator | Fabric filter | Absorber2) | Adsorber3) | Incinerator |
|---|---|---|---|---|---|---|---|
| Initial capital cost | ✓ | ✓✓ | ✓✓✓ | ✓✓✓ | ✓✓✓ | ✓✓ | ✓ |
| Operating cost | ✓ | ✓✓✓ | ✓✓ | ✓✓ | ✓✓ | ✓ | ✓ |
| Complexity4) | ✓ | ✓✓ | ✓✓✓ | ✓✓ | ✓✓✓ | ✓✓ | ✓ |
| Space requirements5) | ✓ | ✓✓ | ✓✓✓ | ✓✓✓ | ✓✓ | ✓✓ | ✓ |
| Removal efficiency @<10 μm | ✓ | ✓✓✓ | ✓✓✓ | ✓✓✓ | ✓✓ | - | - |
| Removal efficiency @<1 μm | - | ✓ | ✓✓ | ✓✓ | ✓ | - | - |
| Sensitivity to particle properties | ✓ | ✓ | ✓✓✓ | ✓✓ | ✓ | - | - |
| Removal efficiency for gases | - | ✓✓ | - | - | ✓✓✓ | ✓✓✓ | ✓✓✓ |
| Can tolerate moisture | ✓✓ | ✓✓✓ | ✓✓ | - | ✓✓✓ | ✓ | - |
| Can tolerate high temperature | ✓✓✓ | ✓ | ✓✓ | ✓ | ✓ | ✓ | ✓✓✓ |

Key: - not applicable
✓ low
✓✓ medium
✓✓✓ high

1) - Collection efficiency raises with the increase in energy (i.e., pressure drop) spent to contact the phases.
2) - These are low energy wet scrubbers where the emphasis is on the provision of an adequate contact time between the phases.
3) - These are gas/solid contacting units where the emphasis is on the provision of an adequate contact time between the phases.
4) - Gives an indication of maintenance requirements and costs (high complexity is a disadvantage).
5) - Gives an indication of retrofitting costs.

### III.6.3 $SO_2$ Removal Technologies

Ambient air samples tell us that sulphur dioxide is the most important precursor of fine particulate matter (RP fraction). During its travel through the air, oxidation to sulphuric acid takes place; its reaction with inorganic substances leads to the creation of sulphate aerosols.

Table III.1.2 (Section III.1) ranks the major known emitters of $SO_2$ in Ontario according to their magnitude. The most important types of sources will be discussed individually in detail.

#### *III.6.3.1 Point Sources*

Non-iron Smelters

The non-iron smelting industry comprises the production of several base metals, amongst which nickel, copper and zinc represent the largest tonnage products. Most ores processed in Ontario consist of sulphides, sometimes in combination with other chemical compounds. The valuable metals are released from the ores by a process that includes an oxidative roasting phase during which massive amounts of $SO_2$ are generated. The process includes, in a most general description, the following steps:

- ore mining and beneficiation;
- oxidative roast;
- smelting;
- refining.

Ore mining and beneficiation does not involve any direct release of $SO_2$ but enrichment in the valuable metal sulphide (e.g., via flotation, etc.) implies the removal of other, less valuable materials, including other metal sulphides, which would otherwise have released $SO_2$ during the subsequent processing steps. The cost of ore beneficiation and the overall $SO_2$ removal efficiency resulting thereof are site specific. Nevertheless, it can be said that good engineering practices would call for this method to be applied before all other control techniques.

The oxidative roast eliminates significant amounts of the sulphur in the ore as well as other metallic impurities (mostly iron). Sulphur oxides generated during roasting can be collected and transformed into sulphuric acid, sulphur, or liquid $SO_2$.

Smelting continues the oxidative removal of the residual sulphur. Again, high concentration sulphur dioxide is released, which can be collected and transformed into sulphuric acid, sulphur, or liquid $SO_2$

Refining releases smaller amounts of $SO_2$, which is usually of low and variable concentration, unsuitable for further processing to make sulphuric acid, sulphur, or liquid $SO_2$. This means that this residual $SO_2$ will end up as an uncontrolled atmospheric emission.

The processing of residual $SO_2$ into sulphuric acid is the preferred control technology for the non-iron smelters in Ontario. Conversion efficiencies of single contact sulphuric acid plants reach, typically, 92.5% to 98%, leaving concentrations of approximately 2000 ppm $SO_2$ in the tail gas. Double contact sulphuric acid plants convert 98% to >99% of the $SO_2$, leaving tail gas concentrations of approximately 500 ppm or less.

## Electric Utilities

$SO_2$ emission rates averaged over the entire U.S. fossil-fired utility sector for year 1990 were on the order of 26 g/W of generating capacity (STAPPA/ALAPCO, June 1996). Eighty percent of the fossil fuel-fired generating capacity was coal-based. In Ontario, Ontario Hydro emitted 124 Gg of $SO_2$ in 1997 for 24.83 TWh of fossil generated electricity out of an 8,689 MW installed (fossil fuel fired) generating capacity (i.e.: 14.3 g/W of generating capacity or 5 mg $SO_2$/Wh).

$SO_2$ generated by electric utilities comes from sulphur contained in the fossil fuels. In Ontario, most fossil-fuel generating stations use coal (as a fuel). Essentially, all the sulphur therein ends up as $SO_2$

Significant $SO_2$ emission has been avoided by coal switching. The use of low sulphur coal though, may reduce the efficiency of the ESPs used to capture the fine ashes carried over by the flue gas. This problem may be alleviated by altering the properties of the (low-sulphur coal) ash by the deliberate addition of small amounts of $SO_3$ and $NH_3$. The efficiency of $SO_2$ removal through fuel switching is 100%, as all the sulphur not entering the furnace anymore is removed. The cost of this alternative for $SO_2$ control is a function of the local conditions at the plant but it is usually lower than that of end-of-pipe control alternatives.

Another common method of removing $SO_2$ from fossil-fired plants is scrubbing. Most scrubbers use an alkaline slurry containing lime, limestone, ordolomite, and sequester $SO_2$ as calcium sulphite or sulphate. The former is usually disposed of in landfills; the latter may be sold as gypsum. $SO_2$ removal efficiency depends on the type of scrubbing process but the range can be as high as 90 to 98%. The total cost for 32 FGD systems recently installed in the US averaged at 227 US$/kW (Keeth, R. 1995).

It should be noted that scrubbing also removes a significant proportion of the particulate matter present in the flue gas. The removal efficiency depends on the type of scrubber. A typical installation reports better than 70% particle removal efficiency (Peterson et al., 1995).

Other $SO_2$ removal techniques involve limestone injection in the furnace, or dry spraying of lime (or other alkaline reagents) in the flue gas, followed by dust capture in a baghouse. These methods, while usually operating at lower $SO_2$ removal efficiencies than straight scrubbing, are also amenable to removing some of the $NO_x$ present in the flue gas, as well as some of the toxic metals, and have high removal rates for particulate matter. They are also easy to retrofit for carbon injection, for the control of mercury emissions.

Petroleum Refineries

$SO_2$ emission rates averaged over the entire U.S. refining sector for the year 1990 were about 40 g/barrel of products (STAPPA/ALAPCO, June 1996). Canadian numbers should be similar.

A large portion of the $SO_2$ emitted by petroleum refineries comes from theburning of high sulphur heavy oils in a multitude of heaters and boilers. As in the case of electric utilities, more than 95% of the sulphur present in the fuel ends up as $SO_2$, with the balance split between $SO_3$ and particulate sulphate. The simplest method to reduce fuel-related $SO_2$ emissions, where feasible, is fuel switching.

Another cause of $SO_2$ emissions is the refining process itself. Several operations that may release large amounts of $SO_2$ are, for example, asphalt blowing, fluid catalytic cracking regeneration, Claus units, etc. For many of these sources, scrubbing with an alkaline solution is the preferred method of treatment. Removal efficiencies of 93%-98% are common for such pollution control operations and, as an added benefit, particulate matter may also be removed at similar rates.

Other small point sources

Many other small point sources contribute to the burden of the airshed in which they are located and, for urban agglomerations, this contribution may become significant. End-of-pipe controls may not be cost effective for most small point sources. Fuel switching, mostly to natural gas, which has almost no sulphur content, is the preferred method of control. For boilers operated on liquid fuels, regulations may establish limits on sulphur in fuel. For example, the Boilers Regulation (R.R.O. 1990, Reg. 338) limits the content of sulphur in fuel to a maximum of 1% for all fossil fuel fired boilers, and the Sulphur Content of Fuels Regulation (R.R.O. 1990, Reg. 361) catches all small boilers used in comfort heating in the Municipality of Metropolitan Toronto (for details, see section II.2.4).

### *III.6.3.2 Area and Mobile Sources*

Transportation Sources

The total amount of $SO_2$ emitted by transportation sources is not as large as that of some of the point sources discussed above but the emissions are of particular concern because of their widespread release in urban areas. Essentially, all the sulphur present in the fuel leaves the tail pipe as $SO_2$ The main control method by which such emissions could be lowered is the reduction of the sulphur content of the fuels.

The average sulphur content of the fuels used in transportation in Canada was estimated at 300 ppm (by weight) for gasoline and 2200 ppm (by weight) for diesel fuel (VHB et al., 1991). At present, the average concentration of sulphur in Ontario gasoline exceeds 500 ppm (by weight). It was estimated that to reduce this concentration to 30 ppm would entail a cost of 1.31 cents/litre (Kilborn, 1997). Were such a level achieved, mathematical models predict a reduction of sulphate and $SO_2$ levels in Toronto of 8% and 30%, respectively, from currently observed levels.

To reduce the levels of sulphur in diesel fuel to 50 ppm would cost an estimated 2.67 cents/litre (Kilborn, 1997).

US EPA estimated that 20 to 40% reductions in particulate matter emissions could be achieved by limiting the sulphur in diesel fuel to 500 ppm (by weight), at a cost of 1.8 to 2.3 cents per gallon (US EPA, 1991).

Advanced technology vehicles, using electric batteries and fuel cells, promise essentially zero emission levels. However, for battery-powered electric vehicles, increased emissions from power generating plants would have to be taken into consideration when estimating overall emission inventories.

Other $SO_2$ emission reduction alternatives include measures that would result in a reduction in the total number of kilometer driven i.e., increased public transit, work-at-home programs, lifestyle changes, etc.

Residential and Industrial Combustion

Like transportation, residential combustion is important not only because of its high total emission but also because the emissions are concentrated in urban areas. In this context we are mostly concerned with the use of fuel oils consumed in individual home furnaces. Industrial combustion, to the extent that it takes place in the light industry present in urban areas, adds to the burden received by their airshed.

Since essentially all the sulphur present in the fuel will end up as $SO_2$ in the flue gas, the main control method by which such emissions could be lowered is by lowering the sulphur content of the fuels i.e., fuel switching. Other alternatives include measures that would result in a reduction in total fuel consumption, like advanced insulation of homes, high efficiency furnaces, and high efficiency industrial processes.

### III.6.4 $NO_x$ Removal Technologies

Nitrogen oxides ($NO_x$) figure prominently among the precursors of fine particulate matter (RP fraction) because of several reaction mechanisms. On theone hand, oxidation to nitric acid and its reaction with inorganic substances leads to the creation of nitrates. On the other hand, reactions of volatile organic substances with (and mediated by) nitrogen oxides provide a critical path for the formation of organic aerosols. Therefore, the importance of $NO_x$ is greater than what would be indicated by their atmospheric tonnage release alone.

Table III.1.2 (Section III.1) ranks the major known emitters of $NO_x$ in the province according to their magnitude. The most important will be discussed individually. Before such discussion though, it would be useful to show how $NO_x$ are generated. Three mechanisms are responsible for the apparition of $NO_x$ in the flue gas of any combustion process. They should be looked at separately because some of the control technologies only address $NO_x$ generated by one mechanism.

*Thermal NO$_x$* is the result of a reaction between molecular nitrogen and oxygen present in the combustion air. This reaction is mediated by oxygen and hydroxyl radicals. It proceeds rapidly at temperatures above $1400^0$C, up to $2000^0$C. The conversion rate is directly proportional to the residence time at the high temperature. Optimum stoichiometric ratio also has a positive influence on the equilibrium curve. A 30% change in the stoichiometry (either towards a rich or lean mixture) can lower the resulting concentration by up to two orders of magnitude, as Figure III.6.1 shows. Thermal NO$_x$ is the largest part of NO$_x$ present in the flue gas and the easiest one to control with process modifications.

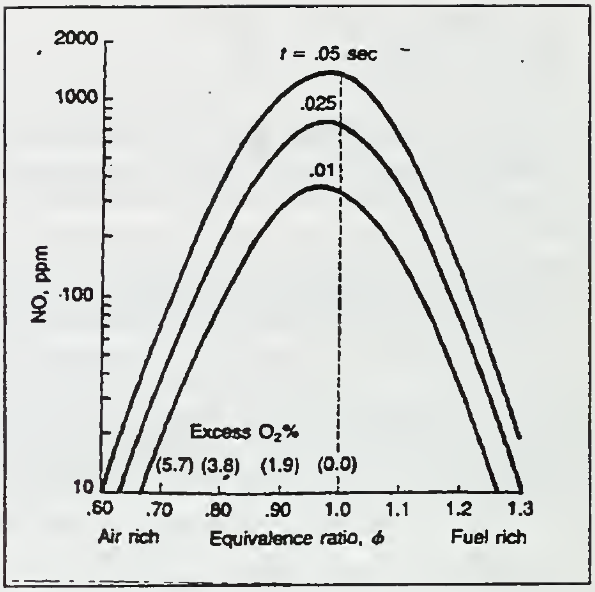

Figure III.6.1
NO versus Stoichiometry and Residence Time (air preheat=$350^0$C).
(Air Pollution Control Manual, 1992, p.217)

*Fuel NO$_x$* is formed by reactions between nitrogen chemically bound in the fuel and oxygen in the combustion air. While fossil fuels have relatively low concentration of nitrogen (0.5%-2.0% in coal and 0.1%-0.5% in oil) compared with that in the combustion air, the fuel bound nitrogen is highly reactive and 30 - 70% of it may be converted into NO$_x$. This NO$_x$ is often removed with end-of-pipe emission controls.

*Prompt NO$_x$* is a minor part of NO$_x$ emissions, resulting from the molecular nitrogen in the combustion zone, in a mechanismmediated by free hydrocarbon radicals available from the fuel. It may be controlled by some process modifications.

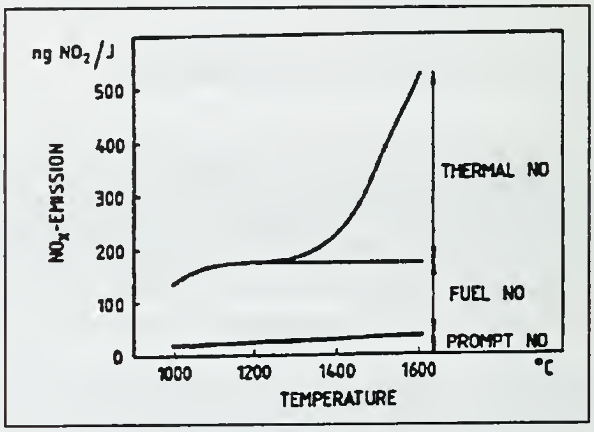

Figure III.6.2
Distribution of Formation of NO between Different Mechanisms when Burning Coal. (Air Pollution Control Manual, 1992, p. 217)

The distribution between the three forms of nitrogen oxide forms depends on the exact fuel composition, combustion zone design, and stoichiometric ratio between fuel and air. Figure III.6.2 shows a typical distribution for coal firing: *prompt NO$_x$* accounts for less than 5% of the total, *fuel NO$_x$* accounts for roughly one third, *thermal NO$_x$* being the remainder . Residual oil combustion produces a higher fraction of *fuel NO$_x$* (up to 50% of the total) than light fuel oils, with solid fuels having the highest *thermal NO$_x$/fuel NO$_x$* ratio. This should be remembered when discussing combustion modifications, one of the preferred methods of control, because the ratio of *thermal* to *fuel NO$_x$*

sets the ceiling for the efficiency of these control methods; *fuel NO$_x$* is largely unaffected by combustion modifications, while *thermal NO$_x$* is independent of the nitrogen content of the fuel.

### *III.6.4.1 Point Sources*

#### Electric Utilities

Electric utilities use a variety of boilers where fossil fuels are burned to free their chemically bound energy, which is then transformed into electricity using a steam cycle. As discussed above, the combustion process generates significant amounts of nitrogen oxides. These oxides consist mostly of NO, with only small amounts of $NO_2$ (approximately 5%) and traces of $N_2O$.

Control technologies for NO$_x$ from combustion processes can be divided into two large classes: (1) combustion control methods, in which operating conditions are modified to reduce the formation of NO$_x$; and (2) post-combustion control methods, in which NO$_x$ is removed at the end of the pipe, after its formation.

#### (1) Combustion Control Methods

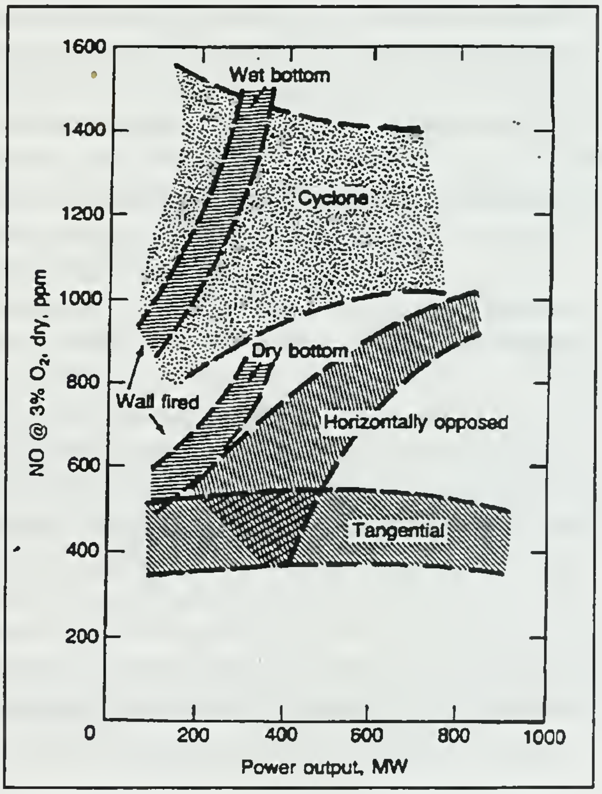

Figure III.6.3
Uncontrolled NO Concentrations for Types of Coal-Fired Boilers. (Air Pollution Control Manual, 1992, p. 216)

Because of the wide variety of boiler designs and operating conditions, the concentration of NO in the flue gas may vary dramatically. Figure III.6.3 shows typical ranges of uncontrolled NO in a variety of coal-fired boilers. This variation is mostly on account of the amount of *thermal NO$_x$* formed. Combustion conditions, and the relative ratio of the various flavours of NO$_x$, change over the operating range of the boiler. This explains why combustion control methods have efficiencies quoted over a wide range.

The underlying concepts of combustion modifications are: reduction of the peak flame temperature, reduction of the gas residence time in the high-temperature zone, operation under fuel rich conditions in the primary flame zone, and low overall excess air.

The main components of a combustion control program include the installation of low NO$_x$ burners (LNB) and the redistribution of the combustion air using over-fire air (OFA) registers.

Results have shown that conventional OFA systems can achieve 30% $NO_x$ reduction by staging 10-20% of the combustion air; advanced OFA can go even higher. LNB and OFA together have been shown to achieve 50% $NO_x$ reduction or better. 1991 estimated capital costs for OFA alone are between 5 and 10 $/kW, with LNB with OFA in the 15 to 25 $/kW (US dollars) range (Eskinazi, 1991). The operating costs are negligible.

Other combustion control methods, involving reburning (i.e., the injection of 5-20% of the fuel in a second combustion zone, maintained at a sub-stoichiometric air ratio, followed by OFA), are less widespread and have relatively lower $NO_x$ reduction capabilities. The capital costs for reburning have been estimated at 35-45 $/kW (US dollars) with operating costs of 2-6 mills/kWh (Eskinazi, 1991), a function mostly of the type of reburn fuel used.

### (2) Post-combustion Control Methods

$NO_x$ removal is difficult because NO, the main component of $NO_x$, is a substance with low reactivity. All widely used post-combustion control methods rely on reduction reactions leading to molecular nitrogen and water. The reducing agent is usually ammonia or a derivative (e.g.: urea). One of the drawbacks of all the reduction reactions is that some of the ammonia will remain unreacted. This slip contributes to the formation of fine particles in the atmosphere. To minimize ammonia slip, its use is always kept at a slight sub-stoichiometric ratio.

Direct reduction, referred to in the literature as *selective non-catalytic reduction* (SNCR), takes place in a relatively narrow temperature range (900-1100$^{0}$C), which places the injection point within the furnace. The method is suitable for boilers that operate in a constant load regime. It is able to achieve between 30% and 70% $NO_x$ reduction at capital costs of 10 to 20 $/kW (US dollars) (Eskinazi, 1991). No reliable documented operating costs were found.

The most developed and widely used post-combustion control technology is *selective catalytic reduction* (SCR). The use of a catalyst for the same ammonia reduction reaction quoted above allows the temperature to be decreased to a 300-400$^{0}$C range. This allows the reactor to be placed outside the boiler; in typical power plants it goes upstream of the air heater. $NO_x$ reduction efficiencies of 60-90% are easily achieved at retrofit capital costs of 75-150 $/kW (US dollars), with levelized operating costs of 5-9 mills/kWh (Eskinazi, 1991).

New generating methods, using integrated gasification combined cycle (IGCC), or renewable resources (e.g., geothermal, wind power, solar, etc.), hold the promise of significantly reduced or no emissions associated with electricity generation.

### All Other Point Sources

$NO_x$ emissions from manufacturing comes largely from combustion processes. To the extent that these emissions can be controlled, the same solutions discussed under Electric Utilities apply. The order in which one would expect to see them implemented would be: process modifications (to make them more energy efficient), fuel switching, combustion modifications (mostly LNB with some flue gas recirculation), post-combustion controls.

### *III.6.4.2 Area and Mobile Sources*

#### Transportation

$NO_x$ emissions from transportation sources come as a by-product of fuel combustion. Because of intrinsic differences between gasoline and diesel engines, the latter emit higher amounts of $NO_x$ expressed as mass per unit heat input, than the former.

The main control method for all transportation sources is the manufacture of cars with engine and combustion control devices that minimize the production of $NO_x$ in the first place. Such controls rely on advanced engine design and on the use of a catalyst known as *three-way type*. Such catalysts are active on both hydrocarbons and CO, released when burning rich mixtures in the engine, as well as $NO_x$, released when burning lean mixtures. For their optimum performance, such catalysts rely on electronic combustion controls which monitor the stoichiometry of the mixture at all times. In actual operation, the sensors cause a rapid cycling between slightly lean and slightly rich combustion, in order to achieve the reduction of $NO_x$ generated during lean combustion intervals by reducing agents generated during rich combustion intervals. The reactions proceed uniformly because the catalyst adsorbs on its surface some of the substances released during one cycle, making them available during the next. These new catalysts are more sensitive to poisoning than older types. One of the poisons is sulphur. This is why the introduction of low emission vehicles, which rely on the use of such catalysts, is predicated upon the wide availability of low sulphur gasoline.

In April 1997, US EPA proposed lowering the emission levels of new automobiles by setting the so-called Tier 2 standards, which would come into force beginning with the 2003 model year and be fully phased-in by model year 2006 (US EPA, 1997). It is expected that the reductions will also be observed in Canada. The standards are still under discussionand the final numbers will have to be modified to reflect some of the lower emissions achieved by the Low Emission Vehicles (LEV) that are already being introduced into the North American markets as a result of low emission standards mandated by California.

Table III.6.2 shows the proposed reduced emissions under Tier 2 standards. They are compared with those of phase 1 (or Tier 1) standards - Tier 1 standards were phased-in between 1994 and 1997 model years - and currently achievable LEV. These emissions reflect the use of low sulphur gasoline.

**Table III.6.2: Exhaust Emission Certification Standards (Federal Test Procedure) and Sales for Light-Duty Vehicles and Trucks in USA**

| | EPA Tier 1 Standards (@160,000 km) | | | EPA Tier 2 Standards (@160,000 km) | | | LEV Standards (@160,000/190,000 km) | | | New vehicle sales in 1996 (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| | NMHC (g/mile) | CO (g/mile) | $NO_x$ (g/mile) | NMHC (g/mile) | CO (g/mile) | $NO_x$ (g/mile) | NMOG (g/mile) | CO (g/mile) | $NO_x$ (g/mile) | |
| **LDV** | 0.31 | 4.2 | 0.6 | 0.125 | 1.7 | 0.2 | 0.09 | 4.2 | 0.3 | 60 |
| **LDT1** | 0.31 | 4.2 | 0.6 | 0.125 | 1.7 | 0.2 | 0.09 | 4.2 | 0.3 | 6 |
| **LDT2** | 0.40 | 5.5 | 0.97 | - | - | - | 0.13 | 5.5 | 0.5 | 25 |
| **LDT3** | 0.46 | 6.4 | 0.98 | - | - | - | 0.23 | 6.4 | 0.6 | 2 |
| **LDT4** | 0.56 | 7.3 | 1.53 | - | - | - | 0.28 | 7.3 | 0.9 | 7 |

where:
NMHC- non methane hydrocarbons
NMOG - non methane organic gases
LDV - all passenger cars
LDT1 - vehicles with a Gross Vehicle Weight Rating (GVWR) of 0 - 6,000 lb, Loaded Vehicle Weight (LVW) 0 - 3,750 lb
LDT2 - GVWR 0 - 6,000 lb, LVW 3,751 - 5750 lb
LDT3 - GVWR 6,001 - 8,500 lb, Adjusted Loaded Vehicle Weight (ALVW) 0 - 5750 lb
LDT4 - GVWR 6,001 - 8,500 lb, ALVW 5751 - 8500 lb
VCW - Vehicle Curb Weight - Vehicle with tank full and components included but no passenger or luggage
LVW - Loaded Vehicle Weight - Vehicle curb weight plus 300 lbs
GVWR - Maximum design loaded weight of a single vehicle
ALVW - ALVW = (GVWR + VCW) / 2

EPA is also working on a proposal for a set of limits expected to come out soon, known as Tier 3 standards, intended for diesel engines. Diesel fuelled road vehicles and air, marine, and rail engines account for about 55% and 15%, respectively, of $NO_x$ emissions from transportation sources (VHB Research & Consulting et al., 1991).

In addition to standard setting, emissions from transportation can also be reduced by preventive-type actions, such as Inspection and Maintenance Programs. According to Hickling (1995), a 100% compliance with each vehicle's performance standard would reduce $NO_x$ emissions by 10% and VOCs by 24%.

Engine rebuilding can make use of the most recent developments in the field. The use of ceramic engine coatings (applied on piston crowns and valves), in conjunction with injection timing retardation (approx. $4^0$) and oxidation catalyst have beenshown to lead to over 40% reductions in $NO_x$ (without any accompanying PM emissions and no increase in fuel consumption) for heavy diesel engines (STAPPA/ALAPCO, June 1996).

Reduction in travel demand is yet another way in which emissions from mobile sources could be reduced. Hickling (1995) considered two actions for reducing emissions of $NO_x$ and VOCs: improvements in traffic management,and shifts in the transit mode split. Based on the estimate for transportation control measures adopted by the Bay Area Air Quality Management District in 1991, the first action predicted a 2% reduction in the $NO_x$ and VOC emissions at costs of 57,000 $/t removed and 59,000 $/t removed, for $NO_x$ and VOCs, respectively.

### III.6.5 Particulate Matter Removal Technologies

Removal technologies for particulate matter depend on the type of sources considered. Most stationary sources would first attempt process modifications that would eliminate the fine particles as a contaminant of their gaseous effluent streams. Such process modifications are highly source and process specific and no general solution, or range of costs, exists.

If fine particles are an inherent part of the manufacturing process, as in milling, attention is directed towards enclosure of the process, in order to minimize fugitive emissions, and toward the treatment of the concentrated gaseous effluent carrying-over the particulate matter entrained. In such cases, a relatively limited number of end-of-pipe solutions: baghouses, electrostatic precipitators, scrubbers, are applied across the board. The selection is made mostly based on the properties of the particles and the intended use of the collected material. The cost of application of such end-of-pipe technologies is fairly constant, regardless of the specifics of the installation (see Figure III.6.4 for capital costs of baghouses and electrostatic precipitators). Project costs though, vary widely because the control equipment may represent anywhere from 20% to 80% of the total cost of the solution, and is a function of the specific details of the installation.

Table III.1.1 (Section III.1) shows major known emitters of particulate matter in Ontario. Some types of sources will be discussed in detail, according to the magnitude of their emissions and the ease of control (i.e., release from a few concentrated sources vs. release from many small dispersed sources). The most important technologies will also be discussed in detail.

### *III.6.5.1 Point Sources*

Industrial point sources are relatively easy to address, as long as the release into the atmosphere takes place through relatively few stacks with concentrated streams. In this case, if process modifications cannot eliminate or alleviate the release, end-of-pipe add-ons are a clear choice.

#### Electric Utilities

The process responsible for the generation of fine particulate matter in electric utilities is the combustion of fossil fuels in large boilers. Such combustion processes are responsible for similar emissions from many other point sources. For ease of treatment, they will all be discussed here. It is important to note though that end-of-pipe controls used for very large boilers remove particulate matter at a much lower cost per tonne removed then when applied to smaller sources. In many cases, their application to small sources may be entirely unfeasible.

Smaller boilers have usually only one solution for lowering their PM emissions: fuel switching. Among the various fossil fuels, coal releases much larger amounts of fine particles, per unit of heat input, than oil. Natural gas is the cleanest fuel and does not require any end-of-pipe particulate matter controls. Emissions and controls when burning wood will be discussed under Area Sources - Residential Combustion.

There is little that can be done to reduce particulate matter emissions from large boilers by process modifications other than fuel switching. While different types of boilers have different uncontrolled emission rates, the selection of the type of boiler is based on the particular kind of fuel available and its properties (e.g.: ash content and chemical composition), rather than its particulate matter emission levels. One operating parameter that leads to increased emissions, namely flyash reinjection, used in the cases where unburnt coal in ash represents a major financial loss, has such good economics on its side, that operators find the payback attractive even after factoring in the cost of adding advanced dust control equipment.

The main kinds of technologies used to remove the fine ashes generated by coal combustion in utility-size boilers are end-of-pipe controls: baghouses and electrostatic precipitators. They are both capable of 99.9+% removal capacities but usual designs are somewhat lower. The capital cost of either device is a function of its collection efficiency. As shown in Figure III.6.4, below a 98% control level, the ESP is favoured; above 99.7%, the baghouse has an edge. This particular example is based on a specific type of coal and various other situations may lead to slightly different results. Baghouses may also be preferred in some situations because of their suitability to being used together with other gas cleaning technologies (e.g., injection of activated carbon for the control of mercury).

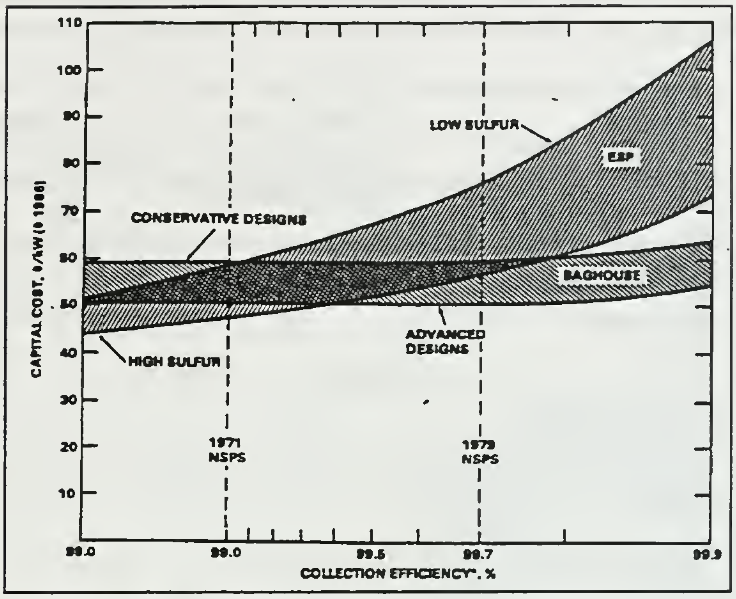

Figure III.6.4
Capital Cost versus Collection Efficiency (based on a 10,000 BTU/lb coal with 10% ash).
1971 NSPS is 0.1 and 1979 NSPS is 0.03 (lb/MMBTU)
(Air Pollution Engineering Manual, 1992, p. 221)

## Iron and Steel Production

Much of the particulate matter emitted from sources in the steel industry is fairly coarse. This means that local effects from such sources are likely to be significant but there is little carry-over by wind to distant receptors.

Major operating steps in the steel industry include the iron ore agglomeration, the processing into molten metal in the blast furnace, the making of steel from molten metal in basic oxygen furnaces and electric arc furnaces. Ancillary processes include coke making and limestone and sand crushing/handling. Some facilities have a significant degree of ladle metal processing, where the composition and temperature of molten steel is further adjusted before casting.

Major point sources, their typical level of uncontrolled emissions and the relative size of the particles emitted (Air CHIEF 5.0) and the best control alternatives (Air Pollution Engineering Manual, 1992, Chapter 14) are summarized in Table III.6.3.

**Table III.6.3: Average Emission Factors, Particle Size Distribution, and Preferred Control Technologies for the Iron and Steel Industry.**

| Source | Emission rate (uncontrolled) (g/kg product) | % at cumulative size less than: | | Control device | Efficiency (%) |
|---|---|---|---|---|---|
| | | 10 $\mu$m | 2.5 $\mu$m | | |
| Ore sintering - windbox | 5.5 | 15 | 5 | ESP, scrubber, baghouse | 95-99+ |
| Ore sintering - discharge end | 3.4 | 32* | 11* | Scrubber, baghouse | 90-99 |
| Blast furnace - slip | 40 | - | - | none | |
| Basic Oxygen Furnace | 14 | 45* | 22* | Scrubber, ESP | 99 |
| Electric Arc Furnace | 19-25 | 58 | 43 | Scrubber, ESP, or baghouse | 99+ |

*) - Particle size information applies to the treated effluent stream.

### Pulp and Paper

The pulp and paper industry is responsible for significant emissions of particulate matter but the location of the plants is often remote from large populated centers. Insofar as some of the sources specific to this industry (i.e., those involving wood combustion) release very fine particles, atmospheric transport may carry such particles considerable distances from the source.

In terms of particulate matter emissions, among the different pulping alternatives, mechanical pulping is much cleaner than chemical pulping. Between the two chemical methods of pulping, i.e. sulphate and sulphite (that, in turn, can be carried out under neutral or acidic conditions) the former, also known under the name of *kraft pulping*, is responsible for most of the production and most of the emissions. This process will be examined more closely.

The first step in the kraft process is carried out in digesters where wood chips are cooked in a sodium hydroxide/sodium sulphide solution called *white liquor*, which dissolves the lignin; the spent solution contains $Na_2SO_4$, is black in colour, and known as *black liquor*. The organics in the concentrated *black liquor* are used as fuel in large recovery furnaces that generate the steam used in the process; the inorganic salts produce a smelt of sodium carbonate/sodium sulphide. The hot smelt is quenched with water and the resulting *green liquor* is then treated with quick lime (generated on site by calcining calcium carbonate in lime kilns), regenerating the *white liquor* and a calcium carbonate mud. Table III.6.4 summarizes the characteristics of the main release sources from this colourful process (Air Pollution Engineering Manual, 1992, Chapter 18) (Air CHIEF 5.0).

**Table III.6.4: Average Emission Factors, Particle Size Distribution and Preferred Control Technologies for Kraft Pulping**

| **Source** | **Emission rate (uncontrolled) (g/kg pulp)** | **% at cumulative size less than:** | | **Control device** | **Efficiency (%)** |
|---|---|---|---|---|---|
| | | **10 $\mu$m** | **2.5 $\mu$m** | | |
| Recovery furnace | 320 | 90 | 80 | Wet ESP | 90-98 |
| Lime kiln | 23 | 17 | 11 | Scrubber or ESP | 90-95 |
| Smelt-dissolving tank | 3.5 | 89 | 73 | Scrubber | 85-95 |

### *III.6.5.2 Area and Mobile Sources*

Transportation

Particles emitted from vehicles result from incomplete combustion of the fuel. Between gasoline and diesel, the former produces insignificant amounts of particulate matter compared with the latter. It was noted previously, though, that both fuels produce significant amounts of precursors to fine particles (i.e., $SO_2$, $NO_x$, and VOCs). In addition to the reduction expected from better engine design mandated through regulatory steps discussed earlier (in section III.6.4.2), some post-combustion control technologies may be applied to existing engines.

Diesel particles consist of approximately 65% to 80% carbon (soot), 10% to 20% sulphates, and polycyclic aromatic hydrocarbons (PAHs) (VHB Research & Consulting et al., 1991). Trap oxidizers are (ceramic or metallic) add-on filters that have 60% to 90+% efficiency in removing such particles. Since the regeneration of the filters is done by burning-off the deposits, and the exhaust temperature of the engines is not high enough to initiate this process such filtersare often installed together with electric heaters as part of engine rebuild/maintenance programs. These filters may cause the engines to incur a small (i.e., 1% to 1.5%) fuel economy penalty.

Some of the costs associated with reductions in PM emissions from vehicles, as estimated by EPA, (STAPPA/ALAPCO, June 1996) are:

a) for heavy duty engines, moving from 0.6 g/bhp-hr (model year 1988-90 standards)to 0.1 g/bhp-hr (model years 1994 and later) - $ 296 to $394 (in 1994 US dollars) per vehicle;

b) for additional reduction from 0.1 to 0.05 g/bhp-hr, urban busses would incur an additional cost of US$ 1,650 per vehicle.

California Air Resources Board has estimated the following costs to reduce PM from two types of diesel engines (STAPPA/ALAPCO, June 1996):

a) 20% reduction in marine diesel PM emissions would cost between 220 and 18,000 $/ton removed (1991 dollars) if accompanying $NO_x$ is also reduced;

b) 50% reduction in PM emissions accompanied by an 80% reduction in $NO_x$ from locomotives would cost between 858 and 14,688 $/ton removed (1994 dollars).

Significant reductions of emissions of particulate matter generated by transportation, through the mechanical actions that lead to the fragmentation and reentrainment of particles deposited on paved road beds, are achieved with the implementation of regular road sweeping programs. Spraying of unpaved roads has similar good effects.

## Wood Combustion - Residential

Residential wood combustion takes place in wood stoves and fireplaces and is responsible for significant emissions of essentially respirable particulate matter. While better designs and some post-combustion treatment may reduce emissions somewhat, most experts agree that banning wood combustion in populated areas may be the only sensible solution.

### (1) Wood stoves

Wood stoves are enclosed wood heaters that control burning or burn time by restricting the amount of air that can be used for combustion; they are commonly used in residences as space heaters. Wood stoves may be used both as the primary source of residential heat and to supplement conventional heating systems. Based on variations in construction, combustion, and emission characteristics, there are five different categories of residential wood stoves: (1) the conventional wood stove; (2) the non-catalytic wood stove; (3) the catalytic wood stove; (4) the pellet stove; (5) the masonry heater.

Stoves in category (1) have no emission reduction technology. Stoves in category (2) may have baffles or secondary combustion chambers.

Catalytic stoves are equipped with a ceramic or metal honeycomb structure coated with a noble metal. The catalyst reduces the ignition temperature and enhances the combustion of volatile organic compounds (VOC) at normal stove operating temperature.

Pellet stoves are designed to use pellets of sawdust, wood products, and other biomass materials. In the US, such stoves are subject to emission limits established by the (1988) New Source Performance Standards (NSPS).

Masonry heaters are large enclosures made of ceramic and masonry products destined to burn a large load of fuel cleanly in a relatively short time and radiate the heat absorbed by the structure. Most of the masonry heaters are exempt from the 1988 NSPS by virtue of their size (i.e., they are heavier than 1,764 lb).

Emissions from wood stoves vary greatly, depending on the type of stove and the time during the burning cycle. Initially, when the charge is introduced, there is a period of high burn rate accompanied by very high emissions. During later stages, the emissions become cyclical, i.e., long periods of low emissions followed by short spikes.

Emissions of $PM_{10}$ from the first three categories of wood stoves vary from 15.3 to 12.1 mg per kg of fuel (Air CHIEF 5.0). No data are available for the other categories. It should be noted that condensed organic products of incomplete combustion form the vast majority of $PM_{10}$ emissions. Rau and Huntzicker (1984) report that 95% of such particles are less than 0.4 $\mu$m in size (aerodynamic diameter). It is known that wood combustion is a major anthropogenic source of polycyclic aromatic hydrocarbons in the atmosphere.

### (2) Residential fireplaces

Fireplaces are used primarily for aesthetic effects and secondarily as supplemental heating sources in houses and other dwellings. Wood is the most common fuel for fireplaces, but coal and "densified wood logs" may also be burned.

Fireplaces can be divided into 2 broad categories:

(1) masonry (generally brick and/or stone, assembled on site, and integral to a structure) and

(2) prefabricated (usually metal, installed on site as a package with appropriate duct work).

Masonry fireplaces have large fixed openings above the fire bed and have dampers in the chimney to limit room air and heat losses when the fireplace is not being used. Some are designed or retrofitted with doors to reduce the intake of combustion air during use.

Prefabricated fireplaces are commonly equipped with louvers and glass doors to reduce the intake of combustion air, and some are surrounded by ducts through which floor level air is drawn in, by natural convection, heated, and returned to the room. Some of these units have operating and combustion characteristics similar to wood stoves.

Masonry fireplaces usually heat a room by radiation, with a significant fraction of the combustion heat lost in the exhaust gases and through fireplace walls. Moreover, some of the radiant heat entering the room goes toward warming the air that is pulled into the residence to make up for that drawn up the chimney. The net effect is that masonry fireplaces are usually inefficient heating devices. Indeed, in cases where combustion is poor, where the outside air is cold, or where the fire is allowed to smolder (thus drawing air into a residence without producing appreciable radiant heat energy), a net heat loss may occur in a residence using a fireplace.

Fireplace emissions, caused mainly by incomplete combustion, include particulate matter (mainly $PM_{10}$), carbon monoxide (CO), volatile organic compounds (VOC), and some sulfur oxides ($SO_x$) and nitrogen oxides ($NO_x$). Significant quantities of unburnt combustibles are produced because fireplaces are inefficient combustion devices, with high uncontrolled excess air rates and without any sort of secondary combustion. The latter is especially important in wood burning because of its high volatile matter content, typically 80 percent by dry weight.

It should be noted that fireplaces are also a source of $N_2O$, a greenhouse gas. Although no test data are available, it is assumed that $N_2O$ emissions from residential fireplaces are significantly higher than either wood stoves or commercial wood-fired boilers because of the combination of low combustion temperatures and high amounts of excess air.

Fireplace emissions are highly variable and are a function of many wood characteristics and operating practices. In general, conditions which promote a fast burn rate and a higher flame intensity enhance secondary combustion and thereby lower emissions. Conversely, higher emissions will result from a slow burn rate and a lower flame intensity. Such generalizations apply particularly to the earlier stages of the burning cycle, when significant quantities of combustible volatile matter are being driven out of the wood. Later in the burning cycle, when all volatile matter has been driven out of the wood, the charcoal that remains burns with relatively low emissions.

In order to decrease PM and CO emissions from fireplaces, combustion must be improved. Combustion efficiency improves as burn rate and flame intensity increase. Non-catalytic fireplace inserts reduce emissions by directing unburned hydrocarbons and CO into an insulated secondary chamber, where mixing with fresh, preheated makeup air occurs and combustion is enhanced.

Typically, emissions of $PM_{10}$ and VOC from fireplaces amount to 17.3 mg/kg of dry fuel and 115 mg/kg of dry fuel, respectively (Air CHIEF 5.0).

### III.6.6 VOC Removal Technologies

While the acronym VOC stands for volatile organic compounds, in the context of this chapter the definition is somewhat stretched. Gaseous hydrocarbons of small molecular mass are not particulate matter but are looked at herein because they may be involved in complex chain reactions that lead to the formation of particles from other contaminants, e.g., $NO_x$. Organic molecules with higher molecular mass may lead directly to the formation of aerosols (see section III.3). Incomplete combustion processes generate substances of still higher molecular mass that will condense upon cooling down, or unburnt particles of fuel leaving with the flue gas.

Removal technologies for VOC depend on the type of sources considered. Table III.1.2 shows major known emitters of VOC in the province. Some source types will be discussed according to their magnitude and ease of control (i.e., releases from few concentrated sources vs. releases from many small dispersed sources). The most important technologies will be discussed in detail.

### *III.6.6.1 Point Sources*

This category includes both many small individual sources that are similar, and therefore grouped together, either stationary (e.g., residential combustion) or mobile (e.g., vehicles), and several larger stack-type sources.

#### Petroleum Refineries

Emissions of VOCs from petroleum refineries come froma variety of sources. Some are confined to stacks and are therefore amenable to end-of-pipe control technologies. Many others are fugitive and their reduction relies less on control devices and more on maintenance-type measures. They are summarized in the table below, based on VHB (1989) data.

**Table III.6.5: VOC Control Technologies Applicable to Petroleum Refineries**

| Process | Type of source | Control efficiency (%) | Equipment life (years) |
|---|---|---|---|
| Thermal incineration | Stack | 99+ | 12.5 |
| Catalytic incineration | Stack | 90-99 | 10[1)] |
| Flare | Stack | 80-99 | 20 |
| Carbon adsorption | Stack | 99 | 12.5[2)] |
| Floating roofs | Tanks | 75 | 40 |
| Inspection and maintenance | Flanges, valves, etc. | 40 | na |

[1)] - Catalyst life estimated at 5 years

[2)] - Carbon bed life estimated at 5 years

Most of the methods quoted above may be also be applied, with similar results, to VOC sources from other industrial sectors.

### *III.6.6.2 Area and Mobile Sources*

Area sources comprise a multitude of individual sources grouped by type. Many would use some of the same technologies highlighted under the previous subsection, while others may have to use special site-specific solutions.

### Transportation

Vehicles emit VOCs either as a result of incomplete combustion or at the time they are refuelled. The two types of emissions are very different in composition. What comes out of the combustion process contains heavy molecular mass condensible compounds. What is lost during refuelling is mostly short chain hydrocarbons that evaporate out of the gasoline.

Reductions in hydrocarbons emitted from combustion will be achieved as emission standards for new vehicles are ratcheted down and as the turnover in fleet takes place (see Table III.6.4 in Section III.6.4.2) .

Technologies applicable to emissions occurring during refuelling include vapor balancing and on-board controls. Vapour balancing refers to connections between the underground storage tank and the external reservoirs. Such balancing is known as StageI, when applied to the truck loading the underground tank, or Stage II, when applied between the underground tank and the automobile being fuelled. On-board controls refer to a carbon canister where gasoline vapours are adsorbed. For good functioning, this requires a good seal at the neck of the vehicle tank.

### Residential Combustion

Residential combustion is a major sourceof emissions of organic matter especially when the fuel is wood. Since most of the organic matter emitted is condensible, both wood stoves and fireplaces have been already discussed in the section addressing particulate matter emissions (Section III.6.5.2).

### Surface Coating

Surface coating operations are common in many industries and VOC emissions consist mainly of the vapour of the solvents used to dissolve the coating. Any such process, when uncontrolled, will emit essentially the entire amount of solvent. Because of the wide variety of processes, no individual description will be attempted here but several general reduction methods can be mentioned.

Solvent replacement falls in the general category of process modifications. Examples of such solutions include the use of water soluble formulations or solid state pigment applications (e.g. electrostatic coating). Such solutions reduce VOC emissions to practically zero.

Good engineering practices are often used in conjunction with emission control devices in the cases where solvent replacement is not feasible. In such cases, good process enclosure minimizes fugitive emissions. Solvents carried over by the process air stream may be recaptured for re-use by condensation or carbon adsorption. Residual amounts can be destroyed with an efficiency of 99+% by thermal or catalytic incineration.

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# IV ANALYSIS OF BENEFITS AND COSTS OF PARTICULATE MATTER EMISSION CONTROL SCENARIOS IN ONTARIO

## IV.1 Purpose

The purpose of this chapter is to present estimates of the costs of program scenarios that specify reductions in emissions of particulates and precursor pollutants such as volatile organic compounds (VOCs), nitrogen oxides ($NO_x$) and sulphur dioxide ($SO_2$). The benefits of associated reductions in ambient concentrations will be identified and, to the extent possible, quantified and valued in order to compare with the relevant costs.

The role and contribution of economic analyses for setting environmental standards is discussed in Section IV.2 below. The benefit-cost analysis framework that forms the basis for this exercise is summarized in Section IV.3. Abatement program scenarios are defined in Section IV.4. Program scenarios consist of two key elements: emissions reduction targets and implementation strategies. Scenarios and assumptions about abatement technologies are necessary to estimate the costs of controlling direct emissions of particulates and of precursor pollutants. Abatement cost functions are derived and economic implications of compliance costs are analyzed in Section IV.5. Tabular versions of these cost functions are displayed in Appendix C.

Methods to quantify and value public benefits of reducing exposures to fine particulate matter are introduced and applied with respect to human health effects in Section IV.6. Benefit estimates are based on the "roll-back" assumptions discussed in Section III.5. Finally, costs and benefits are summarized along with key findings and conclusions in Section IV.7.

## IV.2 Economic Evaluation of Environmental Standards and Programs

The key elements of an environmental protection strategy include 1) statutes, regulations and other *legal instruments* which authorize governments to act, and which codify objectives and requirements or specify rights and responsibilities; 2)*standards* or *guidelines* such as ambient quality standards, discharge/emission limits; 3)*monitoring* emissions and ambient quality concentrations, 4) *implementation incentives* such as prosecutions, fines, user charges or trading schemes which induce sources of pollutants and wastes to comply with standards and other requirements; 5) *research* on pollution effects and abatement (or prevention) technologies; and 6) *subsidies* and other forms of *financial assistance* intended to off-set large compliance costs.

Some strategies are intended to reduce or eliminate existing pollution problems such as direct emissions of particulate matter (PM10), $NO_x$ or $SO_2$. Other strategies are designed to prevent increases in emissions from new sources or expansions at existing sources which could cause future adverse environmental effects and damages.

In the context of the Ontario legislative framework, standards are enforceable with prosecutions while guidelines are not. Environmental standards and guidelines are derived by one of two approaches: *no-effects thresholds* or *technology limits*. The no-effects threshold approach involves setting ambient quality exposure thresholds or standards at levels below which there are no known adverse health or environmental effects. The technology limits approach involves determination of maximum allowable discharges or emissions release limits that could be achieved by the application of "best available (pollution abatement or prevention) technologies". Where compliance costs are high, financial effects on regulated firms may be assessed in order to judge whether standards or objectives are "economically achievable" (whether firms can or cannot afford the costs).

Both of these methods have crucial limitations. First of all, recent research has revealed that many contaminants, including PM$_{10}$ and PM$_{2.5}$, exhibit no ambient concentration thresholds above zero. That is, varying degrees of adverse human health and other effects are observed at any ambient exposure level above zero, although, at lower ambient concentrations, the certainty regarding the relationship between exposure and effects often diminishes. Moreover, as ambient contaminant levels are reduced, implementation costs usually increase at an increasing rate.

On the other hand, basing pollution release limits solely on best available pollution prevention and abatement technologies takes no account of environmental effects. Therefore, the standards derived from them may not adequately prevent damages to the environment or to people. Moreover, such standards may be subject to frequent revisions as "best available" technologies evolve and change over time. Furthermore, what is "best" is best in terms of removal efficiency may not be best in terms of cost-effectiveness or reliability.

The concentration threshold (no-effects) approach focuses on minimizing damages so as to ensure that human health and environmental damages are avoided and benefits are achieved but often ignores the costs of compliance and their economic implications. The best available technology approach concentrates on the technologies, their costs and the financial consequences of these costs but usually ignores the benefits of pollution abatement and protection.

Economic assessments allow for the explicit consideration and integration of both benefits and costs in evaluations of environmental standards and other policies. Two key types of economic assessment approaches can be applied to environmental policy development: cost analyses and benefit-cost comparisons.

Cost analyses consist of the development of *abatement cost functions* and comparisons of the *cost-effectiveness* of abatement or prevention at different pollution sources. Abatement cost functions show the costs and emissions that result from combinations of abatement or prevention technologies that achieve increasingly more stringent pollutant removals. Estimates of the cost per kilogram or tonne of pollutant reduced can be calculated from cost functions and used to determine which sources will yield the largest emission reductions per dollar spent. Cost estimates for various sources can be used to find the least-cost combination to achieve specific standards or objectives.

Abatement or prevention cost estimates can also be used to assess the financial and employment effects of proposed environmental standards and programs on companies and industrial sectors.

Of particular concern are effects on firms' profitability, productivity, competitiveness and employment. Companies in Canada which export a large proportion of their output are particularly concerned about cost competitiveness with offshore competitors who may not face the same degree of regulatory compliance costs. However, competitive pressures within and from without a country are healthy. They force firms to develop new ways of reducing production costs or new products which can command premium prices.

Abatement or protection costs vary widely from plant to plant. Furthermore, different levels of costs are imposed as the result of applying different environmental management or implementation strategies. For example, if all plants that generate $SO_2$ are required to reduce emissions by the same amount or proportion, overall costs will likely be higher than if sources with lower emission reduction costs were required to abate first. Similarly, if emission sources in communities where exposure levels are highest are targeted to abate, total costs will be lower than if all sources had to implement reductions.

Assessments of the distribution of abatement costs on firms and sectors and the effects these costs have on financial and economic indicators can suggest which companies or industrial representatives will likely object to proposed environmental requirements. However, assessments of the financial effects of abatement costs on firms do not provide a clear-cut basis for decisions about the level of abatement or expenditure to impose on emitters. On the other hand, there is wide agreement among economists that environmental protection efforts should be imposed so long as the value of incremental environmental benefits (including private benefits to firms that make these investments) exceeds the incremental costs of these efforts.

Where information is available,*benefit-cost analysis* is the most appropriate economic assessment method to determine whether specific standards or regulatory initiatives are economically justified. So long as the value of the potential benefits of achieving a specific ambient quality standard exceed the potential costs associated with implementing it, the proposed standard is deemed to be economically justified. This decision rule presumes the ability to sum and compare the value of benefits with costs, even if those enjoying benefits are different from those who incur the costs.

Economic analyses have been applied to all major issues and initiatives that the Ministry of the Environment has undertaken including acid rain, industrial water pollution, control of smog, solid waste management and recycling and global warming. Assessments of the financial effects of environmental orders and requirements on individual companies and municipalities have helped Ministry staff develop effective and fair compliance programs for these regulated parties. A *Framework for Economic Analysis* (Ontario Ministry of Environment and Energy, 1996) has been developed which presents procedures and information needs for carrying out benefit-cost assessments and other analytical techniques. A similar framework is available from the Canadian Council of Ministers of the Environment (1998).

## IV.3 A Benefit-cost Analysis Framework for Environmental Issues

Benefit-cost analysis is an analytical tool that has been used for many decades to evaluate public-sector investments, especially large water resource projects in North America. Economists have advanced the theoretical rigor of the technique over the past 20 years and have extended its application to a wide range of public policy questions, including environmental protection (Halvarsen and Ruby, 1981; Hufschmidt*et al.*, 1983; Desvousges and Smith, April 1983; Kneese and Schulze, 1985; Donnan, January 1986; Smith, 1988).

As noted, the primary intent of a benefit-cost analysis is to ensure that public funds and resources are directed at investments and activities whose value of benefits exceed, or at least equal, their costs. At the very least, benefit-cost analyses should help governments and public agencies to avoid investments and activities whose costs greatly exceed the value of benefits. In addition, benefit-cost analyses have been applied to rank potential projects according to the value of their net benefit, to compare and choose among policies or programs that achieve different types of objectives or to determine how much funding to devote to a given project (Krupnick, 1992).

Benefit-cost analyses are applied most often to evaluate the economic efficiency of a project or a program by ascertaining whether the value of all benefits to "gainers" are greater than the value of all costs and losses to "losers". If costs are greater than the value of all quantified benefits, the project or program may not be economically justified. However, if some potential benefits have been identified but cannot be quantified or monetized, there remains the suspicion that the true benefits are under-stated and that the project or program may, in fact, be economically justified. In these cases, the difference between costs and monetized benefits provides decision-makers with a “bench-mark” value to judge the worth of the unquantified and non-monetized benefits and to make more informed choices about costly programs and projects.

Many jurisdictions are convinced that the application of benefit-cost analyses can improve decision-making. The State of New York has embraced the technique as the primary method for evaluating regulatory policies and programs that impose large costs on regulated parties or the government (New York State, Governors's Office of Regulatory Reform, January 1996). The US EPA also applies benefit-cost assessments to various regulatory issues as permitted by law. In Ontario, explicit assessment and comparison of the benefits and costs of new regulatory actions are required by a *Regulatory Impact and Competitiveness Test* which was developed by the Ontario Red Tape Review Commission (Sept. 1997) and was endorsed by the Ontario Cabinet.

These agencies and practitioners argue that the application of benefit-cost analysis has the following advantages.

1) Benefit-cost analysis requires that proponents explicitly identify and link environmental protection benefits with the environmental protection actions that are being proposed.

2) The technique can be used to evaluate objectives established by the traditional approaches (i.e. "no-effects thresholds" or " best-available technology").

3) Results can indicate slight adjustments (more or less stringent) to be made in objectives or policies or provide information that can support such standards.

4) Benefit-cost analysis provides a framework for integrating relevant biophysical and economic data so that costs, benefits and other consequences of a program or project are made explicit and presented in a clear, comparable manner for stakeholder review.

5) Implications for trade-offs among different levels of costs and resulting consequences are made explicit.

6) Completing a detailed benefit-cost analysis often forces analysts to search out and evaluate a wider range of options and technologies that achieve desired benefits or objectives than would otherwise have been considered.

Economists who have applied benefit-cost analyses to environmental and workplace health and safety policy issues have identified operational limitations and other concerns about the way the technique has been applied in the past. Modifications and enhancements that have been recommended by practitioners to make the analytical technique more applicable to environmental issues are summarized in Donnan (January 1986; October 1996) and in the*Supporting Document for Toward a Smog Plan for Ontario* (Ontario Ministry of Environment and Energy, June 1996). The key steps in carrying out an ideal benefit-cost analysis designed to evaluate environmental initiatives or projects are summarized in Text Box 1 on page IV.7. These procedures include modifications that make the benefit-cost framework more suitable for evaluating environmental initiatives. One key step is to display relevant human health and environmental/ecological effects, consequences and benefits of control actions in quantitative, biophysical terms separately from estimates of the monetary values of these consequences. Quantification of environmental/ecological effects often requires a risk assessment of the pollutants or the environmental hazard of concern.

Another important objective of the benefit-cost analysis framework used by the Ministry is to determine the distribution of costs and benefits associated with each scenario among relevant stakeholders and to assess the effects of potential abatement costs on financial and economic indicators. The distributional dichotomy between sources of pollutants that incur abatement costs and those populations and receptors that enjoy the benefits of reduced exposure often constitute barriers to consensus and agreement. Compliance costs are often large, certain and imposed on a few, well-defined pollution sources. On the other hand, the benefits of pollution abatement tend to be uncertain and distributed over a much larger number of stakeholders. Consequently, even if individuals perceive environmental benefits, the value per person would be relatively small. Therefore, those who face abatement costs have proportionately large incentives to avoid them, where possible, and those who perceive environmental benefits often have a proportionately smaller incentive to obtain them.

An empirical (quantitative) economic assessment of potential environmental standards requires the formulation of specific environmental program scenarios, as well as base-case conditions.

Program scenarios and base-case conditions for this study are described below.

## IV.4 Scenarios for Analysis

Program scenarios defined for this analysis are made up of the following components.

1) Selected *aggregate emission reduction goals or targets* specified for each pollutant. For each contaminant, emission reduction goals are based on the following criteria:

    a. Lowest (Technically) Achievable Emission Rate given currently available technologies for which cost estimates can be generated.

    b. Province-wide, population weighted average percent reductions or "roll backs" in anthropogenic emissions, based on community-specific reductions in ambient concentrations needed to achieve potential concentration targets cited in Section III. (Table III.5.5), i.e. 60 µg/m3, 50 µg/m3 or 40 µg/m3. The percent changes in ambient concentrations to achieve these targets are 16%, 28% and 41% respectively. However, because about 5 µg/m3 is the background level, natural particulates which cannot be reduced by abatement methods, higher emission reductions are needed to achieve the desired ambient concentration reduction, i.e. 19%, 34% and 53% respectively.

2) *Implementation strategies* which specify which various sources (whether they be individual plants or groups of plants or sources) should abate and by how much. These strategies are used to define how to achieve the above-noted emission reduction goals. The following implementation strategies will be assessed for each pollutant parameter:

    a. An "efficiency strategy" where sources with the lowest cost per tonne (or highest financial return per tonne) removed would implement abatement first;

    b. An "abatement maximization strategy" whereby sources that can achieve the largest emission reductions implement abatement first,

    c. An "equal reduction strategy" by which all sources must abate by the same degree or amount (e.g. by percent reduction) if it is technically possible. This strategy is intended to ensure that reductions in ambient concentrations are achieved across the province as well as to "share the pain" of abatement costs among all emitters.

    d. A "community strategy" where only sources in specific communities (e.g. Toronto, Windsor, Hamilton, etc.) would implement abatement in order to address the proportion of the IP-RP problem that is due to urban industrial emissions.

## TEXT BOX 1
## STEPS IN AN IDEAL BENEFIT-COST ANALYSIS FOR ENVIRONMENTAL INITIATIVES

1. **Identify benefit categories and quantifiers** relevant to environmental issue or problem. Characterize the key features and nature of the environmental problem to help formulate effective programs and implementation strategies.

2. Define **Initial or Reference Conditions** or **Assumptions** relevant to the issue or problem, against which consequences of remedial actions can be compared.

3. Formulate **Environmental Standards Scenarios** which include pollutant reduction targets (i.e., emission loadings, ambient concentration levels, incidence of exceedences of concentration thresholds, etc.) and implementation strategies (i.e., requiring abatement at sources in certain sectors or locations before others, requiring all sources to abate in order to "share the pain" etc.). Estimates of current and future environmental effects associated with each scenario are generated. A base-case scenario which incorporates initial or reference conditions should be included. Develop forecasts of relevant effects variables under different conditions and assumptions in order to generate other scenarios of environmental programs or goals to be achieved.

4. Postulate potential pollution abatement, pollution prevention, cleanup or remediation technologies or combinations of technologies that would move toward or achieve potential standards or program goals and which form the basis for estimating the costs associated with each scenario. Costs to be estimated include **capital and other one-time developmental costs**, **operating and other recurring costs** associated with these technologies or options, and estimated **annual cash flows** (outlays and revenues) that are expected over a planning period.

5. By means of air quality dispersion modelling, estimate how reductions in emissions will reduce concentration in ambient air quality in specific communities or regions.

6. **Quantify benefits** of proposed standards or programs in relevant biophysical units. This step involves the application of quantitative risk analysis and derivation of biophysical dose-response functions which relate contaminant concentrations and exposure to relevant effects such as mortality or morbidity. Benefits may include damages and costs avoided or reduced, new and increased opportunities for human use and enjoyment and perceptions of the aesthetic aspects of environmental quality.

7. Where possible, assign **monetary value estimates** to the quantities of benefits that are estimated using relevant techniques and procedures including contingent valuation, hedonic methods or transferring value estimates from other locations.

8. Display, in tabular or graphic form, and on an annual basis, estimates of past and/or future costs and benefits, in relevant **bio-physical units** for each cost or benefit category, over the planning period of analysis.

9. Evaluate **uncertainties** of benefit and cost estimates using probibalistic methods such as Monte Carlo or Expected Values where possible. Other techniques such as Delphi or sensitivity testing may also be applied.

10. Where costs and benefit values are to be compared, calculate **present values of all monetized cost and benefit estimates**, using at least 2 relevant discount rates, over the planning period.

11. Sum present values of monetized costs and benefits and compute **differences between total present values of costs and benefits**. Other financial comparisons can be made if estimates are available: **benefit-cost ratios, capitalized values, rates of return, etc.**

12. If the monetary value of benefits exceeds the value of all costs, the project or activity is economically justified. If, on the other hand, the value of costs exceeds the value of all benefits, the difference between costs and monetized benefits provide a benchmark which can be compared with non-monetized, but quantified, benefits (such as reduced mortalities, fish kills avoided or increased visibility in scenic locations). Using this benchmark value, policy makers can ask themselves whether the **additional expected benefits are worth the excess cost.**

There are 52 potential scenarios based on combinations of 4 contaminants, 3 emission reduction targets for each of 4 implementation strategies and one "lowest achievable emission rate" (LAER) for each contaminant [(((3 x 4)+1) x 4) = 52]. About 40 of these scenarios have been studied because no comparable estimates could be made of the "community implementation strategy" scenarios. Some of the implementation strategies may not be entirely realistic. Nevertheless, as in any modelling exercise, evaluation of these scenarios can inform stakeholders and decision-makers of the important implications and consequences of different policy actions.

The US EPA has proposed, evaluated and debated National Ambient Air Quality Standards for Particulate Matter (PM) and Ozone. The benefits and costs of the proposed standards and alternative standards that were more and less stringent were evaluated in a "Regulatory Impact Statement" prepared by EPA staff. As with the present study and previous work carried out by the Ministry of the Environment, reductions of fine particulates (PM2.5 or smaller) will yield the vast majority of reduced mortality and morbidity health effects (Anderson, Feb. 1997).

Ambient air quality standards are also elements of these scenarios. With respect to the IP/RP issue, three province-wide average ambient air quality concentration objectives for $PM_{10}$ were identified in Section III.5: 60 $\mu g/m^3$, 50 $\mu g/m^3$ and 40 $\mu g/m^3$. In order to estimate compliance costs, these potential ambient air quality objectives must be translated into aggregate emission reduction objectives. Ideally, this conversion would be accomplished by source-receptor air quality models that relate emissions to ambient concentrations of relevant air pollutants. With such models, it would be possible to estimate the amount of emission reduction required from specific point sources or source categories in order to achieve the potential ambient air quality objectives. Moreover, estimates of the ambient air quality concentrations that would result from specific emission reduction scenarios could be made. Such models have not yet been applied to the above-noted scenarios other than to show that reductions in current ambient air quality concentrations in specific Ontario cities in order to achieve the goals noted above can vary substantially from 15% to as much as 65%

Lacking such modelling results, the next best approach is to assume equal proportionality between emission reductions and changes in ambient concentrations of $PM_{10}$ and $PM_{2.5}$. Sometimes called the "roll back" approach, a 50% reduction in the anthropogenic portion of particulate matter or precursor emissions is assumed to result in a 50% reduction in ambient concentrations of PM in adjacent regions. These "roll back" assumptions are discussed in Chapter III.5. The portion of the $PM_{10}$ and $PM_{2.5}$ concentrations which are due to uncontrollable natural sources remains unchanged. The proportional assumption implies that reductions of emission sources that contribute to long range transport of sulphate and other relevant pollutants would result in the same percent reductions in ambient concentrations of both primary and secondary $PM_{10}$ and $PM_{2.5}$ that is formed in the atmosphere.

As discussed in Sections III.3 and III.5, prior studies and model simulations have shown that the linearity assumption is reasonable for changes in sulphates which are derived from $SO_2$ reduction but perhaps is less valid for $NO_x$ and VOC emissions. Moreover, the locations of emission reductions affect where changes in ambient concentrations and corresponding beneficial consequences occur. Detailed modelling of the "efficient" or the "abatement maximization" scenarios would be needed to determine exactly where changes in ambient concentrations and beneficial effects would occur.

As noted earlier, three emission reduction goals, expressed as percent reductions in aggregate anthropogenic emissions, are postulated for these scenarios: 19%, 34% and 53%. In addition, the Lowest Achievable Emission Rate (LAER) level of abatement is specified as a fourth emission reduction goal. Each of the aggregate emission reduction goals below LAER can be achieved by means of one or the other of the implementation strategies. LAER implies that the maximum degree of abatement will be applied at all sources. Therefore, the efficient or the abatement maximization strategies make no difference to the final cost or resulting pollutant reduction of the LAER level of abatement.

These strategies can be enforced by imposing control orders or regulations, by establishing appropriate contaminant charges or by setting total emission caps and allowing trading or selling emission reduction credits. Sources may also commit to voluntary agreements to implement emission reductions by a certain deadline. This is the approach being taken with industrial polluters in Ontario to achieve reductions of ground level ozone and PM emissions. In particular, market-based systems such as emissions trading or contaminant charges can be designed to achieve efficiency in reduction, to provide incentives for the largest or the least-cost emitters to reduce first or to achieve equal reduction targets by means of the lowest cost combinations of technologies available. These implications are discussed in detail and shown empirically in a report on $NO_x$ trading by the National Economic Research Associates (October 1992).

The amount of emissions that are actually reduced by postulated abatement or prevention technologies depends critically on the initial or base-case emissions defined for the analysis. Base-case emissions for the analysis at this time are defined as follows:

1) $NO_x$ and VOCs - 1990 emissions are used as reported in *Toward a Smog Plan for Ontario* (Ontario Ministry of Environment and Energy, June 1996). Total emissions of these parameters have not changed substantially over the past 5-6 years except for Inco which implemented a major reduction in $NO_x$ emissions in 1991 (Ontario Ministry of Environment and Energy, 1996). Therefore, total NOx emissions and emissions from the non-ferrous metals sector are reduced by 50,000 tonnes.

2) $SO_2$ - Emissions have declined over the past 6-7 years so that 1990 emissions are not representative of recent years. As reported in the Ministry of the Environment *Fast Reference Emission Document* for 1996, emissions totalled 1,192 kt in 1990 and 619 kt by 1994. Moreover, the Algoma Ore iron sintering plant at Wawa was closed down this year so that base-case emissions are reduced by 80 kt. Therefore, initial total $SO_2$ emissions are assumed to be 805 kt per year which is below the 885 kt/year $SO_2$ emissions cap to which Ontario agreed in 1987. This assumption presumes that other sectors will not be permitted increases in $SO_2$ in place of the reduced tonnage from Algoma Ore. Initial emissions for the other major sources targeted by the Countdown Acid Rain

regulations are assumed to be as follows: Inco and Ontario Hydro are at their maximum allowable rates, 265 kt and 175 kt per year respectively. Falconbridge has an allowable maximum loading of 100 kt annually but, in recent years, has emitted substantially below that limit value. In 1995, Falconbridge emitted about 74 kt. All other emitters are set at their most recent 5-year average emission rates.

It is intended that the analyses presented below will be revised when 1995 base-case emissions become available. However, given the adjustments noted above, the results of the present analysis will demonstrate the analytical framework and provide useful indicators of potential costs and reductions. The analysis also allows readers to make constructive criticisms of the methodology. The results identify sources which may be able to achieve the most cost-effective abatement and which should be studied in greater detail. In short, the present analysis provokes thinking, discussion and debate that would not occur in its absence.

## IV.5 Abatement Cost Analyses

### IV.5.1 Abatement Cost Functions

Specific pollution abatement and prevention systems or technologies must be postulated in order to estimate costs and determine their distribution among individual sources. Cost estimates to implement standards at specific sources include:

1) **Capital Costs** - one-time costs of equipment and structures including separate estimates of installation/labour and land.

2) **Ongoing Operational Costs** - recurrent costs of labour, materials, energy and purchased services for operation and maintenance of systems and equipment. Should include estimates of staff time and other costs to collect data, store records, submit reports and other administrative activities to comply with requirements.

c) **One-time Development, Consulting or Start-up Costs** - separate estimates/data on one-time consulting, engineering, design, etc. costs not captured in above categories.

Estimates of abatement costs are often presented as single values. “Reducing SO2 emissions by 50% will cost company ‘X’ $50 million.” Single-valued estimates are not usually meaningful or helpful in the context of policy discussions. It is appropriate, therefore, to produce and display a ranges of estimated costs to account For most emission sources, whether point or area, stationary or mobile, there are wide ranges of abatement and prevention technologies and process changes that can be combined to achieve various levels of emission reductions. Furthermore, while costs often increase over time due to rising prices of inputs and wages, such factors as technical progress, innovation, increased productivity or price decreases of materials can mitigate and reduce future costs of abatement. Barre (1998) suggests that these uncertainties require that estimates should, on average, vary by at least +/- 30%.

In the following Sections, aggregate costs and their incidence for different scenarios (which consist of emission reduction goals and implementation strategies) will be estimated and compared. The sources for which cost and emission reduction estimates are available include individual plants, grouped industrial sectors, categories of stationary sources (eg. paints, solvents, etc.), and categories of mobile sources (eg. light gasoline vehicles, diesel vehicles). Moreover, sources for which costs are estimated represent varying proportion of total provincial emissions. As noted earlier, the provincial emission reduction goals (i.e., 19%, 34% and 53%) are based on the reductions in IP-RP concentrations that would be needed to achieve three different average ambient concentration targets (40 ug/m$^3$, 50 ug/m$^3$ and 60 ug/m$^3$ respectively) as discussed in Chapter III, plus the LAER level of control.

For each of the emission reduction goals, except LAER, the costs and distributional implications over sources are assessed for each of the three implementation strategies that were described in Section IV.3 ( i.e. an "efficiency strategy," requiring sources with the lowest cost per tonne of abatement to reduce first, followed by higher cost sources; an "abatement maximization strategy" that requires abatement first at those emission sources that can achieve the largest emission reductions, followed by sources with smaller reductions, and an "equal reduction strategy" where an equal degree of abatement (same per cent reduction) is required at each source. Each of these strategies are applied to sources irrespective of their location in the province. A fourth implementation strategy, involving reductions at sources only in selected communities, was examined but data were not sufficient to generate comparable empirical estimates in each municipality.

Previous work by the Ministry and its consultants have shown that, invariably, each individual stationary or mobile source can reduce pollutant emissions by varying amounts and at different costs by combining different abatement technologies and prevention measures. The set of least-cost technology combinations and resulting emissions reductions which can be applied at an individual source or plant is called an*abatement cost function*. However, in order to derive *aggregate (province wide) abatement cost functions* for a selection of different emission sources (including stationary, mobile, point, area and sectoral source), only one potential abatement/prevention technology combination (with associated cost and emission reduction estimates) for a single emission source can be displayed. A multitude of aggregate abatement cost functions can be derived from a set of sources by extracting different technical options from each source-specific cost function.

For the present analyses, two different aggregate abatement cost functions were derived from available data and estimates for individual plants or groups of sources. One aggregate cost function was derived by choosing the technology combination with the lowest cost per tonne removed. The second aggregate cost function was determined by choosing the technology combination that yields the largest reduction in emissions (referred to as the Lowest Achievable Emission Rate or LAER). These two aggregate cost functions could then be used to evaluate the costs and incidence of different scenarios (i.e. reduction goals and implementation strategies). For most of the analyses presented in this report, the cost functions that are based on the abatement technology options with the lowest cost per tonne removed have been used.

Empirical estimates for non-regulated point sources and source categories of SO2 are derived from abatement cost functions developed by SENES Consultants (*Acid Rain and Oxidant Precursors Control: Strategies Beyond 1994*, October 1992). The estimates of SO2 reductions used here were originally produced for the Acidifying Emissions Task Group (October 1997) of the National Air Issues Coordinating Committee and presented in the report, **Towards a National Acid Rain Strategy**. Estimates of emission reduction technology combinations and associated costs for Ontario Hydro, Inco and Falconbridge that are show here are derived from information provided by the respective companies. Representatives from both Inco and Falconbridge recently indicated that plans for further abatement of SO2 may be revised to accommodate efforts to reduce toxic substances. Information found in the report on **Strategic Options for the Management of Toxic Substances from the Base Metal Smelting Sector** is not sufficient to revise cost estimates for the pollutants of interest in the present exercise. Further consultations with these firms, as well as updates on 1995 emission data, will be required to generate new cost estimates from these facilities.

Costs and reduction efficiencies for stationary sources of NOx and VOCs were originally developed by SENES (October 1992) while mobile and area sources of $NO_x$ and VOCs are derived from the report, *Support For the Development of a $NO_x$/VOC Management Plan,* (Hickling Corp., March 1995). The cost functions and other estimates for NOx and VOCs presented in this report were originally derived for, and presented to, the Ontario Smog Plan Steering Committee in early 1997. The supporting documentation was also made available to those stakeholders who asked for them. Comments on these estimates and the supporting documents were requested from stakeholders.

Estimates of costs and emission reductions for 42 stationary sources of PM10 were provided by Environment Canada which derived the estimates from its "AERCo\$t$^{TM}$ Model".

Efforts are currently under way to produce new cost and reduction estimates based on 1995 emissions data as well as further information from industrial stakeholders. The computer-based cost estimating model called AERCo\$t, which has been developed by Environment Canada (Barre, 1998), will be employed to generate these estimates. The discussion in the remainder of this report will be based on current estimates and will demonstrate the analyses that will be carried out and the results that can be generated.

Two tabular versions of aggregate abatement cost functions for $SO_2$, $NO_x$ and VOCs have been derived and are displayed in Tables C.1, to C.8 in Appendix C. One version shows the various point sources and source categories ordered by lowest cost per tonne reduced. The "efficiency" implementation strategies were derived from these versions of the cost functions. The second cost function tables rank sources from those with the largest emission reductions to those with the smallest. These tables were used to derive estimates for the "abatement maximization" implementation strategy as well. Estimates of the "equal reduction strategy" (equal percentage reduction from each source) were derived from these tables as well. These cost function tables were also used to investigate potential costs of abatement at selected sources within specific communities.

Estimates of the "equal reduction" strategy were derived using the method listed in Text Box 2. However, some abatement technologies available for each source could not achieve the target percent reductions (ie. 19%, 34% and 53%) so that equal % reductions could not be achieved for all sources.

### TEXT BOX 2
### ESTIMATING COSTS OF THE "EQUAL REDUCTION" STRATEGIES

1) At each emission source, target emission reductions are compared with the technically feasible percent reductions achievable by each emission source (as shown in Tables C.1 to C.8 in Appendix C).

2) If the source-specific feasible emission reduction is *greater* than the target reduction (eg. in Table C.3, Ontario Hydro can reduce NOx emissions by 76%, which is greater than 19%. 34% or 53%), calculate tonnes to be reduced with the target emission reduction ( eg.. in Table C.3, 19% of 77,000 tonnes of NOx is 14,630 tonnes to be reduced by Ontario Hydro).

3) Multiply tonnes to be reduced by the $ per tonne abatement cost for the particular source as shown in Tables C.1 through C.8. (eg.. 14,630 tonnes to be reduced x $1,315 per tonne for Ontario Hydro equals $19.2 million per year, from Table C.3).

4) If the source-specific feasible emission reduction is *less* than the target reduction percentages abatement performance, calculate tonnes to be reduced using the source-specific reduction percentage. (eg. in Table C.3, the Insp. & Maintenance "source "can reduce NOx emissions from vehicle emissions by only 8%, which is less than 19%. 34% or 53%).

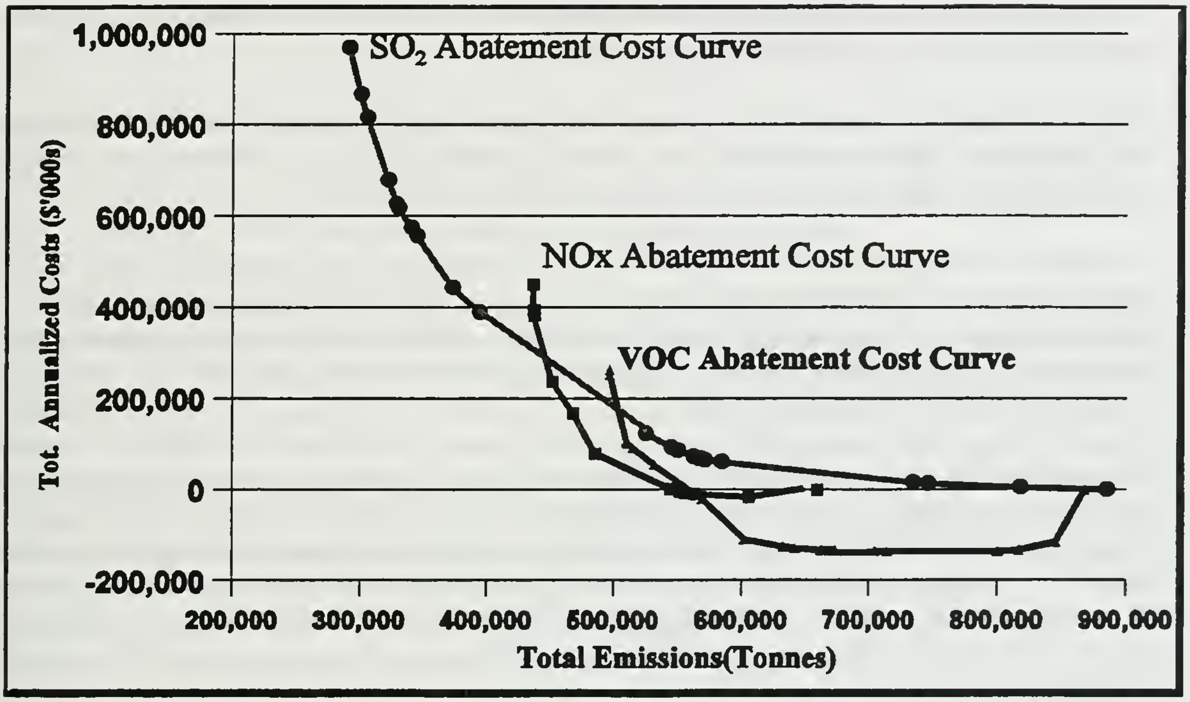
5) Multiply the tonnes to be reduced by the $ per tonne abatement cost for the source. (eg.. in Table C.3, for Insp. & Maintenance, 8% of 213,420 tonnes equals 17,074 tonnes to be reduced x $2,659/tonne equals $45.4 million per year).

6) The sum of the costs from each source or site is the total cost for the "Equal Reduction" scenario.

It is assumed that emission reductions would be realized within one to three years, depending on how long it takes to install and implement the systems. To be conservative, it is assumed that it could take as long as eleven years after emissions are reduced before beneficial effects are fully realized. Consequently, benefit estimates represent under-statements if they are realized in less than 10 years. Furthermore, future values of costs and of benefits must be discounted when they are compared.

As noted, aggregate cost functions used in these analyses are derived from technology combinations at each individual that achieve reductions at the lowest cost per tonne removed. For each pollutant, emissions and sources do not encompass all of the recorded emissions. Sources for which cost and reduction estimates are available account for 87% of 1990 SO2 initial or base case emissions, 82% of VOC base case emissions, 70% of NOx initial emissions and as little as 3% of total PM10 emissions in Ontario. Cost estimates for direct emissions of PM10 from area and mobile sources are not yet available.

Figure IV.1 AGGREGATE ABATEMENT COST FUNCTIONS



The three cost functions for precursor emissions, which are ordered by the lowest cost per tonne to the highest, are plotted in Figure IV.1. The cost and emission reduction estimates presented in these cost functions and discussed in more detail below are subject to the following qualifications:

1) Not all sources that could implement abatement or prevention actions are represented in the estimates, especially for $NO_x$ and PM10 emissions. Including more sources in the cost functions would extend the reach of the curves to the left on the graph.

2) As noted, the single-valued estimates shown in the subsequent graphs and tables are expected to vary by +/- 30% . The lines in the graphs should be viewed as shaded ranges above and below the central estimates.

3) The estimates tend to be very conservative and probably understate the actual costs and reduction efficiencies for some sources. No experimental bench scale technologies are assumed in these estimates.

4) The relative positions of each of the parameter-specific cost functions are more reliable than the absolute values of individual estimates.

5) Emission reductions that might result from the postulated technologies and associated investments could take several years to install and implement.

To be conservative, it is assumed that it could take as long as ten or eleven years after emissions are reduced before beneficial effects are fully realized. Therefore, future values of costs and of benefits will be discounted when they are compared.

Figure IV.1 indicates that substantially more abatement of $SO_2$ can be achieved than for $NO_x$ and VOC emissions. This may, however, be a consequence of having more information about $SO_2$ abatement technologies and their costs than about $NO_x$ and VOCs.

It appears that some sources of NOx and VOCs (e.g. paints, printing, degreasing, solvents and vapour controls and light duty vehicles) can achieve a net cost reduction or a net profit while implementing emission reductions. These opportunities may have already been exploited, but further examination of these sources is warranted to determine if these reductions can be achieved at these sources for little or no net costs.

This graph can be used to estimate how much it might cost to achieve an emission reduction goal or how much abatement a given expenditure could achieve. In doing this, it should be remembered that both the emission loadings and the costs for each curve are independent of the others. For example, an expenditure of about $200 million per year could result in a reduction of $SO_2$ to about 475 kt per year **or** the reduction of VOCs to about 530 kt per year **or** the reduction of $NO_x$ to about 510 kt per year. Otherwise, costs of reducing the more than one pollutant would be additive.

Emissions of each pollutant can be reduced to about 550 kt per year at low (or zero) net cost. Beyond this level, costs increase almost exponentially.

Technical results of cost analyses of scenarios for $SO_2$, $NO_x$ and VOC reductions are presented in the subsequent Sections. The financial effects of these costs on individual firms and industrial sectors are not assessed in this analysis. However, the distribution of the estimated costs over specific sources are shown for each scenario under study.

In the following sections, the costs and their distribution for the relevant program scenarios are presented. Each scenario consists of an emission reduction goal (i.e. 19%, 34%, or 53% ) and an implementation strategy (i.e. most efficient, abatement maximization and equal reduction at each source). The LAER level of abatement is a single scenario that does not vary in cost or total emission reduction according to implementation strategy.

### IV.5.2 $SO_2$ Abatement Scenarios and Cost Estimates

Sulphur dioxide contributes to the formation of fine sulphate particulate matter in the atmosphere. The estimates associated with each scenario are derived from the aggregate abatement cost functions for $SO_2$ shown in Tables C.1 and C.2 which are found in Appendix C. The aggregate cost functions include about 19 point and group sources of $SO_2$ sources in Ontario for which cost estimates are available and account for about 87% of total base-case or initial emissions

Under the Ontario Countdown Acid Rain Program, which was initiated late in 1985, regulations were promulgated which required that four major corporate stationary sulphur dioxide ($SO_2$) sources (Inco, Falconbridge, Algoma Ore at Wawa and all Ontario Hydro fossil fuel thermal power plants) to reduce their total $SO_2$ emissions to 665 kt per year by 1994. Furthermore, as part of its Countdown program, Ontario committed to an overall provincial emissions "cap" of 885 kt of $SO_2$ from all sources after 1993 as part of a Federal-Provincial Agreement signed in 1987on acid rain control. Because the Algoma Ore plant at Wawa has closed, the base-case or “initial emissions” for $SO_2$ has been reduced by 80 kt to 805 kt per year.

Table IV.1 summarizes the results for the scenarios specified earlier. Costs to achieve each emission reduction goal vary substantially depending on the implementation strategy applied. For each emission reduction goal, the “efficiency” strategy is always least cost but abatement is imposed on fewer sources than the abatement maximization or the equal reduction strategies. Sources that have the lowest unit abatement costs and can still implement the largest emission reductions are those regulated under the Countdown Acid Rain Program (Inco, Falconbridge, Algoma Ore at Wawa and Ontario Hydro). These sources have already implemented reductions under the Countdown Acid Rain Program regulations.

Table IV.1 $SO_2$ Emission Reduction Scenarios, Costs and Incidence for Ontario Sources

| Scenarios (Emission reduction goals and Implementation Strategies) | $SO_2$ Cumulative Emission Reductions (t/year) | $SO_2$ Cumulative Final Emissions (t/year) | Average Cost per tonne Reduced $SO_2$ ($/tonne) | Highest Cost per tonne Reduced $SO_2$ ($/tonne) | Cumulative Total Annualized Costs ($M/year) |
|---|---|---|---|---|---|
| Initial Loadings (1) | | 805,000 | | | |
| "19% total reduction" | | | | | |
| Efficiency (28% ) | 228,000 | 576,400 | $228 | $300 | $52 |
| Abatement Maximization (19%) | 150,000 | 655,000 | $300 | $300 | $45 |
| Equal reduction (19% at each source) | 133,600 | 569,500 | $1,617 | $11,053 | $216 |
| "34% total reduction" | | | | | |
| Efficiency (34%) | 267,900 | 537,100 | $317 | $1457 | $85 |
| Abatement Maximization (35%) (2) | 281,200 | 523,760 | $1,110 | $2,034 | $312 |
| Equal reduction (34% at each source) | 239,000 | 464,000 | $1,619 | $11,053 | $387 |
| "53% total reduction" | | | | | |
| Efficiency (55%) | 440,600 | 364,400 | $990 | $2,495 | $436 |
| Abatement Maximization (53%) (2) | 434,300 | 370,700 | $1,501 | $8358 | $652 |

| Scenarios (Emission reduction goals and Implementation Strategies) | $SO_2$ Cumulative Emission Reductions (t/year) | $SO_2$ Cumulative Final Emissions (t/year) | Average Cost per tonne Reduced $SO_2$ ($/tonne) | Highest Cost per tonne Reduced $SO_2$ ($/tonne) | Cumulative Total Annualized Costs ($M/year) |
|---|---|---|---|---|---|
| Equal reduction (53% at each source) | 372,600 | 330,420 | $1,618 | $11,053 | $603 |
| LAER (Max. Technically Achievable) (65% red.) | 522,200 | 282,800 | $1,631 | $11,053 | $962 |

Notes:

(1) Based on the Provincial Cap of 885 kt per year, Inco at regulated limit of 265 kt, Ontario Hydro at regulated limit of 175 kt, Falconbridge at 74 kt and Algoma, Wawa, at 80 kt plus the 5-year average emissions at all other sources. Algoma Ore has closed and so was removed from cost functions and initial emissions were reduced to 805 kt.

(2) Somewhat higher emission reductions are achieved because of technical rigidities in abatement assumptions for each source.

(3) All Ontario Hydro Plants are grouped together as one source. Potential abatement technologies and costs were provided by Ontario Hydro. A 75% reduction in emissions at all Ontario Hydro thermal power plants was assumed.

Source: Senes Consultants, estimates of abatement costs and reductions at Ontario Hydro thermal plants, Inco, Falconbridge and Algoma Ore at Wawa were provided by the respective companies.

Applying the efficiency strategy to achieve the 19% reduction goal would actually require achieving a 28% reduction in SO2 emissions because of technical rigidities. The lowest cost implementation strategy to achieve the 34% reduction goal would amount to $85 million per year while the 53% reduction goal would cost about $436 million per year.

If all sources were required to abate by 34% (the "equal reduction" strategy), they would incur about $312 million per year to achieve a 281 kt reduction in emissions. If all sources had to reduce by 53%, costs would total $603 million.

The Lowest Achievable Emission Rate (LAER) of abatement for $SO_2$ sources could achieve a 65% reduction in emissions and could cost as much as $962 million per year to implement. This amount is about 3 times more costly than the 34% reduction using the least-cost abatement strategy but reduces emissions by less than 2 times as much as would the 34% reduction goal.

Although the equal reduction strategy is generally more costly to achieve than the efficient strategy, this approach is more likely to achieve proportional reductions in ambient sulphate concentrations than would the efficiency implementation strategy. The latter approach requires abatement at sources in only a few locations while the equal reduction strategy would achieve reductions at many different sources across the province. Moreover, costs to achieve the equal reduction strategy could be much lower than estimated here if an emission reduction trading program or a contaminant charge system were introduced rather than a strict command and control approach that is assumed here.

Some source plants that would be subject to $SO_2$ abatement costs also face added costs to comply with other Ministry regulatory initiatives including the "Clean Water" Effluent Regulations and the Ontario Smog Challenge initiative. Consequently, further reductions in $SO_2$, beyond Countdown Acid Rain levels of control, may be best justified on the basis of the potential beneficial consequences that could result from these actions.

As explained earlier, the community strategy could not be assessed in detail. The results of what could be completed for the community strategy analysis are presented and discussed in Section IV.5.6.

### IV.5.3 $NO_x$ Abatement Scenarios and Cost Estimates

Technology and cost estimates used in the $NO_x$ and VOC aggregate cost functions are based on work by SENES (1992) and by Hickling (1995). Cost estimates were derived for 15 aggregated stationary source sectors (e.g., pulp and paper, chemicals, non-ferrous metals, Ontario Hydro thermal plants and Miscellaneous sources) and mobile source categories (e.g., Light duty gasoline vehicles, heavy duty diesel vehicles) rather than for any specific plant or firm. As explained earlier, the initial $NO_x$ emissions for this analysis were set at 659 kt per year 1990 recorded emissions, less 50 kt that were reduced by Inco since that time. Emissions for which costs are available account for about 70% of total initial emissions.

The results of this analysis, which are summarized in Table IV.2, are derived from the aggregate cost functions shown in Tables C.3 and C.4, Appendix C. As shown in Table C.3, there is at least one technology combination for a source category that appears to achieve a financial benefit in terms of reduced fuel consumption by light duty gasoline vehicles if implemented (Hickling, March 1995). This technical option could result in a 2% reduction in $NO_x$ emissions (16,097 tonnes) at a total net cost savings of about $24.3 million per year. Net savings or net revenues are expressed as negative “( )“ costs. Accumulated costs of net $NO_x$ reductions by other sectors are offset by these net savings. It is not clear whether this opportunity for savings is still available. Such savings, if any, may have already been realized.

Implementing abatement at all of the sources for which abatement costs have been estimated LAER) can achieve a maximum of 29% reduction from the initial emissions. Therefore, of the three reduction goals, only the 19% reduction goal may be achieved for $NO_x$ at a total net cost of $72 million per year. The LAER level of abatement would achieve a 29% overall reduction at a total net cost of $451 million.

The Ontario Smog Plan set an optimistic and challenging NOx reduction goal of 45% (Ontario Ministry of Environment and Energy, June 1996). To date, participants in the Smog Plan process have proposed to reduce NOx emissions by 190 to 215 kt (29-33%) per year under voluntary commitments by the end of the century (Ontario Smog Plan, 1998). Clearly, more sources of NOx will have to apply more effective and innovative prevention and control technologies if the 45%, let alone a 34%, reduction goal is ever to become a reality.

Attempting to impose 19% reductions on each source (the “equal reduction” strategy) would cost about $242 million per year and would reduce $NO_x$ emissions by about 81 kilotonnes or 13% of initial emissions for an average cost per tonne of $3,077. Imposing a 53% target reduction target on all sources could achieve a 29% reduction at a cost of $382 million. These results are predicated on the fact that reductions which could be achieved by 6 of the source sectors were substantially less than 19% using current technology.

However, application of an emissions trading policy or a contaminant charge scheme, combined with equal reduction targets, could allow stationary sources to achieve reduction targets at lower costs than those cited in the previous paragraph (Krupnick, April 1997).

Except for light duty gasoline vehicles, $NO_x$ emission reductions from stationary source sectors tend to be less costly (in terms of lower dollar amounts per tonne of $NO_x$ reduced) than reductions from mobile sources.

The potential for $NO_x$ emission reductions seems low because abatement technologies and costs were estimated for 15 source sectors that account for 70% of total initial emissions . Further analyses of abatement at other stationary and area sources of NOx should reveal additional opportunities for emission reductions.

### IV.5.4 VOC Abatement Scenarios and Costs

The initial emissions for VOCs used in this analysis are 868,000 tonnes per year. Based on the results summarized in Table IV.3, emissions from certain volatile organic compound sources can be reduced with a net savings or financial return. According to a 1995 report by Hickling, there are potential cost savings or revenues to offset abatement costs from four source sectors: paints, light duty gasoline vehicles, printing and industrial degreasing operations. Implementing abatement only at these four "no-regrets" source-sectors would yield a cumulative 16% VOC reduction at a total savings or net revenue of $143 million per year.

To achieve the 19% emission reduction goal, abatement at the 4 "no regrets" source sectors plus two other source sectors, would yield a 20% reduction in VOC emissions (176,426 tonnes per year) and the "cost" would be a net savings or revenue of $141 million per year.

Implementing abatement at an additional 12 source sectors would achieve a total reduction in VOC emissions of 35% (302,662 tonnes) in order to implement the 34% reduction goal. These twelve additional source sectors would incur about $139 million per year to reduce VOC emissions. The offsetting potential cost savings and net revenues resulting from the four source sectors noted above could result in a net **savings** of $4 million per year to achieve the 34% reduction target.

These opportunities for reduced costs or increased revenues may have been exploited by now. Nevertheless, a closer review of these four source sectors would be warranted if a targeted program to reduce $NO_x$ or VOC emissions were initiated.

The equal reduction strategy to achieve a 34% reduction could cost as much as $243 million (net cost) per year but would reduce emissions by only 208 kt.

The net cost of the LAER level of abatement for VOC sources could total $264 million (about $778 per tonne) to reduce emissions by about 339 kt. The LAER level of abatement reduces emission by about 39%. The actual total costs incurred by VOC sources would amount to about $406.6 million per year of which $143 million is offset by cost savings and net revenues from four sources.

The equal reduction strategy intended to reduce each emission source by 53% would reduce emissions by about 263 kt (a 40% reduction) at a net cost of $212 million. Twelve of the 26 VOC emission sources for which abatement costs were estimated had reduction efficiencies less than 53%.

Table IV.2 $NO_x$ Emission Reduction Scenarios, Costs and Incidence for Ontario Sources

| Scenarios (Emission reduction goals and Implementation Strategies) | NOX Cumulative Emission Reductions (tonnes) | NOx Cumulative Final Emissions (t/year) | Average Cost per tonne Reduced ($/tonne) | Highest Cost per tonne Reduced ($/tonne) | Net Total Annualized Costs ($M/year) |
|---|---|---|---|---|---|
| Initial Loadings (1) | | 609,000 | | | |
| 19% Reduction Target | | | | | |
| Efficiency (22%) | 131,200 | 477,800 | $549 | $1,315 | $72 (2) |
| Abatement Maximization (21%) | 128,250 | 480,750 | $998 | $4,242 | $128 (3) |
| Equal reduction (19% at each source) | 81,561 | 485,600 | $3,077 | $155,790 | $251 |
| Equal reduction (34% at each source) | 120,100 | 447,700 | $2,606 | $155,790 | $313 |
| Equal reduction (53% at each source) | 158,800 | 408,300 | $2,406 | $155,790 | $382 |
| LAER (29%) (4) | 177,200 | 431,800 | $2,843 | $155,790 | $451 |

Notes:
(1) 1990 emissions. Inco emissions were reduced by 50 kt since 1990. Non-ferrous mining and total base-case emissions were reduced by 50 kt.
(2) Net cost. Light duty gasoline vehicles are expected to save about $24 million per year. Six source sectors/categories would incur a total cost of $96 million. Average cost per tonne without light duty gasoline vehicles is about $800 per tonne removed.
(3) Net cost. Light duty gasoline vehicles controls are expected to save $24 million per year. Average cost per tonne for the two additional sectors which experience positive costs for$_{NOX}$ abatement equals $828 per tonne.
(4) 34% and 53% reduction targets cannot be achieved with the cost and reduction information available.

Source: Hickling, 1995 and Senes, 1992.

Sources with the highest $/tonne VOCs reduced (least cost-effective) include gasoline and diesel trucks, dry cleaners and high degrees of control on paints and volatility changes in gasoline.

### IV.5.5 Particulate Matter Abatement Scenarios and Cost Estimates

Abatement or pollution prevention technologies and systems that can be used to remove particulate matter from emission streams in certain industrial sectors are identified and discussed in Section III.6

and are summarized in the sidebar on page IV.23. While removal efficiency data normally refer to total particulate matter, these devices and practices will also remove PM$_{10}$ and PM$_{2.5}$ to varying degrees. Abatement of fine particulate matter will usually require additional removal devices in a series. In some instances, additional technologies and devices could be applied in tandem so as to remove greater amounts of fine particulate matter. The more devices and systems added, the more costs are incurred. Consequently, the finer the particles to be removed, the more costly it will be.

The primary particulate matter emissions inventory in Section III.1 reveals that industrial point sources only contribute 4% of total particulate matter, 11 % of PM$_{10}$ and 20% of PM$_{2.5}$ emissions throughout the province. Therefore, most direct particulate emissions are generated by area and diffuse sources, especially from combustion sources, motor vehicles and roads. Abatement at stationary sources will, therefore, reduce a relatively small proportion of total PM10 emissions. Furthermore, because most stationary sources are located in or near densely populated urban centres, abatement devices already have been installed on many of these industrial stationary sources. Consequently, incremental costs of added controls on these sources will likely be high.

Environment Canada has developed a computerized computational tool called the "AERCo$t" model that can be used to estimate abatement costs for a variety of pollutants from a stationary and area sources (Barre *et al.*, April 1998). This computational model is derived from work by Senes (1992) on behalf of the Ontario Ministry of the Environment. An aggregate abatement cost function for direct emissions of PM10 from 42 stationary Ontario industrial emitters has been derived from the AERCo$t model estimates. Uncontrolled, these 42 point sources account for approximately 31 kt of direct PM10 emissions.

Preliminary estimates of an aggregate PM10 abatement cost function for stationary sources are summarized in Table IV.4. The cost function is derived from individual plant cost functions by extracting the cost/reduction combination with the lowest cost per tonne of pollutant reduced. Estimates for area and non-point sources are not yet available. However, the stationary source cost function indicated that, under the efficiency implementation strategy, the 19% reduction goal can be achieved by two sources at a cost of about $2.6 million per year; the 34% reduction goal can be achieved by 3 sources at a total annualized cost of about $3.3 million per year, and the 53% reduction goal can be implemented by abatement at 11 establishments at a total annualized cost of $7 million. The LAER level of control involves abatement at all 42 stationary sources to achieve a 66% reduction (about 20.5 kt reduced) for about $25.3 million per year.

Abatement cost estimates for non-point and area sources will be derived from the AERCo$t Model. Most of the total and fine particulate emissions come from construction, dust from paved and unpaved roads, agricultural operations and animal wastes (which can also harbor pathogenic fungi and bacteria). Diesel vehicles and residential wood combustion sources contribute large amounts of fine particulate matter in urban areas where there is high exposure to sensitive populations. Technologies and systems to control non-point, areas and mobile sources are summarized in Text Box 3 on page IV.26.

**Table IV.3 VOC Emission Reduction Scenarios, Costs and Incidence for Ontario Sources**

| Scenarios (Emission reduction goals and Implementation Strategies | VOC Cumulative Emission Reductions (tonnes/year) | VOC Cumulative Final Emissions (tonnes/year) | Average Net Cost per tonne Reduced ($/tonne) | Highest Net Cost per tonne Reduced ($/tonne) | Cumulative Net Annualized Costs ($M/year) |
|---|---|---|---|---|---|
| Initial Loadings (1) | | 868,000 | | | |
| "19% reduction" | | | | | |
| Efficiency (20%) | 176,426 | 691,594 | $-799 | $42 | $-141 (2) |
| Abatement Maximization (21%) | 184,397 | 683,603 | $499 | $1,999 | $92 (3) |
| Equal reduction (19% reduction at each source) | 138,779 | 591,792 | $1,167 | $114,588 | $162 |
| "34% reduction" | | | | | |
| Efficiency (35%) | 302,662 | 565,338 | $-13 | $2,226 | $-4 (4) |
| Abatement Maximization (34%) | 296,931 | 571,069 | $269 | $2,553 | $80 (5) |
| Equal reduction (34% at each source) | 208,452 | 522,119 | $1,166 | $114,588 | $243 |

| **Scenarios (Emission reduction goals and Implementation Strategies** | **VOC Cumulative Emission Reductions (tonnes/year)** | **VOC Cumulative Final Emissions (tonnes/year)** | **Average Net Cost per tonne Reduced ($/tonne)** | **Highest Net Cost per tonne Reduced ($/tonne)** | **Cumulative Net Annualized Costs ($M/year)** |
|---|---|---|---|---|---|
| "53% reduction at each source" (6) | 263,331 | 467,240 | $805 | $114,588 | $212 |
| LAER (39%) | 339,065 | 528,935 | $778 | $114,588 | $264 (7) |

Notes

(1) Based on 1990 emissions with adjustments (see text).
(2) Net return. Each of 5 source categories can apparently reduce VOCs and achieve cost reductions, net revenue gains or zero net cost.
(3) Three source sectors would abate under this rule and none can reduce VOCs and achieve abatement with net returns.
(4) Net return. Five source categories can reduce at no cost or net returns; an additional twelve source categories can reduce VOCs for an annualized cost of about $139 million per year. The average cost per tonne for these sources is about $260 per tonne reduced.
(5) Net cost. Six source categories would reduce emissions at a net cost, two might incur no net cost or enjoy a return.
(6) The percent reduction from initial emissions is about 25% because some sources can reduce emissions by much less than 53%.
(7) The actual costs incurred by these sources totals $406.6 million per year, of which about $143 million per year is offset by cost savings and net revenues from 4 sectors.

Source: Senes, 1992 and Hickling, 1995.

Clearly, more work is needed to estimate the methods, relative costs and effectiveness of controlling direct area and transportation sources of PM10. For example, fine particulate emissions from transportation sources such as road vehicles can be reduced by a variety of technical methods including shifting transportation demand from cars to public transit, by encouraging car pools, by increasing the efficiency of engines, by requiring inspections and maintenance of vehicles, through the development of new types of on-board emission control technologies and by developing alternative fuels and power sources. Further reductions from diesel vehicles can be achieved by similar methods. Estimation of the costs and effectiveness of implementing these technologies is a time-consuming task which requires the use of computer-assisted computational tools such as the AERCo$t Model developed by Environment Canada.

### TEXT BOX 3
### EMISSION CONTROL TECHNOLOGIES FOR PARTICULATE MATTER FROM POINT SOURCES

| | |
|---|---|
| Bag Houses or Filters | Most suitable for cool, dry exhaust gases. Effective for fine particulate matter. |
| Electrostatic Precipitators (ESPs) | Medium to High efficiency (depends partially on the amount of electricity used) |
| Mechanical-Flow Separators (Cyclones) | Often used in series. Can be used in conjunction with other technologies (e.g. ESPs or Bag Houses). |
| Scrubbers (wet or dry) | Can remove gases as well as particulate matter. |
| Switching fuel type and quality. | "Hog fuel", Coal —> oil (No. 2 fuel, bunker C, etc.) —> Natural gas |
| Methods to control fugitive emissions from factories, mines, utilities and other stationary sources. | |
| Stock piles of raw materials, fuels or waste | cover, spray to keep damp. |
| Unpaved private roads | apply chemicals, spray to keep damp. |
| Transferral of materials and products | hooding, enclosing conveyers. |
| Mine tailing piles and fields | cover with vegetation or plastic sheets. |
| Loading/unloading | wetting, covering loading area. |

There are tradeoffs between capital and operating costs (i.e. higher the capital, lower the recurring operating costs). Improved Operation and Maintenance efforts can be applied to each of the technologies noted above.

Table IV.4 Emission Reduction Scenarios, Costs and Incidence for Stationary Sources of PM10 (1)

| Scenarios (Emission reduction goals and Implementation Strategies | Cumulative PM10 Emission Reductions (tonnes/year) | Cumulative Final Emissions (tonnes/year) | Average Net Cost per tonne Reduced ($/tonne) | Highest Net Cost per tonne Reduced ($/tonne) | Cumulative Net Annualized Costs ($M/year) |
|---|---|---|---|---|---|
| Initial Loadings (2) | | 31,156 | | | |
| "19% reduction" | | | | | |
| Efficiency (28%) | 8,763 | 22,392 | $297 | $317 | $2.6 |
| Abatement Maximization (28%) | 8,763 | 22,392 | $297 | $317 | $2.6 |
| Equal reduction (19% reduction at each source) (19%) | 5,910 | 25,246 | $1,303 | $16,165 | $7.7 |
| "34% reduction" | | | | | |
| Efficiency (35%) | 10,941 | 20,215 | $302 | $349 | $3.3 |
| Abatement Maximization (35%) | 10,941 | 20,215 | $302 | $349 | $3.3 |
| Equal reduction (34% at each source) (33%) (23 | 10,211 | 20,944 | $1,283 | $16,165 | $13.10 |

| Scenarios (Emission reduction goals and Implementation Strategies | Cumulative PM10 Emission Reductions (tonnes/year) | Cumulative Final Emissions (tonnes/year) | Average Net Cost per tonne Reduced ($/tonne) | Highest Net Cost per tonne Reduced ($/tonne) | Cumulative Net Annualized Costs ($M/year) |
|---|---|---|---|---|---|
| 53% reduction at each source" | | | | | |
| Efficiency (53%) | 16,618 | 14,537 | $421 | $1,481 | $7 |
| Abatement maximization (54%) | 16,840 | 14,316 | $653 | $4,354 | $11 |
| Equal Reduction (53% at each source) (49%) (3) | 15,166 | 15,990 | $1,279 | $16,165 | $19.4 |
| LAER (66%) | 20,513 | 10,643 | $1,233 | $16,165 | $25.3 |

Notes

(1) Cost function derived from lowest cost per tonne removed technology combinations at individual sources.
(2) Based on 1990 emissions
(3) Some sources cannot reduce emission up to the target level.

Source: Estimates from AERCo$t Model by Environment Canada, 1998

Control methods to reduce emissions generated by agriculture include modified tilling practices and increased vegetation cover. Fine particulate matter generated when applying pesticides and fertilizers can be reduced by choosing favourable climatic conditions for spreading. Particulate matter from these sources expose far fewer people than do emissions from vehicles and road dust.

### IV.5.6 Targeting Specific Communities

Some communities experience greater ambient concentrations of fine particulate matter than others. The percent changes in ambient quality concentrations needed to attain one or the other of the three concentration goals vary substantially from community to community. Populations exposed vary from community to community as well. All things being equal, it is generally more cost-effective to impose emission controls on sources in communities with high levels of ambient exposures than to impose abatement or prevention on sources located in communities with relatively low ambient concentrations. Moreover, the benefits of emissions reductions in densely populated urban centres would be greater than the benefits of reductions at similar sources in rural areas.

Estimates of the relative contributions of different direct and indirect sources of particulate matter to the recorded ambient concentrations of fine particulate matter in selected urban areas throughout Ontario are presented in Section III.4. These inventoried emissions for $PM_{10}$ and $PM_{2.5}$, and for precursor emissions such as $SO_2$, NO2 and VOCs in each of the urban areas, have been disaggregated by industrial sector for stationary sources and by source categories for non-point sources.

Using cost per tonne and reduction efficiency estimates from the cost functions in Appendix C, estimates of the cost of reductions were examined for sources in three of the urban areas: Toronto, Hamilton and Windsor. Unfortunately, such estimates could only be generated for a few of the stationary source sectors in each community. For example, based on the current estimates, the two iron and steel mills in Hamilton could spend as much as $110 million per year to reduce $SO_2$ by about 20 kt tonnes annually. The mills would also have to spend an additional $824,000 per year to reduce $NO_x$ by 1.3 kt and another $500,000 per year to reduce VOCs by 5.1 kt annually. Chemicals and paint manufacturers could spend up to $17.4 million each year to reduce $SO_2$ by 2.2 kt, $NO_x$ by 121 tonnes and VOCs by 319 tonnes per annum.

Emissions for which abatement/prevention costs of reductions could be estimated account for 91% of total $SO_2$ emissions, 37% of total $NO_x$ emissions and 68% of total VOC emissions from both area and stationary sources in Hamilton.

No estimates of non-point source categories in Hamilton or the other communities could be made.

More detailed plant-level cost estimates and analyses would be needed in these communities to be able to compare the cost effectiveness of abatement at various sources among different communities. Such analyses would help authorities in each community prioritize their abatement requirements.

### IV.5.7 Economic and Financial Impacts of Costs

Benefit-cost comparisons are the most appropriate economic basis for standard setting and assessing the overall efficiency of regulatory decisions. However, various stakeholders are legitimately concerned about the economic effects of total abatement and prevention costs on the economy as a whole and about the financial effects on individual firms and on industrial sectors.

Firms who must incur compliance costs are concerned that such costs will increase their cost of production and so reduce their cost competitiveness with firms in other jurisdictions. Empirical analysis of these effects is a formidable task. One needs data or estimates of prevailing abatement or prevention costs being incurred by competing firms or industries in other jurisdictions together with data on average production costs from each competitor. It would not be sufficient just to compare relevant laws and regulations either. Jurisdictions vary widely in the degree to which they enforce their environmental laws. The most appropriate comparison of the competitive effects of potential compliance costs would be the total unit cost of production for all relevant competitors after the potential compliance costs have been incurred. Average production costs (per unit of output) from different competitors are generally difficult to obtain.

Assessment of the effects of compliance costs on a company's financial indicators requires detailed financial data from each firm. Computational protocols to assess these effects are available from different sources, including the Energy Policy Branch of the Ministry of Energy, Science and Technology (formerly the Economic Services Branch of the Ministry of Environment and Energy). Financial impact analyses determine to what extent potential net abatement costs could change measures of profit, cash flow, capital expenditures and certain key ratios. Normally, historical data concerning these indicators are "shocked" by appropriately adding net compliance costs to the company's historical annual average and worst year's financial data over a 5 to 10-year period (in order to capture a business cycle) and recalculating the relevant financial indicators. Alternatively, potential net abatement costs can be used to "shock" forecasts of relevant financial indicators since the abatement costs will be incurred in the future. However, detailed financial forecasts are not readily supplied by regulated companies.

Cost impacts at the firm and sector level can be mitigated and reduced in a number of ways. For example, firms in an oligopolistic market (there are a few large competitors) may be able to increase product prices in order to recover all or a part of the increased costs. Even firms in a highly competitive market can recover costs through higher prices if all firms experience similar cost increases. Another reason why financial effects might be mitigated is that firms would be challenged by the potential increases in abatement costs to find and implement less costly and more efficient means of achieving compliance than the technologies contemplated in this study. As indicated in the foregoing analyses, there are sometimes opportunities to reduce emissions and achieve net benefits in terms of cost savings or increased revenues. Such opportunities are best identified by individual firms when they begin serious efforts to implement abatement requirements. Another potential for cost mitigation occurs when a firm or an industrial sector is fortunate enough to be able to implement abatement requirements at the same time as it implements major capacity expansions or upgrades its production equipment. New production technologies and production facilities can be designed to reduce emissions far more and at far less cost than can add-on abatement or prevention systems and equipment. Unfortunately, industrial sectors vary widely in the timing of their investment cycles.

Assessment of the economic effects of potential net abatement costs on macro-economic variables such as provincial gross domestic product (GDP), net provincial product (NPP), investment, employment and price levels requires the use of complex macro-economic forecasting or input-output models. Application of these models is costly and requires considerable specialized expertise. Furthermore, the economic "shock" or change must be relatively large to show any effect on these models. For example, the total net annualized costs that might be imposed on Ontario firms to reduce the 4 different pollutant emissions range from $500 million to $1.7 billion per year, depending on the level of abatement achieved. These costs range from 0.2% to 0.7% of the Ontario GDP for 1996 and from 0.9% to 2.9% of the total capital investment for Ontario during 1996. Costs of this magnitude would have a very small effect on the relevant macro-economic variables.

Economic effects on specific industrial sectors may be large, however. As can be seen in Table IV.5, estimated total annualized abatement costs for some of the industrial sectors listed account for larger proportions of sectoral GDP than the aggregate amounts noted above.

**Table IV.5 ANNUAL NET ABATEMENT COSTS TO REDUCE PM & PM PRECURSORS AS A PERCENT OF SECTORAL GDP FOR 1996**

| INDUSTRIAL SECTOR | PM & PM Precursors Reductions Expenditures (Million $/Yr) | Sectoral Gross Domestic Product (GDP) (Millions 86$) | Emission Reductions Expenditures as a % of Sectoral GDP |
|---|---|---|---|
| PETROLEUM REFINING | $110.1 | $718.5 | 15% |
| PRIMARY METALS | $183.4 | $4,082.0 | 4% |
| NON-FERROUS METALS | $59.0 | $582.9 | 10% |
| CHEMICALS | $60.3 | $4,166.2 | 1% |
| PULP AND PAPER | $150.1 | $2,240.7 | 7% |
| ONTARIO HYDRO | $343.9 | $4,177.6 | 8% |

Sources: Statistics Canada, Ontario Economic Accounts - 1990, Office of Economic Policy, Ontario Ministry of Finance .

Finally, further analyses of product market competitiveness would be needed to assess whether all or a part of these costs can be passed on as higher prices or that firms would incur reductions in profits as a result of these expenses.

### IV.5.8 Conclusions Regarding Costs

Findings and conclusions drawn from the cost analyses are summarized below.

1) Emission reduction goals evaluated here (e.g., 19%, 32%, 53%) are derived from average province-wide percent reductions in ambient concentrations needed to achieve average potential ambient concentration targets that were suggested in Section III.5: 60μg/m$^3$, 50μg/m$^3$ and 40 μg/m$^3$. Other reduction or ambient quality targets can be evaluated using the aggregate abatement cost functions shown in Appendix C (or revised versions if new cost estimates are provided).

2) Because the technologies that remove these pollutants are generally separate and independent, the costs of controlling these pollutants tend to be additive for plants or industrial sectors that generate all three contaminants. However, some technologies remove more than one contaminant at a time. For example, scrubbing can remove $SO_2$ and VOC gases as well as particulate matter. Fuel switching (e.g., from coal or oil to gas) will reduce $SO_2$, $NO_x$ and particulate matter as well as carbon monoxide and dioxide. Also, to the extent that combustion facilities (boilers, etc.) are made more efficient and less fuel is burned, emissions of all these pollutants will be reduced. To the extent that more than one pollutant is reduced by a technology, the overall cost-effectiveness is enhanced.

3) Assuming independence of technologies for each pollutant, total annualized costs of achieving the four emission reduction goals (e.g. 19%, 34%, 53% and the lowest achievable emission rate [LAER]) for $NO_x$, $SO_2$, VOCs and stationary sources of PM10 are summarized in Table IV.6. These cost estimates are all based on the "efficiency" implementation strategy and so are the lowest costs to achieve relevant objectives.

4) Total net costs for implementing the 19% reduction target would be essentially zero since VOC reduction technologies yield cost savings or net revenues to offset costs incurred by $SO_2$, NOx and PM10 sources. The actual costs incurred by emitters of $SO_2$, NOx and PM10 amount to about $156 million per year before subtracting potential savings and net revenues. Total costs associated with the 34% reduction goal amounts to about $723 million, of which $141 is offset by cost savings and benefits from VOC controls. Finally, trying to reduce emissions by 53% would impose $1.7 billion in net incremental cost on emission sources.

4) As indicated in Table IV.6, a 19% reduction goal could be achieved at a total net cost of about $124 million per year for emitters of $SO_2$ and NOx. VOC emission reductions appear to be achievable at a net savings of as much as $141 million per year following the efficiency implementation strategy. Adding these net revenues and savings could result in a net savings of $14 million per year to achieve the 19% reduction goal. The actual overall emission reduction for all pollutants is about 25%.

5) Setting and implementing a 34% reduction goal rather than the 19% goal would impose an added $535 million per year in net abatement/prevention costs on sources (which includes

possible net savings or revenues for VOC controls in certain sectors). The actual total emissions reduction amounts to about 33% rather than 34% because the maximum percent reduction that can be achieved by NOx emitters, according to available information and assuming current technologies, is 29%.

6) Striving for the 53% reduction goal could cost more than $1.1 billion per year to achieve an actual 43% reduction in total emissions. Implementing abatement that can be achieved would result in a 10% increase in the overall reduction of the three precursor pollutant emissions (i.e. from a 33% reduction in total emissions to a 43% reduction). The incremental cost would amount to about $623 million per year ($1,158 mil. - $535 mil.).

7) The LAER level of abatement (apply maximum available control technologies to all sources) would increase pollutant reductions by another 3% (from 43% to 46% reduction of all pollutants) for an added $544 million per year for a total annualized cost as much as $1.7 billion.

8) The average cost per tonne removed for the LAER level of reduction amounts to $779/tonne for VOCs versus $2,545/tonne for $NO_x$ and $1,842/tonne for $SO_2$. It appears that VOC emissions reduction costs are partially offset by potential cost savings or net revenues that might result from some of the control or protection technologies. It is not certain that these opportunities for savings still exit for VOC emitters.

9) The cost estimates are subject to a +/- 30% range of uncertainty. Actual costs could be lower than estimated because of new technology, achievement of reductions by means of pollution prevention rather than add-on abatement and because most sources generally have many more abatement opportunities than presented here and these can achieve specific reduction targets more precisely and at lower costs. Moreover, where abatement or protection technologies systems reduce more than one type of pollutant at one time, the aggregate costs of implementing each emission reduction goal would be lower than the estimates presented here.

10) Different implementation strategies have major cost implications. For example, the "efficiency strategy" to achieve the 34% reduction goal for SO2 indicates that, due to technical rigidities, eight sources would have to implement abatement at a cost of about $85 million per year. On the other hand, if plants with the largest emission reductions implemented their programs first, it would cost about $312 million per year. If all plants were obliged to implement a reduction of 34%, costs could total more that $387 million per year.

11) Use of implementation strategies have important environmental trade-offs as well. For example, for each type of pollutant, the efficiency or the abatement maximization strategies imply that a relatively few sources abate to achieve the overall reduction goal. Sources with low abatement costs or large reduction potentials may not be located in regions or urban areas where fine particulate matter exposures are a problem. On the other hand, equal reductions at each source would achieve reductions in ambient concentrations at more locations across the province than would the efficiency or abatement maximization approaches.

12) The costs associated with the equal reduction strategy likely could be reduced by implementing emissions reduction trading or a contaminant charge system (Krupnick, April 1997)

13) Estimates presented here indicate that some source sectors of $NO_x$ and VOC emissions might be reduced at a net cost savings or even a net revenue gain. Implementing only those technology/source combinations for which net savings or gains are possible could result in a 2% reduction in $NO_x$ and a 16% reduction in VOC emissions. If such gains were possible when these estimates were first made, it is likely that they would be exploited by now. Nevertheless, abatement or prevention possibilities in these particular source categories should be examined as part of any abatement strategy. At any rate, it appears that VOC reductions could be obtained at a far less overall cost than can reductions in $NO_x$ or $SO_2$.

14) Targeting sources for abatement, whether to achieve reductions at the most cost-effective sources or to achieve the greatest reductions in ambient exposure in specific communities, would be cost-effective approaches to achieve the greatest reduction in emissions or pollutant exposures for the funds spent.

15) Further work is needed to estimate the costs of abatement/prevention using 1995 base-line emissions, to identify technologies and estimate costs of reducing direct area source emissions of fine particulates matter and to explore the implications of focussing control efforts on specific communities.

Atmospheric modelling would be necessary to test the effects that emission reductions discussed in this section might have on ambient concentrations of the different pollutants and on changes to exposures to sensitive populations. Such modelling has not been completed for the emission reduction scenarios discussed in this report. However, the emission reduction goals evaluated are based on achieving province-wide, average ambient concentration targets for $PM_{10}$ (60 $\mu g/m^3$, 50 $\mu g/m^3$ and 40 $\mu g/m^3$), as discussed in Section III.5. Consequently, an analysis of the benefits of achieving these average ambient concentration targets is presented in the next Section.

## Table IV.6 Summary of Lowest Net Costs to Achieve Emission Reduction Scenarios

| Emission Reduction Goals | Initial Emissions (tonnes/yr) | Cumulative Reductions (tonnes/year) | Cumulative Final Emissions (tonnes/year) | Actual % Reduction (1) | Lowest Net Cumulative Annualized Costs ($ Mil./yr) | Average Net Cumulative Costs Per Tonne (2) ($/tonne) |
|---|---|---|---|---|---|---|
| **19% Reduction** | | | | | | |
| $SO_2$ | 805,000 | 228,600 | 576,400 | 28% | $52 | $227 |
| $NO_x$ | 609,000 | 131,200 | 477,800 | 22% | $72 | $549 |
| VOC (3) | 868,000 | 176,406 | 691,594 | 20% | ($141) | ($799) |
| PM10 (4) | 31,160 | 8,763 | 22,392 | 28% | $3 | $297 |
| Subtotal | 2,313,160 | 544,969 | 1,745,794 | 25% | ($14) | ($26) |
| **34% Reduction** | | | | | | |
| $SO_2$ | 805,000 | 267,900 | 537,100 | 33% | $85 | $317 |
| $NO_x$ (5) | 609,000 | 177,200 | 431,800 | 29% | $451 | $2,545 |
| VOC (3) | 868,000 | 296,931 | 571,069 | 34% | ($4) | ($13) |
| PM10 | 31,160 | 10,941 | 20,215 | 35% | $3 | $302 |
| Subtotal | 2,313,160 | 752,972 | 1,539,969 | 33% | $535 | $711 |
| **53% Reduction** | | | | | | |
| $SO_2$ | 805,000 | 440,600 | 364,400 | 55% | $436 | $990 |
| $NO_x$ (5) | 609,000 | 177,200 | 431,800 | 29% | $451 | $2,545 |
| VOC (6) | 868,000 | 339,065 | 528,935 | 39% | $264 | $779 |
| PM10 | 31,160 | 16,618 | 14,537 | 53% | $7 | $421 |
| Subtotal | 2,313,160 | 973,483 | 1,325,135 | 43% | $1,158 | $1,190 |
| **LAER (7)** | | | | | | |
| $SO_2$ | 805,000 | 522,200 | 282,800 | 65% | $962 | $1,842 |
| $NO_x$ | 609,000 | 177,200 | 431,800 | 29% | $451 | $2,545 |
| VOC | 868,000 | 339,065 | 528,935 | 39% | $264 | $779 |
| PM10 | 31,160 | 20,643 | 15,990 | 66% | $25 | $1,226 |
| Subtotal | 2,313,160 | 1,038,465 | 1,243,535 | 46% | $1,702 | $1,639 |

Notes:

(1) Actual % reduction = (Cumulative Reduction/Initial Emissions)
(2) Average Net Cumulative Costs Per Tonne Removed = (Lowest Net Cumulative Annualized Costs/Cumulative Reduction)
(3) Net savings or financial returns indicated for some VOC control technologies or systems. See text for explanation.
(4) Initial emissions and abatement at 42 stationary sources only. Area and non-point source emissions not confirmed.
(5) 34% and 53% reduction goals cannot be achieved with the technology, cost and reduction information available for $NO_X$ controls.
(6) 53% reduction goal cannot be achieved by technology, cost and reduction information available for VOC controls.
(7) Lowest Achievable Emission Rate given available technologies, costs and reduction information.

## IV.6 Benefits Assessment

### IV.6.1 Assessment Methods

Environmental management policies, programs and activities which result in real or perceived improvements in environmental quality or protection of natural resources yield:

- **Private Benefits** include reduced costs of production process or increased revenues from the recovery and sale of secondary materials or improvements in products and services. Enhanced public relations and recognition of products and services for being environmentally responsible constitute private benefits. Many companies try to label their products "green" in order to increase sales. Private benefits can be measured as increased revenues, profits, wages or other beneficial consequences. Examples include sales of recovered by-products, reduced inputs and costs or enhanced goodwill or public relations, increased property values.

- **Public Benefits** include actual and perceived increases in welfare and quality of life received by society as a result of reduced risk of disease or death, increased or enhanced recreational amenities and services, increased productivity of biological systems such as crops, forests or fisheries, avoided costs of clean up and remediation, and other beneficial effects which are valuable to society but are not directly manifested in terms of increased net incomes or profits to regulated parties.

- **Local or Regional Economic Activity and Employment** are expenditures made by emissions sources, whether they be individuals, corporations or groups, to comply with requirements or by government to implement projects which can generate economic activity and employment. However, in many cases, there are offsetting reductions in other expenditures and employment which would have been made if pollution abatement were not required.

Private benefits are cost reductions or extra revenues that are enjoyed by the firms or individuals who incur abatement or prevention costs. The cost analysis of VOC and $NO_x$ emission controls indicated that private benefits might be achieved by certain source sectors in terms of cost reductions or increased revenues. Local economic activity and employment also result from expenditures on abatement or prevention technologies although these effects should not be added to the benefits estimates. Public benefits are the most challenging and difficult to estimate.

Public benefits must be **identified**, **quantified** and, where possible, **valued** in monetary terms in order to use them in policy deliberations. Quantitative estimates of the benefits of emission reductions are expressed primarily as a reduction in adverse health effects and other environmental damages that would occur under a base-case set of present and future emissions. To fully inform stakeholders regarding the consequences of different programs and policy actions, estimates of benefits for at least three scenarios should be produced. Moreover, because monetization of health and environmental benefits is often contentious, benefits are displayed as two separate sets of estimates:

- **physical quantities** of health effects and other environmental damages reduced or avoided, increased crop production or productivity, and
- **monetary values** attributed to reduced damages or other beneficial biological or physical effects.

Reductions in the emissions of $SO_2$, $NO_x$ and VOCs can have a number of beneficial consequences. Reduced mortalities and morbidity effects (illnesses) are associated with reduced concentrations of fine particulate matter (sulphates) and ground level ozone, for which $NO_x$ and VOC emissions are precursors. Reduced soiling of buildings and property is another important benefit associated with reduced particulate emissions. Increased productivity of agricultural crops and ornamental plants is a key benefit of reducing ground level ozone but not from the reduction of particulate matter or of $SO_2$. Ground level ozone also causes damage to certain materials as well as vegetation. Sulphur dioxide and nitrogen oxide emissions are the sources of acidic deposition which is implicated in damages to aquatic organisms and associated aquatic recreational activities, buildings and structures and certain forest products including lumber and maple syrup. Reduced sulphates and particulate matter can result in increased visibility which enhances scenic areas. A final category includes intangible perceptions and concerns people have about the natural environment. Many people believe that they have a right to a clean environment irrespective of the uses that are made of the environmental resources.

Potential benefits associated with each pollutant are summarized in Table IV.7.

**Table IV.7 Identification of Potential Benefits of Reducing IP/RP Related Emissions**

| Damage/Benefit Category | $SO_2$ | NOX | VOCs | PM10/$PM_{2.5}$ |
|---|---|---|---|---|
| Mortality | ✓ | | | ✓ |
| Morbidity | ✓ | ✓ (1) | ✓ (1) | ✓ |
| Crops - ornamental Plants | | ✓(1) | ✓ (1) | |
| Corrosion of materials | ✓ | ✓ (1) | ✓ (1) | |
| Acidic Deposition (2) | ✓ | ✓ | | |
| Soiling of property | ✓ | | | ✓ |
| Visibility improvements | ✓ | | | ✓ |

Notes :
(1) Associated with ground level ozone.
(2) Acid deposition is associated with damages to aquatic ecosystems, aquatic recreational activities, forests and public perceptions.

### IV.6.2 Quantification of Benefits

Human health effects associated with inhalable particulate matter ($PM_{10}$) include premature mortalities and morbidity effects such as bronchitis in adults or children, hospital admissions, reduced activity days, asthma symptom days and acute respiratory symptom days. The benefits of reduced emissions and reduced $PM_{10}$ and $PM_{2.5}$ concentrations are the reductions in these health effects from prevailing levels.

Quantified health benefits are takenfrom Section III.5 which provides "Low", "Central" and "High" estimates of mortality and morbidity effects. "Central Estimates" of current levels of mortality and morbidity effects associated with prevailing levels of inhalable particulate matter for all of Ontario are summarized in Table IV.8. Current levels of health effects are shown along with health effects remaining after ambient concentrations are theoretically "rolled back" to target levels described in Section III.5. Reductions in health effects are shown in brackets, "( )". These estimates are derived from Section III.5 and Table III.5.7. "High," "Central" and "Low" estimates of current levels of effects are shown in Table III.5.2.

Benefit estimates are based on assumed reductions from the 3^d highest average daily $PM_{10}$ concentrations to potential concentration levels of 40, 50 and 60 ug/m3. Estimated reductions in health effects from current levels are shown in Table IV.8. The values shown are "central" estimates of health effects changes associated with changes in particulate concentrations (i.e., reductions in concentrations from current levels to 60, 50 or 40 $\mu g/m^3$). Low and high estimates of current health effects may be seen in Table III.5.2 so that low and high estimates of reductions in mortality and morbidity effects can also be calculated.

Table IV.8 indicates that efforts to reduce $PM_{10}$ concentrations to 40 ug/m3 could result in 720 fewer premature mortalities a year. In addition, up to 52,600 fewer cases of chronic bronchitis (in adults and children) and as many as 575 fewer hospital admissions (for respiratory and cardiac symptoms) a year could result from decreases in average $PM_{10}$ exposure to 40 ug/m3. People in Ontario could experience about 25,700 fewer emergency room visits and about 18 million fewer days of acute respiratory, asthma symptoms and restricted activity days a year.

Table IV.8 also indicates that achieving the least stringent target of 60 ug/m3 would result in 258 fewer untimely mortalities, 19,860 fewer chronic bronchitis events in adults and children, 207 fewer hospital admissions (respiratory and cardiac), 9,212 fewer emergency room visits, and nearly seven million fewer asthma, acute respiratory and restricted activity days than would occur without these changes.

## Table IV.8 Changes in Health Effects Associated with Potential Ambient Concentration "Roll Back" Targets for Inhalable Particulate matter ($PM_{10}$) - Based on Central Estimates of Effects

| Ambient Concentration Target | Premature Mortalities | Adult Chronic Bronchitis | Respiratory Hospital Admissions | Cardiac Hospital Admissions | Emergency Room Visits | Asthma Symptom Days | Restricted Activity Days | Acute Respiratory symptoms | Bronchitis in Children |
|---|---|---|---|---|---|---|---|---|---|
| Current Health Effects (1) | 1,724 | 11,651 | 747 | 632 | 61,515 | 720,323 | 10,593,874 | 32,907,816 | 114,288 |
| "Controllable" Health Effects (2) | 1,359 | 9,183 | 589 | 498 | 48,482 | 567,712 | 8,349,409 | 25,935,821 | 90,074 |
| 60 µg/m³ (3)<br>(reduction) (4) | 1101<br>( 258) | 7,438<br>(1,745) | 477<br>(112) | 403<br>(95) | 39,270<br>(9,212) | 459,847<br>(107,865) | 6,763,021<br>(1,586,388) | 21,008,015<br>(4,927,806) | 72,960<br>(17,114) |
| 50 µg/m³<br>(reduction) | 897<br>(462) | 6,061<br>(3,122) | 389<br>(200) | 329<br>(169) | 31,998<br>(16,484) | 374,690<br>(193,022) | 5,510,610<br>(2,838,799) | 17,117,642<br>(8,818,179) | 59,449<br>(30,625) |
| 40 µg/m³<br>(reduction) | 639<br>(720) | 4,316<br>(4,867) | 277<br>(312) | 234<br>(264) | 22,787<br>(25,695) | 266,824<br>(300,888) | 3,924,222<br>(4,425,187) | 12,189,836<br>(13,745,985) | 42,335<br>(47,739) |

Notes:
Revised 23 November 1998
(1) Includes effects that are associated with non-controllable, "background" concentrations of $PM_{10}$ and $PM_{2.5}$ ($\approx 5$ µg/m³).
(2) Number of health effects associated with concentrations of $PM_{10}/PM_{2.5}$ above 5 µg/m³.
(3) Health effects remaining after achieving target concentration. Includes only effects above 5 µg/m³.
(4) Reduction in health effects above 5 µg/m³.

Derived from Section III.5, Table III.5.4 and Figure III.5.3.

None of the other benefit categories have been quantified with respect to the postulated emission reductions or potential ambient concentration scenarios identified for analysis in this study. Previous work by the Ministry has produced estimates of increased crop production, human health benefits, enhanced production and value of ornamental plants associated with specific scenarios of reduced ground level ozone concentrations associated with reductions in NOx/VOC emissions (Ontario Ministry of Environment & Energy, June 1996; Economics Office, 1993).

The Acidifying Emissions Task Group (October 1997), a federal-provincial task force, produced estimates of benefits associated with further reductions in $SO_2$ emissions and acidic deposition in Ontario and elsewhere. However, these estimates cannot be extrapolated to the current situation because it requires the use of the Air Quality Valuation Model which is maintained by Environment Canada. Consequently, the estimates of health effects presented in this report are likely to be understatements of the actual quantities and values of the beneficial consequences of IP/RP controls.

### IV.6.3 Monetary Values of Reduced Heath Effects

Monetary values are used to transform estimates of health and environmental effects into a common unit that can be summed and compared with each other and with the costs of implementing control or management programs. Monetary values also provide an indication of the relative social or economic importance or weight of the benefits relative to other goods and services. Other units of value or weighting units have been proposed for environmental benefits and damages but monetary values are the most widely understood and accepted measures of social value.

Monetary values are fundamentally based on the maximum amount people would be willing to pay (WTP) to obtain a particular good, service or benefit. Where market prices are available for relevant benefit measures or can be used to determine the value of a good or service (e.g., agricultural crops, materials and structures, cost of medical service, etc.) monetary value estimates are uncontroversial and generally acceptable. Where benefit categories are non-marketed or public goods with no market prices associated with them (e.g., mortality, reduced activity days caused by pollutants, perceptions of environmental quality, etc.), specialized methods and techniques must be applied to estimate the relevant WTP monetary values. One method is to use expenditures on marketed goods and services that are complements to environmental quality to infer the value of increase environmental protection. Another is to ask people carefully designed questions to elicit their willingness-to-pay values for non-marketed environmental goods and services.

Some readers are inclined to attribute far less credibility to estimates of monetary values that are based on contingent value surveys than to estimates of savings in expenditures on marketed goods and services such as health care costs and other expenses associated with premature deaths associated with pollutants. On the other hand, out-of-pocket expenses associated with health care seldom capture the full amount that people individually or collectively are willing to spend to try to avoid morbidity effects or to reduce risks of premature mortalities. Consequently, ignoring the so-called "notional values" that studies have indicated that people are willing to pay to reduce health effects and protect against them will result in under-estimates of the true values that people place on these benefits.

The appropriate monetary values of the human health effects associated with $PM_{10}$ levels of 40 ug/m3, 50 ug/m3 and 60 ug/m3 are the amounts that people are willing to pay to avoid mortalities and morbidity effects (illnesses) or to gain reductions in risk of adverse effects. Unit WTP values have been derived from Lang *et al.* (October 1995) and include "low", "central" and "high" values per incident or death and are summarized in Table IV.9. These values were originally developed for use in a study on clean vehicles and fuels prepared for the Canadian Council of Ministers of the Environment (CCME) and were used for estimating the monetary value of benefits associated with reductions in smog (Inhalable particulates and ozone) levels (Chestnut, August 1995; MOEE, June 1996). These values are deemed to be appropriate for the present exercise because the relative values of the various effects have not changed over the past 3 years. As noted, some of the unit values listed in Table IV.9 are based on health care costs which were then adjusted (by multiplying cost of illness values by 3) to make them equivalent to WTP values. These values are supported by numerous research studies and peer-reviewed articles which are cited in the Lang *et al.* paper.

Monetary value estimates of health effects can vary widely because both the physical estimates and the monetary values are presented as high, central and low ranges. Therefore, the low estimates of mortality and morbidity effects can be multiplied by the low appropriate unit value to get the "lowest" value estimate of health effects. Similarly, high estimates of effects can be multiplied by high unit values to reveal the "highest" value estimate of a particular health effect.

Estimates of the values of each health effect change associated with each ambient concentration target have been estimated using the Central estimates of health effects (as shown in Table IV.9) multiplied by the high, medium and low unit values of each effect. These undiscounted value estimates are summarized in Tables IV.10, IV.11 and IV.12.

**Table IV.9 Monetary Values of Morbidity and Mortality Effects**

| | LOW ($) | CENTRAL ($) | HIGH ($) | Type |
|---|---|---|---|---|
| **MORTALITY** | | | | |
| Age Weighted Average | 2,400,000 | **4,000,000** | 7,900,000 | WTP |
| **MORBIDITY** | | | | |
| Adult Chronic Bronchitis | 174,000 | **279,000** | 442,000 | WTP |
| Cardiac Hospital Admission | 4,200 | **8,300** | 12,500 | CO1 |
| Respiratory Hospital Admission | 3,300 | **6,500** | 9,800 | COI |
| Emergency Room Visit | 300 | **600** | 900 | COI |
| Child Acute Bronchitis | 180 | **360** | 540 | COI |
| Restricted Activity Day | 35 | **70** | 105 | WTP |
| Asthma Symptom Day | 15 | **41** | 68 | WTP |
| Minor Restricted Activity Day | 18 | **30** | 50 | WTP |
| Acute Respiratory Symptom Day | 7 | **14** | 20 | WTP |
| Probability for Uncertainty (1) | 33% | **34%** | 33% | |

**WTP** = Willingness to Pay, **COI** = Cost of Illness (adjusted to yield an equivalent WTP value).

Source: Environmental and Health Benefits of Cleaner Vehicles and Fuels, Supplemental Report 3, Hagler Bailly Consulting, August 1995.

(1) Probability distributions could differ from these values if further empirical studies of contingent values or cost of illness were carried out.

For example, the most stringent reduction in ambient concentration would be to 40 ug/m$^3$. As shown in Table IV.10, the total WTP value of premature mortality risk reductions ranges from $1.7 to $5.7 billion. Table IV.12 indicates that achieving the less stringent 60 ug/m$^3$ target across the province would be valued at between $619 million to $2 billion per year just for reducing premature mortality risks.

Morbidity (illness) effects for the 40 ug/m$^3$ total to $1.1 billion to $3 billion per year in WTP terms. The 60 ug/m$^3$ level would be valued from $400 million to $1.1 billion per year. Total mortality and morbidity benefits could be valued at between $2.8 billion and $8.7 billion per year for the 40 ug/m$^3$

target and between $1.1 billion and $3.1 billion for the 60 ug/m$^3$ target. As noted, this range of estimates assumes only the central estimates of health effects in calculating monetary values.

As of the 1996 census, there were about 11.2 million people in Ontario. These values amount to between $294 and $946 per person for the 40 ug/m$^3$ air quality target and between $ 98 and $286 per person for the 60 ug/m3 target.

The most extreme ranges of these values would be a minimum of $536 million at the 60 ug/m$^3$ target (low estimates of effects times low unit values) to a maximum of $25 billion per year at the 40 ug/m$^3$ target level (high estimates of effects times high unit values). These extreme ranges of estimates can be narrowed by assigning probabilities to the high, central/medium and low estimates of effects and unit values. It is likely that the extremes (highs and lows) will have a lower probability (likelihood) than the central estimates. Lacking evidence of such weights, equal likelihoods have been applied to all estimates, as indicated in Table IV.9.

**Table IV.10 Values of Reduced Mortality and Morbidity Health Effects of ($PM_{10}$) Associated with Target Concentration of 40 $\mu g/m^3$ (1) ($Millions) (R)**

| Unit Value Used (2) | Premature Mortality | Adult Chronic Bronchitis | Respiratory Hospital Admissions | Cardiac Hospital Admissions | Emergency Room Visits | Asthma Symptom Days | Restricted Activity Days | Acute Respiratory symptoms | Bronchitis in Children | Total Morbidity | Total Value of Benefits |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Low | 1,728.0 | 846.9 | 1.0 | 1.1 | 7.7 | 4.5 | 154.9 | 96.2 | 8.6 | 1,121 | 2,849 |
| Medium | 2,880.0 | 1,357.9 | 2.0 | 2.2 | 15.4 | 12.3 | 309.8 | 192.4 | 17.2 | 1,909 | 4,789 |
| High | 5,688.0 | 2,151.2 | 3.1 | 3.3 | 23.1 | 20.5 | 464.6 | 274.9 | 25.8 | 2,967 | 8,655 |

Notes:
Revised 23 November 1998
(1) Based on Central estimates of health effects including non-controllable component.
(2) Values represent Willingness to Pay to gain health benefits or avoid health effects.

### Table IV.11 Values of Reduced Mortality and Morbidity Health Effects of ($PM_{10}$) Associated with Target Concentration of 50 µg/m³ (1) ($Millions) (R)

| Unit Value Used (2) | Premature Mortality | Adult Chronic Bronchitis | Respiratory Hospital Admissions | Cardiac Hospital Admissions | Emergency Room Visits | Asthma Symptom Days | Restricted Activity Days | Acute Respiratory symptoms | Bronchitis in Children | Total Morbidity | Total Value of Benefits |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Low | 1,108.8 | 543.2 | 0.7 | 0.7 | 4.9 | 2.9 | 99.4 | 61.7 | 5.5 | 719 | 1,828 |
| Medium | 1,848.0 | 871.0 | 1.3 | 1.4 | 9.9 | 7.9 | 198.7 | 123.5 | 11.0 | 1,225 | 3,073 |
| High | 3,649.8 | 1,379.9 | 2.0 | 2.1 | 14.8 | 13.1 | 298.1 | 176.4 | 16.5 | 1,903 | 5,553 |

Notes:
Revised 23 November 1998
(1) Based on Central estimates of health effects including non-controllable component.
(2) Values represent Willingness to Pay to gain health benefits or avoid health effects.

### Table IV.12 Values of Reduced Mortality and Morbidity Health Effects of ($PM_{10}$) Associated with Target Concentration of 60 µg/m³ (1) ($Millions) (R)

| Unit Value Used (2) | Premature Mortality | Adult Chronic Bronchitis | Respiratory Hospital Admissions | Cardiac Hospital Admissions | Emergency Room Visits | Asthma Symptom Days | Restricted Activity Days | Acute Respiratory symptoms | Bronchitis in Children | Total Morbidity | Total Value of Benefits |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Low | 619.2 | 303.6 | 0.4 | 0.4 | 2.8 | 1.6 | 55.5 | 34.5 | 3.1 | 402 | 1,021 |
| Medium | 1,032.0 | 486.9 | 0.7 | 0.8 | 5.5 | 4.4 | 111.0 | 69.0 | 6.2 | 685 | 1,717 |
| High | 2,038.2 | 771.3 | 1.1 | 1.2 | 8.3 | 7.3 | 166.6 | 98.6 | 9.2 | 1,064 | 3,102 |

Notes:
Revised 23 November 1998
(1) Based on Central estimates of health effects including non-controllable component.
(2) Values represent Willingness to Pay to gain health benefits or avoid health effects.

These estimates are substantial and imply that further reductions in exposures to fine particulate matter warrant serious consideration.

Ideally, estimates of health and other benefits and their monetary values should be compared with abatement cost estimates in order to judge which ambient quality target and/or level of abatement should be pursued.

### IV.6.4 Comparison of Benefits and Costs

The reader should note that a direct comparison of the value of benefits and cost estimates developed in this report is limited by the lack of dispersion modelling to determine how emission reductions at given sources will reduce ambient pollutant concentrations and exposures over specific communities or regions.

However, based on the "roll back" assumptions used to estimate the numbers of health effects that could be reduced if ambient concentrations were reduced by the same percentage as emissions from key sources, tentative comparisons of values of benefits estimates and costs are presented below. Because abatement costs and benefits would likely be incurred or realized in the future, these estimates must be discounted to be comparable.

The following assumptions and computations were made in order to compare the costs and the value of health benefits generated in this analysis.

1) Under the "roll back" analysis discussed in Section III.5, emission reductions are assumed to be proportional to target reductions in average ambient concentrations across the province.
2) Potential net benefits (cost savings, etc.) estimated for certain $NO_x$ and VOC source categories were removed from the cost estimates and added to the value of benefits.
(3) Least-cost estimates to achieve each emission reduction goal were used in these comparisons.
(4) Costs would be incurred first in 1998 and continue annually for 11 years (to 2008). The discounted sum of these costs over 11 years would be the total costs of the scenarios.
(5) Reduced mortalities and morbidity effects are assumed to start to be realized in year 11 and continue indefinitely. For purposes of this comparison, the health benefits and their associated monetary values are estimated, discounted and summed over 10 years (year 11 through year 20).
(6) A real discount rate of 4% was used in the present value calculations, consistent with the applications in the Ontario Smog Plan analysis (Ontario Ministry of Environment & Energy, June 1996).

The present values of health-related benefits between year 11 and year 20 (10 years) were summed and compared with the summed present value of the costs that would be incurred between years 1 through 11 (11 years). Low and median values of benefits are shown. A single year value and the total discounted values over the relevant time periods are presented in Table

IV.13 for both costs and benefits. Because abatement costs could be +/- 30%, total discounted costs over 11 years are shown as 30% higher in Table IV.13. Only low and median values of benefits are shown.

It is clear that the value of the health benefits alone exceed the costs of abatement for each of the emission reduction/ambient quality scenarios. Even where abatement costs are increased by 30%, the low estimate of the present value of benefits exceeds the present value of costs.

As noted earlier, the link between reduced direct and precursor emissions (and their associated costs) and changes in ambient contaminant concentrations and exposures (and the resulting reductions in health effects) should be confirmed by atmospheric modelling. Furthermore, the monetary values attributed to statistical lives and to certain morbidity (illness) effects could be revisited and any new values revealed from this review could then applied to the analysis.

## Table IV.13 Summary of Costs of Achieving Emission Reduction Scenarios and the Benefits of Achieving Province-wide Average Ambient Quality Reduction Goals over 20 years (1)

| Emission Reduction/Ambient Quality Goals | Total Costs (2) | | | Value of Benefits (3) | | | |
|---|---|---|---|---|---|---|---|
| | 1998 Annualized ($ mil/year) | Total Discounted over 11 years (Mill $) | | Low | | Central/Medium | |
| | | 1998 | 30% higher | Annual in year 11 ($ 1998 mil/year) | Total PV Over 10 years (1998 $ mil.) | Annual in year 11 ($1998 mil/year) | Total PV Over 10 years (1998 $ mil.) |
| 19% Reduction/60 μg/m$^3$ | $146 | $1,332 | $1,732 | $900 | $7,591 | $1,273 | $10,744 |
| 34% Reduction/50 μg/m$^3$ | $678 | $6,180 | $8,034 | $1,348 | $11,780 | $2,188 | $19,155 |
| 53% Reduction/40 μg/m$^3$ | $1,300 | $11,680 | $15,184 | $2,039 | $17,195 | $3,349 | $27,861 |

Notes

Revised 23 November 1998

(1) It is conservatively assumed that emission reductions would be implemented over 11 years before health effects benefits start to be realized in year 11. Therefore, the value of health effects benefits during years 11 through 20 are discounted to 1998 $.

(2) Cost savings and net revenues were removed from NOX and VOC scenario estimates and included with Value of Benefits estimates. Therefore, costs show here are higher than net costs displayed in Table IV.7.

(3) Value of reduced mortalities and morbidity (illness) effects are based on "central" estimates of reduced effects derived from Section III. Low and medium estimates refer to low and medium unit values applied to central estimates of specific health effects displayed in Table IV.8.

If benefits are actually realized earlier than year 11, the value of benefits will not have to be discounted as much so that benefits will exceed costs to a greater extent.

Adding the non-quantified benefits that are associated with the emission reductions would only enhance the value of potential benefits.

## IV.7 Findings and Conclusions

Findings presented here are tentative, subject to revisions to base case emissions and potential modelling work to link more closely costs with benefit scenarios. So far, the analyses indicate that an economic case may be made for further reductions of air pollution emissions that form fine particulate matter in the atmosphere. At the 60 µg/m3 ambient goal, which is equivalent to the 19% emission reduction target, the present value of benefits exceed the present value of abatement costs over 10 year by at least 2 : 1.

As noted, reductions in $SO_2$, $NO_X$, VOC and direct PM10 emissions will result in other beneficial consequences, including increased crop production (from reduced ozone), reduced soiling and materials damages, increased aquatic recreational opportunities, increased visibility and enhanced enjoyment of a cleaner environment which have not been quantified or valued in this analysis. Even without estimates of these benefits, the economic case for further reductions appears optimistic.

Although the value of benefits appear to exceed abatement and prevention costs at all three potential reduction goals, the costs associated with a 53% emission reduction could total as much as $1.7 billion. The costs associated with the 34% reduction goal would amount to less than one-half of the 53% reduction scenario. Although financial impacts of these costs on industrial and other sources have not been assessed as yet, it is clear that the costs associated with the 19% and 34% reduction scenarios would impose much lower financial burdens than the more stringent 53% (equivalent to a 40 µg/m3 ambient quality goal).

The analytical procedure which would yield more accurate estimates of costs and benefits involves the use of air quality source-receptor models to estimate either the amounts and locations of emission reductions needed to achieve specific ambient air concentration targets, or the average ambient air concentrations that would be achieved as a result of potential emission reduction programs at specific sources.

Costs associated with other overall emission reduction targets can be estimated with the aggregate abatement cost functions in Appendix C. For example, Table III.1.1 indicates that industrial processes emitted about 67 kilotonnes of PM10 in 1995. A 10% reduction in $PM_{10}$, the reduction in particulates contemplated under the Smog plan, would amount to 6.7 kilotonnes per year. According to Table C.1, 8.7 kilotonnes of PM10 could be reduced point-source industrial plants at a cost of about $2.6 million per year and only two plants would have to implement reductions. Equivalent 10% reductions in $SO_2$ and $NO_x$ emissions could, according to Tables C.1 and C.3, cost as much as $7.4 million plus $2.7 million respectively or about $10 million per year. According to Table C.5, a 10% reduction in VOC could be achieved at net savings to the sources that implemented reductions.

It is clear that substantial effort would be needed to achieve a 34% reduction in NOX emissions, much less a 53% reduction. To the extent that private benefits associated with VOC and NOX reductions remain unexploited, less effort may need to be applied to these contaminants than to $SO_2$ and NOX in order to achieve reduction goals.

The cost analysis is only part of what is required to achieve the province-wide ambient quality goals. Added reductions may be required in some communities where concentrations are higher than the average ambient concentrations assessed above. Furthermore, a key omission from the cost analysis is the costs of reducing direct emissions of total and fine particulate matter from area sources. Atmospheric modelling work would be needed to determine whether reductions in direct emissions of particulate matter as well as indirect sources of fine particulate matter would have a material effect on changes in ambient air quality and the health effects associated with these pollutants.

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# V CONCLUSIONS

In the preceding sections of this document a considerable amount of information on atmospheric fine particulate matter has been presented. In particular, the origins of IP and RP are understood in good outline. This picture is complicated by the fact that particles are emitted directly to the atmosphere, but are also formed by the reaction of gaseous precursors. However, all the precursors are known, and estimates of emissions have been made.

A considerable effort has been devoted in Ontario to the monitoring of IP and RP, and the data base will continue to grow. The development and implementation of real time monitors has been a significant advance in this respect.

Both in Ontario and elsewhere a number of studies have been carried out on the health impacts of airborne fine particulate matter. The detailed interpretation is still subject to considerable debate, particularly with regard to the role played by co-pollutants found in the atmosphere, but the evidence linking IP/RP to health effects is strong enough to warrant action. In developing the strategies for IP/RP, an analysis of the benefits and costs will play an important role. This is a complex, demanding exercise, whose initial steps have been laid out in this document.

However, even though a large body of knowledge is available, and has been collected in this document, it is acknowledged that data gaps still exist. A number of research needs are identified below.

1. Formation of secondary particulates – mechanisms are complex and not well understood; final composition of particle reflects the chemistry of the primary pollutants and may be modified by meteorology, i.e., temperature, humidity, pollutant levels and other atmospheric conditions.

2. Accurate $PM_{10}$ and $PM_{2.5}$ inventories are needed to assess various control options and to gauge the potential effectiveness of proposed environmental plans and reduction targets.

3. Quantification of the primary and secondary particulate emissions from transboundary sources and determining their effect on air quality in Ontario remains a scientific challenge.

4. Models needed to predict the complex movement and transformation of precursor gases and primary particulates are still under development.

5. Emission inventories of key ingredients (including ammonia, primary fugitive dust and VOCs) are not detailed enough to give reliable results in model simulations.

6. Measurement (ambient air and at source) of PM needs to be improved in the time and

space scales, and speciation, e.g., size range, chemical make-up, shape, etc. to provide basis for source apportionment and health effect assessment.

7. Health effects: work is needed in several areas, including elucidation of the basic mechanism of toxicity of particles, and detailed assessment of the interactive effects of particles and gaseous pollutants; further investigation is needed into which is the most important determinant of particle toxicity, size, number or mass.

8. Control technology applications which are cost effective and environmentally effective.

9. Benefit-cost analysis needs to be updated with current emissions and technology information.

10. Integrated studies (synergies) – changes in emission control of one pollutant may have *nonlinear* effects on other air pollution phenomena.

Because our knowledge of the IP/RP issue is incomplete, concerted efforts are required to bridge the knowledge gaps to prepare Ontario's readiness to develop a comprehensive IP/RP reduction strategy. The following efforts are recommended for bridging these gaps.

1. Monitoring and assessment are required: more ambient air monitoring and source characterization, and assessment will be required, using harmonized pollution measurement methods and network design. Partnerships are encouraged.

2. Additional IP/RP - related research is necessary: further IP/RP related research is needed to fill knowledge gaps; especially in the areas of culpability of $PM_{10}$ vs. $PM_{2.5}$, emission inventories (e.g., IP/RP, $NH_3$, particle sizing information), modelling capability development, benefit-cost assessment, and use of economic instruments (e.g., emission reduction trading).

# Appendix A: Methodologies in Estimating Particulate Matter Emissions in Ontario

## General Approach

The particulate emissions can generally be estimated with the following equation

$$E = A \times EF \times (1 - CTRL/100) \times ADJ \qquad [kg] \qquad (1)$$

Where
E = Emissions, kg
A = Activity Rate (or Base Quantity), unit
EF = Uncontrolled Emission Factor, kg/unit
CTRL = Effective Removal efficiency of control equipment, %
ADJ = Adjustment Factors, dimensionless

The important task in emission estimation is to gather the representative activity rate and the corresponding emission factors for each source category. In some cases, the adjustment factors may be needed to bring the activity rates or emission factors to account for the seasonal variations (e.g. the slowdown of construction activities in winter, minimal emissions from agricultural activities in rainy or snow covered periods, etc)

The estimation of particulate emissions from road dusts involved many variables and will be discussed in details in their respective sections.

The following paragraphs will describe briefly how these activities and emission factors were collected for each category.

## Industrial Point Sources

Point sources are large, stationary, identifiable sources of significant pollutant releases. Point sources process and activity information were obtained from the 1995 emission survey. Particulate emissions were estimated from these process information using source specific factors or generic factors whichever are appropriate. Effective removal efficiencies of any control equipment on the particulate size were considered in estimating $PM_{10}$ and $PM_{2.5}$ emissions.

There are some industrial activities that were not covered by the emission survey were considered in the area sources balance-out approach. Provincial activity statistics for selected industrial sectors were compared with the surveyed activity levels, any unaccounted industrial activities were estimated in order to generate a complete emission profiles for these sectors.

## Mobile Sources

| Category/Sector | Source of Activity Level/Emission Factors |
|---|---|
| Air Transportation | The aircraft operating statistics (land and take-off cycles, flight time) were obtained from Transport Canada's statistics. The Modal emission factors were extracted from the Federal Aviation Administration's Aircraft Engine Emissions Database (AEED) of the US Department of Transportation for different categories of aircraft engine. |
| On-Road Vehicles | The particulate emissions from the road vehicles were estimated using the U.S. EPA PART5 model. The model will generate the exhaust particulate emission factors as well as the brake lining and tire wear for different categories of vehicles. The emissions were obtained by multiplying these factors to the annual vehicle travelling distance (vkmt). |
| Marine Transportation | Marine emissions were estimated for their dockside and underway operations. Vessel movement and port operating statistics were obtained from Statistics Canada. Emissions factor and methodologies from Polar Design Associates Ltd. (report: Marine Atmospheric Pollution in Canadian Waters) were adopted to estimate the emissions. |
| Pleasure Crafts | The number of pleasure crafts were interpolated from the 1990 and 1992 survey. Emission factors from U.S. AP42 document were used for estimating emissions in this sector. |
| Off-road Vehicles/Engines/ Equipment | Statistics Canada provided the diesel/gasoline consumption for different sectors and the estimated percentages used for off-road vehicles. Emission factors from U.S. AP42 document were used for estimating emissions from different industrial sectors and engine sizes. The emissions from other off-road engines/equipment (such as lawnmowers, snowmobiles and snow blowers were estimated from the number of units and emissions factors from AP42 and non-road emission factors database (NEVEZ ) of the Office of Mobile Sources of US-EPA. |
| Railroad Transportation | The diesel fuel consumed by the locomotive were obtained from Statistics Canada Report and the emissions factors from AP42 and the emissions monitoring results by Environment Canada were used. |

## Area Sources

Area sources are group of smaller and widespread sources which individually release small amount of pollutants, e.g. dry-cleaners, gasoline service station, quarrying, residential fuel combustion, consumer solvent use and fires.

### ***Stationary Fuel Combustion***

The fuel demanded by the residential, agricultural, public administration and commercial sectors were obtained from Statistics Canada. The amount of residential fuel wood consumption is projected from the 1993 Logging Statistics/fuelwood production. Emissions factors from AP42 and Environment Canada's tests results were used to estimate emissions. Emissions from the industrial fuel combustion were reconciled with the point source information, any unaccounted industrial fuel consumption (Statistics Canada reported value less point source survey totals for each sector) were estimated for each industrial sector.

Emissions from the utilities sectors were estimated under the point source methodologies with survey information provided by the Ontario Hydro.

### ***Incineration/Miscellaneous Sources***

Information were obtained from various statistics and reports, such as average waste generation per capita in waste incineration; number of bodies cremated; amount of fertilizer sold; average cigarette smoking per capita, amount of meat consumption; and number of structural fires. Appropriate factors were used in each sector.

## Open Sources

Open sources are sources that are emitting emission over a large area. The open sources that are considered in the Ontario IP/RP emission inventory are: agriculture animals, agriculture tiling, construction, road dusts (paved and unpaved road), landfill sites, mine tailing, prescribed burning and the "natural sources": agriculture wind erosion and forest fires.

### ***Road Dust***

One major source of fine particulate in Ontario is road dust resulting from vehicle traffic. USEPA has developed generic equations to estimate particulate emissions from paved and unpaved roads. Depending on road dust source conditions, such as moisture contents, silt loading and contents, the resulting emission calculations can span several orders of magnitude. In order to generate better $PM_{10}$ and $PM_{2.5}$ emissions from paved and unpaved roads in a given geographic location, it is advisable to use direct source field test data. In the absence of the field test data, interpolation of measured data from other areas which have similar climate pattern and geological features would be the next best choice.

The National Emission Inventory and Projection Task Group (NEIPTG) had initiated a study to measure the Canadian road silt content in order to refine the input parameters in the estimation of particulate emission from roads. Limited field tests on the silt content were conducted in selected roads in Ontario and British Columbia that represented most of the Canadian roads at different seasonal conditions.

The length of different road categories ("Highway", "Primary Road", "Secondary Road", "Residential Street" and "limited-Access Road") were extracted from the highway geographic information system. Traffic loading for different road categories were estimated from available traffic count statistics from the Ministry of Transportation and municipalities. The travel pattern on unpaved roads from California approach of 10 daily vehicle-km travelled (vkmt) per km of unpaved road was adopted. The silt content for paved and unpaved roads for different road categories were derived from the NEIPTG Road Dust Test Report and extrapolated to the rest of the untested regions of Ontario.

Basic $PM_{10}$ & $PM_{2.5}$ Emission Factor Equations

Dust emissions from paved roads have been found to vary with the silt loading present on the road surface as well as the weight of vehicles traveling on the road. For unpaved road, besides the variables of silt content and vehicle weight, the dust emissions also vary with vehicle speed, average number of vehicle wheels and the ratio of days where dust emission is significant. Environment Canada has adopted the EPA road dust equations but has applied seasonal adjustments to account for winter days when roads are covered by snow. The modified equation are given as follows :

*Paved Road*

Road dust due to traffic

$$E = k^* (SL/2)^{0.65} (W/3)^{1.5} ((365\text{-snow})/365) \qquad [g/vkmt] \qquad (2)$$

and $k = 4.6$ for $PM_{10}$, 1.1 for $PM_{2.5}$

*Unpaved road*

Road dust due to traffic

$$E = k^*1.7^*(s/12)^*(S/48)^*(W/2.7)^{0.7}{}^*(w/4)^{0.5} * ((365\text{-}(p\text{+snow}))/365) \qquad [g/vkmt] \qquad (3)$$

and $k = 0.36$ for $PM_{10}$, 0.095 for $PM_{2.5}$

Unpaved Road dust entrained to air due to wind erosion

$$Es = a\, I\, C\, K\, L'\, V' \qquad [g/m^2] \qquad (4)$$

WhereE = particulate emission, g/vkmt
Es = wind erosion particulate emission, $g/m^2$

$SL$ = silt loading, g/m$^2$ (for paved roads)
$W$ = ave. vehicle weight, tons
$s$ = silt content, % (for unpaved roads)
$S$ = mean vehicle speed, km/hr
$w$ = mean number of vehicle wheels
$p$ = number of wet days with at least 0.254 mm precipitation
snow = number of days in year with snow covered roads
$a$ = portion of the total roadway wind erosion loses that are assumed to be suspended into air, estimated to be 0.038 for TSP
$I$ = soil erodibility, tons/acre/year
$C$ = Climate factor, dimensionless
$K$ = surface roughness factor, dimensionless
$L'$ = unsheltered field width erosion factor, dimensionless (unprotected width of the area in the prevailing wind direction)
$V'$ = vegetative covered factor, dimensionless

### ***Other Open Sources***

| Category/Sector | Source of Activity Level/Emission Factors |
|---|---|
| Agriculture Tiling | The area of field crop was obtained from Statistics Canada/Agricultural Canada. Particulate emissions were estimated by multiplying the crop area, the silt contents, type of tilling, number of tilling by crops and the associated emission factors. |
| Agriculture wind Erosion | Emission factor is based on the same EPA equation (eq. 4 above) for the wind erosion for the unpaved road. The emission factor is then applied to the total agricultural area to estimate particulate emissions. |
| Agriculture (Animals) | Statistics Canada provided the population counts for cattle, pigs and hogs, sheep and lambs, poultry and horses. Particulate emission factors (kg/head of animal) were based on US-EPA and BC/GVRD data. Climate factor was considered to account for no emission during rainy days. |
| Construction | Particulate emissions were estimated base on the type of constructions, the area of construction and the duration of the construction. |
| Landfills | Landfills waste quantities were estimated from the waste generated by industrial and by capita for municipal, commercial and institutional sectors. Emissions were calculated by multiplying the total waste with appropriate emission factors adopted from British Columbia (BC) and California Air Resources Board (CARB). |

| | |
|---|---|
| Prescribed Burning | The area of forested burned by prescribed method were obtained from Canadian Forest Services/Forestry Canada. Particulate emission factors (per kg of wood burned) from AP-42 were modified to reflect Canadian forest. Particulate emissions were calculated by multiplying the quantity of wood burned with the emission factors. |
| Forest Fires | Emissions were calculated multiplying the hectare of forest burned with emission rate. |

## IP/RP Emissions Estimation Update

Since the release of the first version of 1995 particulate emission estimates, there has been continuing refinement of the estimates. The National Emission Inventory Projection Task Group (NEIPTG) has conducted field study/survey and acquired updated activities statistics which affected the emission estimates. The following is a summary of the major updates on this version of the emission estimates.

| Category/Sector | Update |
|---|---|
| Industrial Process-Area Sources | Revised emission factors and the reconciliation of the point source emissions |
| Fuel Combustion | Reconciled with point sources emissions sector by sector |
| Road Dusts | Updated road type statistics; and updated emission factors based on the NEIPTG road silt content field measurement |
| Construction | Updated activities statistics and emission factors |
| Prescribed Burning/ Forest Fires | Updated emission factors |
| Agriculture Operations | Updated emission factors |
| Agricultural (Animal) | Updated emission factors based on California and British Columbia methodologies |

# APPENDIX B: DEFINITIONS

The description of any two phases dispersed into one another is often done based on the size distribution of the dispersed phase. In this document, the dispersant is always air. The dispersed phase is often solid (as in dusts and many fumes) but it may also be liquid (as in some fumes and fogs) and sometimes a combination of the two (as in soot).

There is always some variation in the size of the particles comprising the dispersed phase and, for ease of further treatment, an average size, most often expressed as an average diameter, is used to describe the whole population. Because the shape of the solid (dispersed) phase can sometimes exhibit extreme variations, e.g., from spherical to long stringy filaments, it is important to define exactly the meaning of such an average.

Some definitions arise from the method by which the diameter is measured. Some others, arise from the method of looking at the distribution of size relative to the number of particles in the sample. Yet another set of definitions arises from the need to define the average in terms of the important parameters that influence the physical and chemical behaviour of the particles. Since the average diameter of the particles contained in a sample may differ greatly according to how it was calculated it is important that the calculation method reflects the intended use of the number.

## B.1 Definitions Based on the Measurement Technique

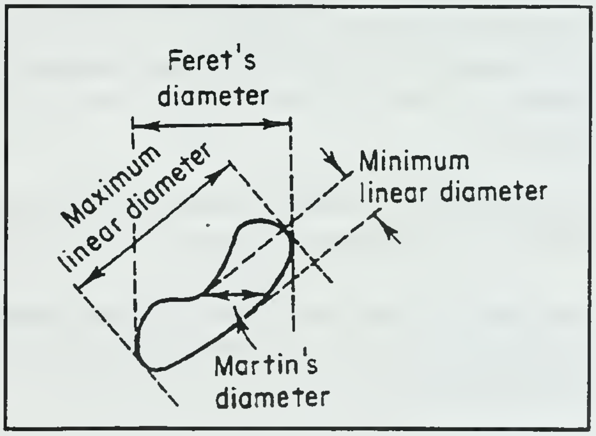
### *B.1.1 Microscopy Techniques*

Many particle size distribution calculations rely on the measurement of individual particles collected on a transparent substrate and evaluated by direct measurements under a microscope. For odd shaped particles the method could produce:

- the *minimum linear diameter* (the shortest distance between two parallel lines tangent to the perpendicular projection of the particle in the measuring plane);

- the *maximum linear diameter* (the longest distance between two parallel lines tangent to the perpendicular projection of the particle in the measuring plane);

- *Feret's diameter* (the perpendicular projection onto a fixed direction of the distance between the two parallel lines,



parallel with the fixed direction, tangent to the extremities of the perpendicular projection of the particle in the measuring plane);

- *Martin's diameter* (the length of the line, parallel to a fixed direction, that divides the perpendicular projection of the particle in the measuring plane into equal areas).

### *B.1.2 Aerodynamic Behaviour Techniques*

Samples of particles of various sizes, shapes, or densities, are often compared, in terms of their aerodynamic behaviour, with uniform ideal particles, defined as spheres of unit density. Settling techniques (either in air or liquids) define the *average aerodynamic diameter* of a sample population as the calculated diameter of ideal particles exhibiting the same aerodynamic behaviour as the sample population (quantified as, for example, their settling speed). For the purpose of this document the Stokes settling regime (i. e.: the Reynolds number for the disperse phase is less than approximately two) is the one of interest.

Experiments conducted under different standard methodologies produce slightly different results.

### *B.1.3 Weighing and Counting Techniques*

When the total mass of dispersed phase and the number of particles involved are known, the *mean mass diameter* can be a useful reference number. This is the average diameter that a population of uniformly sized particles would have if their total number and mass would be equal with the total number and mass of the particles in the actual sample. Most often, the shape of the uniformly sized particles is assumed to be spherical. It is also assumed that the population consists of particles of uniform density.

A closely related definition is that of the *mean volume diameter*.

## B.2 Definitions Based on the Intended Use of the Results

While the aerodynamically equivalent diameter is very useful for the evaluation of the behaviour of particles in their settling down in the environment, including that of people's lungs, calculations of the kinetics involved in the chemical reactions that may be taking place at the surface of the particles, in nature or inside emission control devices, often require the use two other calculated averages:

- the *surface area average diameter*, which is the diameter of a particle in an equal population of uniformly sized particles (of similar density) having the same total surface area as the sample, and

- the *specific surface area average* diameter, which is the diameter of a particle in an equal population of uniformly sized particles (of similar density) having the same specific surface area (i. e.: the surface per unit volume) as the sample.

## B.3 Definitions Based on the Numerical Calculation Method

An average diameter of a sample of particles can be expressed, in terms of the diameter used in the calculation reflecting the total population of particles being evaluated, as a *number mean*, a *median* (the number at which half of the number of particles is smaller and half is larger than the calculated mean), or a *mode mean* (the mean calculated for the most frequently occurring diameter). If the particle size distribution is close to normal (i.e. Gaussian), the three numbers are identical. In practice, the size distribution of atmospheric particles follow a log-normal distribution (i.e. the logarithm of the diameter is normally distributed).

# APPENDIX C: SUPPORTING TABLES FOR
# SECTION IV: ANALYSIS OF BENEFITS AND COSTS

## TABLE C.1 AGGREGATE ABATEMENT COST FUNCTION FOR $SO_2$ - ORDERED BY LOWEST COST PER TONNE REMOVED (1)

| PLANT | CONTROL TECHNOLOGY | INITIAL EMISSIONS (tonnes) | EMISSION REDUCTION/ EFFICIENCIES (3) (%) | EMISSION REDUCTIONS (tonnes) | FINAL EMISSIONS (by source-sector) (tonnes) | CUMULATIVE EMISSION REDUCTIONS (tonnes) | CUMULATIVE FINAL EMISSIONS (tonnes) | CUMULATIVE REDUCTION AS A % OF INITIAL EMISSIONS | $/TONNE REDUCED SO2 ($/tonne) | TOTAL ANNUALIZED COST (per action) ($/year) | CUMULATIVE TOTAL ANNUALIZED COST ($/year) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| INITIAL EMISSIONS (Annual) (2) | | | | | | | 805,000 | | | | |
| Falconbridge, Sudbury | FGD - D.A. | 74,352 | 90.0% | 66,917 | 7,435 | 66,917 | 738,083 | 8.3% | $74 | $4,930,000 | $4,930,000 |
| Algoma Steel, Sault Ste Marie | FGD - D.A. | 13,000 | 90.0% | 11,700 | 1,300 | 78,617 | 726,383 | 9.8% | $212 | $2,479,000 | $7,409,000 |
| Inco, Sudbury (4) | Undefined | 265,000 | 56.6% | 149,990 | 115,010 | 228,607 | 576,393 | 28.4% | $300 | $45,000,000 | $52,409,000 |
| Shell Canada, Corunna | FGD & FS | 13,700 | 95.9% | 13,138 | 562 | 241,745 | 563,255 | 30.0% | $379 | $4,982,000 | $57,391,000 |
| James River Paper, Marathon | FGD - D.A. | 4,500 | 90.0% | 4,050 | 450 | 245,795 | 559,205 | 30.5% | $690 | $2,793,000 | $60,184,000 |
| Novacor, Coronna | FGD - D.A. | 5,600 | 90.0% | 5,040 | 560 | 250,835 | 554,165 | 31.2% | $869 | $4,378,000 | $64,562,000 |
| Dofasco, Hamilton | FGD & FS | 13,440 | 90.6% | 12,177 | 1,263 | 263,012 | 541,988 | 32.7% | $1,092 | $13,296,000 | $77,858,000 |
| Imperial, Nanticoke | FGD & FS | 5,400 | 91.1% | 4,919 | 481 | 267,931 | 537,069 | 33.3% | $1,457 | $7,166,000 | $85,024,000 |
| Imperial Oil, Sarnia | FGD - D.A | 22,100 | 90.0% | 19,890 | 2,210 | 287,821 | 517,179 | 35.8% | $1,536 | $30,544,000 | $115,568,000 |
| Ontario Hydro, ALL PLANTS (5) | Undefined | 175,000 | 75.0% | 131,250 | 43,750 | 419,071 | 385,929 | 52.1% | $2,034 | $267,000,000 | $382,568,000 |
| Petroleum Refineries Group | FGD & FS | 22,800 | 94.4% | 21,523 | 1,277 | 440,594 | 364,406 | 54.7% | $2,495 | $53,698,000 | $436,266,000 |
| Other Manufacturing Group | FGD & FS | 30,200 | 93.3% | 28,177 | 2,023 | 468,771 | 336,229 | 58.2% | $3,998 | $112,644,000 | $548,910,000 |
| Mining & Ores Grouped | FGD & FS | 4,900 | 90.4% | 4,430 | 470 | 473,201 | 331,799 | 58.8% | $4,222 | $18,703,000 | $567,613,000 |
| Other Primary Metals Grouped | FGD & FS | 11,200 | 90.9% | 10,181 | 1,019 | 483,382 | 321,618 | 60.0% | $4,236 | $43,125,000 | $610,738,000 |
| Lake Ontario Cement, Picton | FGD & FS | 1,700 | 92.6% | 1,574 | 126 | 484,956 | 320,044 | 60.2% | $5,658 | $8,906,000 | $619,644,000 |
| Chemical Industries Group | FGD & FS | 6,900 | 93.1% | 6,424 | 476 | 491,380 | 313,620 | 61.0% | $7,946 | $51,047,000 | $670,691,000 |
| Pulp and Paper Grouped | FGD & FS | 17,800 | 92.9% | 16,536 | 1,264 | 507,916 | 297,084 | 63.1% | $8,358 | $138,213,000 | $808,904,000 |
| Misc. Point Sources, Grouped | FUEL SWITCHING | 5,230 | 97.4% | 5,094 | 136 | 513,010 | 291,990 | 63.7% | $10,016 | $51,022,000 | $859,926,000 |
| Stelco, Hamilton | FGD - D.A. | 10,200 | 90.1% | 9,190 | 1,010 | 522,200 | 282,800 | 64.9% | $11,053 | $101,575,000 | $961,501,000 |
| TOTAL | | 703,022 | n/a | 522,200 | 180,822 | n/a | n/a | n/a | n/a | $961,501,000 | n/a |

**Notes:**

(1) Analysis encompasses the 12 largest Ontario stationary sources and 8 industrial sectors Abatement technology combinations and costs chosen from abatement cost functions for individual plants. Technology/cost combinations with lowest cost pe tonne removed were selected for each source.
(2) Based on the Provincial Cap of 805 kt per year inlcuding Inco at regulated limit of 265 kt, Ontario Hydro at regulated limit of 175 kt, Falconbridge at 74 kt plus the 5-year average missions at all other sources. Algoma Ore at Wawa is now closed
(3) Somewhat higher emission reductions are achieved because of technical rigidities in abatement assumptions for each source.
(4) A 57% reduction in emissions at Inco was assumed.
(5) Ontario Hydro thermal power plants are grouped together as one source. An overall 75% reduction in emissions at all power plants was assumed.

Source: MOEE Economic Services Branch files, Senes Consultants, personal correspondence with representatives of Ontario Hydro, Inco and Falconbridge Nickel.

## TABLE C.2 AGGREGATE ABATEMENT COST FUNCTION FOR $SO_2$ - ORDERED BY LARGEST EMISSIONS REDUCED (1)

| PLANT or SOURCE | CONTROL TECHNOLOGY | INITIAL EMISSIONS (tonnes) | EMISSION REDUCTION/ EFFICIENCIES (3) % | EMISSION REDUCTIONS (tonnes) | FINAL EMISSIONS (by source-sector) (tonnes) | CUMULATIVE EMISSION REDUCTIONS (tonnes) | CUMULATIVE FINAL EMISSIONS (tonnes) | CUMULATIVE REDUCTION AS A % OF INITIAL EMISSIONS | $/TONNE REDUCED ($/tonne) | TOTAL ANNUALIZED COST (per action) ($/YEAR) | CUMULATIVE TOTAL ANNUALIZED COST ($/YEAR) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| INITIAL EMISSIONS (Annual) (2) | | | | | | | 805,000 | | | | |
| Inco, Sudbury (4) | Undefined | 265,000 | 56.6% | 149,990 | 115,010 | 149,990 | 655,010 | 18.6% | 300 | 45,000,000 | 45,000,000 |
| Ontario Hydro, ALL PLANTS (5) | Undefined | 175,000 | 75.0% | 131,250 | 43,750 | 281,240 | 523,760 | 34.9% | 2,034 | 267,000,000 | 312,000,000 |
| Falconbridge, Sudbury | FGD - D.A. | 74,352 | 90.0% | 66,917 | 7,435 | 348,157 | 456,843 | 43.2% | 74 | 4,930,000 | 316,930,000 |
| Other Manufacturing Group | FGD & FS | 30,200 | 93.3% | 28,177 | 2,023 | 376,334 | 428,666 | 46.8% | 3,998 | 112,644,000 | 429,574,000 |
| Petroleum Refineries Group | FGD & FS | 22,800 | 94.4% | 21,523 | 1,277 | 397,857 | 407,143 | 49.4% | 2,495 | 53,698,000 | 483,272,000 |
| Imperial Oil, Samia | FGD - D.A. | 22,100 | 90.0% | 19,890 | 2,210 | 417,747 | 387,253 | 51.9% | 1,536 | 30,544,000 | 513,816,000 |
| Pulp and Paper Grouped | FGD & FS | 17,800 | 92.9% | 16,536 | 1,264 | 434,283 | 370,717 | 53.9% | 8,358 | 138,213,000 | 652,029,000 |
| Shell Canada, Corunna | FGD & FS | 13,700 | 95.9% | 13,138 | 562 | 447,421 | 357,579 | 55.6% | 379 | 4,982,000 | 657,011,000 |
| Dofasco, Hamilton | FGD & FS | 13,440 | 90.6% | 12,177 | 1,263 | 459,598 | 345,402 | 57.1% | 1,092 | 13,296,000 | 670,307,000 |
| Algoma Steel, Sault Ste Marie | FGD - D.A. | 13,000 | 90.0% | 11,700 | 1,300 | 471,298 | 333,702 | 58.5% | 212 | 2,479,000 | 672,786,000 |
| Other Primary Metals Grouped | FGD & FS | 11,200 | 90.9% | 10,181 | 1,019 | 481,479 | 323,521 | 59.8% | 4,236 | 43,125,000 | 715,911,000 |
| Chemical Industries Group | FGD & FS | 6,900 | 93.1% | 6,424 | 476 | 487,903 | 317,097 | 60.6% | 7,946 | 51,047,000 | 766,958,000 |
| Miscellaneous Point Source Grouped | FUEL SWITCHING | 5,230 | 97.4% | 5,094 | 136 | 492,997 | 312,003 | 61.2% | 10,016 | 51,022,000 | 817,980,000 |
| Novacor, Coronna | FGD - D.A. | 5,600 | 90.0% | 5,040 | 560 | 498,037 | 306,963 | 61.9% | 869 | 4,378,000 | 822,358,000 |
| Imperial, Nanticoke | FGD & FS | 5,400 | 91.1% | 4,919 | 481 | 502,956 | 302,044 | 62.5% | 1,457 | 7,166,000 | 829,524,000 |
| Mining & Ores Grouped | FGD & FS | 4,900 | 90.4% | 4,430 | 470 | 507,386 | 297,614 | 63.0% | 4,222 | 18,703,000 | 848,227,000 |
| James River Marathon, Marathon | FGD - D.A. | 4,500 | 90.0% | 4,050 | 450 | 511,436 | 293,564 | 63.5% | 690 | 2,793,000 | 851,020,000 |
| Lake Ontario Cement, Picton | FGD & FS | 1,700 | 92.6% | 1,574 | 126 | 513,010 | 291,990 | 63.7% | 5,658 | 8,906,000 | 859,926,000 |
| Stelco, Hamilton | FGD - D.A. | 10,200 | 90.1% | 9,190 | 1,010 | 522,200 | 282,800 | 64.9% | 11,053 | 101,575,000 | 961,501,000 |
| TOTAL (12 plants, 8 Sectors) | | 703,022 | n/a | 522,200 | 180,822 | n/a | n/a | n/a | n/a | 961,501,000 | n/a |

**Notes:**

(1) Analysis encompasses the 12 largest Ontario stationary sources and 8 industrial sectors. Abatement technology combinations and costs chosen from abatement cost functions for individual plants. Technology/cost combinations with lowest cost per tonne removed were selected for each source.

(2) Based on the Provincial Cap of 805 kt per year inlcuding Inco at regulated limit of 265 kt, Ontario Hydro at regulated limit of 175 kt, Falconbridge at 74 kt plus the 5-year average missions at all other sources. Algoma Ore at Wawa is now closed

(3) Somewhat higher emission reductions are achieved because of technical rigidities in abatement assumptions for each source.

(4) A 57% reduction in emissions at Inco was assumed.

(5) Ontario Hydro thermal power plants are grouped together as one source. An overall 75% reduction in emissions at all power plants was assumed.

Source: MOEE Economic Services Branch files, Senes Consultants, personal correspondence with representatives of Ontario Hydro, Inco and Falconbridge Nickel.

## Table C.3 AGGREGATE ABATEMENT COST FUNCTION FOR NOx - ORDERED BY LOWEST COST PER TONNE REMOVED (1)

| PLANT-SECTOR | TECHNOLOGY DESCRIPTION | INITIAL EMISSIONS (2) (tonnes) | EMISSION REDUCTIONS EFFICIENCIES (%) | EMISSION REDUCTIONS (tonnes) | FINAL EMISSIONS (BY SOURCE-SECTOR) (tonnes) | CUMULATIVE EMISSION REDUCTIONS (tonnes) | CUMULATIVE FINAL EMISSIONS (tonnes) | CUMULATIVE REDUCTION AS A % OF INITIAL EMISSIONS (%) | $/TONNE REDUCED (3) ($/tonne) | TOTAL ANNUALIZED COST (3) (per action) ($/YEAR) | CUMULATIVE TOTAL ANNUALIZED COST (3)(4) ($/YEAR) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| INITIAL EMISSIONS | | | | | | | 609,000 | | | | |
| LDGV1 + LDDV2 (light duty gasoline and diesel vehicles) | Reduce VOC from 0.4 to 0.25 g/mile and NOx from 1 to 0.4 g/mile. | 114,000 | 47.0% | 53,580 | 60,420 | 53,580 | 555,420 | 8.8% | ($317) | ($17,001,614) | ($17,001,614) |
| REFINED PETROLEUM (SIC 36) | (for reduction of NOX only) | 14,000 | 50.0% | 7,000 | 7,000 | 60,580 | 548,420 | 9.9% | $387 | $2,711,364 | ($14,290,250) |
| PRIMARY METALS (SIC 29) | (for reduction of NOX only) | 22,000 | 21.0% | 4,620 | 17,380 | 65,200 | 543,800 | 10.7% | $608 | $2,807,943 | ($11,482,307) |
| CHEMICALS IND. (SIC 37) | (for reduction of NOX only) | 16,257 | 45.0% | 7,316 | 8,941 | 72,516 | 536,484 | 11.9% | $938 | $6,865,914 | ($4,616,393) |
| MISCELLANEOUS | (for reduction of NOX only) | 4,188 | 4.0% | 159 | 4,029 | 72,675 | 536,325 | 11.9% | $1,280 | $203,513 | ($4,412,880) |
| ONTARIO HYDRO (SIC 491) | (for reduction of NOX only) | 77,000 | 76.0% | 58,520 | 18,480 | 131,195 | 477,805 | 21.5% | $1,315 | $76,933,116 | $72,520,236 |
| OTHER MANUFACTURING | (for reduction of NOX only) | 14,680 | 2.0% | 235 | 14,445 | 131,430 | 477,570 | 21.6% | $2,113 | $496,484 | $73,016,720 |
| INSP & MAINT (MOBILE VEHICLES) | Enhanced inspection and maintenance program. | 213,420 | 8.0% | 17,074 | 196,346 | 148,504 | 460,496 | 24.4% | $5,205 | $88,878,060 | $161,894,780 |
| NON-FERROUS METALS (SIC 061) | FDG and other technologies at Inco (Sudbury) and Other Non-ferrous Metals | 2,250 | 80.0% | 1,800 | 450 | 150,304 | 458,696 | 24.7% | $3,660 | $6,588,812 | $168,483,592 |
| HDDV1 (heavy duty diesel trucks) | Reduce Nox from heavy duty diesel vehicles from 6.0 to 4.0 g/ghp-hr. | 107,640 | 15.0% | 16,146 | 91,494 | 166,450 | 442,550 | 27.3% | $4,242 | $68,496,486 | $236,980,078 |
| LDGT1 (light duty gasoline trucks) | Reduce VOC from 0.8 to 0.28 g/mile and NOx from 1.7 to 0.7 g/mile. | 29,440 | 50.0% | 14,720 | 14,720 | 181,170 | 427,830 | 29.7% | $9,930 | $146,164,117 | $383,144,195 |
| LDDT1 (light duty diesel trucks) | Reduce VOC from 0.8 to 0.28 g/mile and NOx from 1.7 to 0.7 g/mile. | 920 | 50.0% | 460 | 460 | 181,630 | 427,370 | 29.8% | $23,503 | $10,811,375 | $393,955,570 |
| PULP & PAPER (SIC 27) | (for reduction of NOX only) | 9,000 | 0.1% | 7 | 8,993 | 181,637 | 427,363 | 29.8% | $138,758 | $971,307 | $394,926,877 |
| HDGV1 (heavy duty gasoline trucks) | Reduce Nox from heavy duty gasoline vehicles from 6.0 to 4.0 g/ghp-hr. | 2,760 | 13.0% | 359 | 2,401 | 181,996 | 427,004 | 29.9% | $155,703 | $55,897,412 | $450,824,289 |
| TOTALS | n/a | 627,555 | n/a | 181,996 | 445,559 | n/a | n/a | n/a | n/a | $450,824,289 | n/a |

Notes:

(1) Abatement technology combinations and costs are taken from the report, "Support for the Development of a NOx/VOC Management Plan for Ontario", March 1995. Where more than one technology option is available to reduce emissions from a given source, the technology option with the lowest cost per tonne removed at each source was selected for inclusion in this table.
(2) Based on 1990 Base-case emissions Adjustments have been made in initial emissions for some of the Mobile Source programs.
(3) "Negative" numbers refer to savings or net revenues that result from applying the technology or system. These "low lying fruit" may have been implemented by now and net cost savings from remaining technologies be exploited by now so that net savings may not be available. See "Support for the Development of a NOx/VOC Management Plan for Ontario", March 1995, for further descriptions of these technologies and opportunities for savings.
(4) The actual costs incurred by all sources totals about $467.8 million per year, of which about $17 million per year is offset by cost savings and net revenues from one source category.

Source: MOEE, Economic Services Branch files, Hickling, 1995 and Senes, 1992.

# TABLE C.4 AGGREGATE ABATEMENT COST FUNCTION FOR NOx - ORDERED BY LARGEST EMISSION REDUCED (1)

| PLANT - SECTOR | TECHNOLOGY DESCRIPTION | INITIAL EMISSIONS (2) (tonnes) | EMISSION REDUCTIONS EFFICIENCIES (%) | EMISSION REDUCTIONS (tonnes) | FINAL EMISSIONS (BY SOURCE-/SECTOR (tonnes) | CUMULATIVE EMISSION REDUCTIONS (tonnes) | CUMULATIVE FINAL EMISSIONS (tonnes) | CUMULATIVE EMISSION REDUCTION AS A % OF INITIAL EMISSIONS (%) | $/TONNE REDUCED NOx (3) ($/tonne) | TOTAL ANNUALIZED COST (3) ($/YEAR) | CUMULATIVE TOTAL ANNUALIZED COST (3) (4) ($/YEAR) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| INITIAL EMISSIONS | | | | | | | 609,000 | | | | |
| LDGV1 + LDDV2 (Light Duty Gasoline and Diesel Vehicles) | Reduce VOC from 0.4 to 0.125 G/mile and NOx from 1 to 0.4 G/mile. | 114,000 | 47.0% | 53,580 | 60,420 | 53,580 | 555,420 | 8.8% | ($317) | ($17,001,614) | ($17,001,614) |
| Ontario Hydro (Sic 491) | (For Reduction of NOx Only) | 77,000 | 76.0% | 58,520 | 18,480 | 112,100 | 496,900 | 18.4% | $1,315 | $76,933,116 | $59,931,502 |
| Insp & Maint (Mobile Vehicles) | Annual or biennial Inspection and Maintenance Program. | 213,420 | 8.0% | 17,074 | 196,346 | 129,174 | 479,826 | 21.2% | $5,205 | $88,878,060 | $148,809,562 |
| HDDV1 (Heavy Duty Diesel Trucks) | Reduce NOx from Heavy Duty Diesel Vehicles from 6.0 to 4.0 G/ghp-hr. | 107,640 | 15.0% | 16,146 | 91,494 | 145,320 | 463,680 | 23.9% | $4,242 | $68,496,486 | $217,306,048 |
| LDGT1 (Light Duty Gasoline Trucks) | Reduce Voc from 0.8 to 0 28 G/mile and Nox from 1.7 to 0.7 G/mile. | 29,440 | 50.0% | 14,720 | 14,720 | 160,040 | 448,960 | 26.3% | $9,930 | $146,164,117 | $363,470,165 |
| Chemicals Ind. (Sic 37) | (For Reduction of NOx Only) | 16,257 | 45.0% | 7,316 | 8,941 | 167,356 | 441,644 | 27.5% | $938 | $6,865,914 | $370,336,079 |
| Refined Petroleum (Sic 36) | (For Reduction of NOx Only) | 14,000 | 50.0% | 7,000 | 7,000 | 174,356 | 434,644 | 28.6% | $387 | $2,711,364 | $373,047,443 |
| Primary Metals (Sic 29) | (For Reduction of NOx Only) | 22,000 | 21.0% | 4,620 | 17,380 | 178,976 | 430,024 | 29.4% | $608 | $2,807,943 | $375,855,386 |
| Non-ferrous Metals (Sic 061) | FGD and other technologies at Inco (Sudbury) and other Non-ferrous Metals plants | 2,250 | 80.0% | 1,800 | 450 | 180,776 | 428,224 | 29.7% | $3,660 | $6,588,812 | $382,444,198 |
| LDDT1 (Light Duty Diesel Trucks) | Reduce VOC from 0.8 to 0.28 G/mile and NOx from 1.7 to 0.7 G/mile. | 920 | 50.0% | 460 | 460 | 181,236 | 427,764 | 29.8% | $23,503 | $10,811,375 | $393,255,573 |
| HDGT1 (Heavy Duty Gasoline Trucks) | Reduce NOx from Heavy Duty Gasoline Vehicles from 6.0 to 4.0 G/ghp-hr. | 2,760 | 13.0% | 359 | 2,401 | 181,595 | 427,405 | 29.8% | $155,703 | $55,897,412 | $449,152,985 |
| Other Manufacturing | (For Reduction of NOx Only) | 14,680 | 2.0% | 235 | 14,445 | 181,830 | 427,170 | 29.9% | $2,113 | $496,484 | $449,649,469 |
| Miscellaneous | (For Reduction of NOx Only) | 4,188 | 4.0% | 159 | 4,029 | 181,989 | 427,011 | 29.9% | $1,280 | $203,513 | $449,852,982 |
| Pulp & Paper (Sic 27) | (For Reduction of NOx Only) | 9,000 | 0.1% | 7 | 8,993 | 181,996 | 427,004 | 29.9% | $138,758 | $971,307 | $450,824,289 |
| TOTALS | n/a | 627,555 | n/a | 181,996 | 445,559 | n/a | n/a | n/a | n/a | $450,824,289 | n/a |

Notes:

(1) Abatement technology combinations and costs are taken from the report, "Support for the Development of a NOx/VOC Management Plan for Ontario", March 1995. Where more than one technology option is available to reduce emissions from a given source, the technology option with the lowest cost per tonne removed at each source was selected for inclusion in this table.
(2) Based on 1990 Base-case emissions. Adjustments have been made for some of the Mobile Source programs
(3) "Negative" numbers refer to savings or net revenues that result from applying the technology or system. These "low lying fruit" may have been implemented by now and net cost savings from remaining technologies be exploited by now so that net savings may not be available. See "Support for the Development of a NOx/VOC Management Plan for Ontario", March 1995, for further descriptions of these technologies and opportunities for savings.
(4) The actual costs incurred by all sources totals about $467.8 million per year, of which about $17 million per year is offset by cost savings and net revenues from 4 sectors.

Source: MOEE, Economic Services Branch files, Hickling, 1995 and Senes, 1992.

TABLE C.5 AGGREGATE ABATEMENT COST FUNCTION FOR VOC - ORDERED BY LOWEST COST PER TONNE REMOVED (1)

| PLANT - SECTOR | TECHNOLOGY DESCRIPTION | INITIAL EMISSIONS (2) (tonnes) | EMISSION REDUCTION EFFICIENCIES (%) | EMISSION REDUCTIONS (tonnes) | FINAL EMISSIONS (BY SOURCE/ SECTOR) (tonnas) | CUMULATIVE EMISSION REDUCTIONS (tonnes) | CUMULATIVE FINAL EMISSIONS (tonnas) | CUMULATIVE EMISSION REDUCTION AS A % OF INITIAL EMISSIONS (%) | $/TONNE REDUCED VOC (3) ($/tonne) | TOTAL ANNUALIZED COST (3) ($/YEAR) | CUMULATIVE TOTAL ANNUALIZED COST (3) (4) ($/YEAR) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| INITIAL EMISSIONS | | | | | | | 868,000 | | | | |
| PAINTS 7 (A.S. SC 107) | Substitution/Process Modifications. | 45,006 | 50% | 22,503 | 22,503 | 22,503 | 845,497 | 2.6% | ($5,164) | ($116,206,615) | ($116,206,615 |
| LDGV1+ LDDV2 (light duty gasoline & diesal vehicles) | Reduce VOC from 0.4 to 0.25 g/mile and NOx from 1 to 0.4 g/mile. | 166,000 | 17% | 28,220 | 137,780 | 50,723 | 817,277 | 5.8% | ($602) | ($17,001,614) | ($133,208,229 |
| PRINTING2 (A.S. SC 109) | Carbon Absorption in printing facilities (graphics arts). | 19,032 | 85% | 16,177 | 2,855 | 66,900 | 801,100 | 7.7% | ($138) | ($2,233,944) | ($135,442,173 |
| DEGREASING1 (A.S. SC 104) | Freeboard cover end degreasing operations. | 719 | 83% | 597 | 122 | 67,497 | 800,503 | 7.8% | ($10) | ($6,049) | ($135,448,222 |
| PAINTS5b&6 (A.S. SC 106) | Increase spray transfar efficiency and waterborne coatings. | 111,970 | 77% | 86,217 | 25,753 | 153,714 | 714,286 | 17.7% | $0 | $0 | ($135,448,222 |
| CHEMICALS INDUSTRY (SIC 37) | (for reductions in VOC only) | 12,941 | 77% | 9,965 | 2,976 | 163,679 | 704,321 | 18.9% | $39 | $386,318 | ($135,061,904 |
| REFINEO PETROLEUM (SIC 36) | (for reductions in VOC only) | 35,000 | 87% | 30,450 | 4,550 | 194,129 | 673,871 | 22.4% | $42 | $1,273,911 | ($133,787,993 |
| OTHER MANUFACTURING | (for reductions in VOC only) | 11,919 | 28% | 3,337 | 8,582 | 197,466 | 670,534 | 22.8% | $75 | $251,089 | ($133,536,904 |
| PRIMARY METALS (SIC 29) | (for reductions in VOC only) | 25,000 | 30% | 7,500 | 17,500 | 204,966 | 663,034 | 23.6% | $98 | $734,328 | ($132,802,576 |
| VAPOUR4 (P.S. SIC 5111) | Vapour capture at marketing/bulk terminals. | 1,000 | 90% | 900 | 100 | 205,866 | 662,134 | 23.7% | $143 | $128,560 | ($132,674,016 |
| VAPOUR1 (A.S. SC 101) | Vapour balancing during unloading gasoline at service stations. | 21,358 | 95% | 20,290 | 1,068 | 226,156 | 641,844 | 26.1% | $191 | $3,874,493 | ($128,799,523 |
| PULP AND PAPER (SIC 27) | (for reductions in VOC only) | 8,000 | 67% | 5,360 | 2,640 | 231,516 | 636,484 | 26.7% | $306 | $1,639,302 | ($127,160,221 |
| VAPOUR5 (P.S. SIC 378) | Vapour control devices (organic chemical plants) | 4,272 | 93% | 3,973 | 299 | 235,489 | 632,511 | 27.1% | $378 | $1,499,902 | ($125,660,319 |
| VAPOUR7 (P.S. SIC 361) | LOAR and leaklass equipment. | 38,163 | 80% | 30,530 | 7,633 | 266,019 | 601,981 | 30.6% | $550 | $16,778,093 | ($108,882,226 |
| INSP & MAINT (VEHICLES) | Enhanced inspection and maintenance program ("Orive Clean") | 197,780 | 17% | 32,634 | 165,146 | 298,653 | 569,347 | 34.4% | $2,723 | $88,878,060 | ($20,004,166 |
| SOLVENTS1 (A.S. SC 110) | Raformulated consumer products to lower VOC emissions. | 124,000 | 30% | 37,200 | 86,800 | 335,853 | 532,147 | 38.7% | $1,999 | $74,365,911 | $54,361,745 |
| PAINTS 1 (P.S. SIC 375) | Afterburners for the paints and coatings industry. | 603 | 35% | 211 | 392 | 336,064 | 531,936 | 38.7% | $2,200 | $464,118 | $54,825,863 |
| VAPOUR2 (A.S. SC 102) | Vapour balancing during rafuelling et service stations. | 21,168 | 80% | 16,934 | 4,234 | 352,998 | 515,002 | 40.7% | $2,226 | $37,696,606 | $92,522,469 |
| PAINTS 2 & 5a (P.S. SIC 323) | Incineration of vapours and increased spray transfar. | 3,678 | 93% | 3,421 | 257 | 356,419 | 511,581 | 41.1% | $2,390 | $8,177,332 | $100,699,801 |
| DRY CLEAN1 (A.S. SC 105) | Recovery dryers in petroleum dry cleaning operations. | 6,278 | 18% | 1,099 | 5,179 | 357,518 | 510,482 | 41.2% | $3,612 | $3,969,262 | $104,669,063 |
| PAINTS 3 & 5c (A.S. SC. 108) | Incineration of vapours and increased spray transfer efficiency. | 156 | 93% | 145 | 11 | 357,663 | 510,337 | 41.2% | $5,745 | $832,983 | $105,502,046 |
| MC1 (mobile source) | Reduce VOC emissions from motorcycles to 1.6 g/km. | 694 | 16% | 111 | 583 | 357,774 | 510,226 | 41.2% | $9,746 | $1,081,775 | $106,583,821 |
| VAPOUR3d (A.S. SC 103) | Reduce the volatility of gasoline for 5 months a year. | 327 | 10% | 33 | 294 | 357,807 | 510,193 | 41.2% | $10,586 | $349,333 | $106,933,154 |
| LDGT1 (light duty gasoline trucks) | Reduce VOC from 0.8 to 0.28 g/mile and NOx from 1.7 to 0.7 g/mile. | 36,520 | 36% | 13,147 | 23,373 | 370,954 | 497,046 | 42.7% | $11,118 | $146,164,117 | $253,097,271 |
| LODT1 (light duty diesel trucks) | Reduce VOC from 0.8 to 0.28 g/mile and NOx from 1.7 to 0.7 g/mile. | 212 | 37% | 78 | 134 | 371,032 | 496,968 | 42.7% | $138,607 | $10,811,375 | $263,908,646 |
| TOTALS | n/a | 891,796 | n/a | 371,032 | 520,764 | n/a | n/a | n/a | n/a | $263,908,646 | n/a |

| PLANT - SECTOR | TECHNOLOGY DESCRIPTION | INITIAL EMISSIONS (2) (tonnes) | EMISSION REDUCTION EFFICIENCIES (%) | EMISSION REDUCTIONS (tonnes) | FINAL EMISSIONS (BY SOURCE/ SECTOR) (tonnes) | CUMULATIVE EMISSION REDUCTIONS (tonnes) | CUMULATIVE FINAL EMISSIONS (tonnes) | CUMULATIVE EMISSION REDUCTION AS A % OF INITIAL EMISSIONS (%) | $/TONNE REDUCED VOC (3) ($/tonne) | TOTAL ANNUALIZED COST (3) ($/YEAR) | CUMULATIVE TOTAL ANNUALIZED COST (3) (4) ($/YEAR) |
|---|---|---|---|---|---|---|---|---|---|---|---|

Notes:

(1) Abatement technology combinations and costs are taken from the report, "Support for the Development of a NOx/VOC Management Plan for Ontario", March 1995. Where more than one technology option is available to reduce emissions from a given source, the echnology option with the lowest cost per tonne removed at each source was selected for inclusion in this table.
(2) Based on 1990 Base-case emissions. Adjustments have been made for some of the Mobile Source programs.
(3) "Negative" numbers refer to savings or net revenues that result from applying the technology or system. These "low lying fruit" may have been implemented by now and net cost savings from remaining technologies be exploited by now so that net savings may not be available. See "Support for the Development of a NOx/VOC Management Plan for Ontario", March 1995, for further descriptions of these technologies and opportunities for savings.
(4) The actual costs incurred by all sources totals about $400 million per year, of which about $135 million per year is offset by cost savings and net revenues from 4 sectors.

Source: MOEE, Economic Services Branch files, Hickling, 1995 and Senes, 1992.

TABLE C.8 AGGREGATE ABATEMENT COST FUNCTION FOR VOC - ORDERED BY LARGEST EMISSION REDUCED (1)

| PLANT OR SECTOR (1) | TECHNOLOGY DESCRIPTION | INITIAL EMISSIONS (2) (tonnes) | EMISSION REDUCTION EFFICIENCIES (%) | EMISSION REDUCTIONS (tonnes) | FINAL EMISSIONS (BY SOURCE/ SECTOR) (tonnes) | CUMULATIVE EMISSIDN REDUCTIONS (tonnes) | CUMULATIVE FINAL EMISSIONS (tonnes) | CUMULATIVE EMISSION REDUCTION AS A % OF INITIAL EMISSIONS (%) | $/TONNE REDUCED VOC (3) ($/tonne) | TOTAL ANNUALIZED COST (3) ($/YEAR) | CUMULATIVE TOTAL ANNUALIZED COST (3) (4) ($/YEAR) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| INITIAL EMISSIONS | | | | | | | 868,000 | | | | |
| PAINTS5b&6 (A.S. SC 106) | Increase spray transfer efficiency and waterborne coatings. | 111,970 | 77% | 86,217 | 25,753 | 86,217 | 781,783 | 9.9% | 0 | 0 | 0 |
| SOLVENTS1 (A.S. SC 110) | Reformulated consumer products to lower VOC emissions. | 124,000 | 30% | 37,200 | 86,800 | 123,417 | 744,583 | 14.2% | $1,999 | $74,365,911 | $74,365,911 |
| INSP & MAINT (MOBILE VEHICLES) | Enhanced inspection and maintenance program. ("Drive Clean") | 197,780 | 17% | 32,634 | 165,146 | 156,051 | 711,949 | 18.0% | $2,723 | $88,878,060 | $163,243,971 |
| VAPOUR7 (P.S. SIC 361) | LDAR and leakless equipement | 38,163 | 80% | 30,530 | 7,633 | 186,581 | 681,419 | 21.5% | $550 | $16,778,093 | $180,022,064 |
| REFINED PETROLEUM (SIC 36) | (for reductions in VOC only) | 35,000 | 87% | 30,450 | 4,550 | 217,031 | 650,969 | 25.0% | $42 | $1,273,911 | $181,295,975 |
| LDGV1 + LDDV2 (light duty gasoline and diesel vehicles) | Reduce VOC from 0.4 to 0.25 g/mile and NOx from 1 to 0.4 g/mile | 166,000 | 17% | 28,220 | 137,780 | 245,251 | 622,749 | 28.3% | ($602) | ($17,001,614) | $164,294,361 |
| PAINTS 7 (A.S. SC 107) | Substitution/Process Modifications. | 45,006 | 50% | 22,503 | 22,503 | 267,754 | 600,246 | 30.8% | ($5,164) | ($116,206,615) | $48,087,746 |
| VAPOUR1 (A.S. SC 101) | Vapour balancing during unloading gasoline at service stations. | 21,358 | 95% | 20,290 | 1,068 | 288,044 | 579,956 | 33.2% | $191 | $3,874,493 | $51,962,239 |
| VAPOUR2 (A.S. SC 102) | Vapour balancing during refuelling at service stations. | 21,168 | 80% | 16,934 | 4,234 | 304,978 | 563,022 | 35.1% | $2,226 | $37,696,606 | $89,658,845 |
| PRINTING2 (A.S. SC 109) | Carbon Absorption in printing facilities (graphics arts). | 19,032 | 85% | 16,177 | 2,855 | 321,155 | 546,845 | 37.0% | ($138) | ($2,233,944) | $87,424,901 |
| LDGT1 (light duty gasoline trucks) | Reduce VOC from 0.8 to 0.28 g/mile and NOx from 1.7 to 0.7 g/mile. | 36,520 | 36% | 13,147 | 23,373 | 334,302 | 533,698 | 38.5% | $11,118 | $146,164,117 | $233,589,018 |
| CHEMICALS INDUSTRY (SIC 37) | (for reductions in VOC only) | 12,941 | 77% | 9,965 | 2,976 | 344,267 | 523,733 | 39.7% | $39 | $386,318 | $233,975,336 |
| PRIMARY METALS (SIC 29) | (for reductions in VOC only) | 25,000 | 30% | 7,500 | 17,500 | 351,767 | 516,233 | 40.5% | $98 | $734,328 | $234,709,664 |
| PULP AND PAPER (SIC 27) | (for reductions in VOC only) | 8,000 | 67% | 5,360 | 2,640 | 357,127 | 510,873 | 41.1% | $306 | $1,639,302 | $236,348,966 |
| VAPOUR5 (P.S. SIC 378) | Vapour control devices (organic chemical plants) | 4,272 | 93% | 3,973 | 299 | 361,100 | 506,900 | 41.6% | $378 | $1,499,902 | $237,848,868 |
| PAINTS 2 & 5a (P.S. SIC 323) | Incineration of vapours and increase spray transfer. | 3,678 | 93% | 3,421 | 257 | 364,521 | 503,479 | 42.0% | $2,390 | $8,177,332 | $246,026,200 |
| OTHER MANUFACTURING | (for reductions in VOC only) | 11,919 | 28% | 3,337 | 8,582 | 367,858 | 500,142 | 42.4% | $75 | $251,089 | $246,277,289 |
| DRY CLEAN1 (A.S. SC 105) | Recovery dryers in petroleum dry cleaning operations. | 6,278 | 18% | 1,099 | 5,179 | 368,957 | 499,043 | 42.5% | $3,612 | $3,969,262 | $250,246,551 |
| VAPOUR4 (P.S. SIC 5111) | Vapour capture at marketing/bulk terminals. | 1,000 | 90% | 900 | 100 | 369,857 | 498,143 | 42.6% | $143 | $128,560 | $250,375,111 |
| DEGREASING1 (A.S. SC 104) | Freeboard cover and degreasing operations. | 719 | 83% | 597 | 122 | 370,454 | 497,546 | 42.7% | ($10) | ($6,049) | $250,369,062 |
| PAINTS 1 (P.S. SIC 375) | Afterburners for the plants and coatings industry. | 603 | 35% | 211 | 392 | 370,665 | 497,335 | 42.7% | $2,200 | $464,118 | $250,833,180 |
| PAINTS 3 & 5c (A.S. SC. 108) | Incineration of vapours and increase spray transfer efficiency. | 156 | 93% | 145 | 11 | 370,810 | 497,190 | 42.7% | $5,745 | $832,983 | $251,666,163 |
| MC1 (mobile souce) | Reduce VOC emissions from motorcycles to 1.6 g/km. | 694 | 16% | 111 | 583 | 370,921 | 497,079 | 42.7% | $9,746 | $1,081,775 | $252,747,938 |
| LDDT1 (light duty diesel trucks) | Reduce VOC from 0.8 to 0.28 g/mile and NOx from 1.7 to 0.7 g/mile. | 213 | 37% | 78 | 135 | 370,999 | 497,001 | 42.7% | $138,607 | $10,811,375 | $263,559,313 |
| VAPOUR3d (A.S. SC 103) | Reduce the volatility of gasoline for 5 months a year. | 327 | 10% | 33 | 294 | 371,032 | 496,968 | 42.7% | $10,586 | $349,333 | $263,908,646 |
| TOTALS | n/a | 891,103 | n/a | 371,032 | 520,765 | n/a | n/a | n/a | n/a | $263,908,646 | n/a |

Notes:

(1) Abatement technology combinations and costs are taken from the report, "Support for the Development of a NOx/VOC Management Plan for Ontario", March 1995. Where more than one technology option is available to reduce emissions from a given source, the technology option with the lowest cost per tonne removed at each source was selected for inclusion in this table.
(2) Based on 1990 Base-case emissions. Adjustments have been made for some of the Mobile Source programs.
(3) "Negative" numbers refer to savings or net revenues that result from applying the technology or system. These "low lying fruit" may have been implemented by now and net cost savings from remaining technologies be exploited by now so that net savings may not be available now. See "Support for the Development of a NOx/VOC Management Plan for Ontario", March 1995, for a more complete description of these technologies and opportunities.
(4) The actual costs incurred by all sources totals about $400 million per year, of which about $135 million per year is offset by cost savings and net revenues from 4 sectors.

Source: MOE, Economic Services Branch files, Senes, 1992 and Hickling 1995.

## TABLE C.7 AGGREGATE ABATEMENT COST FUNCTION FOR STATIONARY SOURCES OF PM10 - ORDERED BY LOWEST COST PER TONNE REMOVED (1)

| PLANT/SOURCE | CONTROL TECHNOLOGY (2) | PM10 INITIAL EMISSIONS (tonnes) | PM10 EMISSION REDUCTION/ EFFICIENCIES (%) | PM10 EMISSION REDUCTIONS (tonnes) | PM10 FINAL EMISSIONS BY SOURCE/SECTOR (after abatement) (tonnes) | PM10 CUMULATIVE EMISSION REDUCTIONS (tonnes) | PM10 CUMULATIVE FINAL EMISSIONS (tonnes) | CUMULATIVE REDUCTION AS A % OF INITIAL EMISSIONS (%) | $/TONNE REDUCED PM10 ($/tonne) | TOTAL ANNUALIZED COST (per action) ($/YEAR) | CUMULATIVE TOTAL ANNUALIZED COST ($/YEAR) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| INITIAL EMISSIONS (ANNUAL) | | | | | | | 31,145 | | | | |
| Procter and Gamble Inc. | | 5,777 | 93.99% | 5,430 | 347 | 5,430 | 25,718 | 17.43% | | $1,528,539 | 1,528,539 |
| Dofasco Inc. | | 5,312 | 62.76% | 3,334 | 1,978 | 8,763 | 22,382 | 28.14% | $317 | $1,055,211 | 2,583,750 |
| Stelco Inc. (Hilton Works) | | 3,187 | 68.32% | 2,177 | 1,010 | 10,941 | 20,205 | 35.13% | $349 | $760,669 | 3,344,419 |
| Algoma Steel Inc. | | 2,871 | 70.07% | 2,012 | 859 | 12,952 | 18,193 | 41.59% | $357 | $718,471 | 4,062,890 |
| Stelco Inc. (Lake Erie Works) | | 1,790 | 65.33% | 1,169 | 620 | 14,122 | 17,024 | 45.34% | $431 | $503,867 | 4,566,757 |
| Esso Petroleum | | 303 | 63.58% | 193 | 110 | 14,314 | 16,831 | 45.96% | $769 | $148,203 | 4,714,960 |
| Standard Aggregates (3) | | 2,558 | 40.26% | 1,030 | 1,528 | 15,344 | 15,801 | 49.27% | $858 | $883,466 | 5,598,426 |
| Northern Wood Preservers | | 151 | 96.27% | 145 | 6 | 15,489 | 15,657 | 49.73% | $1,099 | $159,334 | 5,757,760 |
| Novacor Chemical | | 332 | 84.95% | 282 | 50 | 15,771 | 15,374 | 50.64% | $1,146 | $323,377 | 6,081,137 |
| K.J. Beamish Construction | | 347 | 97.90% | 339 | 7 | 16,110 | 15,035 | 51.73% | $1,162 | $394,191 | 6,475,328 |
| Standard Aggregates | | 2,378 | 21.36% | 508 | 1,870 | 16,618 | 14,527 | 53.36% | $1,481 | $752,439 | 7,227,767 |
| St. Mary's Cement Co. | | 170 | 72.55% | 124 | 47 | 16,742 | 14,403 | 53.75% | $1,523 | $188,218 | 7,415,985 |
| Domtar Packaging | | 478 | 25.97% | 124 | 352 | 16,866 | 14,280 | 54.15% | $1,653 | $204,373 | 7,620,358 |
| Consumers Packaging | | 129 | 95.86% | 123 | 5 | 16,989 | 14,156 | 54.55% | $1,864 | $229,951 | 7,850,309 |
| Domtar Inc. | | 107 | 82.84% | 89 | 18 | 17,078 | 14,068 | 54.83% | $2,216 | $196,275 | 8,046,584 |
| Malette Inc. | | 418 | 63.99% | 268 | 151 | 17,345 | 13,800 | 55.69% | $2,280 | $610,454 | 8,657,038 |
| Weldwood of Canada td. | | 73 | 79.83% | 58 | 15 | 17,404 | 13,742 | 55.88% | $2,466 | $144,999 | 8,802,037 |
| General Motors Ltd. | | 58 | 86.40% | 51 | 8 | 17,454 | 13,691 | 56.04% | $2,999 | $151,428 | 8,953,465 |
| Standard Aggregate (3) | | 510 | 42.30% | 216 | 294 | 17,670 | 13,476 | 56.73% | $3,146 | $679,096 | 9,632,561 |
| P.P. G. Canada Inc. | | 165 | 99.73% | 164 | 0 | 17,834 | 13,311 | 57.26% | $3,277 | $538,589 | 10,171,150 |
| Ford Motor Co. of Canada | | 120 | 93.11% | 112 | 8 | 17,946 | 13,199 | 57.62% | $3,739 | $418,928 | 10,590,076 |
| Consumers Glass Inc. | | 68 | 99.34% | 68 | 0 | 18,014 | 13,131 | 57.84% | $3,834 | $280,197 | 10,850,273 |
| Ridgemount Quarries | | 295 | 54.24% | 160 | 135 | 18,174 | 12,971 | 58.35% | $4,153 | $665,150 | 11,515,423 |
| James River-Marathon | | 1,823 | 64.79% | 1,181 | 642 | 19,355 | 11,790 | 62.14% | $4,354 | $5,141,538 | 16,656,961 |
| New Life Mills Limited | | 56 | 92.91% | 52 | 4 | 19,407 | 11,738 | 62.31% | $4,400 | $230,071 | 16,887,032 |
| Consumer Glass | | 111 | 96.10% | 107 | 4 | 19,514 | 11,631 | 62.65% | $5,010 | $535,060 | 17,422,092 |
| Esso Petroleum (Nanticoke) | | 291 | 67.91% | 198 | 93 | 19,712 | 11,434 | 83.29% | $5,601 | $1,106,909 | 18,529,001 |
| Lafarge Canada Inc. | | 221 | 14.64% | 32 | 188 | 19,744 | 11,401 | 63.39% | $5,750 | $185,851 | 18,714,852 |
| A.F.G. Glass Inc. | | 62 | 99.61% | 62 | 0 | 19,806 | 11,340 | 63.59% | $5,865 | $361,458 | 19,076,310 |
| Lejambe Forest Products | | 113 | 92.90% | 105 | 8 | 19,911 | 11,235 | 63.93% | $8,262 | $655,956 | 19,732,266 |
| Columbia Forest Products | | 78 | 77.94% | 61 | 17 | 19,971 | 11,174 | 64.12% | $6,701 | $406,012 | 20,138,278 |
| Shell Canada Ltd. | | 265 | 58.94% | 158 | 109 | 20,128 | 11,018 | 64.62% | $7,008 | $1,096,527 | 21,234,805 |

| PLANT/SOURCE | CONTROL TECHNOLOGY (2) | PM10 INITIAL EMISSIONS (tonnes) | PM10 EMISSION REDUCTION/ EFFICIENCIES (%) | PM10 EMISSION REDUCTIONS (tonnes) | PM10 FINAL EMISSIONS BY SOURCE/SECTOR (after abatement) (tonnes) | PM10 CUMULATIVE EMISSION REDUCTIONS (tonnes) | PM10 CUMULATIVE FINAL EMISSIONS (tonnes) | CUMULATIVE REDUCTION AS A % OF INITIAL EMISSIONS (%) | $/TONNE REDUCED PM10 ($/tonne) | TOTAL ANNUALIZED COST (per action) ($/YEAR) | CUMULATIVE TOTAL ANNUALIZED COST ($/YEAR) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Petro-Canada Product | | 197 | 67.97% | 134 | 63 | 20,262 | 10,884 | 65.06% | $8,131 | $1,090,900 | 22,325,705 |
| Molson (Ont. ) Brewer | | 44 | 60.94% | 27 | 17 | 20,289 | 10,857 | 65.14% | $8,355 | $223,665 | 22,549,370 |
| Owens Corning Canada | | 84 | 86.51% | 72 | 11 | 20,361 | 10,785 | 65.37% | $8,521 | $618,013 | 23,165,383 |
| Archy Greco Paving Ltd. | | 24 | 69.07% | 17 | 7 | 20,377 | 10,768 | 65.43% | $11,838 | $195,908 | 23,361,291 |
| Witco Canada Inc. | | 13 | 94.00% | 13 | 1 | 20,390 | 10,756 | 65.47% | $13,450 | $168,657 | 23,529,948 |
| Suncor | | 131 | 58.71% | 77 | 54 | 20,467 | 10,679 | 65.71% | $14,012 | $1,078,437 | 24,606,385 |
| Stanley Knight Ltd. | | 8 | 95.93% | 8 | 0 | 20,475 | 10,671 | 65.74% | $14,882 | $119,204 | 24,725,589 |
| Quaker Oats Co. of Canada | | 15 | 99.59% | 15 | 0 | 20,489 | 10,656 | 65.79% | $15,182 | $220,593 | 24,946,182 |
| MacMillan-Bloedel | | 15 | 91.35% | 13 | 1 | 20,503 | 10,643 | 65.83% | $16,001 | $212,819 | 25,159,001 |
| Sulco Chemicals Ltd. | | 10 | 99.90% | 10 | 0 | 20,513 | 10,633 | 65.86% | $16,165 | $168,113 | 25,327,114 |
| TOTAL | | 31,145 | n/a | 20,503 | 10,643 | n/a | n/a | n/a | n/a | 25,159,001 | n/a |
| (42 plants) | | | | | | | | | | | |

Notes

) Derived from estimates produced by the Environment Canada AERCo$t Model using 1990 base case emissions. For each plant or source, the abatement level (reduction efficiency), final emissions and cost combination was chosen from available abatement/cost combinations (plant-specific cost functions). The combination with the lowest $/tonne reduced at each plant was selected for this aggregate cost function.
(2) Technologies were not described in information provided by Environment Canada.
(3) There are three locations for this company.

SOURCE: Environment Canada, RDIS Emissions Inventory; Environment Canada, Regulatory And Economic Assessment Branch, AERCo$t Model

SOURCE: Environment Canada, Regulatory and Economic Assessment Branch, AERCost Model.

## TABLE C.8 AGGREGATE ABATEMENT COST FUNCTION FOR STATIONARY SOURCES OF PM10 - ORDERED BY LARGEST EMISSIONS REDUCED PER SOURCE (1)

| PLANT/SOURCE | CONTROL TECHNOLOGY (2) | PM10 INITIAL EMISSIONS (tonnes) | PM10 EMISSION REDUCTION EFFICIENCIES (%) | PM10 EMISSION REDUCTIONS (tonnes) | PM10 FINAL EMISSIONS BY SOURCE/SECTOR (after abatement) (tonnes) | PM10 CUMULATIVE EMISSION REDUCTIONS (tonnes) | PM10 CUMULATIVE FINAL EMISSIONS (tonnes) | CUMULATIVE REDUCTION AS A % OF INITIAL EMISSIONS (%) | $/TONNE REDUCED PM10 ($/tonne) | TOTAL ANNUALIZED COST (per action) ($/YEAR) | CUMULATIVE TOTAL ANNUALIZED COST ($/YEAR) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| INITIAL EMISSIONS (annual) | | | | | | | 31,156 | | | | |
| Procter and Gamble Inc. | | 5,777 | 93.99% | 5,430 | 347 | 5,430 | 25,726 | 17.43% | 282 | 1,528,539 | 1,528,539 |
| Dofasco Inc. | | 5,312 | 62.76% | 3,334 | 1,978 | 8,763 | 22,392 | 28.13% | 317 | 1,055,211 | 2,583,750 |
| Stelco Inc. (Hilton Works) | | 3,187 | 68.32% | 2,177 | 1,010 | 10,941 | 20,215 | 35.12% | 349 | 760,669 | 3,344,419 |
| Algoma Steel Inc. | | 2,871 | 70.07% | 2,012 | 859 | 12,952 | 18,203 | 41.57% | 357 | 718,471 | 4,062,890 |
| James River-Marathon | | 1,823 | 64.79% | 1,181 | 642 | 14,133 | 17,023 | 45.38% | 4,354 | 5,141,538 | 9,204,428 |
| Stelco Inc. (Lake Erie Works) | | 1,790 | 65.33% | 1,169 | 620 | 15,302 | 15,854 | 49.12% | 431 | 503,867 | 9,708,295 |
| Standard Aggregates (3) | | 2,558 | 40.26% | 1,030 | 1,528 | 16,332 | 14,824 | 52.42% | 858 | 883,466 | 10,591,761 |
| Standard Aggregates (3) | | 2,378 | 21.36% | 508 | 1,870 | 16,840 | 14,316 | 54.05% | 1,481 | 752,439 | 11,344,200 |
| K.J. Beamish Construction | | 347 | 97.90% | 339 | 7 | 17,179 | 13,976 | 55.14% | 1,162 | 394,191 | 11,738,391 |
| Novacor Chemical | | 332 | 84.95% | 282 | 50 | 17,462 | 13,694 | 56.05% | 1,146 | 323,377 | 12,061,768 |
| Malette Inc. | | 418 | 63.99% | 268 | 151 | 17,729 | 13,427 | 56.91% | 2,280 | 610,454 | 12,672,222 |
| Standard Aggregate (3) | | 510 | 42.30% | 216 | 294 | 17,945 | 13,211 | 57.60% | 3,148 | 679,096 | 13,351,318 |
| Esso Petroleum (Nanticoke) | | 291 | 67.91% | 198 | 93 | 18,143 | 13,013 | 58.23% | 5,601 | 1,106,909 | 14,458,227 |
| Esso Petroleum | | 303 | 63.58% | 193 | 110 | 18,335 | 12,821 | 58.85% | 769 | 148,203 | 14,606,430 |
| P.P. G. Canada Inc. | | 165 | 99.73% | 164 | 0 | 18,500 | 12,656 | 59.38% | 3,277 | 538,589 | 15,145,019 |
| Ridgemount Quarries | | 295 | 54.24% | 160 | 135 | 18,660 | 12,496 | 59.89% | 4,153 | 665,150 | 15,810,169 |
| Shell Canada Ltd. | | 265 | 58.94% | 156 | 109 | 18,816 | 12,340 | 60.39% | 7,008 | 1,096,527 | 16,906,696 |
| Northern Wood Preservers | | 151 | 96.27% | 145 | 6 | 18,961 | 12,195 | 60.86% | 1,099 | 159,334 | 17,066,030 |
| Petro-Canada Product | | 197 | 67.97% | 134 | 63 | 19,095 | 12,060 | 61.29% | 8,131 | 1,090,900 | 18,156,930 |
| Domtar Packaging | | 476 | 25.97% | 124 | 352 | 19,219 | 11,937 | 61.69% | 1,653 | 204,373 | 18,361,303 |
| St. Mary's Cement Co. | | 170 | 72.55% | 124 | 47 | 19,343 | 11,813 | 62.08% | 1,523 | 188,218 | 18,549,521 |
| Consumers Packaging | | 129 | 95.86% | 123 | 5 | 19,466 | 11,690 | 62.48% | 1,864 | 229,951 | 18,779,472 |
| Ford Motor Co. of Canada | | 120 | 93.11% | 112 | 8 | 19,578 | 11,578 | 62.64% | 3,739 | 418,926 | 19,198,398 |
| Consumer Glass | | 111 | 96.10% | 107 | 4 | 19,685 | 11,471 | 63.18% | 5,010 | 535,060 | 19,733,458 |
| Lajambe Forest Products | | 113 | 92.90% | 105 | 8 | 19,790 | 11,366 | 63.52% | 6,262 | 655,956 | 20,389,414 |
| Domtar Inc. | | 107 | 82.84% | 89 | 18 | 19,878 | 11,278 | 63.80% | 2,216 | 196,275 | 20,585,689 |
| Suncor | | 131 | 58.71% | 77 | 54 | 19,955 | 11,201 | 64.05% | 14,012 | 1,076,437 | 21,662,126 |
| Owens Corning Canada | | 84 | 86.51% | 72 | 11 | 20,027 | 11,129 | 64.28% | 8,521 | 616,013 | 22,278,139 |
| Consumers Glass Inc. | | 68 | 99.34% | 68 | 0 | 20,095 | 11,061 | 64.50% | 3,834 | 260,197 | 22,538,336 |
| A.F.G. Glass Inc. | | 62 | 99.61% | 62 | 0 | 20,157 | 10,999 | 64.70% | 5,865 | 361,458 | 22,899,794 |
| Columbia Forest Products | | 78 | 77.94% | 61 | 17 | 20,217 | 10,938 | 64.89% | 6,701 | 406,012 | 23,305,806 |
| Weldwood of Canada td. | | 73 | 79.63% | 58 | 15 | 20,276 | 10,880 | 65.08% | 2,486 | 144,999 | 23,450,805 |

| PLANT/SOURCE | CONTROL TECHNOLOGY (2) | PM10 INITIAL EMISSIONS (tonnes) | PM10 EMISSION REDUCTION EFFICIENCIES (%) | PM10 EMISSION REDUCTIONS (tonnes) | PM10 FINAL EMISSIONS BY SOURCE/SECTOR (after abatement) (tonnes) | PM10 CUMULATIVE EMISSION REDUCTIONS (tonnes) | PM10 CUMULATIVE FINAL EMISSIONS (tonnes) | CUMULATIVE REDUCTION AS A % OF INITIAL EMISSIONS (%) | $/TONNE REDUCED PM10 ($/tonne) | TOTAL ANNUALIZED COST (per action) ($/YEAR) | CUMULATIVE TOTAL ANNUALIZED COST ($/YEAR) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| New Life Mills Limited | | 56 | 92.91% | 52 | 4 | 20,328 | 10,828 | 65.25% | 4,400 | 230,071 | 23,680,876 |
| General Motors Ltd. | | 58 | 86.40% | 51 | 8 | 20,379 | 10,777 | 65.41% | 2,999 | 151,428 | 23,832,304 |
| Lafarge Canada Inc. | | 221 | 14.84% | 32 | 188 | 20,411 | 10,745 | 65.51% | 5,750 | 185,851 | 24,018,155 |
| Molson (Ont. ) Brewers | | 44 | 60.94% | 27 | 17 | 20,438 | 10,718 | 65.60% | 8,355 | 223,665 | 24,241,820 |
| Archy Greco Paving Ltd. | | 24 | 69.07% | 17 | 7 | 20,454 | 10,702 | 65.65% | 11,838 | 195,908 | 24,437,728 |
| Quaker Oats Co. of Canada | | 15 | 99.59% | 15 | 0 | 20,469 | 10,687 | 65.70% | 15,182 | 220,593 | 24,658,321 |
| MacMillan-Bloedel | | 15 | 91.35% | 13 | 1 | 20,482 | 10,674 | 65.74% | 18,001 | 212,819 | 24,871,140 |
| Witco Canada Inc. | | 13 | 94.00% | 13 | 1 | 20,495 | 10,661 | 65.78% | 13,450 | 168,657 | 25,039,797 |
| Sulco Chemicals Ltd. | | 10 | 99.90% | 10 | 0 | 20,505 | 10,651 | 65.81% | 16,165 | 168,113 | 25,207,910 |
| Stanley Knight Ltd. | | 8 | 95.93% | 8 | 0 | 20,513 | 10,643 | 65.84% | 14,882 | 119,204 | 25,327,114 |
| | | | | | | | | | | | |
| TOTAL 42 Plants | | 31,156 | n/a | 20,513 | 10,643 | n/e | n/a | n/a | n/a | 25,327,114 | n/a |

Notes:

1) Derived from estimates produced by the Environment Canada AERCo$t Model using 1990 base case emissions. For each plant or source, the abatement level (reduction efficiency), final emissions and cost combination was chosen from available abatement/cost combinations (plant-specific cost functions). The combination with the lowest $/tonne reduced at each plant was selected for this aggregate cost function.
(2) Technologies were not described in information provided by Environment Canada.
(3) There are three locations for this company.

SOURCE: Environment Canada, RDIS Emissions Inventory; Environment Canada, Regulatory And Economic Assessment Branch, AERCo$t Model

# APPENDIX D

## COMMENTS FROM OPTIONS ASSESSMENT WORKING GROUP ON

## "A Compendium of Current Knowledge on Fine Particulate Matter in Ontario"

POLLUTION PROBE
CLEAN AIR. CLEAN WATER.

November 4, 1998

Dr. Neville Reid
Ministry of the Environment
2 St. Clair Avenue West - 12th Floor
Toronto, ON
M4V 1L5

Dear Dr. Reid:

On behalf of Pollution Probe, I would like to thank you for the opportunity to submit our comments on the Ministry of the Environment's - Compendium of Current Knowledge on Fine Particulate Matter in Ontario. In general, we were impressed as to breadth of the report, the layout of the data, methodology, and the extensive literature consulted for the document. We believe the health evidence clearly indicates that action must be taken to reduce the levels of fine particles in our air. These microscopic particles are a major component of smog, and a significant threat to the respiratory health of Ontarians.

Our concerns about the health impacts of fine particulate are not frivolous. Measurements of the levels of fine particulates ($PM_{10}$) have been taken in Ontario since 1987 and there has been no evidence that the levels are decreasing. Approximately 10 per cent of all samples in Ontario since 1987 are over 50 micrograms per cubic metre ($ug/m^3$ - 24 hrs) a level shown to be associated with adverse health effects in many studies. Elevated levels of fine particulates have real costs in terms of human health and quality of life in urban centres, as well as environmental impacts including soiling, decreased visibility and damage to vegetation. In the last four years, five epidemiological studies conducted in southwestern Ontario have shown a strong association between short-term (measured in days) increases in exposure to particles and other pollutants, and increased hospitalization for asthma and other respiratory disease, as well as increased mortality in people suffering from chronic respiratory disease. We are asking for a firm commitment by the Ontario Ministry of the Environment toward the implementation of guidelines for $PM_{10}$ and $PM_{2.5}$ and the requisite policy measures to reduce the levels of fine particulate in Ontario.

The following comments are based upon a review of the original July 1998 compendium document. Please note: because Pollution Probe received Section V - Developing An IP/RP Strategy for Ontario on November 3rd, our comments on policy options will be submitted later in the consultation process.

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- *Implementation Timelines*: No date has been set for the implementation of a guideline for $PM_{10}$ and $PM_{2.5}$. Is it the intention of the Ministry (OMOE) to ratify the existing interim guideline for $PM_{10}$ of 50 ug/m$^3$ (24h)? Is the Ministry planning to delay introducing guidelines for $PM_{10}$ and $PM_{2.5}$. until the CWS process is concluded? Much of Ontario's IP/RP comes from American sources, where strong, new clean air legislation is being adopted. If we hope to convince U.S. sources to keep their clean-up on schedule, we will need to demonstrate our own credible actions. When will the OMOE be establishing targets and timelines for Ontario's IP/RP strategy?

- *Ontario still has very inadequate emission inventories for sources of $PM_{10}$ and $PM_{2.5}$*: The compendium document makes it clear that the quality and certainty of OMOE and industry emission estimates for IP/RP are weak. What mechanisms will the ministry employ to ensure that Ontario's IP/RP strategy is based on accurate emission inventories?

- *Commitment to ongoing research*: Pollution Probe is concerned that the OMOE has not made any commitment to research on IP/RP. Even when the scope is restricted to human health effects, air quality research is a highly complicated undertaking. In contrast, the U.S. EPA has invested $444 million into understanding respiratory physiology, pathology, inhalation toxicology, exposure assessment, atmospheric chemistry, epidemiology, risk assessment, biostatistics and so on. Given the unique geographic characteristics of southwestern Ontario (i.e., the lake effect), it's large population base, the heavy concentration of industrial sources and the impact of long range transport of pollutants from the United States, we need to expand our research efforts in this critical area. What commitment is the ministry going to make to research?

- *Long-term trends:* The compendium document does not include trend data or recent policy changes which could have significant impacts on IP/RP levels in Ontario. For example, technological advancements by motor vehicle manufacturers to reduce emissions have been largely negated by the increasing number and use of motor vehicles. The recent de-regulation of Ontario's electricity market could see many Ontarian's purchasing their power from the cheapest source available: old, high polluting coal fired electric stations operating in the Ohio Valley. In some cases, the OMOE's sister ministries (e.g., Transportation, Municipal Affairs and Housing) are pursuing or changing policies that will result in increased levels of $PM_{10}$ and $PM_{2.5}$. The compendium document should include future trend data that reflects the impacts of these and other policy decisions on future IP/RP levels in Ontario.

- *Cost/Benefit Analysis*: The compendium document does not include any discussion of the cost/benefit of implementing an IP/RP strategy. Will this be included in a second version of the document? What are the expected costs and benefits for reducing IP/RP levels? As you know, health costs are among the most significant burdens on the provincial budget; disease prevention and a healthy environment must surely be part of the solution. A study carried out by the Government Working Group on sulphur levels in gasoline showed that a reduction in sulphur would have a positive benefit on avoided health effects (premature mortality, morbidity, hospital admissions, etc.) valued at a net present value of $5.2 billion through to the year 2020. We would encourage the ministry to undertake some economic analysis to substantiate the costs and benefits of reducing IP/RP levels.

- *Public consultation:* The compendium document has not outlined when or how the public will be consulted during the development of the IP/RP strategy. Will this compendium document be posted on the EBR? Will citizens groups, particularly those in industrialized communities, be given the opportunity to voice regional concerns? Will public input genuinely affect the design and the implementation of the strategy? When will your ministry begin consultation on this issue?

Pollution Probe appreciates the opportunity to comment on the compendium document. We fully support the ministry's plan to reduce IP/RP levels in Ontario and look forward to working with you on the implementation strategy.

Sincerely,

Ian C. Morton M.Sc.
Director, Environmental Health

c.c. Ken Ogilvie - Executive Director

ario hydro

700 University Avenue, Toronto, Ontario M5G 1X6

November 3, 1998

FBU-07125

Dr. Neville Reid
Ontario Ministry of the Environment
2 St. Clair Avenue West
14th Floor
Toronto, Ontario
M4V 1L5

Dear Dr. Reid:

### Comments on "A Compendium of Current Knowledge on Fine Particulate Matter in Ontario"

### 1.0 General

The Ontario Ministry of the Environment (MOE) should be applauded for preparing a useful document to initiate discussions on the fine particulate issue amongst the various stakeholders in the province. In order for the document to have been prepared by the IP/RP Working Group, we should have been engaged at the beginning and throughout the development of this document. However, the Fossil Business of Ontario Hydro is pleased to provide written comments on the report for your consideration.

The descriptive language (eg. "...most critical health and general environmental issues of the decade..." , "...strong connection...") within the report should be removed.

It is not clear how PM rates in priority to or with other issues such as Climate Change. The issue should be addressed through an integrated emissions approach, especially when discussing technological controls, and through commitments made to managing greenhouse gas emissions.

### 2.0 Specific Comments

2.1 Summary of the technical document-Section 3 "Where do particulates come from?" states that a large urban populations are affected by industrial processes, transportation and all fuel combustion more than emissions from paved roads and construction. This statement may not be true. Pedestrians within the City of Toronto are subjected to daily **ground level** PM emissions from construction practices, the application of sand to city streets by Public Works crews, the chemical spraying of lawns, and vehicle emissions from improperly installed tailpipes, to name a few. While these emissions are frequent and localized, they could have a far greater impact.

Figure 2 on PM10 should be completed by including emissions from road dusts, construction, agriculture, etc.

Section 4 "How much particulate is in the air?" discusses chemical make-up of PM10 and PM2.5. What percentage of PM 10 and PM2.5 samples have been analyzed for chemical composition, at which monitoring sites, and is this sample population considered representative of the province. A larger sample size could significantly change the pie charts in Figures 6 and 7.

Section 5 "What are the Health problems?" refers to potential emission reductions needed to reach a range of air quality goals. What are the monitoring years and sites on which this analysis is based and is it reasonable to assume that these years and sites are representative of the current growth in the province? An intensive monitoring campaign, such as the one being implemented by the U.S EPA for PM2.5, is needed to monitor current air quality in the province to determine potential emission reductions. It is likely that industry would supportive of such an initiative.

## 2.2 A Compendium of Current Knowledge on Fine Particulate in Ontario

2.2.1 Linkages of the Inhalable and Respirable Particulate Matter Issue to Other Air Quality Issues and Initiatives-This discussion needs to address the impact of all program commitments (eg. Climate Change) on improving air quality.

2.2.2 IP/RP Related Emission Inventory Development for Ontario-Emission inventories establish relative contributions by industrial sectors and are **critical** to the decision making process. Inaccurate emission inventories mean that targets, objectives or standards will likely not be met.

Details on the inventory estimating techniques needs to be provided.

The inventory needs to be verified by all categories/sectors. This process would allow an information exchange to ensure that proper assumptions and operating statistics are used.

2.2.3 Particulate Matter Measurements-It is important to compare data collected from the same type of equipment from site to site. It cannot be determined whether this has been done in this report. Analysis of the chemical composition appears to be sparse and is needed to determine the source and harm of the constituents.

### 2.2.4 Health Effects (PM10/PM2.5) and Health Benefits on Achieving Potential Goals

2.2.4.1 Linkage: Particle Size and Cardiorespiratory Effects-This suggests that there is no mechanism to remove fine particulates that penetrate the lungs deeply. This is not true. Particle clearance and translocation mechanisms exist for extra-thoracic, tracheo-bronchial and alveolar regions. For example, particles can be removed from alveolar regions by macrophages (phagocytosis) and soluble particles can be cleared by dissolution.

2.2.4.2 Epidemiological Evidence and Important Conclusions-Highlights-These sections conclude that the ambient PM levels are linked to increases in mortality due to cardiorespiratory diseases and that demonstrated association cannot be accounted for by confounding factors or covarying pollutants. Experts in the field do not necessarily agree on this point. For example, after completing an extensive review of the evidence on particulate air pollution and mortality, Moolgavkar and Luebeck (1996) concluded "it is not possible with the present evidence to show a convincing correlation between particulate air pollution and mortality". Similar conclusions, regarding $PM_{10}$-related mortality, have been discussed in publications by Henderson (1995), Crandall et al. (1996), Gamble and Lewis (1996), Lipfert and Wyzga (1997), and Kaiser (1997).

2.2.4.3 Possible explanations for the discrepancy between clinical and epidemiological data-Explanations are provided to explain the discrepancy between clinical and epidemiological data. The table does not consider the possibility that the problem may be associated with the accuracy of the epidemiological studies. Perhaps the epidemiological studies have not adequately addressed confounding factors or that PM is acting as a surrogate for another chemical.

2.2.4.4 Lack of Health Effects Threshold and Highlights of rationale for the Ontario interim PM10 ambient air quality criterion-It is concluded that a general consensus supports no clear threshold for health effects. Several investigators have concluded that particulate-related mortality increases linearly with the concentration of particulates with no evidence of a threshold (Pope et al, 1992; Schwartz J., 1994; Dockery and Pope 1994). However, after carefully considering the validity of the statistical analyses performed for these studies, Moolgavkar and Luebeck (1996) conclude that the data do not support a linear no-threshold exposure response relation. In defense of this conclusion, the authors cite problems associated with 1) parametric Poission regression models, 2) failure within the analyses to consider copollutants and 3) failure of the analyses to investigate other possible exposure-response relations.

2.2.4.5 Approach to Estimating Current Impacts-PM10 dose-response functions used in health impact analysis were taken from Hagler-Bailly (1995). Most of these functions were based on epidemiological studies that did ***not*** measure PM10.

Chronic Bronchitis: Dose-response function for PM10 is derived from an epidemiological study based on TSP. Assumes PM10 = 0.55 x TSP.

Respiratory Hospital Admissions: Dose-response function for PM10 is derived from an epidemiological study based on sulfate. Assumes sulfate = 0.18 x PM10.

Emergency Room Visits: Dose response function for PM10 is derived from an epidemiological study based on TSP.

Aggravation of Asthma Symptoms: Dose response functions for PM10 are derived from epidemiological studies based on TSP or sulfate.

Restricted Activity Days: Dose response functions for PM10 are derived from an epidemiological study based on PM2.5. Assumes PM2.5 = 0.625 x PM10.

Acute Respiratory Symptoms: Dose response functions for PM10 are derived from an epidemiological study based on COH. Assumes ratio of COH (units/100 ft) to TSP of 0.116 and PM10/TSP ratio of 0.55.
Lower Respiratory Illness in Children: Dose response functions for PM10 are derived from an epidemiological study based on PM15. Assumes PM10 = 0.9 x PM15.
Acute Mortality: The high estimate for PM10 associated mortality was derived using a dose-response function based on PM2.5 exposure estimates
2.2.4.6 Health Impacts Based on Current Levels of Respirable Particulate Matter (PM10)- Annual mortalities for a few Ontario urban sites were estimated for PM2.5 and PM10. Results indicate that the mortality rate for PM2.5 is 20% higher than that for PM10 even though PM2.5 is a sub-component of PM10. It is suggested that this difference is attributable to the "higher potency of PM2.5". However, this discrepancy suggests that there might be potential problems with the approach; perhaps with the use of generic conversions between TSP, PM10 and PM2.5.

2.2.5 Control Technologies- The report notes that the average cost for 32 FGD systems recently installed in the U.S. is 227 US$/kW. FGD costs are site specific and, as such, there is a wide range in costs. The report also comments on the FGD particulate removal efficiency . Particulate greater than 10 microns is removed but particles less than 2.5 microns in size are unaffected. It may be misleading to state that the retrofit of carbon injection for controlling mercury emissions is easy. Technology for mercury removal from utility boilers is still being researched and developed so there is no practical experience commenting on the ease of retrofit.

The use of excessive over-fire air (OFA) for $NO_x$ control can cause waterwall wasteage. Waterwalls have deteriorated after 5 to 10 years. Gas reburning is an expensive control technology. The use of selective non-catalytic reduction is still unproven on large utility boilers although there is a planned demonstration by AEP on a 600 MW unit.

Particulate matter removal control technologies discusses flyash reinjection. Is there a utility doing this? Other comments on this section include: removal efficiency is not a baghouse removal design parameter, and mercury removal may require a second baghouse to allow carbon recycling and to keep mercury in a separate waste stream.

The discussion of control technologies should cover multi-media since pollution prevention states that the transfer of substances between media is not acceptable. Industry could, in effect, be penalized for transferring a substance from air to land by implementing a specific control technology.

2.2.6 Developing An IP/RP Strategy for Ontario- The "Guiding Principles for Developing an IP/RP Strategy" are a good building block. The challenge will be in their application as individual stakeholders have different concepts for each principle.

Please contact me at (416) 592-6995 if you would like to discuss this matter further.

Yours truly,

Anne Douglas

Anne Douglas
Environmental Programming
Fossil

cc.: Walter Chan, MOE
Tom Hewitt, Imperial Oil
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November 3, 1998

Dr. W. Chan
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Dear Walter

Attached please find my comments on "A Compendium of Current Knowledge on Fine Particulate Matter in Ontario". I had hoped to e-mail them to allow you to provide a clean copy to the section authors. Unfortunately, a computer gremlin corrupted the comment file. As soon as we can reconstruct the file, I will e-mail it to Eric Loi's attention.

Although the opportunity to participate on the Working Group is much appreciated, I am deeply concerned that the time constraints imposed upon the working group have gravely restricted our ability make an effective contribution.

As you know, one of my major concerns is that long-term (for more than a generation), ambient particulate matter levels have declined, yet identification of the health concern is recent. Either much health improvement should be already measurable, or additional factors are involved. If that improvement can't be quantified, we will never be able to quantify the improved health outcomes that are the stated drivers for IP/RP regulation.

Data quality is a continuing issue. Emission inventories, as the document states, need improvement. Ambient data also need improvement, at least to ensure that data now available are representative. The LIS has contributed data that I hope will help fill this need. Because our database stretches back some 47 years, I am continuing to work to address the historical issues raised above. This effort will not be complete within the imposed timeframe; however, I think the historical record is an essential part of the issue, and will provide it as quickly as possible.

The benefit-cost analysis needs development, and a lot more input from the affected facilities. In our cursory review, much of the material appears to be dated, uses the 1990 inventory, and appears to significantly underestimate costs.

Finally, the science regarding associations between particulate matter in ambient air and health outcomes is far from as clear-cut as the compendium implies, particularly in the absence of any strong biological or mechanistic support.

In summary, the compendium needs much work, in closer collaboration with all stakeholders, before I could support it. As always, I continue to offer my assistance in any effort to produce equitable regulations, based on sound science.

Yours truly,

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Recycled Paper

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# Comments on Draft Report "A Compendium of Current Knowledge on Fine Particulate Matter in Ontario"

Scott Munro, October 21, 1998

## General Comments

The MOE is to be commended for the effort involved in producing a first draft review of IP/RP issues. The time and effort of the many contributors to the compendium is much appreciated.

Comments are provided on the assumption that the MOE will be identified as author of the final document. Members of the working group will be acknowledged as having provided comments on a draft of the report. No comments are offered on the draft summary chapter, in the expectation that an appropriate summary will be developed, based on the text of the final compendium.

Unfortunately, development of the compendium did not seek early input from industry and other stakeholders. Full involvement at its inception might have allowed development of a much stronger document, particularly with respect to emissions inventories; source apportionment; technology and, economic assessment.

Given the time frame and confidentiality constraints imposed on the working group, the comments must be taken as comments from me as a representative of the Lambton Industrial Society, but not as a representative for the LIS. Comments are based on personal review of the document and the supporting presentations made to the IP/RP Working Group, supplemented by limited input from members of the LIS Technical Committee.

Two sections of the compendium (Inventory and Cost/Benefit Analysis) were circulated within the LIS for comment and provision of supplementary information. Time constraints allowed only a superficial and incomplete review, with no opportunity to discuss and review methodology. Some anecdotal evidence raising concern with these sections is provided. Without a full understanding of the input and methodology used in developing these sections, endorsement of their conclusions is not possible.

Historical context is lacking throughout the document, weakening sections related to ambient levels and efforts to associate those levels with health outcomes. Nowhere does the report identify the costs or benefits of the reductions already achieved. In my opinion, this lack of historical context is the fundamental underlying weakness in this report. Particulate levels have been declining for more than a generation. Both measurement and anecdotal observation support the observation. Thus, either the adverse health outcomes are also diminishing, the causative agent has been misidentified, or a new, unidentified synergistic agent that exacerbates IP/RP effects has been introduced during the period that particulate matter exposures have been in decline.

The LIS has provided an overview of additional ambient data for the period 1952 through 1998 for a small part of southern Ontario. A more thorough review of LIS data records is in progress, and will be forwarded as quickly as possible.

The draft report reads as a review of selective sources supportive of an advocacy position, rather than a compendium of knowledge. If it is intended to provide a balanced review of current knowledge, the report should eliminate editorial comment throughout the text. Graphical and tabular support for the text should represent the normal situation identified in the text, not the exception to it. An example of this inconsistency is found in II.1.1 with accompanying Figure II.1.1. The text identifies an overall decline in particulate matter concentrations; the Figure describes the non-conforming situation in Hamilton.

Speculation regarding outcomes of other regulatory initiatives, such as Canada Wide Standards development, should be avoided. Speculation biases this report, and undermines the credibility of the ongoing CWS process.

References should be provided throughout the text, in sufficient detail to allow interested readers to consult the reference. Where references are internal MOE reports, or other sources not generally available, they should be provided as appendices to the compendium.

## I INTRODUCTION

### I.1 Background

This section needs considerable expansion, to put some perspective on the typical as well as episodic levels of particulate matter such as the London incident, In comparison to typical and episodic levels in Canada in the same era. Inclusion of the London incident in 1962 would be useful, as it demonstrates a different outcome, resulting from significant changes in heating fuels.

The statement that particulate matter is emerging as one of the most critical environmental health issues is misleading. It may be that improved understanding of an existing problem is emerging, in which case the problem is not new. If so, the compendium needs to clearly document the reductions in ambient particulate matter achieved in the decades since the London fog era and the improvements in health and reductions in health costs associated with the those changes. Alternatively, if a new problem is emerging, the document must address the difficult question "why now, when ambient concentrations are declining?".

## II POLICY AND STRATEGIC ISSUES

A much more complete and representative section on historical ambient levels in Ontario is needed, to put the issue in full perspective. Although the text identifies COH as the only real time long-term data, there are high volume and dichotomous sampling records for significant periods that can effectively identify trends.

Sections II.1.2, II.1.3, and II.1.4 have only a peripheral connection to IP/RP issues; do not impact on problem analysis or problem resolution; and, should be dropped from the text.

Section II.1.5, Primary Particulate Matter vs Secondary Particulate Matter, needs considerable development. Words like "mostly", "usually", "probably", and "some evidence" leaves a strong impression of unsupported speculation.

Section II.3, Linkage of the IP/RP Matter Issue to Other Air Quality Issues and Initiatives, raises the important issue: which side of a linkage best addresses resolution of a problem? For example, any program initiative addressing acid rain or ground-level ozone (para.6 in II.3.1) will have a positive impact on the IP/RP issue. Depending on the elements of a control strategy for IP/RP matter, the reverse may not be true. An important component of issue linkages not addressed in this brief section is a relationship among environmental linkages and health effects. Development of this addition would help focus priorities, and ensure that regulatory program development was complementary.

The text describing programs in other jurisdictions is inconsistent, and needs frequent reference to Table II.4.1 to make it readable. For example, section II.4.2.1 United States, does not identify the proposed standards in eight pages of text, while discussing compliance costs and regulatory implementation strategies.

## III SCIENCE AND TECHNOLOGY

### III.1 IP/RP Related Emission Inventory Development for Ontario

This section is a crucial component in the development of an appropriate, equitable particulate matter control strategy for Ontario, and, from the information provided, a very weak link. As the text emphasizes, the questionable quality of the data needs improvement, and **"requires meaningful co-operation and participation from industry sources in the characterization of emissions"**. There has as yet been no opportunity offered to begin that step. Understanding of the current inventory is hampered by lack of detail on estimating techniques.

The revised version of the emission inventory has exacerbated concerns about data quality. Revisions of estimates include both trivial changes and significant alterations - from adjustments of a few tonnes to factors of 2, to an order of magnitude, without explanation.

Considerable text is devoted to the limitations of the 1990 inventory, although the data are not provided. A fuller discussion on 1995 data quality would be more helpful.

The conclusion (III.1.1.2, para.4) that "The existing uncertainty and information gaps in the PM10 and PM 2.5 emission data should not be considered a serious impediment to initiating the development of workable IP/RP emission reduction strategies" is unacceptable. Earlier statements repeatedly make a plea for better data to support the standard setting process.

Figures III.1.1a and 1b should be deleted. Neither indicates clearly that the charts represent only a small fraction of the Ontario emission inventory, nor is there any identification of the total emissions represented by the charts. Figure III.1.1b cannot be reconciled with Table III.1.1, as sector identifications are not consistent. Most importantly, the charts are not a fair reflection of the emissions inventory. The 1995 chart, for example, appears to include only about 18% of the emissions quantified in Table III.1.1.

Even if data are completely compatible between the charts for 1990 and 1995, the statement that there is little relative change among sectors is invalid. In fact, the charts suggest some very large changes within sectors. For example, the charts imply that emissions from mining and rock quarrying have been reduced by 67% or more, depending on the relative size of the total emissions for the two years. Transportation sources, on the other hand, appear to have increased substantially, or at least not decreased at the pace of other sectors.

Without substantial detail on the estimating techniques and baseline information used, little comment on the quality of data in Tables III.1.1 through III.1.6 is possible. The magnitude of the changes to some categories between drafts is striking, and requires explanation, as do the large reductions in estimated total emissions for all particle sizes. The Tables report estimated emissions to the nearest tonne (particulate matter), an unwarranted level of precision and accuracy.

Tables III.1.1, III.1.2, III.1.3 and III.1.4 should use the same sector and category breakouts, at least at the level of category totals.

Table III.1.5 should provide ammonia emissions for 1995, for consistency with the other data. Point source data from NPRI suggest a much lower point source emission, 5338 tonnes per year, than the 14,781 reported for 1988.

## III.2 PARTICULATE MATTER ($PM_{10}/PM_{2.5}$) MEASUREMENTS

Section III.2 provides a good overview of available data relevant to Ontario air quality.

For clarity and consistency throughout this section, care should be taken to ensure that numerical values reported are completely identified, particularly as data from a number of jurisdictions are reported. For example, the choice of means used in averaging data should be identified as geometric or arithmetic, to ensure that comparisons are valid. This detail should appear on all accompanying tables and figures.

There is little to comment on with respect to the Environment Canada data presented. It is notable that US data show a 40% decline in $PM_{10}$ between 1986 and1993 (III.2.1, para.4), while Environment Canada data for Ontario show no significant changes between 1984 and 1993 (III.2.3.2, para.4). LIS data over a similar period are consistent with the US trends. The LIS data were provided to the working group at the October meeting. Limited LIS data comparing $PM_{10}$ and $PM_{2.5}$ fractions suggests a ratio of 40% $PM_{2.5}$, significantly lower than the 60% identified in the Environment Canada studies.

Comment on MOE data was hampered by the internal nature of the MOE reports cited, and by the illegible reproduction quality of most of the supporting maps and figures.

LIS data for 1997 (submitted) show fewer exceedence days than Windsor - in the range of 2% - always during periods of south to southwesterly winds, at monitoring site south and north of the industrial complex.

The suggestion (III.1.2.3.3, last para.) that neighbouring US states are significant contributors to the high levels of sulphate and fine particles in southern Ontario needs elaboration. Section III.2.1 identifies a 40% reduction in US levels between 1986 and 1993. Section III.2.3.2 states that there was no corresponding decrease in Ontario in the 1984 to 1993 period. Rationalization of these three statements is needed. LIS data for the Sarnia/Lambton County area, as indicated, support the US trend.

## III.3 THE ATMOSPHERIC CHEMISTRY OF FINE PARTICLE FORMATION

The clarity of this brief section is much appreciated.

## 111.4 SOURCE APPORTIONMENT: DATA ANALYSIS AND MODELLING

This section provides a useful background on models, their status and development, and the information needed to make them useful. The outline identifies data gaps and references limited studies, such as the brief paired study involving Egbert and Toronto, and the Hamilton Air Quality study. It is apparent that undue reliance is being placed on these studies, neither of which is representative of the province as a whole.

Section III.4.3.4 references use of models to back estimate emission rates. This questionable application of models must be used only as a last resort. Uncertainties in estimations of point source emissions are small relative to the product of multiple uncertainties inherent in a back calculation.

## III.5 HEALTH EFFECTS ($PM_{10}/PM_{2.5}$) AND HEALTH BENEFITS ON ACHIEVING POTENTIAL GOALS

This section provides an overview of selected studies previously reported elsewhere. The text requires editing to delete speculation and overstatement that detracts from the quality and careful qualification of conclusions found in the primary literature. There are a number of instances in which there are conclusions drawn with no identification of supporting references. An example is found in para.4 of Longer Term and Chronic Effects: "Recent evidence shows increases in... " with no study referenced.

It is striking that the literature related to health and occupational exposure to particles is completely ignored in this review.

The science is neither as well developed nor conclusive as this compendium asserts. A recent (1997) Critical Review and Discussion (J. Air & Waste Manag. Assoc. **47**: 551-581 and **47**: 995-1008) raises and debates the many issues surrounding the uncertainties regarding this science. As noted by Vedal in the critical review, "**the study of the health effects of ambient particles is plagued by a weak biological foundation. This makes it tempting to base what understanding we have on the results of statistical modelling, but which should, in addition, heighten our healthy suspicion that biases are at work.**"

Box II.5.1 identifies three common approaches to health effect evaluations but leaps to the conclusion that epidemiology provides the best approach - exactly the caution raised in the Critical Review. It is essential that the other approaches be used to adopt a weight of evidence approach, to resolve those "healthy suspicions".

Section III.5.1.2.1, Epidemiological Evidence, implies that epidemiological studies conclude that cardiorespiratory effects are <u>causally</u> related to airborne particulate matter. At best, they show <u>associations</u> between the two.

The increased risk of mortality for $PM_{2.5}$ is stated to be twice that of $PM_{10}$ for each10 microgram per cubic metre increase in mass, implying increased potency. This ignores the actual exposure situation - in general, $PM_{2.5}$ is about 50% of $PM_{10}$, thus in a population exposure study $PM_{10}$ rises at double the rise of $PM_{2.5}$. The relative potencies cannot be distinguished.

The extrapolation of low magnitude increases in mortality or morbidity to entire exposed populations implies acceptance of five assumptions:

1.) Confounding and covariance has been addressed.
2.) Those included in study data were representative of the full population.
3.) The full population is equally sensitive.
4.) Those in the study were exposed to the ambient concentrations - i.e. measurement, or exposure, misclassification
5.) Ranges of concentrations studied are representative ambient concentrations to which the full population is exposed.

Unless and until these assumptions are validated, extrapolation of study mortality and morbidity rates to the provincial population is unwarranted.

The discussion of evidence from controlled human studies concluding that clinical data do not lend much support to the epidemiology brings Vedal's comment regarding bias into focus. Box III.5.2 begins with the bias that it is the clinical studies that are limited. The alternate possibility should be considered, carefully.

Repeated statistical evidence of an association between particulate matter and cardiovascular health is not alone evidence of causality. As the first bullet in Box III.5.3 points out, epidemiological studies directly assess health outcomes in response to "complex mixtures of pollutants". They do not independently establish causality. Most studies referenced here did not include multiple contaminants; those that did found larger responses among gases and specific particulate species. It is interesting to note that each bullet in Box III.5.3 could be rephrased to identify a limitation on epidemiological studies.

The Bradford Hill criteria for evaluating causality are a useful, if subjective framework. This compendium finds that many of the criteria have been satisfied. Others (e.g. Vostal, discussing the Critical Review, JAWMA 47: 999) find that as few as two of the criteria have been satisfied - a weak link at best.

It is exceedingly difficult to characterize the evidence presented as remarkable, robust, or compelling. Studies that examined only associations between particles and health outcomes are consistent. Studies that include other air quality parameters cloud this consistency. The evidence certainly does not support that particulate matter, rather than other parameters is associated with health effects.

The application of the "no minimum threshold" theory is unwarranted, and unsupported. Clinical and toxicological studies have defined no observable effect levels. No epidemiological study can includes zero exposure - the real-world baseline includes biogenic and crustal material exposure. Box III.5.5 is similarly unsupportable based on the studies reported in the compendium.

The question remains whether exptrapolation to the general population is justified. It would be instructive to review historical records of indoor and outdoor exposures and corresponding health outcomes to gain some perspective on this issue. The statement that the measurable effects straddle a much greater burden of illness is speculation and should be deleted.

The conclusion (III.5.1.3, para.5) that the fine fraction has the highest association with adverse health effects is not supported within the document. The Shwartz study described in section III.5.1.2 identifies a larger association with sulphate, as do a number of other studies. Burnett et al (JAWMA 48: 689-700) found stronger associations with gaseous air contaminants, notably CO and $NO_2$.

There is insufficient description of methodology used to estimate population effects to comment effectively on the approach. For reasons developed above, the no threshold approach is unwarranted. The five assumptions regarding extrapolation to the general population, outlined above, need consideration, to at least provide ranges around the estimated outcomes.

## III.6 CONTROL TECHNOLOGIES

This is an acceptable generalized overview of standard design and operating practice, although it leaves the impression that such practices and devices are not currently in place. Most are, or are not readily or economically applicable to a specific service.

## IV BENEFIT-COST ANALYSIS OF PARTICULATE MATTER EMISSION CONTROL OBJECTIVES IN ONTARIO

It was not possible, given the time and circulation constraints imposed, to gather information to allow a full response to either the methodology employed, or the outcome of the analysis.

Four points are very clear on a brief overview:

1.) The analysis is based on a 1990 emissions inventory, while the rest of the document references 1995 data. The analysis should be repeated using 1995 data, consistent with the rest of the report. Given the large reductions in emissions in some areas (locally VOC reductions in the 40 50% range), the cost structure may be markedly different.

2.) The analysis should only be undertaken in full consultation with the industries involved, to ensure that the analytical methodology is appropriate, the "scenarios" realistic, and the cost functions representative. Site-specific anecdotal reports are provided below to illustrate the need for this consultation.

3.) The methodology does not address the problem that occurs when the "cost" is borne by one party, and the "benefits" or values accrue to others.

4.) The indicated positive return on VOC reductions (Figure IV.1) is inexplicable.

Anecdotal comment on this section:

- One local facility reduced VOC discharges by 875 tonnes/year (24%) between 1993 and 1996 at a capital cost of $5.4 million. The $6179 per annual tonne, exclusive of operating cost, compares to Table A.6's average of about $700 per tonne.

- Each tonne of solvent reduced in paint manufacturing through substitution is stated to save industry $5164. At solvent costs less than 30 cents per litre, or roughly $400 per tonne, how is this saving achieved?

- Imperial Oil's Sarnia refinery costs for $PM_{10}$ reduction appear to be low by an order of magnitude.

- Fuel switching does not appear to be fully costed. As an example, the Table A1 estimate of $379 per tonne to reduce Shell's Corunna facility $SO_2$ emissions by 96% clearly does not include the capital cost to replace oil fired equipment.

- Estimates for 50% reductions in NOx emissions from refineries, completed for the NOx/VOC Code were in the $2000-3000 per tonne range for retrofitting boilers, not the $387 used in Table A3.

- Most refineries and petrochemical facilities now have LDAR programs for VOCs in place, reducing fugitive emissions by 80% and overall VOC emissions by at least 30%. Table A.6 estimates $42 per tonne for this range of emission reduction. Actual LDAR costs, at more that $1500 per tonne, are still more cost effective than measures such as secondary seals, retrofitting of floating roofs, etc.

- Locally, fuel switching under the LIMA regulation carries an hourly incremental cost, accumulated for all affected facilities, of about $3000. If the lower POI were imposed year-round, the incremental annual cost would be about $26 million.

## V DEVELOPING AN IP/RP STRATEGY FOR ONTARIO

This section will need some rework following revisions to the main text. Any IP/RP strategy for Ontario should be equitable, efficient and effective. It will be none of these if implementation does not lead to measurable change in the health outcomes.

## IV (or should it be VI) SYNTHESIS OF RESULTS

This section will also require reworking following revisions. As it is currently constituted, the emphasis on cities implies that IP/RP concerns are limited to large urban areas. Elsewhere in the report, a major source is identified as cross-border transport, which effects rural areas. Regional transport is evident in the LIS $PM_{10}$ data supplied for the Moore Line site, which represents rural levels at least with southerly flows of air. Some focus must remain on influencing reduction programs in the US.

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November 9, 1998

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**RE:** CPPI Comments on ...
<u>*"A Compendium of current knowledge on fine particulate matter in Ontario"*</u>

Dear Neville,

Thank you for the opportunity to provide comments on the above Compendium. The Canadian Petroleum Products Institute (CPPI) applauds the Ontario Ministry of the Environment for compiling the first draft of the current knowledge of fine particulate matter in Ontario. This effort has prepared the groundwork for the multi-stakeholder discussion of PM that has been taking place within the Inhalable Particulate-Respirable Particulate Work Group of the Ontario Smog Plan.

*CONSIDERATIONS IN DEVELOPING AN IP-RP STRATEGY FOR ONTARIO*
Ontario's air quality has been continuously improving. That's not to say we shouldn't all strive to improve air quality. However, we must be mindful of the fact that our immediate neighbor and largest trading partner produces emissions that significantly impact our airshed. Setting standards, options and strategies in isolation of U.S. air quality planning will place Ontario at an economic disadvantage. The CPPI suggests that any Ontario PM option be developed keeping in mind the significant PM research and policy effort underway in the US; as well, any Ontario PM option must be developed in context with the efforts and timeline on the Canadian national (and regional) scene (Canada Wide Standards - fall '99). We should look for consistencies and efficiencies with Canadian (national and regional) processes. Finally, any Ontario PM strategy must be developed in a transparent, open (i.e., full-consultation) process with all relevant stakeholders.

## <u>COMMENTS ON COMPENDIUM</u>

Our comments are provided on the understanding that the Compendium is basically a compilation of scientific knowledge, a "Technical Resource Document", compiled and authored by MOE staff for the purpose of discussing the PM issue with relevant stakeholders. Furthermore, in keeping with the MOE's request to restrict the sharing of the Compendium, we have only circulated specific sections of the document to our member companies. Hence, our comments should be regarded as limited. They do not provide a line-by-line review, but do offer general and, where warranted, specific comments. Our specific comments follow the outline of the Compendium.

## GENERAL COMMENTS

### *1. ADVOCACY TONE & LANGUAGE*

The document carries a definite "advocacy" tone. It appears to be a compilation of selected references, perspectives, speculations and editorials. For example, if calling PM the "most critical" environmental health issue and immediately linking it to the "killer-fog" is designed to impart anxiety to the readers, it will. We suggest that the Compendium be edited to reflect its intention: a "technical resource document"; and that it present a more "balanced" review of the PM information available.

Furthermore, given the Compendium is primarily scientific in nature, Section 5 of the Compendium "Developing an IP-RP strategy for Ontario" seems out of place. We suggest you remove this section from the Compendium, which will allow a wider circulation of the Compendium.

### *2. PM SCIENCE ERRONEOUSLY POSITIONED AS COMPLETE/ COMPELLING*

The Compendium positions most of the science underpinning PM policy as robust, remarkable, complete and compelling. There is insufficient mention of the uncertainty associated with much of the PM science and the fact that the US EPA has allocated in excess of $400 million over the next 12 years to study PM.

### *3. PM POSITIONED AS THE "MOST CRITICAL" OF AIR QUALITY ISSUES*

In the Compendium, PM is positioned as one of the "most critical" air quality issues. The CPPI suggests that PM should be put into perspective with other air quality issues. That is, PM needs to be discussed in a more comprehensive air quality context. Will action on one substance (e.g., PM) cause issues with another AQ substance? Will action on PM merely shift issue to another media?

There has been significant improvement in PM and air quality since the 1970's. The Compendium needs to discuss why there is a statistical link between health outcomes and PM, given that PM measurements show a decline over the last 25 years.

Also, Health Canada's most recent work suggest that it is the entire air pollution "mix" that is responsible for negative human health effects. This aspect needs more prominence in the Compendium, as it adds to the uncertainties associated with the effect of air pollution on human health.

## SPECIFIC COMMENTS ON COMPENDIUM

### *Section 1: BACKGROUND*

- More perspective and context is needed, including discussion of
    + Trans-boundary emissions
    + Existing AQ policy in Canada, U.S. and Ontario
        US EPA 5 year review is not mentioned; neither is the US re-adoption of PM10 = 150 ug/m3 and the PM2.5 = 65ug/m3
    + Linkage to other AQ issues (e.g., Climate Change)

- In section 1.2, the mention that "40/20" will be a reference point for the CWS, as a longer- term objective, is presumptive and implies that 40/20 is the right answer. These levels are not supported by a complete analysis (including socio-economics) and reference to the numbers should be removed, lest it misleads the reader.

### *Section 2: POLICY & STRATEGIC ISSUES*

- Not sure of the value of this section as currently drafted.
- Needs more details on historical background. Need less (perhaps delete) sections on Black Fallout, Complaints and Visibility.
- Needs much more detail on section on Primary and Secondary PM.
- Need further development on the "linkage" section, i.e., PM with other AQ issues.

### *Section 3: SCIENCE & TECHNOLOGY*

### *3.1 EMISSION INVENTORIES*

- Emission inventories are critical to underpinning effective PM policy.

The CPPI would like to see clarification on how the emission data has been derived?

- + Details on inventory estimating methodologies/techniques are needed
- + Stakeholders need to verify/validate emissions
  - (Precision/"significant figures" of emission data is not realistic)
- + Emission data needs to be effectively characterized/speciated

- Revisions to database without adequate explanation has exacerbated stakeholder concerns that the data lacks legitimacy.
- Less detail on the 1990 inventory/more on the 1995
- Graphical & pictorial representations are not balanced. Need to include all emissions.
- Need to be consistent in sectors/categories for data to be comparable

Are the VOC and NOx estimates based on the NOx/VOC management plan? The Plan assumed a 2-3 % growth rate per year for chemical and petrochemical industry and this was reflected in the total emission projections. The demand for petroleum product has gone down and some refineries and chemical plants have been shutdown. Also all petroleum and chemical facilities have implemented Leak Detection and Repair (LDAR) programs. Does the emission database reflect these efforts?

SO2 emissions from CPPI member companies may be overstated, given the Compendium reports SO2 emissions from individual facilities: Shell, IOL Sarnia , NOVA, IOL Nanticoke; and from the refinery group (presumably Sunoco and Petro Canada) as 22,800 tonnes per year.

### *3.2: PM MEASUREMENTS* "Compare apples with apples!"

- + It is important to compare data collected from the same type of monitoring equipment. It is unclear from the Compendium whether this is the case.
- + Rationalize/discuss why the U.S./Ontario data trends are different!

### *3.3: ATMOSPHERIC CHEMISTRY OF PM FORMATION*

### *3.4: SOURCE APPORTIONMENT (DATA ANALYSIS & MODELING)*

- Danger in high reliance on models
- Critical for area sources to be included in regional/urban modeling

Uncertainties involved in the analysis (Bottom-up inventories do not agree with Chemical Mass Balance apportionment) need to be discussed. When the bottom-up inventories are used for Cost-Benefit Analysis in Section 4 (i.e., roll back analysis) there should be a quantitative assessment of the possible error/uncertainty due to the difference between what is estimated from the source and what is seen in the air (via CMB). This would put uncertainties in better perspective.

Before controls can be advocated/implemented, we should know the relationships between sources and receptors if we don't want to waste societies precious resources. Without more source apportionment information we cannot effectively implement control strategies.

### *3.5: HEALTH EFFECTS*

- Not realistic to characterize health evidence as remarkable, robust, compelling, complete
- Correlation between health and PM is statistically based.
- No causality has been established.
- Recent Health Canada info diminishes impact of PM, and points to entire air mix
- Need statement at start of section: "we are just beginning to understand the complexities and impact of air pollution on human health."

This section needs to be rewritten to be more objective. Currently, the reader is lead to believe we know everything we need to know about this topic and can "quantify" health effects with great certainty, which is clearly wrong. The section needs to address the uncertainties in a way that will give the reader a sense of the possible range of responses. Currently, the range of responses presented is derived from selected studies, which use the same or similar databases.

### *3.6: CONTROL TECHNOLOGIES*

## *Section 4 -BENEFIT COST ANALYSIS*

We have great concerns about the data collected to support CBA, the integrity of the methodologies, and the applicaiton of the CBA. What we offer are some highlights of our concerns. What is needed is a much more thorough review of this subject, probably outside of this Compendium.

- Needs consistency in analyzing cost data (i.e., using 1990 vs. 1995 data)
- Analysis needs to be redone given significant reduction in emissions from many sectors
- Consultation with relevant sites is critical to validating data

  E.g., Estimated annualized cost of reducing PM from one refinery is approx. $150K, whereas another refinery is estimated at $1Million. Why the difference?
- Cost Abatement Function chart needs to be updated to include abatement actions that have occurred over the past decade.
- Competitiveness costs needs to be included, i.e., the "cost" of business decisions to

relocate to other jurisdictions or shut down operations.
- Estimating Benefits using "the value of a human life" is very contentious
- Willingness-to-pay" approach has been roundly criticized.
- Understand Health Canada has revised their numerical value of a human life :

This section will confuse people by speaking in terms of "value" for benefits, and "costs" for abatement technology. It needs a full and clear description that explains that value is, by-and-large, a non-market based measure, unlike costs, which are tangible and market-based.

The "roll back" method (assumption of equal proportionality) for assessing emission reductions needed to achieve a concentration goal is overly simplistic. It is difficult to accept for primary particulate matter and totally unacceptable for secondary particulate matter. This method needs review by a panel of independent experts.

The uncertainties associated with whatever approach is used should be quantified. This is very important when importing the results into the benefits (AQVM) model.

May be substantial errors with respect to the technologies used and their costs:
- Failure to include capital cost for fuel switching at a refinery ($10's of millions).
- Assumes single source for SO2 scrubbing; numerous/smaller sources mean more costly units
- Reducing refinery NOx is quoted at $387/T. Cost effectiveness of retrofitting our heaters and boilers is more in the range of $2000 to 3000/T (See figures generated in developing CCME N306 NOx Code
- VOC reduction from refineries is quoted at $42/T. The most cost effective VOC reduction is through LDAR at >$1500/T. Installing secondary seals on tanks is much more expensive.
- Stage I (VOC control from gasoline distribution) is quoted at $42/T, whereas the industry costs are >$500/T
- Stage 2 is >>$1000 verses Compendium's $191.

Our main areas of concern with calculating benefits using AQVM are:
- The dose response curves used for health effects
- The monetary value assigned to premature mortality (effect of age)
- The monetary value assigned to chronic mortality
- The discount factor applies does not correspond to the treasury board recommendations

*Section 5 - DEVELOPING AN IP-RP STRATEGY FOR ONTARIO*
- We support policy that is protective of public health and the environment
- We support the development of policy that uses a multi-stakeholder participatory process
- We support decisions that are fact based, where unknowns and uncertainties are recognized
- We support the identification of cost-effective control measures aimed at an integrated

reduction, where we can be relatively sure that action on one front is not making matters worse on another.

- We support alignment with the Canada Wide Standard setting process in form and timing
- We support the alignment with the significant efforts underway in the U.S. to understand and revise their standards
- We support the concept of risk assessment/management in setting air quality standards
- We need to put in place a measurement system to determine if our actions are having a positive effect

## COMMENTS ON SUMMARY DOCUMENT

It is our belief and understanding that the Summary Document will be prepared upon completion of the basic Compendium. Accordingly, we will withhold detailed comments on the current version of the summary document and offer the following general, guiding comments.

Since the Summary Document will be the most widely read, it must be a stand-alone document.

PM must be put in perspective with air quality issues and historical trending, i.e., MOE data show that air quality has significantly improved and PM levels have declined since the 1970's. What is the impact of transboundary emissions/sources?

PM emission inventories are critical to underpinning any Ontario PM strategy. PM data needs validation by all relevant stakeholders. Pictorial/graphical representation of PM emissions/source apportionment needs to include all sources not only anthropogenic sources. (See Section 3, Fig. No. 2 of the current Summary Document)

Larger sample sizes are needed before general judgements can be made. (See Section 4, "How much particulate is in the air?") It is not clear whether the data selected reflects the typical Ontario situation.

**IN CONCLUSION**

Thank you again for the opportunity to provide comments on the PM Compendium.

The CPPI remains strongly committed to the Ontario Smog Plan, and the development of responsible clean air strategies that are based on the use of scientific principles, sound knowledge, risk management, where socio-economic impacts have been understood and accepted; and where development has been guided by a disciplined management process.

Should you wish to discuss any of the above, please call me at 416-968-4038

Sincerely,

Hewitt

Thomas Hewitt
Chair, Ontario Air Quality Task Group
Canadian Petroleum Products Institute

cc: Walter Chan, Ministry of Environment, IP-RP work group
Howard Carter, Chair, CPPI Ont EH&S Cttee
Bob Clapp, Vice President, CPPI Ontario Division
Gail Bolubash, Dir. Environmental Affairs, CPPI Ontario Division

**Canadian Vehicle Manufacturers' Association**
**Association canadienne des constructeurs de véhicules**

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November 6, 1998

Mr. Walter Chan
Co-Chair IP/RP Options Assessment Working Group
Ontario Ministry of the Environment
2 St. Clair Avenue West, 12th Floor
Toronto, Ontario
M4V 1L5

Dear Mr. Chan:

The Canadian Vehicle Manufacturers' Association (CVMA) is pleased to be an active member of the Ontario Inhalable Particulate / Respirable Particulate Working Group (IR/PR). CVMA is supportive of the Ministry's approach of having a multi-stakeholder working group review.

As part of the working group objectives (tasks), the CVMA has reviewed the draft document entitled "A Compendium of Current Knowledge on Fine Particulate Matter in Ontario". The CVMA has reviewed the document and ahs the following comments to offer. Our comments have been focused on ensuring that the reference document is balanced and contains credible and unbiased information so that the reader can be well informed on the issue(s) surrounding particulates. Overall the compendium document contains detailed and useful information which with the appropriate changes could be used as background technical document for the development of an appropriate strategy to address particulates in the future.

General Comments:

1. It is our understanding that this document will be providing a "snap shot", view of the existing scientific data and present regulatory requirements for particulates. Unfortunately, the approach and wording in the document does not just report these findings but has an advocacy tone. The wording seems to validate findings particularly in the area of health impacts even thought the science has a large degree of uncertainty and it is still evolving. This document seems to favour or defend epidemiology studies that conclude a positive association between existing ambient PM levels and mortality /morbidity. It fails to clearly identify the real uncertainties and knowledge gaps surrounding the studies. If this document is to be a representation of the existing level of scientific knowledge on this subject, it must provide a balanced presentation of the studies and not prejudge the findings.

2. The scientific data reported in the document does not state the appropriate confidence levels. This is essential to give the reader a numerical appreciation of the uncertainties of the findings. Without having a more complete discussion outlining the confidence level of the numerical findings, the assumptions in the underlining studies and the related uncertainties involved in the findings in the document, it leaves the reader with the inaccurate picture that the science involved with particulates is known and complete. As you are aware, this is not the case, especially in the area of causality of human health effects and mortality from particulates. It is also clear that the relationship between primary and secondary PM and ambient air is largely unknown.

3. The document does not adequately address natural sources of particulates and the background level that can be attributed to these sources. Without this essential discussion

and data, it is very possible that any proposed standard could be stricter than what is found naturally in the environment in a given area and that the public will be misinformed about all the particulate sources. This issue is also important because if the background levels are not presented it leads to the impression that PM air quality is much worse than is really the case. The document should include pie charts which set a national context and Ontario's context with respect to particulates.

4. Based upon the material and the existing level of uncertainty with the science presented in the document it would seem premature to be proposing options as outlined in Section V. It would however make sense for the document to outline the next steps in the Province's process of reviewing and improving the existing knowledge and then developing options. As part of this process the CVMA is committed to a more collaborative approach towards the next steps which could include but not limited to assessing and costing control technologies and the development of socio-economic impact statements.

5. The development of any future PM standards in Ontario or Canada needs to be further assessed and prioritized in light of all of the air quality, as well as other environmental issues, such as Climate Change. This needs to be done to ensure that the most environmentally and cost effective approach is taken in dealing with all of these combined issues and that the interrelationships are clearly understood. This is even more crucial since prevention and / or abatement technologies for one environmental issues such as PM may actually be counter productive to the technological and other solutions required for other key environmental concerns.

6. The draft document does not include or reference to Manganese Oxides from vehicles and their potential contribution to this issue.

7. The development of any future PM standards also must take into account the standards of our largest trading partner the United States. Given the economic links between Ontario and the United States and the fact that the United States is a major influence on Ontario's air quality standards must be developed on a harmonized basis. This will ensure an overall improvement to Ontario's air quality without unnecessarily putting Ontario's industries at a competitive disadvantage.

8. The CVMA agrees with the statements in the document that "several years of ambient air monitoring and source characterization and assessment will be required" and that further IP/RP related research is needed to fill knowledge gaps". Given the impact that this work could have on Ontario's environment and economy it is important that we have a clearer understanding of this issue prior to acting. This way we can ensure that any standards developed will be supportable and beneficial to the province.

Specific comments in addition to the general comments are as follows:

Page I.1 First paragraph - Since there are significant uncertainties with the data linking PM health effects, the justification for the statement that "PM is emerging as one of the most critical environmental issues" is unclear. This is an example of how this document has an advocacy tone to it as opposed to an unbiased review of the available information.

Section II.2 – It is assumed that given all of the changes which are being proposed under Regulatory Reform and Approvals Reform, this section will have to continue to be updated as the document is revised into its final form.

Page II.2-2 First Paragraph Last Sentence - need to remove a space between "...regulations  as well...".

Page II.3-1 – The text should include a discussion of priorities of this issue relative to other environmental issues not just air quality.

Page II3.3-1 Last paragraph – The text should also reference the potential trade-off between environmental issues. For example, the vehicle emission control technology for hydrocarbons, NOx and CO Increases fuel consumption.

Page II.3-3 Last paragraph - What is the rationale supporting the statement that a 45% reduction In total NOx and VOCs emissions will reduce exceedances by 75% by the year 2015.

Page II.3-4 Third Bullet – spelling error "tmasportation" changed to "transportation"

Page II.3-4 Under Drive Clean, second sentence – spelling error "theredby" to "there by"

Page II.3-4 Under Sulphur in Gasoline and Diesel – This section needs to be updated in light of the recent Federal announcement on Sulphur in Gasoline. The last sentence should be revised to include the sulphur in gasoline has also been shown by the U.S. EPA to increase N20 emissions.

Page II.4-6 Under Congress First Paragraph - define "NAAQOS"

Table III.1.1 – It is unclear if these are only "primary" numbers. Given the estimation involved in developing these numbers they appear to very precise numbers. Please include confidence levels to show uncertainty.

Table III.1.2 – Under Area Sources there is no reference to rail.

Figure III.1.1a – Under "Transportation's 11%" does that include all transportation (road, marine, rail and air). Please clarify on the Figure.

Figure III1.1b – Under Transportation's 18%" does that include all transportation (road, marine, rail and air). Please clarify on the Figure.

Page III.4-14 Second Paragraph – Discussions on vehicle emissions and controls must also include fuels, since vehicle emission control systems are always limited by the quality of fuels.

Section III.6 Control Technologies – This section needs to include a better recognition of the technologies that have already been implemented by industry. With the way the document now reads it leaves the reader with the impression that many of these technologies are not already in use. There needs to be a paragraph that shows that industry has and continues to use these technologies.

Table 6.2 EPA Tier 1 Standards – to be consistent with the rest of the chart the Tier 1 Standards should be the 160,000/190,000 Requirements:

| | NMHC | CO | NOx |
|---|---|---|---|
| LDV | 0.31 | 4.2 | 0.6 |
| LDV1 | 0.31 | 4.2 | 0.6 |
| LDV2 | 0.40 | 5.5 | 0.97 |
| LDT3 | 0.46 | 6.4 | 0.98 |
| LDT4 | 0.56 | 7.3 | 1.53 |

Page III.6-13- Under Control Technologies for Transportation, the need for vehicles and fuels to be dealt with as a system needs to be addressed especially in terms of its impact on not only SO2 emissions but Hydrocarbons, NOx and CO. In the document, reference should be made to the limitation that fuel quality can place on vehicle emission control technology. Inappropriate fuel quality can inhibit emission control technology from providing its designed environmental benefits.

In the worst case, fuel quality and its characteristic can make emission control technology and its on board diagnostic systems malfunction.

PageIII.6-17 Transportation needs a more detailed discussion of the mechanisms that contribute to particulate emissions in vehicles. Further explanation of why vehicles and fuels need to be dealt with a system should be Included. This section should also have more detail about the costs associated with emission reduction from vehicles including the introduction of Low Emission Vehicle Technology and the required fuels.

Table IV.5 Local Sources of IP/RP – Related Emissions in Hamilton, Table IV Sources of IP/RP – Related Emissions In Windsor Table IV.9, Table IV.10 Table IV.11, Table IV.12 – The reference to transportation should be clarified. Is it all transportation or just road?

Chapter IV Benefit-Cost Analysis of Particulates Matter Emission Control Objective – the Costing Information in this chapter is dated. This information needs to be updated prior to finalizing this document to provide the reader a completed and updated understanding of the present day costs and relative benefits involved with this issue.

The CVMA is committed to continue working with the province under Ontario's IP/RP Working Group. It is our request that these comments will be considered and incorporated into a revised text.

Should you have any questions please do not hesitate to contact me.

Sincerely,

Keith B. Madill
Manager, Policy Development

c.c. Dr. Neville Reid, Environment Ontario

54020AKS.DOC
Ontario Smog Plan

CPCA
CANADIAN
PORTLAND CEMENT ASSOCIATION
ASSOCIATION
CANADIENNE DU CIMENT PORTLAND

November 4, 1998

Mr. Walter H. Chan
MINISTRY OF ENVIRONMENT
2 St. Clair Avenue West
Toronto, Ontario
M4V 1L5

**Subject: Comments on "A Compendium of current knowledge on fine particulate matter in Ontario"**

Dear Mr. Chan:

Further to the publication of draft **"A Compendium of current knowledge on fine particulate matter in Ontario"**, CPCA Ontario gray cement producer is submitting the attached comments and recommendations. Specifically, we would like to mention that particulate matter (PM) science described in the document is not giving a clear evidence that PM is the causal agent for linkage that exists between health and PM.

Your efforts to get Ontario's strategy on particulate matter in partnership with stakeholders are greatly appreciated by our association. Cement industry values the opportunities that it has to participate in this process. Decisions involving interest stakeholders will provide fair, practical and efficient policies on this environmental issue for Ontario.

Cement industry has decrease its emission and its energy use since the last 20 years. Particulate matter is currently under strict control and emission is periodically verified. New challenge on particulate matter and further reduction need to be addressed from a holistic approach in order to understand mechanism, contribution and consequences to the environment. We hope that a better understanding of the overall contribution by all stakeholders and its consequences will make better decisions for Ontario.

Our main concerns with the July 98 compendium document are:

- Particulate matter (PM) science described in the document is not giving a clear evidence that PM is the causal agent for linkage that exists between health and

PM. However, it is obvious that studies indicate a underlying issue associated with PM. Therefore, efforts should be done to better understand the causal agent before setting any standards that would not benefit the environment or create another environmental issue (co-lateral effect);

- The PM level for cement and concrete sectors seems high and should not be aggregated together. CPCA is conducting a survey to evaluate cement contribution to PM 2.5. The numbers in the compendium document seem high. However, the data provided in section III of the document have been aggregated with concrete industry, so we are unable to assess the validity of this data. Concrete industry is very different from cement industry. Concrete process consists of mixing cement, aggregates and water. Cement is made by heating at high temperature fine powder to produce clinker that is grinded with gypsum to form cement. Therefore, data from these two industries should be split off in the table. In the meantime CPCA Ontario region will validate their numbers that will be forwarded to MOE.
- The structure of the document should be modified. We propose to present

| | |
|---|---|
| -Issue | *What is particulate matter*<br>*Why it poses a health concern* |
| -Contributors | *Source apportioning* |
| -Control | *How could we control PM*<br>*Legal tools* |
| -Economics | |

- Remove the strategy section and make a stand-alone document in which each option is described with pros and cons of each.
- Wording of some sections should be revised. Readers of this compendium document could interpret that PM is the most critical environmental issue of the century. We do recommend that professional feelings should be removed (e.g. heroic, emerging most critical environmental issue). Besides, some sections should be revised to get rid of redundancy (e.g. Regulation topics are addressed in three different sections).
- Make a clear statement at the beginning that environmental indicators show that PM could be an issue. However, the state of the science does not give a clear evidence and a lot of uncertainty exists regarding the environmental risk of PM. Therefore, PM strategy should recognize it like in the United States.

Ontario should investigate particulate matter. This assessment has to be carried over within the principles' framework as set out by the Smog plan (Balanced approach, Fairness, Harmonization, Sound science and Flexibility). Ontario PM strategy should be harmonized with Canada and United States counterparts because Ontario's could affect its competitiveness with its largest trading partner, the United States and with other countries that export into Canada.

CPCA Ontario gray cement producers do recommend:

- the compendium document be revised;
- data of concrete and cement be split in two categories;
- Ontario PM strategy considers science development and be harmonized with Canada and United States strategy.

If you or your staff wishes to schedule any meetings or require any further particulars regarding the comments and recommendations, please contact the undersigned.

Yours truly,

Denis Beaulieu
Environmental Director

DB/fc

attachment

c.c. Peter Waisenen
CPCA Ontario region
Tom Hewitt
Imperial Oil

## COMMENTS ON

## *A compendium of current Knowledge on fine particulate matter in Ontario, July 1998*

### INTRODUCTION

Canadian Portland Cement Association (CPCA) Ontario region represents cement producers in Ontario. Cement is a commodity used in concrete as a binder. Concrete is then used to construct roads, buildings, bridges etc. Cement is prepared in large vessels where raw materials are heated up to 1450 °C.

In 1997, CPCA Ontario region has signed the Smog Accord. In essence, our association recognizes that smog is an environmental issue in Ontario and that we will collaborate with other stakeholders to find efficient ways to address this environmental concern. This participation is, however, directly related to guiding principles stated in the Smog plan, that we would like to mention.

1. **Balanced approach,** on problems involving a great risk to human health and the environment;
2. **Fairness,** on stakeholders' contribution regarding the environmental risk associated with it;
3. **Harmonization,** with other jurisdictions in order to maintain Ontario competitiveness;
4. **Sound science,** decision will be based on science nor then easy manageable target;
5. **Flexibility,** ensure that processes are unambiguous, understandable and applicable.

In our view, the proposed MOE PM compendium is a good document. However, it is in conflict with some of the aforementioned principles. Therefore, we do recommend that this document be reviewed and corrected.

Here are our comments:

### *General*

- Structure of the document should be modified. We propose to present

| | |
|---|---|
| -Issue | *What is particulate matter*<br>*Why does it create a health concern* |
| -Contributors | *Source apportioning* |
| -Control | *How could we control PM*<br>*Legal tools* |
| -Economics | |

- Wording of some sections should be revised. Readers of this compendium document could interpret that PM is the most critical environmental issue in the century. We do recommend that professional feelings should be eliminated (e.g. heroic, emerging most critical environmental issue). Besides, some sections should be revised to get rid of redundancy (e.g. Regulation topics are addressed in three different sections).
- Make a clear statement at the beginning that indication shows that PM could be an issue. However, the state of the science does not give a clear evidence and a lot of uncertainty exists about the environmental risk and the health causality of PM. Therefore, PM strategy should recognize it like in the United States.
- The strategy should recognize works done in the United States and be in some extend harmonized with it. Ontario PM strategy should be based on the science. The United States expresses that the science of PM is uncertain. Therefore, their strategy is based on a step-approach (develop ambient air network, measure, gather other scientific evidences, learn, adjust). Ontario should set a PM strategy that will protect environment, the public and the economic development. If PM strategy is stringent than United States will put Ontario in a competitive disadvantage without clear benefit for the environment.

## *Details*

Cover page

- Change IP/RP working group. It is a MOE document submit to.

Section I

- Change words most critical and harmful level. As the document and the reference suggest (ex. Rick Burnett, Stephen Hueber, Kenneth Chilton) causality of PM 10 and 2.5 have not been established. Uncertainty associated with epidemiological study of PM do not demonstrate the relationship between PM and health. Therefore, particulate matter could be a surrogate of another issue and it needs further investigation. So, the use of advocate wording is innapropriate.

Section II.1

- From historical background, it seems that the statement is strong. The United States ambient air network monitoring station is insufficient. The Ontario network could give indication but it seems too weak to support the fact that it represents PM situation in Ontario.
- The complaint section is irrelevant. If the PM issue is driven by health perspective then complaint section should be removed.
- Visibility section, same comments as above.
- Ambient monitoring section, again the statement seems strong. No representative samplings have been done in Ontario for $PM_{10}$ or $PM_{2.5}$. Data have been collected and it seems to have a correlation but further investigation has to be done in order to do the apportioning with transboundary, industries, roads, cars and natural background.

Section II.2

- Group that section with control section.

Section II.3

- This section should indicate that reducing one parameter could influence others. For example, in the cement industry, control of NOx could increase emission of SOx and $CO_2$. Therefore, a holistic approach should be taken in the assessment of PM issue to evaluate benefits and priorities in term of pollutant.

Section III.1

- Table III.1.1, PM level for cement and concrete sectors seems high and should not be aggregated together. Cement and concrete data in the compendium document seem high based on a quick evaluation using USEPA AP-42 emission rate factor. However, the data provided in section III of the document have been aggregated with the concrete industry and we do not know if those numbers include fugitive emission (roads, raw material, stockpiles etc.) at those facilities, so we are unable to assess the validity of this data. Concrete industry is very different from cement industry. Concrete process consists of mixing of cement, aggregates and water. Cement is made by heating at high temperature fine powder to produce clinker that is grinded with gypsum to form cement. Therefore, data from these two industries should be separated in the table. In the meantime, CPCA Ontario region will validate their numbers that will be forwarded to MOE.
- Table III.1.1, mention should be made that those data are estimated from MOE and what are the estimated techniques used (put in appendix).
- Table III.1.1 data should be presented by PM contributor order. We suggest to classify by % contribution nor by sector.
- Figure III.1.1a, include other sectors. This figure is misleading. The figure of the major sectors gives the impression that the only contributors are industries but in fact the roads are major. Besides, readers have to understand that if all Ontario industries are shut down, PM issue will persist because of other major sources like roads.

Section III.2

- Page III.2-8, last paragraph states that more research is needed to better understand the distribution of PM. We agree with that statement. Therefore, argument that PM is the cause of health problem is not scientifically demonstrated.

Section III.3

- Page III.3-7, non linearity is very important. From our experience, when you decrease a parameter, you do not see a linear decrease and you could have side effects. For example, cement plant could decrease NOx emission by putting SNCR technology but it will increase secondary PM because of ammonia slip that will generate aerosol. Therefore, it is important that the compendium document recognizes it and evaluates PM from a holistic approach.

Section III.4

- Page III.4-7, last paragraph, it seems clear the data from modeling of aerosol (secondary particulate) are not reliable. Models have limitations. Try to mathematically represent the reality and could give helpful indication. Therefore, it seems that aerosol data are insufficient to make a sound risk management strategy for PM2.5.
- Page III.4-8, last paragraph, the source-receptor modeling seems inappropriate at this time. This modeling is based on hypothesis that a decrease of PM is linear. As the compendium states at page III.3.-7 it is not the case.

Section III.5

- Page III.5-1, last paragraph first sentence, *By far best evidence that cardio-respiratory effects are causally related to airborne PM at levels that are currently experienced comes from the epidemiological study.* This sentence is not scientifically correct. Based on Center for the study of American Business, Annapolis center, Sheldon K. Friedlander, Morton Lippman and Rick Burnett, epidemiological data show a link and a correlation between PM and health but not the causality. Those organizations and researchers conclude, that there are insufficient evidences as a basis for a sound risk management decision. Besides, epidemiologist Suresh Moolgavkar of the University of Washington argues that *"Pollution is a very complex mixture and there's simply not enough information to single out anyone component and say that's responsible for the health effects". He proposes that EPA should take a holistic approach in order to give more flexibility to areas that have high levels of some pollutants and low levels of others. Sheila West of Johns Hopkins University says " ...epidemiology can only find a relationship exists between a cause and a disease—it can never prove the causation".*
- Include a box that describes epidemiological study, its use and its limitation.
- Sheila West of Johns Hopkins University, describe a strong epidemiological relationship as:

  ⇒ *use data from a large number of people*
  ⇒ *shows up in many population groups*
  ⇒ *is backed by laboratory studies into the cause*
  ⇒ *shows a dose response relationship*

  It seems that the last two points have not been demonstrated yet. Therefore, epidemiological studies conducted show an association between PM and health diseases but it is not a strong study that shows clearly the causality.

- Section III.5.3, integrate that section with legal control or standards.
- Page III.5-26, it seems that the authors calculate potential benefits from reducing PM2.5. It appears difficult to do such assessment because of the non-linear effect and the co-lateral effect. Non linear effects have been described in the compendium. The co-lateral effect is an increase of other pollutants that could generate a new problem. So, exercise is good but the reader should be aware of those limitations.

- Page III.5-27, second paragraph, remove the word heroic.

Section III.6

- Page III.6-1, introduction should indicate that control technology chapter covers control technology of anthropogenic sources. A mention should be made that those sources generate x% of PM.
- Table III.6.1 this table has to be explained or removed. It could confuse the reader. For example, the term scrubber has different interpretations. Besides, this table generalizes too much. Some technologies are inapplicable to cement industry.
- Section III.6-4 and 6-5, a brief mention should be made to allow the reader to understand why the compendium document describes SOx and NOx removal technology.
- For those two same sections, a lot of removal technologies are inapplicable to cement industry for technical and economical reasons. For example, the cost of NOx control technologies varies from US$3,000 to US$8,800 per ton of NOx (capital cost for those technologies varies from 4 to US$14 M). In some cases those technologies do not work in cement industry. For instance, SCR technology does not work in cement industry because some constituents in the gas, poison the catalyst. Gas stream has, in some cases, to be reheated (increase of $CO_2$ release).
- Page III.6-1, first paragraph should be changed according to the previous comments.
- page III.6-13, last paragraph remove the word concentrated gaseous effluent. This term could mislead.

Section IV

- With the short period of time allow to comments the compendium document, we are unable to give detailed comments on this section. However, it seems, based on our recent evaluation in the United States, that costs are underestimated. For NOx, cement industry would have to invest between 4 to US$14 million that could threat the cement industry and put it in a disadvantage competitive position with other provinces, with United States and other countries. In the case of cement, this commodity is shipped from all over the world and therefore our industries have to compete with North-American competitors but either with other countries where such standards are not required. The economic model should consider the importation reality.

Section V

- The strategy section should be removed from the compendium and be a stand-alone document.
- For each option, describe pros and cons in the context of the 5 guiding principles of the Smog plan.

**DOFASCO**

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Date: November 4, 1998
To: Walter Chan, MOE
From: Jamie Skimming, Extension 6584
Re.: Comments on Compendium Documents

## Introduction

- The suggestion that IR/RP is one of the most critical environmental health issues may be an premature, considering the results of recent health studies (R. Burnett et al). We recognize that as recent as earlier this year, general consensus would support this statement. However, as recent studies reveal the uncertainty of the science behind the health impacts, the general tone should be modified to reflect this fact.

## Science & Technology – Inventories

- There are some major discrepancies in the inventory data presented throughout the document. For example, Table V.5 shows Iron & Steel sector PM10 data for Hamilton as 2,323 tonnes/year. In comparison, Table A.7 from the Cost-Benefit section shows (if you combined Dofasco and Stelco Hilton Work) a total of 8,499 tonnes/year. To add to the confusion, Table III.1.1 shows total Ontario numbers for PM10 as 7,971. Given that emission inventories are the foundation for future work on this issue, there is a pressing need to provide accurate and consistent information. Industry could provide this data, as long as there were assurances for how the data would be managed.
- Significant figures are not taken in account when presenting inventory data (e.g., total of 162,729 tonnes of PM in Ontario). Given the large margin of errors associated with inventory data (at least +/- 30%), the use of two (or even only one) significant figures is more appropriate (e.g., use 160,000 tonnes in the table)
- Figure III.1.1 misrepresents the industrial contribution to PM10 with the exclusion of open area sources. The total industrial numbers (67,000 tonnes/year) represent about 9% of the grand total, in comparison to open sources (650,000 tonnes/year – 84%.)
- We agree that the community-based emission inventory is essential for our IR/RP strategy. To determine the atmospheric loading within an urban airshed, it is important to determine contribution from all sources (natural and anthropogenic). The community-based inventory data presented in the *Section V - Synthesis of Results* currently misrepresents industrial contributions. For example, Table V.5 provides qualitative descriptions of open source contribution (e.g., "low" for paved road dust). Given the numbers presented in Table III.1.1 for paved roads (330,000 tonnes/year province wide), it is reasonable to expect that estimates could be arrived at for these sources for urban areas. A simple allocation by population for Hamilton-Wentworth (assuming 450,000 people in a province with 10,000,000 people) would provide an estimate of 15,000 tonnes/year from paved roads. This number is hardly "low" in comparison to 2,300 tonnes/year for the Iron & Steel sector. I'm sure that MTO would have more accurate traffic flow data for urban areas.

## Science & Technology – Measurements

- Page III.2.6 makes an interesting reference to weekday variations in PM10 levels, suggesting a potential contribution from transportation sources. It's an important fact that seems to be glossed over within the text. This relationship should be given more prominence within the text. Given the significance of paved road dust emissions mentioned in the inventory section, there could be a linkage here that needs to be explored. For example, Dr. McCarry of McMaster University recently shared with me excerpts from a thesis that identified elevated PM10 levels in Hamilton during the daytime for all four seasons. Since the major industrial sources in Hamilton are 24-hour operations, this may provide some insight into relative contributions of industrial and urban area sources.
- The data presented suggests a linkage between IP/RP and other pollutants (i.e., IP/RP concentrations rise and fall with other pollutants). This fact, tied in with Rick Burnett's recent paper on the association between morbidity and other pollutants (NOx, SO2, CO, etc.), suggests that PM10 is part of an overall air pollution problem. Therefore, this relationship needs to given more prominence within the document.

## Science & Technology – Source Apportionment

- It is critical for area sources, such as agricultural sources and paved roads, to be included in any regional/urban modelling work regardless of data confidence. Excluding these sources from any modelling work could lead to the wrong conclusions regarding "inherent" background levels.

## Science & Technology – Health Effects

- There is at best, a robust association between IP/RP and health effects. Given that IP/RP is just one of many airborne pollutants present in the urban airshed, allocating the health effect solely to IR/RP may be premature. The ambient air monitoring data shows that IP/RP rises and falls with other pollutants. Rick Burnett's recent paper shows an association between morbidity and other pollutants ($NO_x$, $SO_2$, CO, $O_3$, etc.), in some cases more significant than IP/RP. As of yet, no one has looked at the potential synergistic relationships between different pollutants. Given all of this, it is possible that previous studies' linkage between IP/RP and health may ONLY demonstrate that IP/RP is a surrogate indicator of the overall atmospheric soup's impact on health. This fact needs to be stated within the documentation, with a proviso that we are "just beginning to understand the complex nature" of air pollution and health.
- A section on Rick Burnett's latest study should be inserted at the beginning of this section, since it is the most recent information on health effects.
- Page III.5-15 makes reference to a "natural non-anthropogenic background" of 5 µg/m$^3$. For urban areas, it is important to recognize that there are anthropogenic sources that are for all intents and purposes fixed. For example, dust from roads will continue to contribute to urban airsheds after the introduction of zero-emission vehicles. It is important to take into account the contribution of these anthropogenic sources when determining the "fixed" background.

## Science & Technology – Control Technologies

- For the Area Sources section, a discussion of paved and unpaved road dust emissions should be included in the Transportation section.

<u>Cost-Benefit Analysis</u>

- The current analysis presented here is of little or no value for this process. The basis of the analysis is 1990 emissions. Given that there has been significant reductions in emissions over the last eight years from many sectors, this analysis gives a false impression that there are relatively easy gains to be made. This analysis needs to redone, based on the most current emission information.
- We understand the importance of full-cost accounting for developing Ontario's strategies. However, we have a number of concerns about the approach taken so far:
    - *Competitiveness* -- In addition to the capital & operating costs for controls, we need to take into consideration "competitiveness" costs. As the differential in "mandated" pollution control costs grows in relation to other jurisdictions (within Canada, NAFTA, and/or globally), Ontario may be faced with economic costs incurred by business decisions to shut-down manufacturing operations here and relocate to jurisdictions with less-restrictive regulations. These "costs" to Ontario's economy need to be considered in the analysis.
    - *Capital Stock Turnover* -- One factor that isn't taken into consideration is capital turnover. The existing analysis assumes that industries will rush out and invest in pollution control devices. Given the current focus on pollution prevention activities, this runs counter to that philosophy. For example, there is technology in the steel industry that is less-polluting than "traditional" technology (e.g., electric arc furnaces versus oxygen furnaces, non-recovery coke batteries). However, we are restricted by capital turnover restraints in implementing new technologies (i.e., long operating lives were built into the capital considerations for existing equipment). This turnover will occur, and cleaner technologies will be adopted, but more realistically within a longer timeframe.
    - *Control Options* -- The authors need to consult the various industrial sectors to obtain a better understanding of sources and control options for various pollutants. For example, flue gas desulphurisation and fuel switching are cited as options for steel mills to use for achieving significant reduction in $SO_2$ emissions. For integrated steel mills, there is a significant portion (approximately one-third) associated with fugitive sources
    - *Impacts on Other Media* -- The costs of alternatives and impacts on other media need to be considered. For example, alternatives to coal-fired stations could include hydroelectric generation. However, what are the direct and indirect costs of these options?
    - *Emissions Trading* -- For parameters such as $NO_x$ and $SO_2$, there is a higher likelihood that emissions trading will be used. In the case of $NO_x$, the existing PERT project includes major point-source contributors such as Ontario Hydro and Dofasco. Any analysis undertaken should include scenarios with "return on investment" from sold credits.
    - *Benefits* -- The "value" of human life is an <u>extremely</u> emotionally charged issue which is difficult to deal with, especially since ethics dictate that "no price is too high" when it comes to human life. However, the unfortunate reality is that our society does not value human life as highly as indicated in the analysis. If we did, then there would be much greater efforts towards eliminating child poverty, providing food and shelter for the homeless, restricting consumption of harmful consumer goods (tobacco, alcohol, fast food etc.) and so on. When determining the benefits, we need to take these factors into account. Otherwise, we may end up "over-estimating" the public's will to support these strategies

- The proposed strategies used in the analysis each have unique strengths, which would be appropriate for different steps of any program. When recalculating the cost-benefit analysis, the following should be recognized:
    - The "efficiency strategy" is the one most likely to succeed in the short-term.
    - The "abatement maximization strategy" is the one that will be most effective in the long-term, taking into account capital stock turnover.
    - For those parameters with limited transport capability (e.g., PM10), the "community strategy" is most effective.
    - The "equal reduction strategy" is the least likely to succeed, since the main contributors are not on a level playing field to start off with (i.e., could be "too easy" for some sectors, "impossible" for others)
- The suggestion for increased enforcement through control orders and regulations is too adversarial. This could result in costly legal battles from which no one benefits, except a few consulting and legal firms. The voluntary approach is more effective, especially if public attention is placed on meeting these commitments. Programs such as ARET, the *Steel Sector's Strategic Options Process*, and the CCPA's *Responsible Care* are both good examples of voluntary measures achieving more than regulatory measures.
- The suggestion for emission caps and trading is supported, but in the context of those parameters with "reliable" and "auditable" performance data, such as $NO_x$ and $SO_2$. Measurement and estimation techniques for these parameters are much more robust than those for TSP, $PM_{10}$ and $PM_{2.5}$.

### Synthesis of Results

- Given the latest health studies and the lack of consensus on IP/RP health impact amongst stakeholders, reference to this fact should be presented here.
- The tone of the text makes it sound like IP/RP is a "new" threat to public health, when in fact these issues have been present throughout the industrial and post-industrial era. There has been significant reductions achieved from historic levels for most pollutants. This fact needs to be acknowledged in the text.
- As mentioned earlier, the tables illustrating source apportionment in urban areas does not include quantitative estimates of area sources. As a result, an emphasis is placed on industrial sources. These tables should be modified to present numerical values for area sources, in order to provide a fair and balanced understanding of significant sources.

### Developing an IP/RP Strategy for Ontario

- We support the principle of an integrated approach with other air issues
- We support the principle of a collective effort approach amongst all stakeholders
- We support the strategy to put in place interim measures for an AAQC and an emission reduction target. There are a number of compelling reasons for taking this approach:
    - There is still a considerable amount of work needed to understand the health impacts of pollutants, on an individual and synergistic basis,
    - There is still a considerable amount of work to fully understand the contribution of natural and man-made sources to urban air quality,

  - There is still uncertainty regarding the direction the US will be taking in modifying their standards, and
  - There needs to be better co-ordination of any IP/RP initiatives with other air pollution reduction programs such as climate change and ground-level ozone, since there are common roots. Ideally, there should be one over-arching program for all of these issues.
  - Given the various regulatory and voluntary initiatives currently underway to reduce emissions of particulate and their precursors, it is reasonable to expect that some sort of measurable reductions in ambient air quality levels, hospital admissions, and premature mortality should be seen within the next couple of years. We should have in place extensive health and air quality studies to look for these reductions. If the expected reductions take place, then we will know that we are on the right track. If not, then this suggests that there may be other factors at play (e.g., is transboundary pollution the main source? Indoor air pollutants? Or is there in fact no relation at all?)

- We want to clarify the principle of sharing the financial burden across all contributors. Each sector should be expected to implement a strategy that is based on "efficiency" reductions appropriate for their sector.
- We support the concept of using a longer timeframe for meeting the AAQC in non-attainment areas. However, this could be a tough sell for the public in these areas (i.e., "Why should we have to live with poorer air quality?"). Since the US has already gone though this exercise, we should base any similar approach on the lessons-learned from the US experience.
- Will there be recognition for those sectors that have taken early action (within a reasonable time frame?). Some steel companies have recently put in place particulate reduction commitments.
- We have strong concerns about the proposed interim measure for "vigilant compliance" with POI standards. There are numerous, serious faults with the use of POI standards as a compliance and predictive air quality tool, for example:
  - The original concept of a 30-minute POI standard was to apply to a single emission point to support CofA applications. When this approach was changed in the late 1980s, this resulted in the situation where large, multi-source facilities were out of compliance with the POI standard, yet they had MOE-approved CofAs for all these sources.
  - The POI standard's design intent was for modelling emissions from stacks. The model was never intended to apply to fugitive dust sources such as stockpiles and roadways.
  - The 30-minute POI standard is not an accurate indicator of contribution to ambient air quality. The focus of the POI standard is to evaluate the short-term impact of "worst-case" emissions off property, either from a nuisance perspective or an acute-toxicity perspective. As a result, an exceedence of the POI standard typically involves a low- level "virtual source" emission in close proximity to the fence-line. For example, the POI approach would likely indicate that a steel mill's coal piles are the highest contributors to POI exceedences. In reality, emissions from coal piles represent a small fraction (about 1%) of total emissions on an annual basis.

Dofasco is currently working with an atmospheric dispersion-modelling consultant to evaluate plant-wide emissions of TSP, $NO_x$, and $SO_2$. Our consultant has recommended that we demonstrate compliance in terms of the 24-hour and annual TSP AAQCs, since this is a more realistic assessment of the impact of our operations on ambient air quality. We propose that this approach be adopted for all facilities that are "complex" in nature.

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December 3, 1998

Mr. Walter Chan
Ministry of Environment and Energy
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Dear Walter:

Re: November 27, 1998 draft "Compendium"

On November 27th a draft "compendium" document was distributed to the IP/RP working group members. You asked the work group members for suggestions that might be incorporated prior to the document being circulated for broader consultation through the EBR registry.

I have reviewed the draft "Compendium" document, and find in it much useful information.

I do however, have one concern (and a suggestion) regarding the section on costs and benefits.

The title (*Cost-Benefit Analysis....*) and text of section IV of the draft compendium document may give the impression that a rigorous cost-benefit analysis has been conducted, and that section IV is the record of that analysis. In fact, section IV is not a rigorous cost-benefit analysis, for the following reasons:

1. The costs and benefits that were developed were based on different scenarios.
2. Neither the cost scenarios nor the benefit scenarios are linked to the draft AAQC's.
3. Scenarios with potentially highest benefit-to-cost ratio were not included in the options or the analysis.

So as not to mislead readers, it may be useful to present the compendium material as a cost analysis and a benefits analysis, with clarification that the material is not a cost-benefit analysis.

The three issues listed above are discussed in turn below.

### 1. Costs and benefits that were developed were based on different scenarios.

While several cost analyses were conducted, and a benefits analysis was conducted, the costs and benefits developed were based on different scenarios. The analysis cannot therefore be called a cost-benefit assessment.

Costs were assessed for three different strategies:

1. efficiency (defined as lowest cost per tonne of emission reduced).
2. abatement maximization (largest sources first).
3. equal reduction.

A fourth strategy, called "community strategy" was not evaluated for costs (or benefits).

The benefits analysis was conducted using the implicit assumptions that Ontario's ambient air is a closed box within which particulates emissions are perfectly and instantly mixed.

It might be possible to develop an argument to the effect that this closed box/ perfect mixing assumption might be supportable for the purpose of further analysis regarding the "equal reduction" strategy. But without validation it is clearly inappropriate for the "efficiency" and "abatement maximization" strategies.

It is inappropriate because Ontario is not a closed box and particulate matter is not perfectly and instantly mixed. (If it was all monitors in Ontario would read the same, and we would only need one monitor.)

The problem in relying on the closed box/ perfect mixing assumption can be illustrated by example.

Consider a case of a source which is either the largest source or the source with the best efficiency opportunity (or both) located on the west shore of Hudsons Bay. Consider further that the wind carries emissions Northeastward over Hudsons Bay. Consider that an emissions reduction of 20% from this source is being evaluated. and that this reduction would represent 5% of all Ontario sources.

The benefits of a 20% reduction of emissions from this source could be estimated, using a knowledge of particle species, transport pattern, transport range, and population density in the transport path. Under the scenario as presented, there would be no benefits in Southern Ontario, and there might be no benefits at all.

The section IV model considers none of the particle species, transport pattern, transport range, and population density issues, and instead would assume that all of Ontario would see a 5% reduction, and that there would be commensurate benefits in Toronto, Hamilton, and all other regions. The section IV model would indicate substantial benefits where in fact there would be few or none. The model is thus flawed.

That the model might be usable with the "equal reduction" scenario is of little consolation, as the equal reductions scenario is incompatible with our goal of environmental spending efficiency, and has thus only limited informational value.

Since the cost scenarios are different than the benefits scenario, the analysis cannot be called a cost-benefit analysis.

### 2. Neither the cost scenarios nor the benefit scenarios are linked to the draft AAQC's.

All of the reduction scenarios will result in some reduction in "population-weighted average ambient concentration". But none of the scenarios are designed to achieve a particular ambient concentration in all areas. (The efficiency and abatement maximization could give this result by chance, but it would not be by scenario design).

The AAQC "scenarios" are therefore not rigorously linked to the "implementation strategy scenarios".

The analysis in section IV cannot therefore be called a cost-benefit analysis of several AAQC's options.

### 3. Scenarios with potentially highest benefit-to-cost ratio were not included in the options or the analysis.

While the analysis develops and analyses a scenario that is efficient with respect to the parameter of $ per tonne of emissions reduced, no scenario is developed or evaluated in terms of minimizing dollar cost per unit of benefit, or alternatively maximizing benefit per dollar of cost. The text in section IV alludes to this analysis gap as follows:

> *"Moreover, the locations of emission reductions affect where changes in ambient concentrations and corresponding beneficial effects occur. Detailed modelling of the "efficient" or the "abatement maximization" scenarios would be needed to determine exactly where changes in ambient concentration and beneficial effects would occur."* (Paragraph 1 page IV.9. Compendium, November 27, 1998 draft)

The goal of the cost-benefit analysis is not only to decide whether to proceed with emissions reduction, but also how to proceed most efficiently. One of the most important factors in deciding how to proceed is to determine the environmental efficiency of a range of scenarios that has been designed so as to include the most environmentally efficient scenarios. Since section IV neither includes nor evaluates these scenarios, it cannot be called a true cost-benefit analysis of a full range of scenarios.

**Summary**

For the three reasons provided, the analysis in section IV should not be call a cost-benefit analysis.

On the other hand, since the document is a compendium of knowledge, it is appropriate to include both the cost assessments and the benefits assessments.

But they should be presented as separate analyses, so as not to misguide readers into thinking that a cost-benefit analysis has been conducted, or that section IV provides the results of such an analysis.

**Recommendations:**

1. Edit the term "cost-benefit" out of section IV anywhere that the term could suggest that a cost-benefit analysis has been conducted.
2. Separate the cost analyses information and the benefits analysis information into two different sections.
3. Where assumptions or models are used to derive costs or benefits, state them clearly, along with implications regarding limitations on results.

I look forward to discussing these ideas in our workgoup meeting on December 3rd.

Regards,

Craig Gammie
Manager - Environment and Energy

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November 20, 1998

Re: **ONGA Comments on '*A Compendium of Current Knowledge on Fine Particulate Matter in Ontario*'**

Dear Neville:

The Ontario Natural Gas Association appreciates the opportunity to provide comments on the above-noted document. The Ontario Ministry of the Environment has obviously put considerable time into assembling this summary of current knowledge about fine particulate matter in Ontario and we appreciate this effort.

We have reviewed this document with the understanding that it represents a summary of scientific knowledge which the MOE eventually will use as a resource document for broader stakeholder discussion about PM regulatory options in Ontario. Given the restrictions on time and circulation of the draft Compendium, the core document was reviewed by a small task group under the ONGA Environment Committee. Our comments thus reflect the collective views of the task group and not necessarily the larger ONGA membership. It was not possible to circulate copies of the Cost/Benefit Analysis, which I received at a later point in time, and the few comments on this section are based only on my personal review.

## Overview Comments

ONGA has a number of overarching comments as follow:

- ONGA advises that the development of an IP/RP strategy and related standards for Ontario must be in concert with the Canada Wide Standards for PM. It also must take into account the PM research and policy approaches being undertaken in the U.S. given that the emissions in the U.S. have a significant impact on our airshed.

- We understand that the compendium is intended as a technical resource document that summarizes current scientific knowledge about PM in Ontario. The language and tone of

- such a report should be factual rather than editorial, which is the case in the current document. Editorial and speculative comments should be eliminated.

- The compendium needs to present a balanced viewpoint and clearly identify knowledge gaps. For example, the apparent statistical correlation between health outcomes and PM levels must be examined in light of the substantial decline in measured PM over nearly three decades. There is a growing body of evidence which suggests, as was noted at our last Working Group meeting, that it may well be the 'soup' of airborne contaminants that drives the health issues, not PM alone. The Compendium should consider PM in the broader context of other air quality issues rather than positioning it as the most 'critical'. Dealing with PM in isolation could exacerbate other air pollution issues. This is an issue of synergism and ONGA believes that the MOE should not be presenting air issues one pollutant at a time. This should be made clear in this document.

## Specific Comments

### I. Background

This section needs to be revised and expanded to set the proper context for discussion around PM. The linkage to other air quality issues (e.g., climate change and smog) need to be more clearly drawn and consideration given to U.S. and Canadian policy approaches to PM. It should be noted where there is non linearity (i.e. reduction of one pollutant could make things worse for another), a sense of priority should be given to the stakeholders. However, numerical references to possible National Ambient Air Quality Objectives for the CWS should be deleted as these are speculative at this point.

### II. Policy and Strategic Issues

The historical context needs to be elaborated. The discussion on black fallout, complaints and visibility, on the other hand, does not contribute directly to the IP/RP issue and could be removed.

Section II.1.5 on primary versus secondary particulate matter and Section II.3, which links IP/RP to other air quality issues needs further development. For example, how would control strategies taken with respect to other air issues affect IP/RP and vice versa? What would be the impacts of parallel strategies on the health issues?

Section II.4 addressing other jurisdictions is difficult to follow. Specifically, on page II.4.2 there is a discussion of the work being conducted by OTAG. It is our understanding that this work is a "desk top" study only on this issue with no field work being conducted. Reference should also be made to the work being conducted under the NARSTO framework in which considerable effort is being spent on the collection of field samples to help improve the models being used.

## III Science and Technology

### III.1 Emissions Inventories

The emissions inventories are the foundation of an appropriate IP/RP strategy. Therefore, ONGA cannot agree with the suggestion in III.1.1.2 that the existing uncertainty and data gaps in the inventory are not a serious impediment to workable IP/RP emission reduction strategies. Details are needed on estimating methods and bases for the information presented. Explanation is needed about the surprisingly significant changes to the inventory data between drafts.

### III.2 Particulate Matter Measurement

This section presents a good summary of available data. Given the varied sources of these data, it is not always clear whether numbers are comparable. On page III.2.5 mention is made that the MOE started collecting $PM_{10}$ samples in 1989 at 23 sites across the province and that these are "state of the art" real time instruments. There should be a discussion of how these 23 sites were selected and furthermore what the link is between the selection of these sites and the various models being used.

In section III.2.2 there is a discussion of the errors in the sampling and that across Canada in one study as much as 45% of the $PM_{10}$ fraction sampled went "missing". In our view there are significant sampling problems that need to be addressed, not the least of which is the fact that not a lot of confidence can be placed in the analytical results obtained. This confirms that the techniques using filters and subsequent laboratory analysis render the results prone to errors and artifacts. This should be listed in the section on data gaps.

In the same section, reference is made to the crustal/soil component, which can make up as much as 50% of the $PM_{10}$ fraction in Ontario. As this speciation fraction contributes so much to the overall quantity, it follows that any strategy should address reducing this component. ONGA believes that there should be, at minimum, a general discussion of this fraction, listing sources etc. as this fraction has to be reduced for the required improvement to be achieved

As a data gap, ONGA believes that the sampling techniques currently available are not able to distinguish effectively between closely spaced sources that emit particulates. This is not discussed in the data gaps and yet this represents a significant aspect to be resolved.

Some of the details on the Figures were difficult to follow; for example Figure III.2.7.

### III.4 Source Apportionment

Effective control strategies depend on improving the understanding of the relationships between sources and receptors. The role of models needs to be examined carefully and models need to be available for examination and validated through field trials.

In section III.4.2, there is a discussion concerning the various models that are being used. ONGA recognizes the need for having different models in order to be able to help provide different perspectives on this issue. Much has been written about the various models being used. However, there are still only a handful of experts in Ontario that are able to run the various scenarios on these models. As with the Climate Change models being used, it is ONGA's contention that the various models being proposed in the strategy plan should be made freely available on the web, so that participants can have access to them and more importantly perhaps, be able to question the assumptions being made and gain expertise in running various scenarios. At the present time this is not able to be done unless they hire someone with access to the codes being used (e.g. York University). This will also help industry (and other participants) decide what priorities they should be placing on their limited resources. In addition, the assumption has been made that one of these models will be selected under the regulatory framework to help determine what improvements will have been made in future years. A synposis of how it is envisaged by the MOE to select "one model" for regulatory purposes is to be undertaken would be helpful.

### III.5 Health Effects

ONGA's comments regarding the health effects were presented in *Overview Comments* at the beginning of this letter. This section needs to be reworked to correct the false impression that causality has been established and that the science is conclusive on this subject as neither is the case.

### III.6 Control Technologies

This section is a reasonable general overview. It should also address the emissions prevention option and clearly indicate those options, which are already in use.

## IV Benefit-Cost Analysis

We have been able to give this section only cursory and preliminary review and have concerns with the methodolgy and the cost data. The analysis is based on a 1990 emissions inventory, but remaining data are for 1995. The analysis does not appear to recognize emissions reductions between 1990 and 1995, which could affect costing.

It is not clear whether the scenarios presented or applied costs are reasonable. There may be significant errors, for example, regarding the technologies implemented and associated costs.

We are not currently in a position to set out concerns regarding the appropriateness estimating benefits based on valuation of a human life but, will listen with interest to what others have to say in this regard.

**Developing an IP/RP Strategy for Ontario**

ONGA endorses the development of an IP/RP policy through a multi-stakeholder process. The development of this policy must be in concert with the Canada Wide Standard setting process and recognize the research being undertaken in the U.S. regarding this matter. Where possible, the strategy should adopt integrated approaches to multiple air quality issues, thereby ensuring that measures taken in one area are not detrimental in another.

ONGA was disappointed in the short section concerning "Bridging the Knowledge Gaps" in such a major and otherwise comprehensive document.

ONGA agrees that additional ambient monitoring is required and more importantly source characterization. In our view efforts should be made to develop sampling techniques that will help characterize source apportionment in real time and in-situ in an economically acceptable manner. For example, the presence of inclusions such as carbon makes a significant difference to the spectra obtained when using remote sensing techniques. We understand this is no easy task and yet this will help foster "buy-in" for the strategy. In addition, the height of the samplers needs to be addressed, as it is our understanding that the atmospheric chemistry interactions occur primarily at a height of a few hundred metres and not at 10 metres above the earth's surface. This is a question of scientific validity versus economic practicality, which should be addressed in the document, as ultimately obviously the decision will be a compromise.

Network design in part should be predicated on the requirements of the models being used. ONGA would like to suggest that there should be a discussion around this issue , for example should we be monitoring at the 5 sq. km grid or 20 sq. km grid? How will the network design account for source emissions?

Modelling capability also needs to be discussed in more detail. ONGA has already indicated above what should be done concerning placing the models in the public domain. Linking this discussion, ONGA believes that there should also be a discussion on the risk assessment aspects in which there is an evaluation of the likelihood that adverse human effects may occur as a result of exposure to IP/RP. This will help develop plans in the context of "risk management".

There needs to be a discussion around what strategies can be implemented that will reduce IP/RP emissions at source. Fuel switching is one example of where reductions could be achieved. In a study done in Denver, for example, it was shown that in 1987, $SO_2$ emissions were reduced by 70% by burning natural gas instead of coal in the areas power plants. (EM, Air and Waste Management Association, January 1998).

Ultimately, the strategy must lead to measurable improvements in the health outcomes.

Yours truly,

Jasmine Urisk
ONGA Environment Committee

cc: Bernie Jones, President ONGA
Peter Prier, Chair ONGA Environment Committee

**Alliance of Manufacturers & Exporters Canada**

CANADA'S
LEADING
BUSINESS
NETWORK

November 4, 1998

Walter Chan
Chair, IP/RP Options Assessment Working Group
Ministry of Environment
135 St. Clair Avenue West
Toronto, Ontario
M4V 1P5

Dear Walter,

Subject: IP/RP Compendium

The Alliance of Manufacturers & Exporters Canada appreciate the opportunity to play an active role in the development of the Ontario Smog Plan. We are pleased to participate in the IP/RP Work Group, and to comment specifically on the "Compendium of Current Knowledge on Fine Particulate Matter in Ontario."

It must be noted, however, that due to the limited time available for our members to thoroughly review the Compendium, the Alliance will be submitting very general comments. It must also be noted that the apparent "rush" for the MOE to complete such a significant resource document, which will ultimately play a key role in the the development of the Ontario Smog Plan, is concerning.

Our comments relate to the general "philosophy" or "mandate" of the Compendium document, as well as some specifics regarding its' content . The Alliance's comments and suggestions are as follows:

1.) With respect to the overall mandate or intended goal of the Compendium, it is important that the document be used and depicted as a *technical resource document* . With this in mind, all editorial comments reflecting the opinion of specific stakeholders and/or unscientific conclusions should be omitted.

2) As a *technical resource*, the Compendium should also indicate that the information contained within it, does NOT reflect a complete and conclusive picture of all "current knowledge" (unlike the title denotes). In fact, we believe that a large portion of the information is based purely on mathematical models

and statistical analyses, which have often used out-dated and unconfirmed data. These assumptions and deficiencies must be communicated to the reader up front, or alternatively, the data should be significantly expanded and improved upon.

3) In order to continually update and Improve the overall content of the Compendium, a process should be outlined within the document to ensure that new scientific findings and relevant knowledge are appropriately added. In light of the fact that the Compendium currently contains many "gaps," this is an important consideration.

4) In terms of the "science" behind the Compendium document, we have concerns that there has been an unjustified focus on isolating particulate matter (PM), in exclusion of other pollutants. This appears to contradict a key point made by Rick Burnett in his technical presentation. He stated that a "holistic approach" which considers the entire "pollution mix" and takes into account the interrelationships of PM with other pollutants is important when developing reduction strategies. We believe that a true "no regrets strategy" would not ignore the important relationships between pollutants.

5) Expanding on comment #4, it is therefore important to ensure a full integration with other existing pollution reduction programs (which encompass additional pollutants). This integration must take into account US and Canadian initiatives and processes that are already underway (e.g.. Canada Wide Standards). The focus should be on making strategies *complementary* with one another and work effectively on key priorities.

The MOE is to be commended for the significant amount of time and effort already put forth in the development of the first draft of the IP/RP Compendium document. We look forward to continued work with the MOE and jointly participating in the development of the Ontario Smog Plan.

Sincerely,

Joanne McGovern
Director, Taxation & Ontario Environmental Policy
Alliance of Manufactures & Exporters Canada

Alliance of
Manufacturers &
Exporters
Canada

CANADA'S
LEADING
BUSINESS
NETWORK

February 2, 1999

Walter Chan
Co-chair, IP/RP Options Assessment Working Group
Ministry of the Environment
136 St. Clair Avenue West
Toronto, Ontario
M4V 1P5

Dear Walter,

Subject: IP/RP Compendium

In addition to the comments submitted by the Alliance of Manufacturers & Exporters Canada on November 4, 1999 on the "Compendium of Current Knowledge on Fine Particulate Matter in Ontario", please find attached additional comments. We understand that the Compendium is in draft form as a "living document" and therefore trust that these comments will be considered within part of the overall review.

The Alliance has been participating in the development of the Ontario Smog Plan since its early inception in 1996, and look forward to our continued involvement in 1999.

Sincerely,

JMcGovern

Joanne McGovern
Director, Taxation & Ontario Environmental Policy

Cc. Tom Hewitt
Chair, IP/RP Options Assessment Working Group

Attachment: 2 pages

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## Comments on the Ontario Ministry of the Environment Document Entitled: *Strategic Options To Address the Fine Particulate Issue In Ontario*

General
"The Strategic Options to Address the Fine Particulate Issue in Ontario" contains many excellent points. For example, the Guiding Principles describe the need for a balanced approach that pursues activities that are environmentally sustainable, cost effective and technologically feasible; the need for sound science, harmonization, fairness and flexibility. Additional considerations are also to be given for coordination and stakeholder participation in strategy development. On the other hand. we have serious concerns with the subject document as described below.

Introduction
The first paragraph in the introduction states that "......, for PM there is no known threshold concentration above which effects begin to be observed or below which exposures are deemed safe." It also states that susceptible individuals may respond adversely to low PM levels. These statements do not fairly represent the current state of the science. The current state of the science is that some (but not all) epidemiology studies have found a statistical association between health effects and PM levels recorded at ambient monitors. These studies are plagued with numerous problems. To mention a few, 1) actual personal exposures are unknown, 2) results are a function of the models and statistical techniques used in the analyses, and changing these models/techniques often result in different conclusions, and 3) co-pollutants and other confounding factors are often ignored in the analyses.

Further, it is well understood that statistical associations do not imply causality. Therefore, it is presently unknown whether exposure to PM causes the health effects being seen in the epidemiology studies. This being the case, one should not make any statements related to whether or not a threshold concentration might exist, or whether susceptible populations may or may not respond adversely to exposure to PM. This is especially true with respect to fine particles ($PM_{2.5}$), for which very little data is available to draw even preliminary conclusions.

We therefore recommend that the first paragraph of the Introduction be deleted, and replaced with a new paragraph that puts the PM health issue into proper perspective. We reference the massive effort currently in progress in the United States (e.g., Congress has appropriated some $50 million for near-term research; HEI has numerous health/exposure studies underway) to help determine whether or not PM is a health concern at ambient levels, whether a threshold might exist, what are actual personal exposures, what are the roles of the co-pollutants, etc., etc. Unless this issue is placed into the proper perspective, huge resources could be expended to control a pollutant that may not be responsible for health effects being reported in the epidemiology studies. We recommend a more cautious approach on this issue, with major involvement in the developing science.

The above recommendations are, in fact, consistent with the Strategic Options Document Guiding Principe #6, which calls for a commitment to continuous improvement through research and phased implementation. They are also consistent with the "strategy" section on page 5, which states that "..... however, it is also recognized that there is not full scientific certainty yet on this issue. A better understanding of the science would help refine, optimize and refine a strategy; however, it should not be used a as reason for postponing actions to deal with the issue."

Strategic Options
- The Ontario Ministry of the Environment appears to have already made up its mind to pursue eventual air quality goals of 40 $\mu g/m^3$ for 24-h $PM_{10}$ and 20 $\mu g/m^3$ for 24-h $PM_{2.5}$ as the annual third maximum

values. It is not clear if the stakeholders' input has ever been considered to arrive at these targets. It is well known that these targets are regularly exceeded in the remote areas, and to expect that an interim 24-h PM$_{10}$ target of 50 $\mu$g/m$^3$ would require only a 34% reduction in PM$_{10}$ air quality indicates a serious misunderstanding of the ambient concentration distribution. There are significant day-to-day fluctuations in PM concentration. Sharp daily spikes occur frequently, and the ratio of a "typical" 24-h peak to the annual mean is about 3. Since the concentration cannot go negative, reducing the upper tail of the concentration distribution to 50 $\mu$g/m$^3$ would require the annual mean concentration to be as low as, say, 15 $\mu$g/m$^3$. Annual means of this magnitude are practically unachievable. It is our opinion that sound science has already been ignored in this very critical and fundamental issue as the amazingly low eventual targets for PM are being championed. We urge the Ministry to study the PM concentration distributions more carefully and investigate the data available from US.

- The proposal of at least 10% emission reduction (no time period is given, more discussions with stakeholders are absolutely necessary.) will almost definitely not lead to the interim 24-h PM$_{10}$ level of 50 $\mu$g/m$^3$. However, this emission reduction may serve as a testing ground to see what PM$_{10}$ level will actually be achieved. Information from this result can then be used to ascertain a more sensible and achievable PM air quality goal.

- On page 3, it is stated that "For PM$_{2.5}$, values corresponding to half of the PM$_{10}$ values are included here since about half of the PM$_{10}$ mass is due to PM$_{2.5}$." The selection of ambient air quality standards should be based primarily on health considerations, with allowances for susceptible populations, background levels, feasibility of achieving the standards, costs, etc. The proportion of PM$_{10}$ mass that is PM$_{2.5}$ is not a valid methodology for establishing the PM$_{2.5}$ standard level.

- Strategic option #4 proposes different AAQCs for AQMAs. Again, ambient air quality criteria (standards) should be based primarily on health concerns which are in turn determined through the science. AAQCs should not vary by air quality management areas.

Measures to Reduce IP/RP-Related Emissions

One of the reduction measures listed in this section is that "Ontario and federal governments continue to urge the US EPA to move towards more stringent PM standards when the US Clean Air Act regulations associated with ozone and PM are subject to review." The level of standards set by any country should be determined through scientific methods (e.g., modeling) such that air quality standards will be met in a reasonable time period. In this regard, it is critical that collaborative efforts between Canada and the US be conducted so that health-based standards for PM are the same for both countries. Once this step is accomplished, then it becomes appropriate to discuss specific source PM standards that might be needed to meet the health-based air quality standards.

As discussed earlier, the Health Effects Institute (HEI) is conducting significant research on the health effects associated with PM. HEI is an independent and objective institute sponsored 50% by the US EPA and 50% by some 28 manufacturers (selling in the US) of vehicles/engines. HEI is in the process of expanding its charter to European countries. We strongly recommend that Canada also consider sponsorship of the HEI, thereby becoming part of a well-known and well-respected international institute for helping to resolve key health issues such as those that may be associated with exposure to PM.

*Ontario Smog Plan Steering Committee*
*IP/RP Working Group*
*"A Compendium of Current Knowledge of Fine Particulate Matter in Ontario"*

Comments from City of Toronto: Kevin Loughborough

## Introduction

The Chapter on Control Technologies should be supplemented by a section describing measures to improve energy efficiency across all sectors of the economy and the impact efficiency measures will have on reducing emissions. As described below, improving fuel conversion efficiency from 33 to 90 percent is possible. Burning much less means emitting much less.

## Transportation

In addition to add-on devices to capture, recirculate or catalyze emissions, the improvement in fuel efficiency will reduce emissions significantly. Doubling the fuel efficiency of vehicles through hybrid technology would have a significant impact on reducing emissions. Energy conversion technologies that are more fuel efficient that the internal combustion engine will reduce emissions. Fuel cell buses emit less that diesel powered ones. Natural gas buses emit less that diesel fueled buses. Modal shift to electrically powered transit vehicles from single occupant automobiles powered by the internal combustion engine will reduce emissions significantly. Electric motors convert electricity to motion more efficiently that gasoline fueled motors convert gasoline to motion.

## Power Generation

A conventional steam condensing power generating station operates at an energy efficiency of approximately 33 percent. A cogeneration unit operates at an energy efficiency of 80 percent or more through recovery of the heat by product of the generation process. The heat by product can be used to displace fuel burning for space heating or for absorption cooling in summer. The net effect on the atmosphere is a significant reduction in total emissions.

Industrial processes requiring both heat and electricity are candidates for cogeneration. Municipal waste water treatment plants requiring heat to digest sludge and electricity to run pumps and aerators are candidates for cogeneration.

Fuel switching from coal to natural gas reduces emissions significantly.

Renewable energy technologies such as wind and solar power both active and passive can displace coal burning at conventional generating stations.

## Building Energy Efficiency

Cooling buildings using deep cold lake water consumes 90 percent less energy than conventional electrical chillers and more than 90 less electricity than ice storage, load displacement technologies.

Energy management measures including efficient lighting reduce electricity consumption more than 20 percent. Less energy consumption in buildings means less generation of electricity at coal fired generating stations.

Residential/Commercial

Conventional gas and oil furnaces operating at seasonal efficiencies of 65 % emit more than high efficiency furnaces operating at better seasonal efficiencies. As conventional furnaces age and are replaced the emissions from the sector will improve.

District heating systems deliver heating efficiencies of over 80 percent. Replacing conventional stand alone furnaces with central district heating based on cogeneration, displaces significant amounts of heating fuel. District heating units operate at greater efficiency due to economies of scale and due to close supervision of equipment performance.

# APPENDIX E: RESPONSE TO COMMENTS RECEIVED FROM IP/RP OPTIONS ASSESSMENT WORKING GROUP

| Comment | Response |
|---|---|
| **Verbal comments received at IP/RP OAWG meetings** | |
| the control technology table (Table 2 - Summary document) is ambiguous and should be removed from the summary document. It can be retained in the compendium but will have to be improved. | Table was modified to clarify. It has merit as a condensed source of comparative information. |
| concerns over the strong statements on the linkage between health effects and IP/RP, since the relationship (causal mechanism) has not been proven yet. | Statements modified to conform as much as possible to the scientific discussions and conclusions of the extensively peer-reviewed Federal-Provincial Science Assessment Document (PM SAD) and its Executive Summary. This includes not only the conclusions, but the discussion of uncertainties, confounding factors, views of different investigators on addressing the uncertainties and the attributes used by different investigators to build a causal link between an agent and its health effects. Although a causal mechanism has not been proven yet a weight of evidence can and has been used (as in the Federal-Provincial Science Assessment Document; PM SAD), whereby multiple lines of evidence are brought together and duly considered to build a case for the health effects of fine particulate matter. |
| need to improve the referencing of information | Further references have been added to the extent possible |
| lack of details on the health (epidemiological) data | This section has been expanded. Space does not allow the tabulation and discussion of individual studies. This is covered in great detail with several tables on the premature mortality, hospitalization and emergency room visit studies in PM SAD |
| need for more focus on historical trends showing the past improvements (e.g., total suspended particulates) | Some historical air quality data have been shown for context. However, since the health effects work has been carried out in recent years, the emphasis has been on the corresponding time frame. Some historical perspective is now provided in the first paragraph of Section III.2.3.1. |
| lack of details on how the emission estimates were generated | Appendix A provides the details. |

| Comment | Response |
|---|---|
| completeness of the emission inventory and differences between various sources of inventory information (e.g., NPRI ammonia data versus compendium data) were questioned | Ontario developed the 1995 $PM_{10}$ & $PM_{2.5}$ emission inventories based on best available emission source information and up-to-date emission factors and methodologies in quantifying emissions. The data quality of this particulate emission inventory for some source sectors is better than that of some IP/RP emission inventories developed by other jurisdictions. There will be continuous inventory improvement activities done under cooperative effort of the federal-provincial National Emission Inventory and Projection Task Group (NEIPTG).<br>NPRI emission inventory is an on-site multi-media releases reporting inventory for those companies that release pollutants to the environment. Not all the Ontario companies are required to report to NPRI and only those companies exceeding certain discharge criteria need to report. NPRI does not have area sources and natural sources components in its emission inventory. |
| need to improve the presentation of manmade/natural emissions data | Additional figures have been added in the revised document (figures III.1.2a,b,c, III.1.3a,b and c) |
| clarity on the classification of sources types (e.g., manmade/natural, open/point/area, etc.) | Appendix A provides the details |
| lack of up-to-date data on pollutant reductions in the US; | Will be included in final version. |
| need for more information on the transport of smaller versus large particles | Covered in Section III.4 |
| need to show the contribution of transboundary pollution in the emissions inventory charts | For scientific discussion on the contribution of transboundary pollutants, please refer to section III.4 : Sources Apportionment: Data Analysis & Modelling |
| lack of an integrated approach, with consideration for measures that could be counter-productive to other environmental issues. | IP/RP is targeted as an issue by the Ministry. However, the document recognises in several places the importance of both primary emissions and of the precursors, and the fact that the commonality of precursors ties together most of the air pollution issues currently confronting us. Some material has been added in Section II.3 regarding the possibility that certain controls could be counter-productive for other pollutants. |
| the relative importance of indoor air quality (IAQ) versus outdoor air pollutants was discussed, and inclusion of very brief discussion may be warranted | IAQ is not an issue that the Ministry can address at present. However, a very brief discussion is included in Section I |
| several questions were raised on how road dust is estimated and how the different sources are categorized (e.g.,open/area/manmade, etc). | Appendix A provides the details. |

| Comment | Response |
|---|---|
| consistency in the grouping of sectors/sources between the different pollutants | The revised document has provided consistency in the grouping of sectors/sources between pollutants. It should be noted that IP/RP inventory has some unique sectors in the open source category such as road dust, agricultural wind erosion, etc. which are significant IP/RP contributing sectors but are insignificant in other inventories for NOx/VOC/$SO_2$. |
| replacing the $PM_{10}$ manmade sources pie chart with one showing manmade and other sources | Additional figures have been added in the revised document (figures III.1.2a,b,c, III.1.3a,b and c) |
| qualifiers that these are only estimates; | The titles of the tables and figures in section III.1 have been modified to reflect that these emissions are estimated values. In fact most emission inventories are best estimates. Mandatory reporting of emission inventory of IP and RP through source testing and comprehensive process emission calculation may improve this situation. |
| explanation on the method changes that led to the large reduction in IP/RP emissions estimates in the updated version of the document | Appendix 2 of the revised Section III.1, "Updates on Particulate Emissions in Ontario" provided the explanation. |
| clarification on what is classified as low/high/medium in the city data tables (Tables IV.5 to IV.12. | These designations have been removed |
| LIS data should be included if it improves the document (Scott Munro to provide a written section to the report) | Information in LIS report acknowledged in reference and included in text, Section III.2.3.1., paragraphs 1 and 5. |
| Insert qualifiers into text regarding applicability of technologies – e.g., many of technologies applicable to combustion sources are not relevant to cement industry | Addressed. Qualifiers inserted throughout. The document is not specific to the cement industry. In this section the cement industry is not even mentioned. |
| Qualify possibility of other problems arising from application of control technology, e.g., ammonia slippage in reduction technologies for controlling $NO_x$ | Some disadvantages of specific control technologies are mentioned, where appropriate. |
| Caution that fuel switching is not necessarily easy (e.g., shortage of low sulphur fuel) | This is a market issue, not a technology control issue |
| Inspection and maintenance for refinery fugitive emissions is much more effective than indicated in this section. Tom Hewitt to supply information | No additional information was supplied yet. |
| Change "scrubber" to "wet scrubber" in summary table | Addressed. |

| Comment | Response |
|---|---|
| Reflect the fact that many industries already have control technology in place. | Addressed (2nd paragraph in III.6.1). |
| Cost curves need adjustment to be consistent with 1995 emissions | This will be done when Airco$t model runs become available |
| Tables in the Appendix show sectors in some cases, individual companies in others. Should be consistent in final version, and show only sectors. | Addressed |
| Are estimated costs sustainable for the Province as a whole? For individual sectors? | This is a difficult question to answer at this stage. |
| Linkage to other issues should be mentioned in the introduction. N.B. Control strategies for IP/RP can be beneficial for other pollutants, or may have an adverse effect. | This point is covered in Section II.3 |
| All possible strategies should include both $PM_{10}$ and $PM_{2.5}$ | Agree, since health effects have been associated with both fine and coarse fractions of $PM_{10}$. The approach taken in the compendium document reflects that. |
| **Pollution Probe** | |
| Implementation timelines? | We are at the stage of preparing background information to prepare stakeholders consultation on the IP/RP issues in order to develop Ontario IP/RP strategy. Implementation will reflect what is in the strategy and the associated time lines. |
| Ontario still has very inadequate emission inventories for sources of $PM_{10}$ and $PM_{2.5}$: The compendium document makes it clear that the quality and certainty of OMOE and industry emission estimates for IP/RP are weak. What mechanisms will the ministry employ to ensure that Ontario's IP/RP strategy is based on accurate emission inventories? | The current Ontario $PM_{10}$ & $PM_{2.5}$ emission inventories were developed based on best available emission source information and up-to-date emission factors and methodologies in quantifying emissions. Ontario is working with the National Emissions Inventory and Projections Task Group (NEIPTG) to continue to improve the IP/RP emission inventory. NEIPTG has committed projects to improve the quality and accuracy of the IP/RP emission methodologies in some of the major sectors. There is an annual emission inventory survey for the purpose of updating the emission profiles of various pollutants including IP and RP. The active participation of all industries will bring better accuracy and completeness to the emission inventories. |
| Commitment to ongoing research? | The Ministry remains committed to monitoring of IP/RP using state of the art equipment. A number of special studies have been carried out, or are planned, and MOE is involved in a project to improve the capability to model IP/RP. In addition, MOE staff continue to monitor scientific advances in the field. |

| Comment | Response |
|---|---|
| Long-term trends: The compendium document does not include trend data or recent policy changes which could have significant impacts on IP/RP levels in Ontario | Relevant air monitoring and emission data have been included in section 3 and some of the key related policies in chapter 2 |
| **Toronto** | |
| The Chapter on Control Technologies should be supplemented by a section describing measures to improve energy efficiency across all sectors of the economy and the impact efficiency measures will have on reducing emissions. Improving fuel conversion efficiency from 33 to 90 percent is possible. Burning much less means emitting much less. | Addressed (5$^{th}$ paragraph added in III.6.2.2 and other references throughout III.6.2) |
| **Ontario Hydro** | |
| In order for the document to have been prepared by the IP/RP Working Group, we should have been engaged at the beginning and throughout the development of this document | An IP/RP working group under the Smog Plan Steering Committee was formed early in 1997, and took input at that stage. |
| The descriptive language (eg. "…most critical health and general environmental issues of the decade…" , "…strong connection…") within the report should be removed | This suggestion has been followed as far as possible throughout the document |
| It is not clear how PM rates in priority to or with other issues such as Climate Change. The issue should be addressed through an integrated emissions approach, especially when discussing technological controls, and through commitments made to managing greenhouse gas emissions. | Covered in Section II.3 |
| <u>Linkages of the Inhalable and Respirable Particulate Matter Issue to Other Air Quality Issues and Initiatives-</u>This discussion needs to address the impact of all program commitments (eg. Climate Change) on improving air quality. | Covered in Section II.3 |
| Details on the inventory estimating techniques needs to be provided. | Appendix A provides the details. |

| Comment | Response |
|---|---|
| The inventory needs to be verified by all categories/sectors. This process would allow an information exchange to ensure that proper assumptions and operating statistics are used | The industrial facilities are always welcome to participate in the ongoing industrial emission survey activities conducted by NEIPTG (a joint Federal/Provincial task group). A majority of the industries depends on the government agencies to estimate their emissions. The estimated 1995 IP/RP profiles for individual industrial source from this NEIPTG emission survey will be sent back to the facility for review and feed back in the next few months. For industries that did not respond to the 1995 survey, the agencies have used best available source information collected from past years to work out the projected and estimated emissions. |
| Linkage: Particle Size and Cardiorespiratory Effects-This suggests that there is no mechanism to remove fine particulates that penetrate the lungs deeply. This is not true. Particle clearance and translocation mechanisms exist for extra-thoracic, tracheo-bronchial and alveolar regions. For example, particles can be removed from alveolar regions by macrophages (phagocytosis) and soluble particles can be cleared by dissolution. | Addressed |
| 2.2.4.2 Epidemiological Evidence and Important Conclusions-Highlights-These sections conclude that the ambient PM levels are linked to increases in mortality due to cardiorespiratory diseases and that demonstrated association cannot be accounted for by confounding factors or covarying pollutants. Experts in the field do not necessarily agree on this point. For example, after completing an extensive review of the evidence on particulate air pollution and mortality, Moolgavkar and Luebeck (1996) concluded "it is not possible with the present evidence to show a convincing correlation between particulate air pollution and mortality". Similar conclusions, regarding $PM_{10}$-related mortality, have been discussed in publications by Henderson (1995), Crandall et al. (1996), Gamble and Lewis (1996), Lipfert and Wyzga (1997), and Kaiser (1997). | Addressed. The difficult question regarding the role played by other gaseous pollutants (particularly $SO_2$, $NO_2$, CO and $O_3$) in the toxicity of particulate matter is discussed and a brief section on 'Multiple Pollutants' has been added which highlights the underlying issues and the various approaches (univariate, bivariate and multipollutant models and their strengths and weaknesses when addressing highly correlated/nonindependent variables) different investigators (Moolgavkar, Lipfert) have taken to address them. One weight of evidence conclusion of the PM SAD '...the magnitude, robustness, and consistency of the association across so many locations with differing air pollutant mixtures supports the position that particulate matter of some kind is the best indicator for the effects of air pollution on adverse health outcomes' is not too different from one of Moolgavkar's (Moolgavkar and Luebeck/1996) concluding statements '...Levels of the particulate component serve as a rough proxy measure of total pollution. The data are consistent with the conclusion that increases in air pollution as roughly indexed by levels of particulates are associated with adverse effects on human health.' |

| Comment | Response |
|---|---|
| 2.2.4.3 Possible explanations for the discrepancy between clinical and epidemiological data-Explanations are provided to explain the discrepancy between clinical and epidemiological data. The table does not consider the possibility that the problem may be associated with the accuracy of the epidemiological studies. Perhaps the epidemiological studies have not adequately addressed confounding factors or that PM is acting as a surrogate for another chemical. | Addressed the strengths and weaknesses of both clinical and epidemiological data. Multiple pollutant issues and confounding factors have also been addressed. |
| 2.2.4.4 Lack of Health Effects Threshold and Highlights of rationale for the Ontario interim PM10 ambient air quality criterion-It is concluded that a general consensus supports no clear threshold for health effects. Several investigators have concluded that particulate-related mortality increases linearly with the concentration of particulates with no evidence of a threshold (Pope et al, 1992; Schwartz J., 1994; Dockery and Pope 1994). However, after carefully considering the validity of the statistical analyses performed for these studies, Moolgavkar and Luebeck (1996) conclude that the data do not support a linear no-threshold exposure response relation. In defense of this conclusion, the authors cite problems associated with 1) parametric Poission regression models, 2) failure within the analyses to consider copollutants and 3) failure of the analyses to investigate other possible exposure-response relations. | Addressed. It is acknowledged that the statement, regarding no threshold, in the rationale for the Ontario interim PM10 ambient air quality criterion could have been phrased differently. It merely reflected the conclusions of several agencies (WHO, US EPA, U.K. Expert Panel, Health Canada, Canadian Fed-Prov.) that the epidemiological studies could not identify a threshold. This may need to be rephrased when/if the criterion is changed. The monotonically increasing (no threshold) concentration-response curve has been observed from very low ambient levels up to much higher levels with remarkable consistency in many of the studies on acute and chronic mortality and hospitalization. |

| Comment | Response |
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| 2.2.4.5 Approach to Estimating Current Impacts-PM10 dose-response functions used in health impact analysis were taken from Hagler-Bailly (1995). Most of these functions were based on epidemiological studies that did ***not*** measure PM10.<br>Chronic Bronchitis: Dose-response function for PM10 is derived from an epidemiological study based on TSP. Assumes PM10 = 0.55 x TSP.<br>Respiratory Hospital Admissions: Dose-response function for PM10 is derived from an epidemiological study based on sulfate. Assumes sulfate = 0.18 x PM10.<br>Emergency Room Visits: Dose response function for PM10 is derived from an epidemiological study based on TSP.<br>Aggravation of Asthma Symptoms: Dose response functions for PM10 are derived from epidemiological studies based on TSP or sulfate.<br>Restricted Activity Days: Dose response functions for PM10 are derived from an epidemiological study based on PM2.5. Assumes PM2.5 = 0.625 x PM10.<br>Acute Respiratory Symptoms: Dose response functions for PM10 are derived from an epidemiological study based on COH. Assumes ratio of COH (units/100 ft) to TSP of 0.116 and PM10/TSP ratio of 0.55.<br>Lower Respiratory Illness in Children: Dose response functions for PM10 are derived from an epidemiological study based on PM15. Assumes PM10 = 0.9 x PM15.<br>Acute Mortality: The high estimate for PM10 associated mortality was derived using a dose-response function based on PM2.5 exposure estimates | These dose-response functions have been selected by the CCME Clean Vehicles and Fuels expert panel on health (Ref: *Environmental and Health Benefits of Cleaner Vehicles and Fuels. Supplemental Report 2: Selected Concentration-Response Functions for Human Health Effects - 1995)*. Several criteria had to be satisfied for an epidemiological study to be selected by this panel. The panel also acknowledged several points. Air quality monitoring systems in North America have only recently been measuring $PM_{10}$. Previously, TSP was the most common measure used. Although these measures are different they are related. The panel also made two important assumptions (noted in ref. above) regarding the available results and converting estimates from one measure to another. First, it was assumed that no health effects are caused by particles larger than $PM_{10}$, and second, it was assumed that particle measures that represent a component of $PM_{10}$ (e.g., sulphates or $PM_{2.5}$ ) are a proxy for $PM_{10}$ levels in the original study locations. Furthermore, it can be noted that this methodology, these concentration-response functions (or modifications of them e.g., sulphates) have been used in and published by several agencies/initiatives/journals. (Pierce et al. Particulate matter and human health in the U.K. 1996. *Energy Policy* 24(7): 609-619; Ostro et al. Assessing the health benefits of reducing particulate matter air pollution in the US 1998. *Environmental Research*, Sect A 76:94-106; used for the US Acid Rain Program and elevated to US EPA study 'Human health benefits from sulphate reductions under Title IV of the 1990 Clean Air Act Amendments'- 1995; used in an industry-government - CPPI/EC/HC - Expert Panel Study (S in Fuels) -1997 ; the Acidifying Emission Task Force in evaluating further $SO_2$ emission reductions in Canada - 1997; 'Towards a Smog Plan for Ontario' - 1996. |

| Comment | Response |
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| 2.2.4.6 Health Impacts Based on Current Levels of Respirable Particulate Matter (PM10)-<br>Annual mortalities for a few Ontario urban sites were estimated for PM2.5 and PM10. Results indicate that the mortality rate for PM2.5 is 20% higher than that for PM10 even though PM2.5 is a sub-component of PM10. It is suggested that this difference is attributable to the "higher potency of PM2.5". However, this discrepancy suggests that there might be potential problems with the approach; perhaps with the use of generic conversions between TSP, PM10 and PM2.5. | Addressed. Clarified, using more appropriate data and analysis. |
| 2.2.5 Control Technologies- The report notes that the average cost for 32 FGD systems recently installed in the U.S. is 227 US$/kW. FGD costs are site specific and, as such, there is a wide range in costs. The report also comments on the FGD particulate removal efficiency . Particulate greater than 10 microns is removed but particles less than 2.5 microns in size are unaffected. It may be misleading to state that the retrofit of carbon injection for controlling mercury emissions is easy. Technology for mercury removal from utility boilers is still being researched and developed so there is no practical experience commenting on the ease of retrofit. | Addressed (although the 1st paragraph of III.6.2 states that each solution should be customized for the application a hand, a 2nd paragraph was added to the Introduction to answer the reviewer's concern). Disagree with the comment of 0% efficiency of scrubbers on particles ≤ 2.5$\mu$m. The document does not say that "retrofit .... is easy". It says that retrofit would be easier when using some (specific) technologies. |
| The use of excessive over-fire air (OFA) for $NO_x$ control can cause waterwall wasteage. Waterwalls have deteriorated after 5 to 10 years. Gas reburning is an expensive control technology. The use of selective non-catalytic reduction is still unproven on large utility boilers although there is a planned demonstration by AEP on a 600 MW unit. | The document does not recommend "excessive over-fire air (OFA) for $NO_x$ control. Some costs for reburning are quoted on page III.6-11. Agree with the reviewer (see last sentence in 2nd paragraph of (2) Post-combustion Control Methods (page III.6-11). |
| Particulate matter removal control technologies discusses flyash reinjection. Is there a utility doing this? Other comments on this section include: removal efficiency is not a baghouse removal design parameter, and mercury removal may require a second baghouse to allow carbon recycling and to keep mercury in a separate waste stream. | The description of Control Technologies is orientative and not source specific; many boilers use flyash reinjection. Comment about "removal efficiency...." is unclear; please re-state. Last comment is speculative. |

| Comment | Response |
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| The discussion of control technologies should cover multi-media since pollution prevention states that the transfer of substances between media is not acceptable. Industry could, in effect, be penalized for transferring a substance from air to land by implementing a specific control technology. | The approach chosen for the discussion of Control Technologies is justified in the 1st paragraph of the section (Introduction). |
| 2.2.6 Developing An IP/RP Strategy for Ontario- The "Guiding Principles for Developing an IP/RP Strategy" are a good building block. The challenge will be in their application as individual stakeholders have different concepts for each principle. | Smog Accord principles have been included into the current draft. Previous principles are now labelled as additional considerations. |
| **Lambton Industrial Society** | |
| Comments are provided on the assumption that the MOE will be identified as author of the final document. Members of the working group will be acknowledged as having provided comments on a draft of the report. | Done. See front cover and Preface |
| development of the compendium did not seek early input from industry and other stakeholders | Under the Smog Plan Steering Committee (SPSC), an IP/RP work group was established to help develop an IP/RP strategy. In order to facilitate the process, the MOE prepared a draft compendium document on the issue for SPSC's use. The document has been reviewed by the IP/RP work group and when endorsed by SPSC, document will be used for Ontario stakeholder consultation purposes. |
| Historical context is lacking throughout the document, weakening sections related to ambient levels and efforts to associate those levels with health outcomes | Health effects have been linked to $PM_{10}$ and $PM_{2.5}$ concentrations, in studies carried out mainly in the nineties. For the most part, therefore, data discussed in the document have been limited to these two components of particulate matter, and this time period. However, some examples of TSP trends over much longer time periods are shown in Section II.1. Some historical perspective is provided in the first paragraph of Section III.2.3.1. |

| Comment | Response |
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| Nowhere does the report identify the costs or benefits of the reductions already achieved. Particulate levels have been declining for more than a generation. Both measurement and anecdotal observation support that conclusion. Thus, either the adverse health outcomes are also diminishing, the causative agent has been misidentified, or a new, unidentified synergistic agent that exacerbates IP/RP effects has been introduced during the period that particulate matter exposures have been in decline. | This is a difficult thing to do, and would involve a substantial amount of work. In particular, it would be difficult to decide what time period to cover. |
| The LIS has provided an overview of additional ambient data for the period 1952 through 1998 for a small part of southern Ontario | Some of this information has been incorporated in Section III.2.3.1 paragraphs 1 and 5. |
| The draft report reads as a review of selective sources supportive of an advocacy position, rather than a compendium of knowledge | A consistent effort has been made to avoid advocacy |
| Speculation regarding outcomes of other regulatory initiatives, such as Canada Wide Standards development, should be avoided. Speculation biases this report, and undermines the credibility of the ongoing CWS process. | Removed. See Section I |
| References should be provided throughout the text, in sufficient detail to allow interested readers to consult the reference. Where references are internal MOE reports, or other sources not generally available, they should be provided as appendices to the compendium. | Further references have been incorporated to the fullest extent possible. |
| This section needs considerable expansion, to put some perspective on the typical as well as episodic levels of particulate matter | It is not clear which section is referred to. If it is the monitoring and meteorology section, reference is made to all of the data that is currently publically available in the Province. |
| The statement that particulate matter is emerging as one of the most critical environmental health issues is misleading | This statement has been modified |

| Comment | Response |
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| A much more complete and representative section on historical ambient levels in Ontario is needed, to put the issue in full perspective | Health effects have been linked to $PM_{10}$ and $PM_{2.5}$ concentrations, in studies carried out mainly in the nineties. For the most part, therefore, data discussed in the document have been limited to these two components of particulate matter, and this time period. However, some examples of TSP trends over much longer time periods are shown in Section II.1. Some historical perspective is provided in Section III.2.3.1. par. 1. |
| *Sections II.1.2, II.1.3*, and *II.1.4* have only a peripheral connection to IP/RP issues; do not impact on problem analysis or problem resolution; and, should be dropped from the text. | These other concerns associated with airborne particulate matter are important for context and completeness |
| *Section II.1.5*, *Primary Particulate Matter vs. Secondary Particulate Matter*, needs considerable development. Words like “mostly”, “usually”, “probably”, and “some evidence” leaves a strong impression of unsupported speculation | There are few absolutes when analyzing ambient air quality data. Nothing happens all the time and no source contributes 100%. Therefore, generalized wording is employed. The inferences are not unsubstantiated. Data can be shown to the reviewer. |
| *Section II.3, Linkage of IP/RP Matter Issue to Other Air Quality Issues and Initiatives*, raises the important issue: which side of a linkage best addresses resolution of a problem? For example, any program initiative addressing acid rain or ground-level ozone (para.6 in II.3.1) will have a positive impact on the IP/RP issues. Depending on the elements of a control strategy for IP/RP matter, the reverse may not be true. An important component of issue linkages not addressed in this brief section is a relationship among environmental linkages and health effects | Covered in Section II.3, as modified |
| The text describing programs in other jurisdictions is inconsistent, and needs frequent reference to *Table II.4.1* to make it readable. For example, *section II.4.2.1* United States, does not identify the proposed standards in eight pages of text, while discussing compliance costs and regulatory implementation strategies. | A reference to Table II.4.1 has been placed at the start of the section |

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| This section (Emission Inventory) is a crucial component in the development of an appropriate, equitable particulate matter control strategy for Ontario, and, from the information provided, a very weak link. As the text emphasizes, the questionable quality of the data needs improvement, and "**requires meaningful co-operation and participation from industry sources in the characterization of emissions**". There has as yet been no opportunity offered to begin that step. Understanding of the current inventory is hampered by lack of detail on estimating techniques. | The Emission Inventory Group has always sought industry input in the construction and maintenance of emission inventories. The industrial facilities are always welcome to participate in the ongoing industrial emission survey activities conducted by NEIPTG (a joint Federal/Provincial task group).<br>Since early 1990s , there has been continuous request for emission inventory information for the purpose of environmental program developments. With the overwhelming participation of various industries and industrial associations in various stages of environment program developments including Smog, acid rain, greenhouse gases, COA, the request for emission information through annual voluntary survey for the purpose of tracking emission reduction was undertaken. However, the support of the annual emission inventory survey has become less than desirable. In recent years less than 20% of the surveys were returned.<br>A majority of the industries depends on the government agencies to estimate their emissions. The estimated 1995 IP/RP profiles for individual industrial source from this NEIPTG Emission Survey will be sent back to the facility for review and feed back in the next few months. For industries that did not response to the 1995 survey, the agencies have used best available source information collected from past years and worked out the projected and estimated emissions.<br>Workshops hosted by MOE and Environment Canada were held this summer to outreach and provide opportunity to industries in Ontario to cooperate and participate in the emission inventory development. |
| The revised version of the emission inventory has exacerbated concerns about data quality. Revisions of estimates include both trivial changes and significant alterations – from adjustments of a few tonnes to factors of 2, to an order of magnitude, without explanation. | The sectors which are affected by the revision are given in Appendix A . The major changes are in the open sources categories. Ontario has adopted some of the updated emission methodologies proposed by Environment Canada such that the emission estimates will be consistent with other Canadian Provinces.<br>Emission inventory development is always dynamic, as better source information and methodologies of emission estimation become available, the emission profiles will be improved. While area and open source emission inventory improvements are generally developed by government agencies, point source IP/RP emission improvement will rely on the effort of the industries. Participating in the industrial emission inventory survey is one of the most important step in eliminating excessive changes and alteration of provincial emissions due to lack of useable source-emission information. |

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| Considerable text is devoted to the limitations of the 1990 inventory, although the data are not provided. A fuller discussion on 1995 data quality would be more helpful | When MOE initiated the development of the Smog Plan in 1995/96, 1990 was selected as the base year. At the time of developing IP/RP for the Smog Plan, some of the source information and methodologies for estimation IP/RP emission for 1990 were not readily available or could not easily be recovered. Therefore, we tried to provide more perspectives on the development of 1990 base year IP/RP inventory using the best available information at that time.<br>For the 1995 emission inventory, we have expanded on the description of the methodologies.<br>The underlying factor to reduce limitations or completeness of the IP/RP emission inventory is the strong participation of the industries in the province-wide annual emission inventory survey covering various pollutants and IP/RP. |
| The conclusion *(III.1.1.2, para.4)* that "The existing uncertainty and information gaps in the $PM_{10}$ and $PM_{2.5}$ emission data should not be considered a serious impediment to initiating the development of workable IP/RP emission reduction strategies" is unacceptable. Earlier statements repeatedly make a plea for better data to support the standard setting process. | Data gaps and uncertainties are acknowledged in the document. However, there is considerable evidence to support the initiation of a process leading to IP/RP strategies. Emission inventory development is a dynamic process. As better data become available, the emission will be re-estimated, backcast or forecast. Therefore, one should continue to develop the reduction strategy while the 'numeric reduction' target is being improved.<br>As mentioned, this phenomenon is universal to the current North America IP/RP or $PM_{10}/PM_{2.5}$ emission inventory development. |
| *Figures III.1.1a and 1b* should be deleted. Neither indicates clearly that the charts represent only a small fraction of the Ontario emission inventory, nor is there any identification of the total emissions represented by the charts. *Figure III.1.1b* cannot be reconciled with *Table III.1.1*, as sector identifications are not consistent. Most importantly, the charts are not a fair reflection of the emissions inventory. The 1995 chart, for example, appears to include only about 18% of the emissions quantified in *Table III.1.1*. | The intent for Figures III.1.1 and III.1.2 is to focus on the IP/RP contribution from point, mobile and area sources. Additional figures (III.1.2a,b,c, III.1.3a,b and c) are provided in the revised Section III.1 document to illustrate the 1995 emissions. |
| Even if data are completely compatible between the charts for 1990 and 1995, the statement that there is little relative change among sectors is invalid. In fact, the charts suggest some very large changes within sectors. For example, the charts imply that emission from mining and rock quarrying have been reduced by 67% or more, depending on the relative size of the total emissions for the two years. Transportation sources, on the other hand, appear to have increased substantially, or a least not decreased at the pace of other sectors. | It is not appropriate to compare the 1995 to the 1990 emission profile at this time. The 1990 IP/RP emission inventory will be updated by NEIPTG with the current 1995 methodologies and thereafter, will provide a more appropriate comparison. Environment Canada is assisting the provinces in the revision or backcast of the 1990 IP/RP emissions. It is expected that the revised 1990 IP/RP to be available for review by MOE soon. The revised 1990 IP/RP emissions will be incorporated in future IP/RP document. |

| Comment | Response |
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| Without substantial detail on the estimating techniques and baseline information used, little comment on the quality of data in *Tables III.1.1 through III.1.6* is possible. The magnitude of the changes to some categories between drafts is striking, and requires explanation, as do the large reductions in estimated total emission for all particle sizes. The Tables report estimated emissions to the nearest tonne (particulate matter), an unwarranted level of precision and accuracy. | Appendix A provides additional details. |
| *Tables III.1.1, III.1.2, III.1.3 and III.1.4* should use the same sector and category breakouts, at least at the level of category totals. | The revised document has provided consistency in the grouping of sectors/sources between pollutants. It should be noted that IP/RP inventory has some unique sectors in the open source category such as road dust, agricultural wind erosion etc. which are significant IP/RP contributing sectors but are insignificant in other inventories for NOx/VOC/$SO_2$. |
| *Table III.1.5* should provide ammonia emissions for 1995, for consistency with the other data. Point source data from NPRI suggest a much lower point source emission, 5338 tonnes per year, than the 14,781 reported for 1988. | As mentioned in the report, MOE and NEIPTG are compiling an updated ammonia emission inventory for 1995.<br>Owing to the reporting criteria of NPRI, it may not provide a complete point source inventory for Ontario. It is also not appropriate to compare the two years of data that were developed under two methodologies and requirements. |
| For clarity and consistency throughout section III.2, care should be taken to ensure that numerical values reported are completely identified, particularly as data from a number of jurisdictions are reported. For example, the choice of means used in averaging data should be identified as geometric or arithmetic, to ensure that comparisons are valid. This detail should appear on all accompanying tables and figures. | Where possible and available, all attempts have been made to indicate the averaging period of the pollutants on the figures or tables. |

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| It is notable that US data show a 40% decline in $PM_{10}$ between 1986 and 1993 (III.2.1, para.4), while Environment Canada data for Ontario show no significant changes between 1984 and 1993 (III.2.3.2, para.4). LIS data over a similar period are consistent with the US trends | A paragraph has been added to the beginning of Section III.2.3.1 discussing the decline in particulate matter concentrations in Ontario. Most of the decrease occurred from the early 1970s to the early 1980s. The LIS data are now referenced in the document. $PM_{15}$ data from Lambton County for 1980 to 1993 also showed some decline in the early 1980s. As indicated in the text (Section III.2.3.2), the Environment Canada study of $PM_{10}$ and $PM_{2.5}$ for the period 1984-1993 did not show a decreasing trend in Ontario unlike other sites in Canada. It was also noted that U.S. data for $PM_{10}$ show a decreasing trend over the period 1986 to 1993. These observations perhaps suggest that long-range transport and transboundary impacts in Ontario may be playing a significant role on the levels monitored here. Secondary pollutants, such as sulphates and nitrates, are significant fractions of PM in Ontario and are largely the result of gas to particle conversion, and subsequent transport from primary pollutant source regions |
| Limited LIS data comparing $PM_{10}$ and $PM_{2.5}$ fractions suggest a ratio of 40% $PM_{2.5}$, significantly lower than the 60% identified in the Environment Canada studies. | As noted, this is based on very limited LIS data. The lower ratio for Sarnia could mean that there are more local sources of $PM_{10}$ there than in other parts of Ontario. Measurements in the eastern US also show that $PM_{2.5}$ contributes about 60% of the $PM_{10}$ mass. The LIS data for $PM_{10}$and $PM_{2.5}$ fractions is a small data set. When more data are available from paired $PM_{10}$ and $PM_{2.5}$ monitors in Lambton, in the Nanticoke area (Ontario Hydro) and at some MOE sites it will be possible to provide a more definitive discussion of the variability of these measurements at different locations. |
| Comment on MOE data was hampered by the internal nature of the MOE reports cited, and by the illegible reproduction quality of most of the supporting maps and figures. | Measures have been taken to improve reproduction quality. |
| LIS data for 1997 (submitted) show fewer exceedence days than Windsor – in the range of 2% - always during periods of south to southwesterly winds, at monitoring sites south and north of the industrial complex. | This review considered only data up to the year 1996. There are considerable variation from year to year which may account for the lower number of exceedence days in 1997 for Sarnia. |

| Comment | Response |
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| The suggestion (III.1.2.3.3, last para.) that neighbouring US states are significant contributors to the high levels of sulphate and fine particles in southern Ontario needs elaboration.<br>*Section III.2.1* identifies a 40% reduction in US levels between 1986 and 1993. *Section III.2.1* identifies a 40% reduction in US levels between 1986 and 1993. *Section III.2.3.2* states that there was no corresponding decrease in Ontario in the 1984 to 1993 period. Rationalization of these three statements is needed. LIS data for the Sarnia/Lambton County area, as indicated, support the US trend. | This paragraph refers to "episodic" conditions and is based on back trajectory analysis on days with elevated PM levels in Ontario. It is now explicitly stated in the text.<br>As indicated in the text (Section III.2.3.2), the Environment Canada study of $PM_{10}$ and $PM_{2.5}$ for the period 1984-1993 did not show a decreasing trend in Ontario unlike other sites in Canada. It was also noted that U.S. data for $PM_{10}$ show a decreasing trend over the period 1986 to 1993. These observations perhaps suggest that long-range transport and transboundary impacts in Ontario may be playing a significant role on the levels monitored here. Secondary pollutants, such as sulphates and nitrates, are significant fractions of PM in Ontario and are largely the result of gas to particle conversion, and subsequent transport from primary pollutant source regions. |
| Section III.4 identifies data gaps and references limited studies, such as the brief paired study involving Egbert and Toronto, and the Hamilton Air Quality study. It is apparent that undue reliance is being placed on these studies, neither of which is representative of the province as a whole. | In this section we have attempted to include descriptions of the main methods of analysing particulate monitoring data which could be used in assessing the source sectors, precursor gases and/or the source regions which contribute to the fine and coarse fraction of $PM_{10}$ concentrations. As new and more complete data become available, that data would be used to improve source apportionment analyses. The studies LIS refers to in Toronto and Hamilton were used in Table IV.14 specifically for estimates of the local urban/industrial contribution to sulphate (Toronto study) and $PM_{10}$ (Hamilton study) in those urban areas. The results were not extrapolated to other parts of Ontario. |
| *Section III.4.3.4* references use of models to back estimate emission rates. This questionable application of models must be used only as a last resort | Use of models combined with monitoring data to make back estimates of emission rates can only be done if extensive monitoring data are available; which was the case for the Hamilton study described in Section III..4.3.4. The accuracy of this analysis method depends on how much is known about the emission source release characteristics such as stack heights. For the Hamilton study the emission sources of $PM_{10}$ included emissions from stacks, large volume sources and fugitive dust emission from roads etc. The emission rates from a number of these sources are not well known and the back estimates from modelling/monitoring data provided an independent check on the emission inventory estimates. |

| Comment | Response |
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| This section (III.5) provides an overview of selected studies previously reported elsewhere. The text requires editing to delete speculation and overstatement that detracts from the quality and careful qualification of conclusions found in the primary literature. There are a number of instances in which there are conclusions drawn with no identification of supporting references. An example is found in para.4 of Longer Term and Chronic Effects: "Recent evidence shows increases in… " with no study referenced | Addressed. Difficult issues acknowledged, supporting references added as much as possible. |
| It is striking that the literature related to health and occupational exposure to particles is completely ignored in this review | Since public health protection and ambient (outdoor air pollution) are the two focussing factors, occupational exposure studies would be considered less relevant than outdoor epidemiological studies. |
| The science is neither as well developed nor conclusive as this compendium asserts. A recent (1997) Critical Review and Discussion (J. Air & Waste Manage. Assoc. **47**: 551-581 and **47**: 995-1008) raises and debates the many issues surrounding the uncertainties regarding this science. As noted by Vedal in the critical review, **"the study of the health effects of ambient particles is plagued by a weak biological foundation. This makes it tempting to base what understanding we have on the results of statistical modelling, but which should, in addition, heighten our healthy suspicion that biases are at work."** | Addressed. Difficult issues remaining discussed and acknowledged. Uncertainties noted. |
| *Box II.5.1* identifies three common approaches to health effect evaluations but leaps to the conclusion that epidemiology provides the best approach – exactly the caution raised in the Critical Review. It is essential that the other approaches be used to adopt a weight of evidence approach, to resolve those "healthy suspicions". | Addressed in Box III.5.1 and in new/revised section 'Weight of Evidence-Causality, Multiple Pollutant Issues and Recent Development'. |
| *Section III.5.1.2.1*, Epidemiological Evidence, implies that epidemiological studies conclude that cardiorespiratory effects are causally related to airborne particulate matter. At best, they show associations between the two. | Addressed. |

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| The increased risk of mortality for $PM_{2.5}$ is stated to be twice that of $PM_{10}$ for each 10 microgram per cubic metre increase in mass, implying increased potency. This ignores the actual exposure situation – in general, $PM_{2.5}$ is about 50% of $PM_{10}$, thus in a population exposure study $PM_{10}$ rises at double the rise of $PM_{2.5}$. The relative potencies cannot be distinguished. | Nothing was *implied*. The findings from the studies regarding the increase of mortality per 10 $\mu g/m^3$ increase of $PM_{2.5}$ and $PM_{10}$ was stated. |
| The extrapolation of low magnitude increases in mortality or morbidity to entire exposed populations implies acceptance of five assumptions:<br>1. Confounding and covariance has been addressed.<br>2. Those included in study data were representative of the full population.<br>3. The full population is equally sensitive.<br>4. Those in the study were exposed to the ambient concentrations – i.e. measurement, or exposure, misclassification has not occurred.<br>5. Ranges of concentrations studied are representative ambient concentrations to which the full population is exposed.<br>Unless and until these assumptions are validated, extrapolation of study mortality and morbidity rates to the provincial population is unwarranted. | The time-series type epidemiological studies (on which the dose-response functions used in the estimates are based) associated changes in ambient air quality and the number of adverse health events observed in the population. This was consistently observed in several different locations, climactic conditions, representing different and broad populations. Health effects were observed throughout the entire range of pollution exposure <u>not dissimilar</u> to what exists in Ontario's urban centres and rural areas. Therefore it is completely appropriate to translate existing (or reductions in) pollution levels to existing health impacts (or to benefits) based on time series studies. There is some variability in the epidemiological studies from various locations. Table III.5.2 reflects this variability by providing 'low', 'central' and 'high' estimates of existing impacts. This range approach of low to high is also carried through in the benefit analysis of section IV resulting from PM reductions. |
| The discussion of evidence from controlled human studies concluding that clinical data do not lend much support to the epidemiology brings Vedal's comment regarding bias into focus. *Box III.5.2* begins with the bias that it is the clinical studies that are limited. The alternate possibility should be considered, carefully. | Addressed. Strengths and weaknesses of all three types of studies (Clinical, toxicological and epidemiological) are discussed. See Box III.5.1 and also section III.5.1.2.2. Clinical studies though *still remain limited* by virtue of the fact that due to ethical reasons one cannot conduct clinical/chamber-type studies on compromised people. |

| Comment | Response |
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| Repeated statistical evidence of an association between particulate matter and cardiovascular health is not alone evidence of causality. As the first bullet in *Box III.5.3* points out, epidemiological studies directly assess health outcomes in response to "complex mixtures of pollutants". They do not independently establish causality. Most studies referenced here did not include multiple contaminants; those that did found larger responses among gases and specific particulate species. It is interesting to note that each bullet in *Box III.5.3* could be rephrased to identify a limitation on epidemiological studies. | Agree with first sentence. Addressed in new/revised section 'Weight of evidence - Causality, multiple pollutant issues and recent developments' (III.5.1.2.4). Although not included here because of space considerations, many studies in the PM SAD did consider other pollutants (one at a time in bivariate regression models) and found that the association of PM with adverse health outcomes was remarkably robust to inclusion (one at a time) of the four gaseous air pollutants. |
| The Bradford Hill criteria for evaluating causality are a useful, if subjective framework. This compendium finds that many of the criteria have been satisfied. Others (e.g. Vostal, discussing the Critical Review, JAWMA **47**:999) find that as few as two of the criteria have been satisfied – a weak link at best. | Addressed. See section III.5.1.2.4 and also the discussion on the B-H criteria . |
| It is exceedingly difficult to characterize the evidence presented as remarkable, robust, or compelling. Studies that examined only associations between particles and health outcomes are consistent. Studies that include other air quality parameters cloud this consistency. The evidence certainly does <u>not</u> support that particulate matter, <u>rather than</u> other parameters is associated with health effects | Addressed. See new/revised section III.5.1.2.4. and revised section III.5.1.3. |
| The application of the "no minimum threshold" theory is unwarranted, and unsupported. Clinical and toxicological studies have defined no observable effect levels. No epidemiological study can include zero exposure – the real-world baseline includes biogenic and crustal material exposure. *Box III.5.5* is similarly unsupportable based on the studies reported in the compendium. | While an epidemiological study cannot identify a '*toxicological' threshold* (the type that a clinical or toxicological study would identify), nevertheless, a monotonically increasing (no threshold) concentration-response curve has been observed from very low ambient levels up to much higher levels with remarkable consistency in many of the studies on acute and chronic mortality and hospitalization. This points in the direction that epidemiological studies have not been able to identify a 'threshold' (or level), below which there are no effects. The studies identify a LOAEL (lowest **observed** adverse effect level) not a NOEL (no observed effect level). When a toxicology or clinical study identifies a LOAEL, it is assumed that there ARE effects below the LOAEL. |

| Comment | Response |
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| The question remains whether extrapolation to the general population is justified. It would be instructive to review historical records of indoor and outdoor exposures and corresponding health outcomes to gain some perspective on this issue. The statement that the measurable effects straddle a much greater burden of illness is speculation and should be deleted. | See answer/discussion above on the time-series epidemiological studies and why it is entirely appropriate to use these to extrapolate to the general population. The comment suggest use of the word 'measurable' in 'The statement that the *measurable* effects...' . The previous wording was 'high-profile' effect not *measurable*. The revised wording now is 'the more serious effects of mortality and hospital admissions straddle a much greater number of illness cases...'. Regarding these illness cases, see section discussing lung function decrements, restricted activity days, absenteeism and also the section on 'Longer term and Chronic Effects'. |
| The conclusion (III.5.1.3, para.5) that the fine fraction has the highest association with adverse health effects is not supported within the document. The Shwartz study described in **Section III.5.1.2** identifies a larger association with sulphate, as do a number of other studies. Burnett et al (JAWMA **48**: 689-700) found stronger associations with gaseous air contaminants, notably CO and $NO_2$. | Note in section on mortality 'the magnitude of the mortality risk was greater ...for sulphate compared to $PM_{2.5}$ ..., the strength of the association was greater for $PM_{2.5}$ than sulphate. Burnett's work discussed in new/revised section III.5.1.2.4. |
| There is insufficient description of methodology used to estimate population effects to comment effectively on the approach. For reasons developed above, the no threshold approach is unwarranted. The five assumptions regarding extrapolation to the general population, outlined above, need consideration, to at least provide ranges around the estimated outcomes. | See discussion above on thresholds. Essentially the document acknowledges the natural non-anthropogenic background as the level above which impacts can be considered and benefits to be counted. See discussion above on time series studies and see Table III.5.2 which provides 'low', 'central' and 'high' estimates of outcomes. Similar ranges are used in the benefit analysis. |
| Section III.6 leaves the impression that many of the practices and devices described are not currently in place. Most are, or are not readily or economically applicable to a specific service | Addressed (2nd paragraph in III.6.1). |
| The benefit-cost analysis is based on a 1990 emissions inventory, while the rest of the document references 1995 data. The analysis should be repeated using 1995 data, consistent with the rest of the report. Given the large reductions in emissions in some areas (locally VOC reductions in the 40-50% range), the cost structure may be markedly different. | The intent is to re-estimate abatement-prevention costs with the Environment Canada AERCo$t model using 1995 base-case emissions. Environment Canada have not yet been able to put the 1995 emissions into their model. |
| The analysis should only be undertaken in full consultation with the industries involved, to ensure that the analytical methodology is appropriate, the "scenarios" realistic, and the cost functions representative | Many attempts have been made by Ministry staff to involve industry representatives in these economic and cost analysis, to obtain data from them, to have them comment on estimates of postulated technologies, costs and emission reductions. However, to date, no substantive information or involvement has been forthcoming. |

| Comment | Response |
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| The methodology does not address the problem that occurs when the "cost" is borne by one party, and the "benefits" of values accrue to others. | This dichotomy of incidence is a fundamental aspect of environmental pollution issues. The best we can do is to identify the incidence of costs and benefits among sources and receptor populations. We also comment on the economic incentives facing various stakeholders so that we can predict their reactions to specific programs, For example, polluters who must invest in abatement technologies have an incentive to delay expenditures - the higher the compliance costs, the greater the incentive. |
| The indicated positive return on VOC reductions (Figure IV.1) is inexplicable | The positive returns are explained in the text of the report. It is also noted that these opportunities may have already been implemented between the time they were first estimated and the present. |

| Comment | Response |
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| Anecdotal comment on benefit-cost section:<br>§ One local facility reduced VOC discharges by 875 tonnes/year (24%) between 1993 and 1996 at a capital cost of $5.4 million. The $6179 per annual tonne, exclusive of operating cost, compares to *Table A.6's* average of about $700 per tonne.<br>§ Each tonne of solvent reduced in paint manufacturing through substitution is stated to save industry $5164. At solvent costs less than 30 cents per litre, or roughly $400 per tonne, how is this saving achieved?<br>§ Imperial Oil's Sarnia refinery costs for $PM_{10}$ reduction appear to be low by an order of magnitude.<br>§ Fuel switching does not appear to be fully costed. As an example, the *Table A1* estimate of $379 per tonne to reduce Shell's Corunna facility $SO_2$ emissions by 96% clearly does not include the capital cost to replace oil fired equipment.<br>§ Estimates for 50% reductions in NOx emissions from refineries, completed for the NOx/VOC Code were in the $2000-3000 per tonne range for retrofitting boilers, not the $387 used in Table A3.<br>§ Most refineries and petrochemical facilities now have LDAR programs for VOCs in place, reducing fugitive emissions by 80% and overall VOC emissions by at least 30%. *Table A.6* estimates $42 per tonne for this range of emission reduction. Actual LDAR costs, at more than $1500 per tonne, are still more cost effective than measures such as secondary seals, retrofitting of floating roofs, etc.<br>§ Locally, fuel switching under the LIMA regulation carries an hourly incremental cost, accumulated for all affected facilities, of about $3000. If the lower POI were imposed year-round, the incremental annual cost would be about $26 million. | We would be happy to incorporate the information cited in the 7 bullets under this section if LIS can supply more details than provided in this letter. We would also like some kind of written documentation for these estimates rather than just assertions. |

| Comment | Response |
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| Strategy and Synthesis of Results sections will need some rework following revisions to the main text. Any IP/RP strategy for Ontario should be equitable, efficient and effective. It will be none of these of these if implementation does not lead to measurable change in the health outcomes | As agreed at the November 26 Work Group meeting, strategic options now appear as an independent document. Data analysis in the previous version is now included in the Compendium document. Based on what is known about air quality and health effects, one would expect that decreases in air pollutant emissions would lead to imposement in air quality, hence avoided health effects due to air pollution. However, it would not be possible to sort out avoided health effects due to air pollution alone from many other contributing factors, (other than from indirect statistical relationships). |
| **CPPI** | |
| The CPPI suggests that any Ontario PM option be developed keeping in mind the significant PM research and policy effort underway in the US; as well, any Ontario PM option must be developed in context with the efforts and timeline on the Canadian national (and regional) scene (Canada Wide Standards - fall '99). We should look for consistencies and efficiencies with Canadian (national and regional) processes | Harmonization with the US now appears as one of the strategic options in section V. It should be noted that the United States has standards for $PM_{10}$ and $PM_{2.5}$. As well, in the United States, states are expected to submit State Implementation Plans (SIPs) to the US EPA concerning how they would comply with these standards. Conscious efforts have been made to ensure integration of Ontario IP/RP strategy development with that of the Canada-wide IP/RP standards. |
| The document carries a definite "advocacy" tone. | A conscious effort has been made to avoid advocacy throughout the document |
| given the Compendium is primarily scientific in nature, Section 5 of the Compendium "Developing an IP-RP strategy for Ontario" seems out of place. We suggest you remove this section from the Compendium, which will allow a wider circulation of the Compendium. | As agreed at the November 26 Work Group meeting, strategic options now appear as an independent document. |
| Compendium positions most of the science underpinning PM policy as robust! remarkable, complete and compelling. There is insufficient mention of the uncertainty associated with much of the PM science and the fact that the US EPA has allocated in excess of S400 million over the next 12 years to study PM. | Areas of uncertainty have been noted throughout the compendium document. Scientific research needs are summarised in Section V, Conclusions. |
| In the Compendium, PM is positioned as one of the "most critical" air quality issues. | This statement has been modified (see Section I) |
| The Compendium needs to discuss why there is a statistical link between health outcomes and PM, given that PM measurements show a decline over the last 25 years;. | Do not understand why a decline over the last 25 years should mean that there can not be a statistical link between PM and health outcomes. |

| Comment | Response |
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| Health Canada's most recent work suggest that it is the entire air pollution "mix" that is responsible for negative human health effects. This aspect needs more prominence in the Compendium. as it adds to the uncertainties associated with the effect of air pollution on human health. | Further information has been added to Section III.5 -- see earlier responses. |
| *Section 1: BACKGROUND*<br>- More perspective and context is needed, including discussion of<br>+ Trans-boundary emissions<br>+ Existing AQ policy in Canada, U.S. and Ontario<br>US EPA 5 year review is not mentioned; neither is the US re-adoption of<br>PM10 = 15~) µg/m3 and the PM2.5 = 65u~m3<br>+ Linkage to other AQ issues (c.g., Climate Change)<br>- In section 1.2, the mention that "40/20" will be a reference point for the COOS, as a longer- term is presumptive and implies that 40/20 is the right answer. These levels are not supported by a complete analysis (including socio-economics) and reference to the numbers should be removed, lest it misleads the reader. | This information has been included mainly in Sections II.3 and II.4 |
| *Section 2: POLICY & STRATEGIC ISSUES*<br>- Not sure of the value of this section as currently drafted.<br>- Needs more details on historical background. Need less (perhaps delete) sections on<br>Black Fallout, Complaints and Visibility.<br>- Needs much more detail on section on Primary and Secondary PM.<br>- Need further development on the "linkage" section, i.e., PM with other AQ issues. | This section is designed to fill in more of the background. The brief discussions on black fallout, complaints and visibility provide information on the effects of fine particulate matter on the environment. More detail on primary versus secondary particulate matter is provided in other sections of the document, including III.2, III.3 and III.4. The question of linkages is open ended, and should perhaps be revisited at a later stage. |

| Comment | Response |
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| *3.1 EMISSION INVENTORIES*<br>- Emission inventories are critical to underpinning effective PM policy.<br>The CPPI would like to see clarification on how the emission data has been derived?<br>+ Details on inventory estimating methodologies/techniques are needed<br>+ Stakeholders need to verify/validate emissions (Precision/"significant figures" of emission data is not realistic)<br>+ Emission data needs to be effectively characterized/speciated<br>- Revisions to database without adequate explanation has exacerbated stakeholder<br>concerns that the data lacks legitimacy.<br>- Less detail on the 1990 inventory/more on the 1995<br>- Graphical & pictorial representations are not balanced. Need to include all emissions.<br>- Need to be consistent in sectors/categories for data to be comparable | Appendix A provides the details.<br><br>The industrial facilities are always welcome to participate in the ongoing industrial emission survey activities conducted by NEIPTG (a joint Federal/Provincial task group).<br><br>Since early 1990s, there has been continuous request for emission inventory information for the purpose of environmental program developments. With the overwhelming participation of various industries and industrial associations in various stages of environment program developments including Smog, acid rain, greenhouse gases, COA, the request for emission information through annual voluntary survey for the purpose of tracking emission reduction was undertaken. However, the support of the annual emission inventory survey has become less than desirable. In recent years less than 20% of the surveys were returned.<br><br>The majority of the industries depend on the government agencies to estimate their emissions. The estimated 1995 IP/RP profiles for individual industrial source from this NEIPTG Emission Survey will be sent back to the facility for review and feed back in the next few months. For industries that did not respond to the 1995 survey, the agencies have used best available source information collected from past years to work out the projected and estimated emissions.<br><br>Workshops hosted by MOE and Environment Canada were held this summer to outreach and provide opportunity to industries in Ontario to cooperate and participate in the emission inventory development. |
| Are the VOC and .NOx estimates based on the NOx/VOC management plan? The Plan assumed a 2-3 % growth rate per year for chemical and petrochemical industry and this was reflected in the total emission projections. The demand for petroleum product has gone down and some refineries and chemical plants have been shutdown. Also all petroleum and chemical facilities have implemented Leak Detection and Repair (LDAR) programs. Does the emission database reflect these efforts? | The 1995 Ontario industrial VOC and NOx estimates are based on the NEIPTG industrial survey results. For those companies who did not respond to the industrial survey, emissions will be estimated for them based on past emission information and other information such as growth rate, fuel statistics etc. that are available to MOE. All major chemical plants and petroleum refineries in Ontario have been surveyed for the year 1995. The emission data base reflects the information returned to this survey. |
| S02 emissions from CPPI member companies may be overstated, given the Compendium reports S02 emissions from individual facilities: Shell, IOL Sarnia, NOVA. IOL Nanticoke; and from the refinery group (presumably Sunoco and Petro Canada) as 29,800 tonnes per year. | The 1995 $SO_2$ emissions from the CPPI facilities are based on the industrial survey data submitted. Five out of seven refineries provided their plantwise $SO_2$ emissions (one more later). The emission profiles for the remaining facility were estimated by MOE. These six facilities reported a combined SO2 emission of over 57,000 tonnes. |

| Comment | Response |
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| *3.2: PM MEASUREMENTS* "Compare apples with apples!"<br>+ It is important to compare data collected from the same type of monitoring equipment. It is unclear from the Compendium whether this is the case.<br>+ Rationalize/discuss why the U.S./Ontario data trends are different! | As indicated in Section III.2.3.1, PM is collected by a number of methods, e.g., dichotomous and size selective inlet, as well as by the continuous TEOM. The results from these different methods appear to be reasonable (e.g. see last paragraph of this section). Further work is needed, and a special study is currently underway by Environment Canada to compare a number of samplers (R&P Partisol-WINS impactor, Graseby-Anderson Dichotomous, IMPROVE and R&P TEOM). Initial results show reasonable agreement between the samplers.<br>The lack of trend in the Ontario PM data over the period since 1984 was noted in the Environment Canada studies. This could be related to the fact that Ontario is downwind of major U.S. source regions and hence is subjected to significant transboundary and long-range transport effects, especially of secondary sources such as sulphates and nitrates. |
| *3.4: SOURCE APPORTIONMENT /DATA ANALYSIS & MODELING*<br>**- Danger in high reliance on models**<br>- Critical for area sources to be included in regional/urban modeling | Comprehensive modelling of particulate matter for eastern Canada and northeastern U.S. is available for sulphate but is not currently available for the formation of nitrate, secondary organic aerosols and primary particle emissions. When we do have such comprehensive evaluated models, they would be a primary tool in assessing the relationships between emission reductions and ambient concentrations of $PM_{10}$ and $PM_{2.5}$. However the other analysis approaches described in Section III.4 would still be used in evaluating the particulate matter concentrations. Area sources will be included in comprehensive regional/urban modelling. Evaluations with chemically speciated observed data will be required to test the adequacy of the input emission data; especially the fugitive dust and ammonia emissions. |
| Uncertainties involved in the analysis (Bottom-up inventories not agree with Chemical Mass Balance apportionment) need to be discussed. When the bottom-up inventories are used for Cost-Benefit Analysis in Section 4 (i.e., roll back analysis) there should be a quantitative assessment of the possible error/uncertainty due to the difference between what is estimated from the source and what is seen in the air (via CMB). This would put uncertainties in better perspective. | The relative importance of various source sectors in emission inventories is, for fugitive dust emissions, in disagreement with the limited number of chemically speciated measurements of $PM_{2.5}$ in urban and rural areas in eastern Canada and the northeastern U.S.. Emission inventories indicate that dust entrained from paved road is larger than emissions from all fuel combustion and transportation sources combined. However, chemical analysis of fine particulate data ($PM_{2.5}$) indicates that the elemental and organic carbon mass (emitted mainly from combustion sources) is 5 to 20 times the mass of soil/crustal material which is emitted from fugitive sources including paved roads (Figure III.4.3).<br>By separating the emission inventories into the individual precursor gases and grouping the primary particulate emissions into sources categories, information on measured chemical composition of the fine and coarse fractions of $PM_{10}$ can be used in assessing the reductions in particulate mass associated with emission reductions of these precursor and primary emissions. As indicated on Figures III.4.3 and III.4.4, the limited number of chemically speciated particulate data shows variability in the composition. More chemically speciated measurements would be needed to accurately assess the relative contributions of the precursor gases and primary particulate emissions across Ontario. As indicated above, once comprehensive evaluated models for particulate matter are available they would be primary tools in assessing the impacts of emission reductions on particulate mass. |

| Comment | Response |
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| *3.5: HEALTH EFFECTS*<br>- Not realistic to characterize health evidence as remarkable, robust. compelling.<br>complete<br>- Correlation between health and PM is statistically based.<br>- No causality has been established.<br>- Recent Health Canada info diminishes impact of PM, and points to entire air mix<br>- Need statement at start of section: "we are just beginning to understand the complexities<br>and impact of air pollution on human health."<br><br>This section needs to be rewritten to be more objective. Currently, the reader is lead to believe we know everything we need to know about this topic and can "quantify" health effects with great certainty, which is clearly wrong. The section needs to address the uncertainties in a way that will give the reader a sense of the possible range of responses Currently, the range of responses presented is derived from selected studies. which use the same or similar databases | Addressed . Statements modified to conform as much as possible to the scientific discussions and conclusions of the extensively peer-reviewed Federal-Provincial Science Assessment Document (PM SAD) and its Executive Summary. This includes not only the conclusions, but the discussion of uncertainties, confounding factors, views of different investigators on addressing the uncertainties and the attributes used by different investigators to build a causal link between an agent and its health effects. Although a causal mechanism has not been proven yet a weight of evidence can and has been used (as in PM SAD), whereby multiple lines of evidence are brought together and duly considered to build a case for the health effects of fine particulate matter. See new/revised section on ‘Weight of evidence -causality, multiple pollutant issues and recent developments’. Difficult issues, uncertainties acknowledged. |

| Comment | Response |
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| Section 4 -BENEFIT COST ANALYSIS<br>We have great concerns about the data collected to support CBA' the integrity of the methodologies, and the application of the CBA. What we offer are some highlights of our concerns. What is needed is a much more thorough review of this subject, probably outside of this Compendium.<br>- Needs consistency in analyzing cost data (i.e., using 1990 vs 1995 data)<br>- Analysis needs to be redone given significant reduction in emissions from many sectors<br>- Consultation with relevant sites is critical to validating data E.g., Estimated annualized cost of reducing PM from one refinery is approx. $150K, whereas another refinery is estimated at $1Million. Why the difference?<br>- Cost Abatement Function chart needs to be updated to include abatement actions that have occurred over the past decade.<br>- Competitiveness costs needs to be included, i.e., the "cost" of business decisions to relocate to other jurisdictions or shut down operations.<br>- Estimating Benefits using "the value of a human life" is very contentious<br>- Willingness-to-pay" approach has been roundly criticized<br>- Understand Health Canada has revised their numerical value of a human life | Costs will be reestimated when Environment Canada incorporate new emissions data into the AERCo$t Model, and provide the results (this is an outstanding request to them). An alternative would be to request further input from individual companies. This would require written response. Previous requests of this nature have not been very successful.<br>The latest version of the report has updated key reductions in SO2 and NOX emissions. Economic and financial impacts and cost competitiveness issues have been discussed in the revised report. Financial data from individual plants and companies are required to carry out these analyses properly.<br>Please provide references to Health Canada's figures. It is preferable to rely on the published peer-reviewed literature for estimates of the value of statistical lives and other health effects. |
| This section will confuse people by speaking in terms of "value" for benefits, and "costs for abatement technology. It needs a full and clear description that explains that value is, by-and-large. a non-market based measure, unlike costs, which are tangible and market based | This distinction has been made, although there is not always a clear-cut difference that is implied. Many types of environmental benefits can be based on market and price data including health care costs. |

| Comment | Response |
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| The "roll back" method (assumption of equal proportionality) for assessing emission reductions needed to achieve a concentration goal is overly simplistic. It is difficult to accept for primary particulate matter and totally unacceptable for secondary particulate matter. This method needs review by a panel of independent experts. | The need for atmospheric modelling to make the scenarios and analyses more realistic has been described. In the absence of this information, best judgement has been applied. It is doubtful that a panel of independent experts could do more without further modelling work.<br>Until a supermodel with detailed gridded emissions inventories and full complete understanding of all the atmospheric chemistry among all the pollutants (with an understanding of the non-linearities as well) are available, simplifying assumptions need to be made and simplified approaches need to be used. There is a discussion in section III.5.4.1 regarding the various rollback approaches which have been investigated by the US EPA (to support their risk assessment prior to proposing their new PM standards), and their finding that the linear proportional rollback 'accounted for the vast majority of the variation between consecutive years of data'. Thus it appears that at this stage this method is the most suitable for simulating attainment of various potential goals given the above limitations. EPA's work is subject to peer review through CASAC. |
| The uncertainties associated with whatever approach is used should be quantified. This is very important when importing the results into the benefits (AQM) model. | Uncertainties have been highlighted. |
| May be substantial errors with respect to the technologies used and their costs:<br>- Failure to include capital cost for fuel switching at a refinery ($10's of millions)<br>- Assumes single source for SO: scrubbing; numerous/smaller sources mean more costly units<br>- Reducing refinery NOx is quoted at $387~T. Cost effectiveness of retrofitting o or heaters and boilers is more in the range of $2000 to 3000/T (See figures generated in developing CCME N306 NOx Code<br>- VOC reduction from refineries is quoted at S421T. The most cost effective VOC reduction is through LDAR at >$1500/T. Installing secondary seals on tanks is much more expensive.<br>- Stage I (VOC control from gasoline distribution) is quoted at 542/T, whereas the industry costs are >5500/T<br>- Stage 2 is >>$1000 verses Compendium's $191. | Estimates reflect uncertainties, not errors. Industry's meaningful consultation and involvement in developing cost estimates will improve the quality of the data. |

| Comment | Response |
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| Our main areas of concern with calculating benefits using AQVM are The dose response curves used for health effects The monetary value assigned to premature mortality (effect of age) The monetary value assigned to chronic mortality The discount factor applies does not correspond to the treasury board recommendations | The AQVM was not used in this analysis. |
| *Section 5 - DEVELOPING AN IP/RP STRATEGY FOR ONTARIO*<br>- We need to put in place a measurement system to determine if our actions are having a positive effect | It is assumed that the Smog Plan Steering Committee will address this through its Performance Monitoring and Reporting Work Group. |
| **CVMA** | |
| the approach and wording in the document does not just report these findings but has an advocacy tone. The wording seems to validate findings particularly in the area of health impacts even thought the science has a large degree of uncertainty and it is still evolving. This document seems to favour or defend epidemiology studies that conclude a positive association between existing ambient PM levels and mortality /morbidity. It fails to clearly identify the real uncertainties and knowledge gaps surrounding the studies | A conscious effort has been made to avoid advocacy throughout the document Addressed . Statements modified to conform as much as possible to the scientific discussions and conclusions of the extensively peer-reviewed Federal-Provincial Science Assessment Document (PM SAD) and its Executive Summary. This includes not only the conclusions, but the discussion of uncertainties, confounding factors, views of different investigators on addressing the uncertainties and the attributes used by different investigators to build a causal link between an agent and its health effects. Although a causal mechanism has not been proven yet a weight of evidence can and has been used (as in PM SAD), whereby multiple lines of evidence are brought together and duly considered to build a case for the health effects of fine particulate matter. See new/revised section on 'Weight of evidence -causality, multiple pollutant issues and recent developments'. Difficult issues, uncertainties acknowledged. |
| The scientific data reported in the document does not state the appropriate confidence levels. It is also clear that the relationship between primary and secondary PM and ambient air is largely unknown | Efforts have been made to indicate confidence levels where possible. It is not clear what the second sentence of this comment means. |
| The document does not adequately address natural sources of particulates and the background level that can be attributed to these sources | Efforts were made to incorporate current knowledge on these areas in Sections III.2, III.4 and III.5. |

| Comment | Response |
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| Based upon the material and the existing level of uncertainty with the science presented in the document it would seem premature to be proposing options as outlined in Section V. It would however make sense for the document to outline the next steps in the Province's process of reviewing and improving the existing knowledge and then developing options. | Strategic options and next steps now appear in a separate section |
| The development of any future PM standards in Ontario or Canada needs to be further assessed and prioritized in light of all of the air quality as well as other environmental issues such as Climate Change This needs to be done to ensure that the most environmentally and cost effective approach is taken in dealing with all of these combined issues and that the interrelationships are dearly understood. This is even more crucial since prevention and/or abatement technologies for one environmental issues such as PM may actually be counter productive to the technological and other solutions required for other key environmental concerns. | The issues have been prioritized and agreed to by all the CCME Ministers. Particulate matter and ozone have been selected as the first two priorities for which Canada Wide Standards are to be developed. Both the CWS and the Ontario IP/RP strategy approaches include PM, ozone and all the relevant precursor gases. |
| The draft document does not include or reference to Manganese Oxides from vehicles and their potential contribution to this issue. | The intent of the document is to focus on broad pollutant groups, i.e., primary emissions of $PM_{10}$ and $PM_{2.5}$ and precursor gases contributing to IP/RP in the atmosphere. |
| The development of any future PM standards also must take into account the standards of our largest trading partner the United States. | Historically Canadian standards for PM (i.e., TSP) and Ozone have always been more stringent than that of the US. The US standard for TSP used to be 270 ug/m$^3$. Canada's and Ontario's standard for the past 25 years has been 120 ug/m$^3$. The US standard for ozone used to be 120 ppb, while the Canadian and Ontario standards are 82 and 80 ppb respectively. Based on the ambient air ratio ($\approx$ 0.5) between $PM_{10}$ and TSP, Ontario is approximately at 60 µg/m$^3$ for $PM_{10}$ (Note that there is also an interim AAQC of 50 ug/m$^3$ for $PM_{10}$). Harmonization with the US $PM_{10}$ standard would mean essentially relaxing (i.e., backsliding) the Canadian and Ontario TSP standards to 300 ug/m$^3$. |
| The CVMA agrees with the statements in the document that "several years of ambient air monitoring and source characterization and assessment will be required" and that "further IP/RP related research is needed to fill knowledge gaps . Given the impact that this work could have on Ontario's environment and economy it is important that we have a clearer understanding of this issue prior to acting. | Given the strength of the evidence that is available and the long time scales involved it is not inappropriate to start development now. |

| Comment | Response |
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| Page I.1 First paragraph - Since there are significant uncertainties with the data linking PM health effects the justification for the statement that PM is emerging as one of the most critical environmental issues' is unclear. | This statement has been removed |
| Section II.2 - It is assumed that given all of the changes which are being proposed under Regulatory Reform and Approvals Reform this section will have to continue to be updated as the document is revised into its final form. | Agree. |
| Page II.2-2 First Paragraph Last Sentence - need to remove a space between '...regulations as well... " | Done. |
| Page II.3-1 - The text should include a discussion of priorities of this issue relative to other environmental issues not just air quality | IP/RP is currently regarded as the most critical air quality issue facing the Province. |
| Page II.3-1 Last paragraph - The text should also reference the potential trade-off between environmental issues. For example, the vehicle emission control technology for hydrocarbons, NOx and CO increases fuel consumption. | Included. |
| Page II.3-3 Last paragraph - What is the rationale supporting the statement that a 45% reduction In total NOx and VOCs emissions will reduce exceedances by 75% by the year 2015. | This is covered in "Towards a Smog Plan for Ontario" and the Smog Plan, and does not need to be spelled out in the IP/RP document |
| Page II.3.4 - Third Bullet - spelling error trnasportation changed to transportation | Done |
| Page II.3-4 Under Drive Clean. second sentence - spelling error theredby to there by. | Done |
| Page II.3-4 Under Sulphur in Gasoline and Diesel - This section needs to be updated in light of the recent Federal announcement on Sulphur in Gasoline. The last sentence should be revised to include the sulphur in gasoline has also been shown by the U.S. EPA to increase N20 emissions | Will be incorporated in final version. |
| Page II.4-6 Under Congress First Paragraph - define 'NAAQOS' | Done. |

| Comment | Response |
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| Table III.1.1 - It is unclear if these are only primary numbers. Given the estimation involved in developing these numbers they appear to very precise numbers. Please include confidence levels to show uncertainty. | The confidence levels for the IP/RP emission inventory cannot be established at this time. The current IP/RP emission inventory is developed based on adopted emission factor and available source activity information. There is not adequate source testing information available from the industries for further improvement on accuracy and confidence. |
| Table III.1.2 - Under Area Sources there is no reference to rail. | This table has been revised. |
| Figure III.1.1a - Under Transportation's 11% does that include all transportation (road, marine, rail and air). Please clarify on the figure. | Both Transportation percentages in Figure III.1.1a and III.1.1b in the original IP/RP document include all transportation (road vehicles, off-road, marine, rail and air).<br>Figure III.1.1a was re-titled to Figure III.1.1 in the revised document. The Transportation's 11% remained. |
| Figure III.1.1 b - Under Transportation's 18%. does that include all transportation (road, marine, rail and air). Please clarify on the Figure. | Figure III.1.1b was re-titled to Figure III.1.2b in the revised document and the total transportation's 18% was further split into road vehicles's 11% and other transportation's 6% (off-road, marine, rail and air). NB Rounding prevents these numbers from adding to 18. |
| Page III.4-14 Second Paragraph - Discussions on vehicle emissions and controls must also include fuels, since vehicle emission control systems are always limited by the quality of fuels. | This is covered in Section III.6 |
| Section III.6 Control Technologies - This section needs to include a better recognition of the technologies that have already been implemented by industry. | Addressed (2$^{nd}$ paragraph in III.6.1 and throughout the text, when known). |
| Table 6.2 EPA Tier 1 Standards - to be consistent with the rest of the chart the Tier 1 Standards should be the 160,000/190,000 Requirements:<br>NMHC CO NOx<br>LDV 0.31 4.2 0.6<br>LDV1 0.31 4.2 0.6<br>LDV2 0.40 5.5 0.97<br>LDT3 0.46 6.4 0.98<br>LDT4 0.56 7.3 1.53 | Addressed (Table III.6.2 modified accordingly). |

| Comment | Response |
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| Page III.6-13- Under Control Technologies for Transportation, the need for vehicles and fuels to be dealt with as a system needs to be addressed especially in terms of its impact on not only S02 emissions but Hydrocarbons, NOx and CO In the document, reference should be made to the limitation that fuel quality can place on vehicle emission control technology. | See last sentence in 2nd paragraph of III.6.4.2 (page III.6-12). |
| Page III.6-17 Transportation needs a more detailed discussion of the mechanisms that contribute to particulate emissions in vehicles. Further explanation of why vehicles and fuels need to be dealt with a system should be included. This section should also have more detail about the costs associated with emission reduction from vehicles including the introduction of Low Emission Vehicle Technology and the required fuels. | Section presents Control Technology rather than particle formation mechanisms.<br>re: fuels - see answer above.<br>If cost figures for LEV are available, please supply. |
| Table IV.5 Local Sources of IP/RP - Related Emissions in Hamilton, Table IV Sources of IP/RP -Related Emissions In Windsor Table IV.9, Table IV.10 Table IV.11, Table IV.12 - The reference to transportation should be clarified. Is it all transportation or just road? | Transportation percentages in the original IP/RP document included all transportation (road vehicles, off-road, marine, rail and air). |
| Chapter IV Benefit-Cost Analysis of Particulates Matter Emission Control Objective - the Costing Information in this chapter is dated. This information needs to be updated prior to finalizing this document to provide the reader a completed and updated understanding of the present day costs and relative benefits involved with this issue. | Given the amount of work and effort involved, estimates will always be a couple of years behind. Given the fact that technologies and environmental conditions generally do not change all that rapidly, the impact of not being fully up to date may be insignificant. |
| **CPCA** | |
| In our view, the proposed MOE PM compendium is a good document. However, it is in conflict with some of the aforementioned (i.e., Smog Plan principles. Therefore, we do recommend that this document be reviewed and corrected. | There is no apparent inconsistency with the Smog Plan principles. However, in order to allow easy reference to the Smog Plan, the five principles therein have been incorporated in the “strategic options”document and those initially labelled “principles” are now referred to as additional considerations. |
| Structure of the document should be modified | A separate document on “Strategic Options” has now been prepared. |

| Comment | Response |
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| Wording of some sections should be revised. Readers of this compendium document could interpret that PM is the most critical environmental issue in the century. We do recommend that professional feelings should be eliminated (e.g. heroic, emerging most critical environmental issue). Besides, some sections should be revised to get rid of redundancy (e.g. Regulation topics are addressed in three different sections). | A conscious effort has been made to avoid advocacy throughout the document. However, there is considerable evidence to support the view that IP/RP constitutes a significant environmental issue |
| Make a clear statement at the beginning that indication shows that PM could be an issue. However, the state of the science does not give a clear evidence and a lot of uncertainty exists about the environmental risk and the health causality of PM. Therefore, PM strategy should recognize it like in the United States. | See above. |
| The strategy should recognize works done in the United States and be in some extend harmonized with it. If PM strategy is stringent than United States will put Ontario in a competitive disadvantage without clear benefit for the environment. | Developments on PM standards in the US are covered in Section II.4. |
| Change IP/RP working group on cover. It is a MOE document submit to. | Done |
| **Section I:** Change words most critical and harmful level. As the document and the reference suggest (ex. Rick Burnett, Stephen Hueber, Kenneth Chilton) causality of PM 10 and 2.5 have not been established | Done |
| **Section II. I**:From historical background, it seems that the statement is strong. The United States ambient air network monitoring station is insufficient. The Ontario network could give indication but it seems too weak to support the fact that it represents PM situation in Ontario. | Not clear what this comment refers to. |
| The complaint section is irrelevant. If the PM issue is **driven by health** perspective then complaint section should be removed. Visibility section, same comments as above. | This material is included for context and completeness |

| Comment | Response |
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| Ambient monitoring section, again the statement seems strong. No representative samplings have been done in Ontario for PM10 or PM2.5. Data have been collected and it seems to have a correlation but further investigation has to be done in order to do the apportioning with transboundary, industries, roads, cars and natural background. | As above |
| Group Section II.2 with control section | Do not agree. Section II.2 describes the approvals process in Ontario, while Section III.6 discusses control technologies (in general, not restricted to Ontario). |
| Section II.3 should indicate that reducing one parameter could influence others | See modifications made to this section. |
| Table III. 1.1, PM level for cement and concrete sectors seems high and should not be aggregated together. | The emission figures for cement and concrete will be presented separately in the revised document. MOE always encourages and welcomes the industries to submit their PM, $PM_{10}$ & $PM_{2.5}$ data for review and refinement of the inventory. |
| Table III. 1.1, mention should be made that those data are estimated from MOE and what are the estimated techniques used (put in appendix). | Please refer to the response on similar comments. |
| Table III. 1.1 data should be presented by PM contributor order. We suggest to classify by % contribution not by sector. | The emission tables will became too congested if % contributions for PM, $PM_{10}$ & $PM_{2.5}$ were given. However, the % contribution by major source categories were provided in the revised figures III.1.1;III.1.2a,b,c; III.1.3a,b,c;III.1.4;III1.5 and III.1.6. |
| Figure III.1.1a, include other sectors. This figure is misleading. The figure of the major sectors gives the impression that the only contributors are industries but in fact the roads are major. Besides, readers have to understand that if all Ontario industries are shut down, PM issue will persist because of other major sources like roads. | Figure III 1.1a has been modified. |
| Page III.2-8, last paragraph states that more research is needed to better understand the distribution of PM. We agree with that statement. Therefore, argument that PM is the cause of health problem is not scientifically demonstrated. | The fact that more research is needed to understand better the distribution of PM should not in itself lead to the conclusion that health effects of PM has not been scientifically demonstrated. They are not synonymous. |

| Comment | Response |
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| Page III.3-7, non linearity is very important. From our experience, when you decrease a parameter, you do not see a linear decrease and you could have side effects. For example, cement plant could decrease NOx emission by putting SNCR technology but it will increase secondary PM because of ammonia slip that will generate aerosol. | This section discusses non-linearity of the atmospheric process, not the type of problem indicated in the comment. See Section II.3. |
| Page III.4-7, last paragraph, it seems clear the data from modeling of aerosol (secondary particulate) are not reliable. Models have limitations. | Comprehensive modelling of secondary aerosols for eastern Canada and the northeastern U.S is available for sulphate as a result of extensive work done for acid deposition studies but is not currently available for the formation of nitrate and secondary organic aerosols. Section III.4.2 has discussed the current limitations on the data inputs and scientific components of comprehensive aerosol models and the status of efforts to model particulate matter in Canada. The remainder of Section III.4 has discussed what source apportionment information can be estimated from observed atmospheric aerosol data. The chemical composition data for $PM_{2.5}$ shows the major components of the mass to be sulphate (dominantly from secondary aerosol formation), elemental and organic carbon (dominantly due to combustion related emissions) and nitrate at sites away from large local sources. This information clearly indicates that reductions in emissions of $SO_2$, $NO_x$, and combustion particulate emissions would be needed to significantly reduce $PM_{2.5}$ concentrations at most locations. Other data analysis/modelling techniques to assist in apportioning the relative contributions of local sources, emissions from the overall urban area and region wide emissions have also been discussed in Section III.4. Within the limitations of available monitoring data, these techniques were used to estimate the local urban/industrial contributions for various Ontario communities (Table IV.14). |
| Page III.4-8, last paragraph, the source-receptor modeling seems inappropriate at this time. This modeling is based on hypothesis that a decrease of PM is linear. As the compendium states at page III.3.-7 it is not the case | It isn't clear what is meant by this comment. Source-receptor modelling is an analysis of chemically speciated particulate mass measurements to estimate the contributions of various source sectors. This analysis provides estimates of the contribution of secondary aerosols to the mass but it can't provide any information on the response of secondary aerosols to reductions in precursor gas emissions. Photochemical model simulations are needed to estimate how secondary aerosol concentrations will change as precursor gas emissions decrease. |

| Comment | Response |
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| Page III.5-1, last paragraph first sentence, By *far best evidence that cardiorespiratory effects are causally related to airborne PM at levels that are currently experienced comes from the epidemiological study.* This sentence is not scientifically correct. Based on Center for the study of American Business, Annapolis center, Sheldon K. Friedlander, Morton Lippman and Rick Burnett, epidemiological data show a link and a correlation between PM and health but not the causality. | Addressed . Statements modified to conform as much as possible to the scientific discussions and conclusions of the extensively peer-reviewed Federal-Provincial Science Assessment Document (PM SAD) and its Executive Summary. This includes not only the conclusions, but the discussion of uncertainties, confounding factors, views of different investigators on addressing the uncertainties and the attributes used by different investigators to build a causal link between an agent and its health effects. Although a causal mechanism has not been proven yet a weight of evidence can and has been used (as in PM SAD), whereby multiple lines of evidence are brought together and duly considered to build a case for the health effects of fine particulate matter. See new/revised section on 'Weight of evidence -causality, multiple pollutant issues and recent developments'. Difficult issues, uncertainties acknowledged.<br>We would be interested in seeing a copy of the report ('Center for the study of American Business' Friedlander et al.). Left voice-mail message with CPCA but have not heard back. |
| Include a box that describes epidemiological study, its use and its limitation. | Addressed in revised Box III.5.1 and new/revised section III.5.1.2.4. |
| Sheila West of Johns Hopkins University, describe a strong epidemiological relationship as:<br>- *use data from a large number of people*<br>- *shows up in many population groups*<br>- *is backed by laboratory studies into the cause*<br>- *shows a dose response relationship*<br>It seems that the last two points have not been demonstrated yet. | The most widely accepted attributes for helping to gauge the strength of evidence that exists at a given point in time, upon which judgements are made regarding the likelihood that epidemiologically-demonstrated associations reflect actual cause-effect relationships - judgments that often serve as the basis for taking preventive measures to protect the public health of human populations, are those cited Bradford Hill (Hill, 1965) and others. See discussion in III.5.1.2.4 on these criteria and also the new evidence emerging from human and canine studies. |
| Section III.5.3, integrate that section with legal control or standards | This discussion is included in Section III.5 because it is so closely linked to health impacts. |
| Page III.5-26, it seems that the authors calculate potential benefits from reducing PM2.5. It appears difficult to do such assessment because of the nonlinear effect and the co-lateral effect. | Clarified with new, albeit very limited, data and hence caution should exercised in its interpretation. |
| Page III.5-27 second paragraph, remove the word heroic | Addressed |
| Page III. 6-1, introduction should indicate that control technology chapter covers control technology of anthropogenic sources. A mention should be made that those sources generate x% of PM. | Addressed. |

| Comment | Response |
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| Table III.6.1 this table has to be explained or removed. It could confuse the reader. | Addressed. The table was modified and further clarification was provided. |
| Section III.6-4 and 6-5, a brief mention should be made to allow the reader to understand why the compendium document describes SOx and NOx removal technology. | Such mentions appear in the introductory paragraph of each respective sub-section (i.e., III.6.3 - for $SO_2$, and III.6.4 - for $SO_x$) |
| For those two same sections, a lot of removal technologies are inapplicable to cement industry for technical and economical reasons. | The Control Technology section is not cement industry-specific. The cement industry is not discussed in detail. |
| Page III.6-1, first paragraph should be changed according to the previous comments. | Addressed. 2nd paragraph added at the end of III.6.1 answers this concern. |
| Page III.6-13, last paragraph remove the word concentrated gaseous effluent. This term could mislead. | Addressed. |
| With the short period of time allow to comments the compendium document, we are unable to give detailed comments on this section (Benefit-Cost). However, it seems, based on our recent evaluation in the United States, that costs are underestimated. | Association should send MOE the "recent evaluation"; Association and/or member firms are encouraged to submit to MOE information on technology options, cost estimates and emission reductions for Ontario plants. |
| The strategy section should be removed from the compendium and be a stand-alone document. | Done. |
| For each option, describe pros and cons in the context of the 5 guiding principles of the Smog plan. | The Smog Plan principles include balanced approach, sound science, harmonization, fairness and flexibility. They are applicable to the IP/RP strategy development and implementation stages. The current document provides background information forming the basis for strategy development. A table is included in the "Strategic Options" document listing the considerations of the various possible strategic options. The Smog Plan principles should be applied when these options are further developed into a strategy and implementation plan. |
| **Dofasco** | |
| The suggestion that IP/RP is one of the most critical environmental health issues may be an premature, considering the results of recent health studies (R. Burnett et al). | Modified in Section I |
| Significant figures are not taken into account when presenting inventory data (e.g., total of 162,729 tonnes of PM in Ontario). | Additional figures (III.1.2a,b,c, III.1.3a,b and c) are provided in the revised Section III.1 document to illustrate the 1995 emissions. The focus of this document is on $PM_{10}$ and $PM_{2.5}$. |

| Comment | Response |
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| Figure III.1.1 misrepresents the industrial contribution to PM10 with the exclusion of open area sources. The total industrial numbers (67,000 tonnes/year) represent about 9% of the grand total, in comparison to open sources (650,000 tonnes/year - 84%.) | The intent of Figures III.1.1 and III.1.2 is to focus on the IP/RP contribution from point, mobile and area sources. Additional figures (III.1.2a,b,c, III.1.3a,b and c) are provided in the revised Section III.1 document to illustrate the 1995 emissions. |
| We agree that the community-based emission inventory is essential for our IR/RP strategy. The community-based inventory data presented in the *Section V- Synthesis of Results* currently misrepresents industrial contributions. For example, Table V.5 provides qualitative descriptions of open source contribution (e.g., "low" for paved road dust). Given the numbers presented in Table III.1.1 for paved roads (330,000 tonnes/year province wide), it is reasonable to expect that estimates could be arrived at for these sources for urban areas. A simple allocation by population for Hamilton-Wentworth (assuming 450,000 people in a province with 10,000,000 people) would provide an estimate of 15,000 tonnes/year from paved roads. This number is hardly "low" in comparison to 2,300 tonnes/year for the Iron &: Steel sector. I'm sure that MTO would have more accurate traffic flow data for urban areas. | Qualitative labelling (as high, medium or low) has been deleted from the table in the original version. Comprehensive emission inventory development will require better demographic source-emission statistics to prepare the emission inventory at the urban scale. Comprehensive community-base emission inventory useable for IP/RP strategy development will require similar effort as in the Windsor Air Quality Study performed in the early 1990's. As well, the full support of local community and industries affecting the urban airshed is also required. |
| Page III.2.6 makes an interesting reference to weekday variations in PM10 levels, suggesting a potential contribution from transportation sources. It's an important fact that seems to be glossed over within the text. This relationship should be given more prominence within the text. Given the significance of paved road dust emissions mentioned in the inventory section, there could be a linkage here that needs to be explored. | The text has been modified to incorporate this point (Section III.2.3.2 par. 3. |
| The data presented suggests a linkage between IP/RP and other pollutants (i.e., IP/RP concentrations rise and fall with other pollutants). This fact tied in with Rick Burnett's recent paper on the association between morbidity and other pollutants (NOx , S02, CO, etc.), suggests that PM10 is part of an overall air pollution problem. Therefore, this relationship needs to given more prominence within the document | The discussion on this point has been expanded in Section I. Burnett et. al. (1998) work on air pollution mixtures has been incorporated in the concluding paragraph of Section III.2.3.4 par.2. |

| Comment | Response |
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| It is critical for area sources. such as agricultural sources and paved roads, to be included in any regional/urban modelling work regardless of data confidence. | When comprehensive particulate models along with the required primary particulate and precursor gas emissions are available to perform simulations, fugitive dust sources such as paved roads and agricultural sources along with other area sources would be included. Model results would then be compared with available monitoring data to help identify deficiencies in the model chemistry/physics and in the input emission data. |
| There is at best, a robust association between IP/RP and health effects. Given that IP/RP is just one of many airborne pollutants present in the urban airshed, allocating the health effect solely to IR/RP may be premature. The ambient air monitoring data shows that IP/RP rises and falls with other pollutants. Rick Burnett's recent paper shows an association between morbidity, and other pollutants (NOx, SO2, CO, O3, etc.), in some cases more significant than IP/RP. As of yet, no one has looked at the potential synergistic relationships between different pollutants. Given all of this, it is possible that previous studies' linkage between IP/RP and health may **ONLY** demonstrate that IP/RP is a surrogate indicator of the overall atmospheric soup's impact on health. This fact needs to be stated within the documentation, with a proviso that we are "just beginning to understand the complex nature" of air pollution and health. | Addressed. Statements modified to conform as much as possible to the scientific discussions and conclusions of the extensively peer-reviewed Federal-Provincial Science Assessment Document (PM SAD) and its Executive Summary. This includes not only the conclusions, but the discussion of uncertainties, confounding factors, views of different investigators on addressing the uncertainties and the attributes used by different investigators to build a causal link between an agent and its health effects. Although a causal mechanism has not been proven yet a weight of evidence can and has been used (as in PM SAD), whereby multiple lines of evidence are brought together and duly considered to build a case for the health effects of fine particulate matter. See new/revised section on 'Weight of evidence -causality, multiple pollutant issues and recent developments'. Difficult issues, uncertainties acknowledged. |
| A section on Rick Burnett's latest study should be inserted at the beginning of this section, since it is the most recent information on health effects. | Included in section III.5.I.2.4. |
| Page III.5 - 15 makes reference to a "natural non-anthropogenic background" of 5 µg/m3. For urban areas, it is important to recognize that there are anthropogenic sources that are for all intents and purposes fixed. For example, dust from roads will continue to contribute to urban airsheds after the introduction of zero-emission vehicles. It is important to take into account the contribution of these anthropogenic sources when determining the 'fixed" background. | Needs to be noted (not done yet) where the 'natural non-anthropogenic background' is discussed. In terms of taking this 'fixed urban' background into account, this is probably best addressed in the strategy/community strategy itself. |
| For the Area Sources section, a discussion of paved and unpaved road dust emissions should be included in the Transportation section. | Addressed (paragraph added at the end of III.6.5.2, Transportation - seep page III.6.19). Appendix A provides the details. |

| Comment | Response |
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| The current analysis presented here is of little or no value for this process. The basis of the analysis is 1990 emissions. Given that there has been significant reductions in emissions over the last eight years from many sectors, this analysis gives a false impression that there are relatively easy gains to be made. This analysis needs to redone, based on the most current emission information. | Strongly disagree. The analysis clearly shows the analytical framework and allows readers to make extensive comments and suggestions on methods. It identifies sources for which reduction and cost estimates must be made. It identifies benefit categories and estimates for readers to comment on. It provokes thinking, discussion and discourse that would not occur in its absence. By easy, presumably the comment means "inexpensive". This impression is not intended and it is not made in the text.<br>1990 emission data and estimates were the most current when this analysis was completed. As of Nov. 16, Arthur Sheffield in Environment Canada stated that the federal RIS database has still not been incorporated into the AERCo$t model so that EC is producing estimates of abatement costs for the Particulate and Ozone CWS process using 1990 emissions as a base case. Rerunning the model using 1995 emissions data is required.. |

| Comment | Response |
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| We understand the importance of full-cost accounting for developing Ontario's strategies However we have a number of concerns about the approach taken so far | |
| *Competitiveness* -- In addition to the capital & operating costs for controls, we need to take into consideration "competitiveness" costs. As the differential in "mandated" pollution control costs grow in relation to other jurisdictions (within Canada, NAFTA, and/or globally), Ontario may be faced with economic costs incurred by business decisions to shut-down manufacturing operations here and relocate to jurisdictions with less restrictive regulations. These "costs" to Ontario's economy need to be considered in the analysis. | "Competitiveness" effects will be evaluated to the extent possible. If available, please supply measures of the "...differential in mandated pollution control costs.." |
| *Capital Stock Turnover* -- One factor that isn't taken into consideration is capital turnover. The existing analysis assumes that industries will rush out and invest in pollution control devices. Given the current focus on pollution prevention activities, this runs counter to that philosophy. For example, there is technology in the steel industry that is less-polluting than "traditional" technology (e.g., electric arc furnaces versus oxygen furnaces, non-recovery coke batteries). However, we are restricted by capital turnover restraints in implementing new technologies (i.e., long operating lives were built into the capital considerations for the existing equipment. This turnover will occur, and cleaner technologies will be adopted, but more realistically within a longer time frame. | *Capital Stock Turnover:* This economic phenomenon is well known, but was not mentioned in the report. This will be done, although it is unlikely that quantitative estimates or analyses will be possible. |

| Comment | Response |
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| *Control Options* - The authors need to consult the various industrial sectors to obtain a better understanding of sources and control options for various pollutants. For example, flu gas desulphurisation and fuel switching are cited as options for steel mills to use for achieving significant reduction in SO2 emissions. For integrated steel mills. there is a significant portion (approximately one-third) associated with fugitive sources<br>*Impacts on Other Media* -- The costs of alternatives and impacts on other media need to be considered. For ,example, alternatives to coal-fired stations could include hydroelectric generation. However, what are the direct and indirect costs of these options?<br>*Emissions Trading* -- For parameters such as NOx and SO2, there is a higher likelihood that emissions trading will be used. In the case of NOx the existing PERT project includes major point-source contributors such as Ontario Hydro and Dofasco. Any analysis undertaken should include scenarios with "return on investment" from sold credits.<br>*Benefits* -- The "value" of human life is an extremely emotionally charged issue which is difficult to deal with, especially; since ethics dictate that "no price is too high" when it comes to human life. However, the unfortunate reality is that our society does not value human life as highly as indicated in the analysis. If we did, then there would be much greater efforts towards eliminating child poverty, providing food and shelter for the homeless, restricting consumption of harmful consumer goods (tobacco, alcohol, fast food, etc.) and so on. When determining the benefits, we need to take these factors into account Otherwise, we may end up "over-estimating" the public's will to support these strategies. | *Control Options:* Estimates have been provided at Smog Plan meetings over the past 2 years but no responses have been received that could be used to revise cost estimates. |

| Comment | Response |
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| The proposed strategies used in the analysis have unique strengths, which would be appropriate for different steps of any program When recalculating the cost-benefit analysis, the following should be recognized<br>The "efficiency strategy" is the one most likely to succeed in the short-term.<br>The "abatement maximization strategy" is the one that will be most effective in the long-term, taking into account capital stock turnover.<br>For those parameters with limited transport capability (e.g., PM10), the "community strategy" is most effective.<br>The"equal reduction strategy" is the least likely to succeed, since the main contributors are not on a level playing field to start off with (i.e., could be "too easy" for some sectors, "impossible" for others) | The reader offers a number of his opinions about which implementation strategies in the scenarios would be "successful" and which would be "most effective." He should define what he means by successful and most effective. |
| The suggestion for increased enforcement through control orders and regulations is too adversarial. This could result in costly legal battles from which no one benefits, except a few consulting and legal firms. | The revised version (as part of the Strategic Options document) now reads, "compliance with current POI standards for suspended particulate matter, $NO_x$, $SO_2$, $NH_3$, and VOCs". |
| Given the latest health studies and the lack of consensus on IP/RP health impact amongst stakeholders, reference to this fact should be presented here. | Reference to the lack of consensus is now included |
| The tone of the text makes it sound like IP/RP is a "new" threat to public health when in fact these issues have been present throughout the industrial and post-industrial era. There has been significant reductions achieved from historic levels for most pollutants. This fact needs to be acknowledged in the text | This point is covered in Section I. Some acknowledgement of reduction in particulate matter over the past 25 years is provided in Section III 2.3.1, par. 1. |

| Comment | Response |
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| As mentioned the tables illustrating source apportionment in urban areas does not include quantitative estimates of area sources. As a result, an emphasis is placed on industrial sources. These tables should be modified to present numerical values for area sources, in order to provide a fair and balanced understanding of significant sources. | Tables IV.5 to IV.12 have been modified to remove the qualitative descriptions of the relative importance of the open fugitive dust sources. There is insufficient information to quantify the relative contributions of the fugitive dust sources in individual Ontario communities. Figures III.4.3 and III.4.4 provide an overall breakdown with uncertainty/variability estimates of the contributions of fugitive dust sources as well as other source types to the fine and coarse fractions of $PM_{10}$.Fugitive dust sources contribute a small amount to measured $PM_{2.5}$ mass but are usually the largest contributor to the measured mass of the coarse fraction of $PM_{10}$. |
| We want to clarify the principle of sharing the financial burden across all contributors. Each sector should be expected to implement a strategy that is based on "efficiency" reductions appropriate for their sector. | This statement (now in Strategic Options document)now reads “all emitting sources share responsibilities to improve the IP/RP problem”, i.e., all sources which contribute to the IP/RP problem in Ontario should bear their fair share of the emission reductions and costs in achieving a solution to the problem. |
| We support the concept of using a longer time frame for meeting the AAQC in non-attainment areas. However, this could be a tough sell for the public in these areas (i.e., "Why should we have to live with poorer air quality?) Since the US has already gone though this exercise, we should base any similar approach on the lessons learned from the US experience. | Options are developed to form a basis for stakeholder consultation. |
| Will there be recognition for those sectors that have taken early action (within a reasonable time frame?). Some steel companies have recently put in place particulate reduction commitments. | Issue will be channelled to appropriate Ministry staff for consideration. |

| Comment | Response |
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| We have strong concerns about the proposed interim measure for “vigilant compliance" with POI standards. There are numerous serious faults with the use of POI standards as a compliance and predictive air quality tool | Use of POI Standards; Bullet #3: The 30 minute POI standards used in MOE’s Certificate of Approval process have been developed to provide simple screening level evaluations of a facility’s impact. In the case of TSP, the half hour average POI standard was set lower than the 24 hour average Ambient Air Quality Criterion to take into account that many sources; including area wide sources such as paved roads; contribute to the ambient concentrations.<br>Where fugitive dust from an industrial facility is a significant or dominant contributor to local exceedances of POI standards, a fugitive dust control program employing best practical control measures such as paving heavily used areas, cleaning roadways, etc. might (would?) be part of an overall control program to reduce the impacts of primary particulate emissions. A facility wide emission inventory would identify the largest emission sources and these data coupled with dispersion modelling could then give the relative contributions of the sources at the location of the maximum POI as well as the impacts in the broader community over the averaging times in MOE’s AAQCs (i.e., 24 hour and annual averages). For a facility that is out of compliance with the TSP POI standard, an abatement program might consider best practical control measures for smaller sources that have impacts over only small areas with more effort spent on controlling/reducing emissions from the larger sources. |
| **Ontario Forest Industries Association** | |
| Section IV is not a rigorous cost-benefit analysis because the costs and benefits that were developed were based on different scenarios. | Addressed by referring to the work as an analysis of benefits and costs. |
| **Ontario Natural Gas Association** | |
| ONGA advises that the development of an IP/RP strategy and related standards for Ontario must be in concert with the Canada Wide Standards for PM. It also must take into account the PM research and policy approaches being undertaken in the U.S. given that the emissions in the U.S. have a significant impact on our airshed. | Developments on PM standards in the US are covered in Section II.4 |
| We understand that the compendium is intended as a technical resource document that summarizes current scientific knowledge about PM in Ontario. The language and tone of such a report should be factual rather than editorial, which is the case in the current document. Editorial and speculative comments should be eliminated. | Addressed throughout the report to the extent possible. |

| Comment | Response |
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| The compendium needs to present a balanced viewpoint and clearly identify knowledge gaps. For example, the apparent statistical correlation between health outcomes and PM levels must be examined in light of the substantial decline in measured PM over nearly three decades. There is a growing body of evidence which suggests, as was noted at our last Working Group meeting, that it may well be the 'soup' of airborne contaminants that drives the health issues, not PM alone. The Compendium should consider PM in the broader context of other air quality issues rather than positioning it as the most 'critical'. Dealing with PM in isolation could exacerbate other air pollution issues. This is an issue of synergism and ONGA believes that the MOE should not be presenting air issues one pollutant at a time. This should be made clear in this document. | Statements modified to conform as much as possible to the scientific discussions and conclusions of the extensively peer-reviewed Federal-Provincial Science Assessment Document (PM SAD) and its Executive Summary. This includes not only the conclusions, but the discussion of uncertainties, confounding factors, views of different investigators on addressing the uncertainties and the attributes used by different investigators to build a causal link between an agent and its health effects. Although a causal mechanism has not been proven yet a weight of evidence can and has been used (as in PM SAD), whereby multiple lines of evidence are brought together and duly considered to build a case for the health effects of fine particulate matter. See new/revised section on 'Weight of evidence -causality, multiple pollutant issues and recent developments'. Difficult issues, uncertainties acknowledged. |
| **Background**<br>This section needs to be revised and expanded to set the proper context for discussion around PM. The linkage to other air quality issues (e.g., climate change and smog) need to be more clearly drawn and consideration given to U.S. and Canadian policy approaches to PM. It should be noted where there is non linearity i.e. reduction of one pollutant could make things worse for another, a sense of priority should be given to the stakeholders. | These points are covered in Sections II.3 and II.4 |
| Numerical references to possible National Ambient Air Quality Objectives for the CWS should be deleted as these are speculative at this point. | Done |
| **Policy and Strategic Issues**<br>The historical context needs to be elaborated. | Health effects have been linked to $PM_{10}$ and $PM_{2.5}$ concentrations, in studies carried out mainly in the nineties. For the most part, therefore, data discussed in the document have been limited to these two components of particulate matter, and this time period. However, some examples of TSP trends over much longer time periods are shown in Section II.1. Some historical perspective is provided in Section III.2.3.1. par. 1. |
| Section II.4 addressing other jurisdictions is difficult to follow. | A reference to Table II.4.1, summarising the state of standards, guidelines, etc. in other jurisdictions, has now been placed at the start of the section. |

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| The discussion on black fallout, complaints and visibility, on the other hand, does not contribute directly to the IP/RP issue and could be removed. | Discussion of these other concerns associated with airborne particulate matte context and completeness. |
| Section II.1.5 on primary versus secondary particulate matter and Section II.3, which links IP/RP to other air quality issues needs further development. For example, how would control strategies taken with respect to other air issues affect IP/RP and vice versa? What would be the impacts of parallel strategies on the health issues? | Further discussion has been added in the relevant sections. |
| On page II.4.2 there is a discussion of the work being conducted by OTAG. It is our understanding that this work is a "desk top" study only on this issue with no field work being conducted. Reference should also be made to the work being conducted under the NARSTO framework in which considerable effort is being spent on the collection of field samples to help improve the models being used. | The OTAG work was a very detailed modelling study. |
| **Emissions Inventories**<br>The emissions inventories are the foundation of an appropriate IP/RP strategy. Therefore, ONGA cannot agree with the suggestion in III.1.1.2 that the existing uncertainty and data gaps in the inventory are not a serious impediment to workable IP/RP emission reduction strategies. Details are needed on estimating methods and bases for the information presented. Explanation is needed about the surprisingly significant changes to the inventory data between drafts. | Data gaps and uncertainties are acknowledged in the document. However, th evidence to support the initiation of a process leading to IP/RP strategies. Em development is a dynamic process. As better data become available, the emis estimated, backcast or forecast. Therefore, one should continue to develop th while the 'numeric reduction' target is being improved.<br>As mentioned, this phenomenon is universal to the current North America IP/ emission inventory development. |
| **Particulate Matter Measurement**<br>Given the varied sources of this data, it is not always clear whether numbers are comparable. On page III.2.5 mention is made that the MOE started collecting $PM_{10}$ samples in 1989 at 23 sites across the province and that these are "state of the art" real time instruments. There should be a discussion of how these 23 sites were selected and furthermore what the link is between the selection of these sites and the various models being used. | Site and instrument selection is dealt with in detail in documentation of the m This level of detail is not really appropriate for the compendium document. |

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| In section III.2.2 there is a discussion of the errors in the sampling and that across Canada in one study as much as 45% of the $PM_{10}$ fraction sampled went "missing". In our view there are significant sampling problems that need to be addressed, not the least of which is the fact that not a lot of confidence can be placed in the analytical results obtained. This confirms that the techniques using filters and subsequent laboratory analysis render the results prone to errors and artifacts. This should be listed in the section on data gaps. | The "missing" mass referred to is not due to analytical or sampling error. It is a consequence of not analysing for all chemical constituents of the collected particulate matter |
| In the same section, reference is made to the crustal/soil component, which can make up as much as 50% of the $PM_{10}$ fraction in Ontario. As this speciation fraction contributes so much to the overall quantity, it follows that any strategy should address reducing this component. ONGA believes that there should be a minimum of a general discussion of this fraction, listing sources etc. as this fraction has to be reduced for the required improvement to be achieved. | Section III.1 contains considerable information on open sources, which are the sources of crustal material. Methods used to estimate these emissions are described in Appendix A. |
| As a data gap, ONGA believes that the sampling techniques currently available are not able to distinguish effectively between closely spaced sources that emit particulates. This is not discussed in the data gaps and yet this represents a significant aspect to be resolved. | The resolution of closely spaced sources is very difficult or impossible if the chemical composition of the emitted material is similar. In the limit, if the composition is identical, there is no possible way of distinguishing the sources using composition data alone. |
| Some of the details on the Figures were difficult to follow; for example Figure III.2.7. | Addressed |

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| In section III.4.2 there is a discussion concerning the various models that are being used. ONGA recognizes the need for having different models in order to be able to help provide different perspectives on this issue. Much has been written about the various models being used. However, there are still only a handful of experts in Ontario that are able to run the various scenarios on these models. As with the Climate Change models being used, it is ONGA's contention that the various models being proposed in the strategy plan should be made freely available on the web, so that participants can have access to them and more importantly perhaps, be able to question the assumptions being made and gain expertise in running various scenarios. At the present time this is not able to be done unless they hire someone with access to the codes being used (e.g. York University). This will also help industry (and other participants) decide what priorities they should be placing on their limited resources. In addition, the assumption has been made that one of these models will be selected to help in the regulatory framework to help determine what improvements will have been made in future years. A synopsis of how it is envisaged by the MOE to select "one model" for regulatory purposes is to be undertaken would be helpful. | Unfortunately, modelling does not just amount to obtaining and running the code. Considerable operator skill is required in the use of the more complex models (including those that deal with IP and RP) to ensure that meaningful results are obtained. |
| **Control Technologies**<br>This section is a reasonable general overview. It should also address emissions prevention option and clearly indicate those options, which are already in use. | Addressed (2nd paragraph in III.6.1). |
| **Benefit-Cost Analysis**<br>We have been able to give this section only cursory and preliminary review and have concerns with the methodolgy and the cost data. The analysis is based on a 1990 emissions inventory, but remaining data is for 1995. The analysis does not appear to recognize emissions reductions between 1990 and 1995, which could affect costing.<br>It is not clear whether the scenarios presented or applied costs are reasonable. There may be significant errors, for example, regarding the technologies implemented and associated costs. | The intent is to re-estimate abatement-prevention costs with the Environment Canada AERCo$t model using 1995 base-case emissions. Environment Canada have not yet been able to put the 1995 emissions into their model. |

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| **Developing an IP/RP Strategy for Ontario**<br>ONGA endorses the development of an IP/RP policy through a multi-stakeholder process. The development of this policy must be in concert with the Canada Wide Standard setting process and recognize the research being undertaken in the U.S. regarding this matter. Where possible, the strategy should adopt integrated approaches to multiple air quality issues, thereby ensuring that measures taken in one area are not detrimental in another. | Agree. |
| ONGA was disappointed in the short section concerning "Bridging the Knowledge Gaps" that are associated with such a major and comprehensive document. | The list of data gaps has been expanded. |
| ONGA agrees that additional ambient monitoring is required and more importantly source characterization. In our view efforts should be made to develop sampling techniques that will help characterize source apportionment in real time and in-situ in an economically acceptable manner. For example, the presence of inclusions such as carbon makes a significant difference to the spectra obtained when using remote sensing techniques. As a result, we understand this is no easy task and yet this will help foster "buy-in" for the strategy. In addition, the height of the samplers needs to be addressed, as it is our understanding that the atmospheric chemistry interactions occur primarily at a height of a few hundred metres and not at 10 metres above the earth's surface. This is a question of scientific validity versus economic practicality, which should be addressed in the document, as ultimately obviously the decision will be a compromise.<br>Network design in part should be predicated on the requirements of the models being used. ONGA would like to suggest that there should be a discussion around this issue , for example should we be monitoring at the 5 sq. km grid or 20 sq. km grid? How will the network design account for source emissions? | The document includes recommendations for continued/expanded monitoring. However, the details of monitoring and network design are not appropriate for inclusion in the Compendium |

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| Modelling capability also needs to be discussed in more detail. ONGA has already indicated above what should be done concerning placing the models in the public domain. Linking this discussion, ONGA believes that there should also be a discussion on the risk assessment aspects in which there is an evaluation of the likelihood that adverse human effects may occur as a result of exposure to IP/RP. This will help strategy components develop plans in the context of "risk management". There needs to be a discussion around what strategies can be implemented that will reduce IP/RP emissions at source. Fuel switching is one example of where reductions could be achieved. In a study done in Denver , for example, it was shown that in 1987, $SO_2$ emissions were reduced by 70% by burning natural gas instead of coal in the areas power plants. (EM, Air and Waste Management Association, January 1998). | Unfortunately, modelling does not just amount to obtaining and running the code. Considerable operator skill is required in the use of the more complex models (including those that deal with IP and RP) to ensure that meaningful results are obtained.<br>Fuel switching is discussed in Section III.6 as a technology option. |
| **Alliance of Manufacturers and Exporters Canada** | |
| All editorial comments reflecting the opinion of specific stakeholders and/or unscientific conclusions should be omitted | Addressed. |
| As a technical resource the Compendium should also indicate that the information contained within it does NOT reflect a complete and conclusive picture of all "current knowledge" (unlike the title denotes). In fact, we believe that a large portion of the information is based purely on mathematical models and statistical analyses, which have often used out-dated and unconfirmed data. These assumptions and deficiencies must be communicated to the reader up front, or alternatively, the data should be significantly expanded and improved upon | The title of the document now reads "A Compendium of Current Knowledge of Fine Particulate Matter in Ontario". The most recent data currently available were used in the analyses presented in the document, which now also includes some discussion of uncertainties in several places. |
| In order to continually update and improve the overall content of the Compendium, a process should be outlined within the document to ensure that new scientific findings and relevant knowledge are appropriately added. | The question of when or whether to update the document are most appropriately addressed during the stakeholder consultations. |

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| In terms of the "science" behind the Compendium document, we have concerns that there has been an unjustified focus on isolating particulate matter (PM), in exclusion of other pollutants. This appears to contradict a key point made by Rick Burnett in his technical presentation. | As is stated in the Introduction "It must be recognised that PM is just one of several pollutants found in the atmosphere, and diverging opinions spark a healthy debate. In particular, opinions differ on whether causality has been demonstrated between airborne PM and health effects, and also on the relative importance of PM and co-pollutants, such as $NO_x$, $SO_2$, CO, etc. However, as will be discussed in subsequent sections of this document, many of the copollutants are actually precursors to fine particulate matter formed in the atmosphere, and a strategy for PM must therefore also consider these copollutants anyway. Furthermore, the precautionary principle suggests that ample evidence exists that PM affects human health. |
| It is important to ensure a full integration with other existing pollution reduction programs (which encompass additional pollutants). This integration must take into account US and Canadian initiatives and processes that are already underway (e.g., Canada Wide Standards) | Agree |

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| **Alliance of Manufacturers and Exporters Canada**<br>The first paragraph in the introduction (to the strategy document) states that "...., for PM there is no known threshold concentration above which effects begin to be observed or below which exposures are deemed safe." It also states that susceptible individuals may respond adversely to low PM levels. These do not fairly represent the current sate of the science. The current state of the science is that some (but not all) epidemiology studies have found a statistical association between health effects and PM levels recorded at ambient monitors. These studies are plagued with numerous problems. To mention a few, 1) actual personal exposures are unknown, 2) results are a function of the models and statistical techniques used in the analyses, and changing these models/techniques often results in different conclusion, and 3) copollutants and other confounding factors are often ignored in the analysis.<br>Further, it is well understood that statistical associations do not imply causality. Therefore, it is presently unknown whether exposure to PM causes the health effects being seen in the epidemiology studies. This being the case, one should not make any statements related to whether or not a threshold concentration might exist, or whether susceptible populations may or may not respond adversely to exposure to PM. This is especially true with respect to fine particles (PM2.5) for which very little data is available to draw even preliminary conclusions.<br>(Continued) | These points have been addressed in the body of the compendium document. The statement regarding no threshold in the rationale for the Ontario interim PM10 ambient air quality criterion reflects the conclusions of several agencies (WHO, US EPA, U.K. Expert Panel, Health Canada, Canadian Fed-Prov.) that the epidemiological studies could not identify a threshold. This may need to be rephrased when/if the criterion is changed. The monotonically increasing (no threshold) concentration-response curve has been observed from very low ambient levels up to much higher levels with remarkable consistency in many of the studies on acute and chronic mortality and hospitalization.<br>The difficult question regarding the role played by other gaseous pollutants (particularly $SO_2$, $NO_2$, CO and $O_3$) in the toxicity of particulate matter is discussed and a brief section on 'Multiple Pollutants' has been added which highlights the underlying issues and the various approaches (univariate, bivariate and multipollutant models and their strengths and weaknesses when addressing highly correlated/nonindependent variables) different investigators (Moolgavkar, Lipfert) have taken to address them. One weight of evidence conclusion of the PM SAD '...the magnitude, robustness, and consistency of the association across so many locations with differing air pollutant mixtures supports the position that particulate matter of some kind is the best indicator for the effects of air pollution on adverse health outcomes' is not too different from one of Moolgavkar's (Moolgavkar and Luebeck/1996) concluding statements '...Levels of the particulate component serve as a rough proxy measure of total pollution. The data are consistent with the conclusion that increases in air pollution as roughly indexed by levels of particulates are associated with adverse effects on human health.' |

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| We therefore recommend that the first paragraph of the Introduction be deleted, and replaced with a new paragraph that puts the PM health issue into proper perspective. We reference the massive effort currently in progress in the United Sums (e.g., Congress has appropriated some $50 million for near-term research; HEI has numerous health/exposure studies underway) to help determine whether or not PM is a health concern at ambient levels, whether a threshold might exist, what are actual personal exposures, what are the roles of the co-pollutants, etc., etc. Unless this issue is placed into the proper perspective, huge resources could be expended to control a pollutant that may not be responsible for health effects being reported in epidemiology studies. We recommend a more cautious approach on this issue, with major involvement in the developing science. | |

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| The Ontario Ministry of the Environment appears to have already made up its mind to pursue eventual air quality goals of 40 µg/m$^3$ for 24-h PM$_{10}$ and 20 µg/m$^3$ for 24-h PM$_{2.5}$ as the annual third maximum values. It is not clear if the stakeholders' input has ever been considered to arrive at these targets. It is well known that these targets are regularly exceeded in the remote areas and to expect that an interim 24-h PM$_{10}$ target of 50 µg/m$^3$ would require only a 34% reduction in PM$_{10}$ air quality indicates a serious misunderstanding of the ambient concentration distribution. There are significant day-to-day fluctuations in PM concentration. Sharp daily spikes occur frequently, and the ratio of a "typical" 24-h peak to the annual mean is about 3. Since the concentration cannot go negative, reducing the upper tail of the concentration distribution to 50 µg/m$^3$ would require the annual mean concentration to be as low as, say, 15 µg/m$^3$. Annual means of this magnitude are practically unachievable. It is our opinion that sound science has already been ignored in this very critical and fundamental issue as the amazingly low eventual targets are being championed. We urge the Ministry to study the PM concentration distributions more carefully and investigate the data available from the US. | The Ministry has no preconceived ideas concerning the eventual numerical goals to be set for fine particulate matters. Other points to be made in connection with this comment are:<br>• If the ratio of "typical" 24-h peak to annual mean is indeed three (and we do not necessarily agree with this figure), then reducing the peak to 50 µg/m$^3$ will necessarily reduce the annual average to 15 µg/m$^3$<br>• Control measures would not just reduce the upper tail of the concentration distribution; all concentrations would be reduced approximately proportionately. |
| The proposal of at least 10% emission reduction (no time period is given, more discussions with stakeholders are absolutely necessary) will almost certainly not lead to the interim 24-h level of 50 µg/m$^3$. However, this emission reduction may serve as a testing ground to see what PM$_{10}$ level will actually be achieved. Information from this result can then be used to ascertain a more sensible and achievable PM air quality goal. | This comment is based on a misunderstanding of the "10% emission reduction" proposal. This proposal was an interim measure proposed at an early stage in the evolution of the Ontario Smog Plan, and was always intended to be superseded by measures developed in a strategy for fine particulate matter. Nobody has ever suggested that a 10% reduction would produce compliance with the interim criterion of 50 µg/m$^3$. |

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| On page 3 it is stated that "For $PM_{2.5}$, values corresponding to half of the $PM_{10}$ values are included here since about half the $PM_{10}$ mass is due to $PM_{2.5}$." The selection of ambient air quality standards should be base primarily on health considerations, with allowances for susceptible populations, background levels, feasibility of achieving the standards, costs, etc. The proportion of $PM_{10}$ mass that is $PM_{2.5}$ is not a valid methodology for establishing the PM2.5 standard level. | This suggestion is advanced as a rule of thumb, because of the limited amount of $PM_{2.5}$ data currently available |
| Strategic option #4 proposes different AAQCs fir AQMAs. Again, ambient air quality criteria (standards) should be based primarily on health concerns which are in turn determined through the science. AAQCs should not vary by air quality management areas | The proposal for different targets for different areas is just one possibility that has been proposed, and is an intermediate step. It recognises the pragmatic factors included in the Alliance comment given above (i.e., background levels, feasibility of achieving and costs) |
| One of the reduction measures listed in this section is that "Ontario and federal governments continue to urge the US EPA to move towards more stringent PM standards when the US Clean Air Act regulations associated with ozone and PM are subject to review." The level of standards set by any country should be determined through scientific methods (e.g., modelling) such that air quality standards will be met in a reasonable time period. In this regard it is critical that collaborative efforts between Canada and the US be conducted so that health-based standards for PM are the same for both countries. | We agree with the need for close cooperation between jurisdictions. In principle, a standard based solely on science would have exactly the same numerical value regardless of jurisdiction. It is recognition of the practical factors that generally leads to divergence. |