



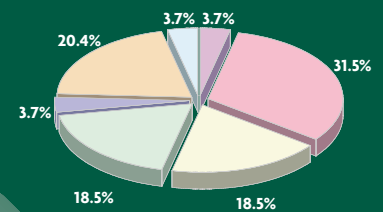
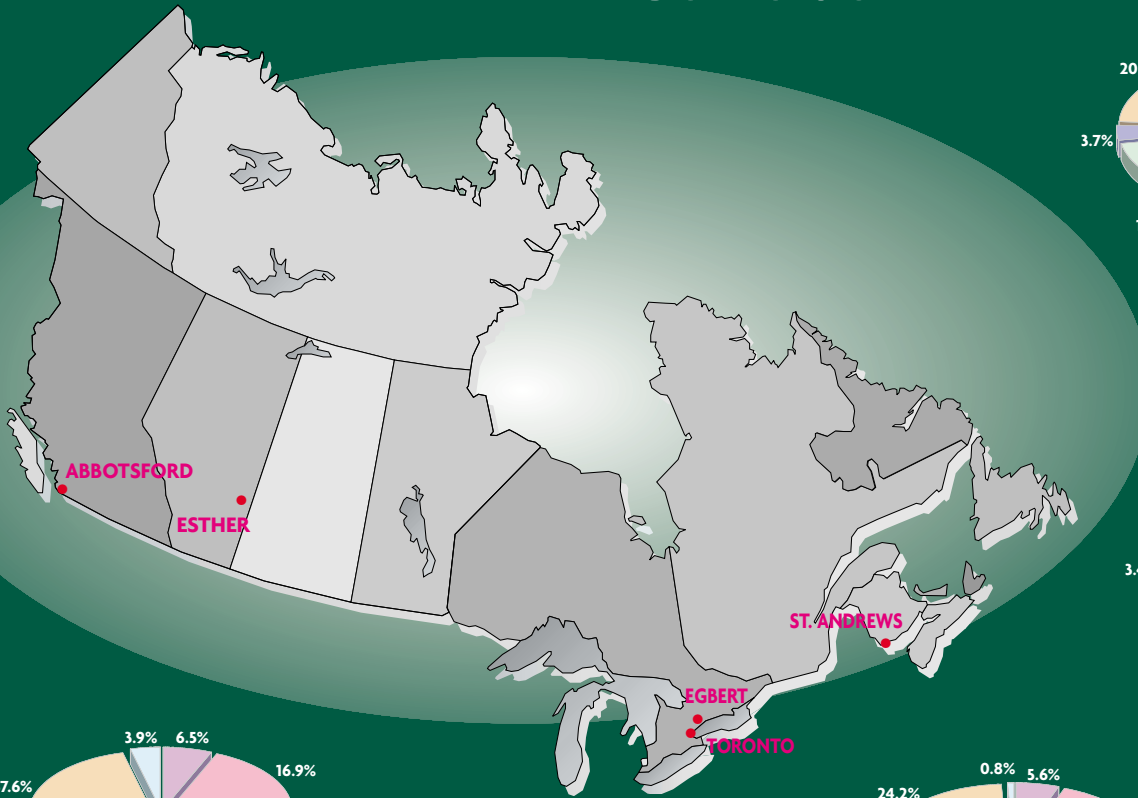
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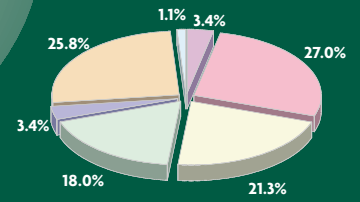
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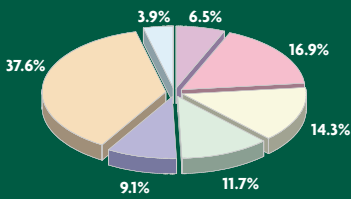
Precursor Contributions to Ambient Fine Particulate Matter in Canada



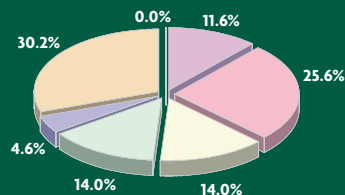
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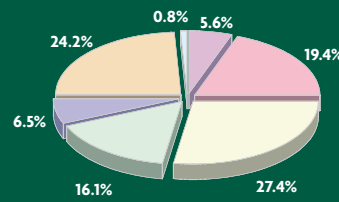
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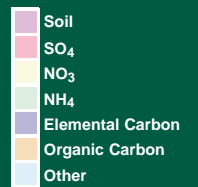


ESTHER



TORONTO

LEGEND



SUMMARY

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Cover illustration depicts the *fractional composition* (percentage) of $PM_{2.5}$ measured in the GAViM network at Toronto (ON), Egbert (ON), Abbotsford (BC), St. Andrews (NB) and Esther (AB). The area of the pie is proportional to the period average $PM_{2.5}$ mass concentration at each site. All sites are located in rural locations except Toronto.



Preface

This brochure is based upon the report Precursor Contributions to Ambient Fine Particulate Matter in Canada written by the following people...

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FINE PARTICULATE MATTER AND ITS PRECURSORS

Air is a mixture of gases and most of the substances that pollute it are also gases. However, some of the most common air pollutants are not gases at all but are small particles of solid or liquid matter. These tiny bits of material are known as particulate matter (PM for short), airborne particles or aerosols, and they are key players in several air pollution issues, including smog, climate change, acid rain, and hazardous air pollutants.

What is PM?

There are many different kinds of PM, but these can be classified into just a few categories on the basis of their size, their source (whether natural or related to human activities), and their composition. Airborne particles can be as large as 100 micrometres (μm) in diameter or as small as $0.005 \mu\text{m}$ – in other words, anywhere from almost one and a half times larger than the thickness of a typical human hair to about 14,000 times smaller. The larger particles settle out of the air quickly, but those less than about $40 \mu\text{m}$ in diameter tend to remain in the air much longer. It is these suspended particles that are at the root of many problems connected with poor air quality. These problems can range from aesthetic impacts, such as regional haze and reduced visibility, or soiled and eroded surfaces on buildings and monuments, to serious health impacts, such as heart and respiratory problems.

Scientists routinely measure the amount of total suspended particulate in the air, but increasingly they are concerned with the smallest particles in this category, those that are less than $10 \mu\text{m}$ in diameter. These are classified as coarse PM (between $10 \mu\text{m}$ and $2.5 \mu\text{m}$ in diameter), fine PM (less than $2.5 \mu\text{m}$), and ultrafine PM (less than $0.1 \mu\text{m}$). For convenience, all particles less than $10 \mu\text{m}$ in diameter are referred to as PM_{10} and particles less than $2.5 \mu\text{m}$ are referred to as $\text{PM}_{2.5}$. The smaller particles are of special concern because they can remain airborne for days or weeks, and once inside the lungs, their small size allows them to penetrate deeply.

Particulate matter can be classified as either primary or secondary. Primary particles are those that are emitted

directly into the atmosphere from a source. Some of these are produced by physical processes such as erosion and tend to be coarse. Some other primary particles, however, such as carbon particles that are emitted from combustion sources are considerably smaller. Secondary particles are mostly in the fine category and are a product of chemical reactions that involve what are known as precursor gases. The precursor gases that form secondary particles are nitric oxide and nitrogen dioxide (known collectively as NO_x), sulphur dioxide (SO_2), a large number of carbon-containing compounds known as volatile organic compounds (VOCs), and ammonia (NH_3). All of these substances occur naturally, but in our modern industrialized world the use of fossil fuels and various industrial processes contribute by far the largest proportion of these substances in populated areas.

Particulate matter is produced both by natural processes and by human activities. Natural PM includes mostly coarse material, such as windblown soil, volcanic dust, sea salt spray, and pollen, although some fine particles, such as ash from forest fires and particles formed from chemicals released by vegetation, are also of natural origin. PM produced by human activities is known as anthropogenic PM and includes both coarse and fine particles. Generally, coarse particles come from sources such as farmlands, roads, and construction sites, and fine particles result from the burning of fossil fuels in electrical power plants, motor vehicles, heating systems, and industrial boilers, and from reactions between industrially produced chemicals and other chemical substances already present in the atmosphere.

Particulate matter is a major contributor to smog and plays a key role in smog-related health problems. Smog has been linked to a variety of heart and respiratory problems that can result in absenteeism from school and work, hospital admissions, or even lead to premature deaths. These health responses tend to track ambient $\text{PM}_{2.5}$ concentrations. Although average $\text{PM}_{2.5}$ concentrations vary considerably across the country, every major urban centre in Canada has levels high enough to pose a health risk. Figure 1 shows 1998 average annual concentrations of $\text{PM}_{2.5}$ across Canada in mass units of micrograms per cubic metre of air.

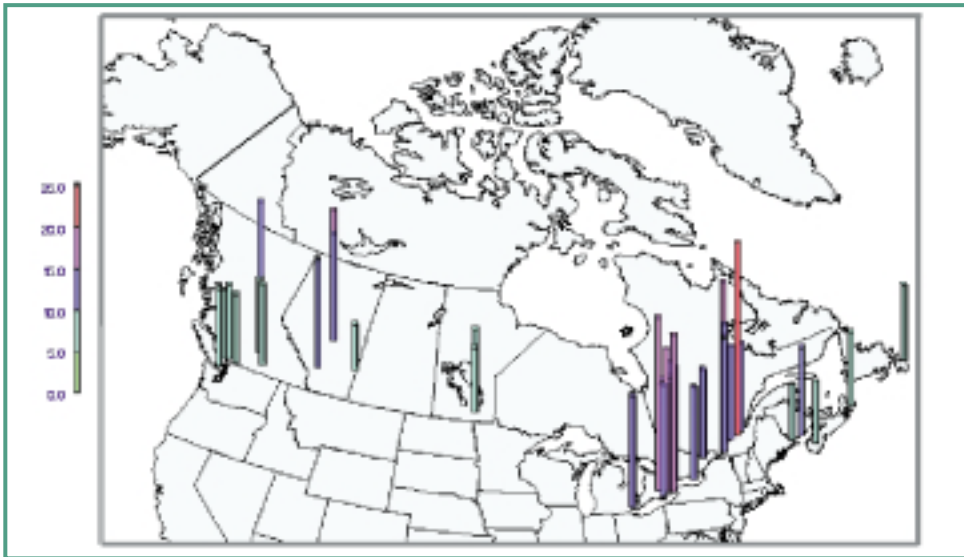


Figure 1:
1998 annual average
PM_{2.5} mass concentrations (µg/m³).
PM_{2.5} concentrations
are highest in the
Windsor-Québec City
corridor, but levels in
every major urban
centre in Canada,
and in some rural areas,
are high enough to
pose a health risk.

PM_{2.5}: A pollutant with many impacts

Smog:

Fine particulate matter is one of the principal constituents of smog. It is a serious human health concern because fine particles can be inhaled into the alveoli, the air sacs of the lungs, where they cause inflammation that can lead to breathing difficulties or more serious cardio-respiratory problems. There appears to be no lower threshold below which these effects do not occur in at least some sensitive people, and the number of people affected increases as atmospheric concentrations of PM_{2.5} rise.

Acid Rain:

PM_{2.5} is also an important factor in other atmospheric issues. The formation of inorganic (non-carbon containing) particles, for example, is closely associated with acid rain. The chemical reactions that turn sulphur dioxide (SO₂) and nitric oxides (NO_x) into the sulphuric and nitric acids that become acid rain are also part of the processes that lead to the formation of sulphate and nitrate particles. These particles may themselves contribute to acidification when they settle out of the air and deposit onto soils and into lakes and rivers.

Climate Change:

Climate is affected by airborne particles such as sulphates and black carbon (soot). Airborne particles can affect climate in a number of ways contributing to either cooling or warming of the climate. The net effect of airborne particles on the climate varies over time and space. Particles influence temperatures at the earth's surface directly by reflecting or absorbing incoming sunlight. Sulphate particles, for instance, exert a cooling force at the earth's surface because they reflect incoming sunlight. Black carbon, on the other hand, has mostly a warming force, because it is a strong absorber of sunlight. Particles also have an indirect effect on climate because they contribute to cloud formation.

Hazardous Air Pollutants:

Some airborne particles are also classified as hazardous or toxic air pollutants. Mercury and a number of other metals may be directly emitted as particles from the burning of fossil fuels, especially coal, and from smelting and a variety of other industrial processes. Some of the volatile organic compounds that contribute to particulate matter (e.g., polycyclic aromatic hydrocarbons or PAHs) are also important hazardous air pollutants. These particles are of concern because of their persistent nature and tendency to bioaccumulation.

Understanding PM_{2.5}

To develop effective control measures for PM_{2.5}, we need to know more about the relationships between particles in the atmosphere and the emissions that produce them or lead to their formation. To do that, we need detailed answers to a number of questions. What, for instance, are the main components of PM_{2.5}? Where do they come from? What factors affect the formation, concentration, and transport of PM_{2.5}? How do we explain seasonal and regional variations in PM_{2.5} concentrations? What accounts for the occurrence of PM_{2.5} episodes in which unusually high concentrations of particles may persist for a number of days?

Particulate matter, as total suspended particulate matter and PM₁₀, has been monitored in Canada by the federal and provincial governments since 1974 through the National Air Pollution Surveillance network (NAPS). In 1984, it added PM_{2.5} to its measurement program. What we know about PM_{2.5} in Canada comes from these ongoing monitoring programs and a variety of shorter-term research studies.

The composition of PM_{2.5}

PM_{2.5} samples are collected hourly or daily at urban and non-urban sites across Canada. When these samples are analysed in a laboratory, the results from all locations show that PM_{2.5} is comprised of six major fractions: organic compounds (carbon-containing*) and elemental or black carbon, inorganic compounds composed of sulphate, nitrate, and ammonium, and soil or crustal material and metals.

Figure 2 shows how the average proportion of each of these constituents varies across Canada. At the eastern sites (Toronto and Egbert in southern Ontario and St. Andrews in southern New Brunswick), the inorganic particles make up about two thirds of the total particle mass. At the western sites (Abbotsford in B.C.'s Lower Fraser Valley and Esther on the Alberta-Saskatchewan border), inorganic particles make up only about half of the total particle mass.

Primary and Secondary Particles: Where do these various particle components come from? Only a very small proportion of the sulphate, nitrate, and ammonium found

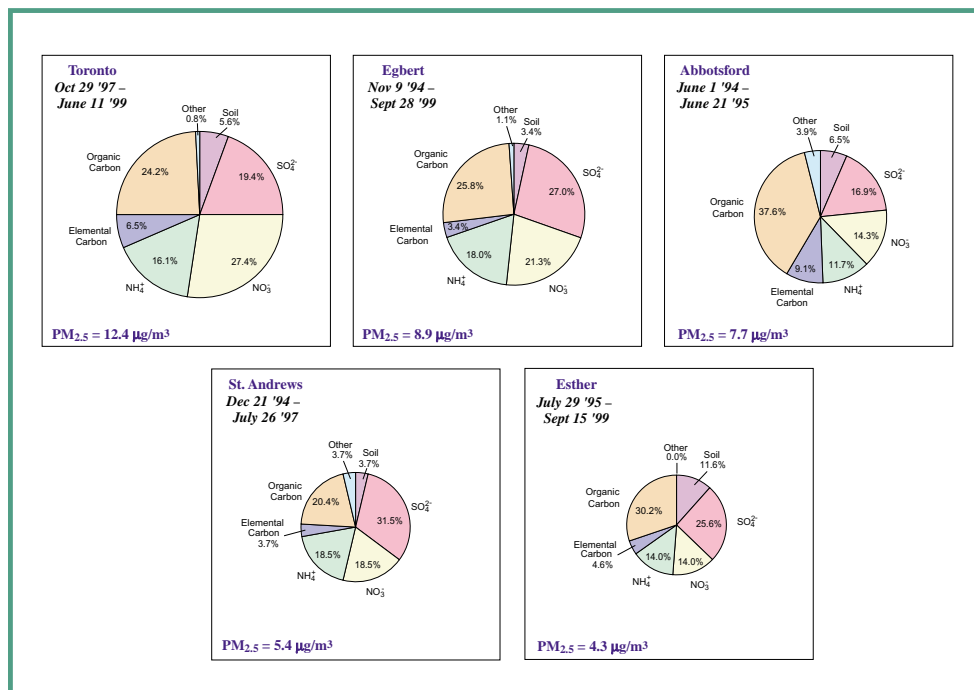


Figure 2: Composition of PM_{2.5} (µg/m³) at five urban and rural sites. The composition of PM_{2.5} varies considerably from place to place, but inorganic particles (sulphates, nitrates, and ammonium) make up the largest group of constituents, while organic compounds form another large category. Some of the organic particles and almost all of the inorganic particles are of secondary origin, formed as a result of atmospheric reactions involving sulphur dioxide, NO_x, and ammonia (in the case of the inorganic particles) and a variety of volatile organic compounds (in the case of the organic particles).

*Almost all compounds that contain carbon and hydrogen are called organic compounds. Carbon monoxide and carbon dioxide are among the few carbon-containing compounds that are not classified as organic.

in the inorganic portion of $PM_{2.5}$ is actually emitted directly by either natural or human sources. Instead, these compounds are the products of atmospheric reactions that start with both natural and human-related emissions of sulphur dioxide (SO_2), nitric oxides (NO_x), and ammonia (NH_3). The organic portion is a mix of directly emitted primary particles and indirectly formed secondary particles. Because so many organic compounds are involved in the formation of fine PM, and their presence in the atmosphere has not been measured extensively, it is not possible at present to determine precisely whether most of the organic material is of primary or secondary origin. Presently, fewer than 10% - 20% of the organic components of fine PM at North American sites have been identified, but within this group, it is estimated that more of the organic particles were of primary origin than secondary. Soil, of course, is of primary origin, as is the elemental carbon component that is released when there is incomplete combustion in, for example, forest fires and diesel engines.

Precursor Sources: The precursor gases that lead to the formation of fine secondary particles are largely a result of human activity. Sulphur dioxide in Canada comes mostly from large point sources such as smelters, electric power plants that burn fossil fuels, oil and gas wells and refineries, and pulp and paper mills. NO_x emissions come from both large point sources such as fossil-fuelled power plants and area sources such as transportation. In summer, there is also a small but significant contribution, amounting to about 15% of total emissions, from natural sources that consist primarily of lightning, forest fires, and emissions from soils. Ammonia is mostly agricultural in origin, with livestock operations and the production and use of commercial fertilizers being the predominant sources. Some ammonia is also emitted from industrial and transportation sources. Volatile organic compounds (VOCs) originate mostly in fuels, solvents, and industrial chemicals. They are also released into the atmosphere from trees and other vegetation (that pine-forest smell). In the summer the most abundant VOCs on a regional scale are, of biological origin.

Secondary inorganic particles formed from the precursor gases sulphur dioxide, nitric oxides, and ammonia comprise anywhere from one third to two thirds of fine particulate matter in Canada. In eastern Canada, where the proportion of these inorganic particles is generally higher than in the West, sulphate particles are the most predomi-

nant component. The greater proportion of sulphate in eastern Canadian $PM_{2.5}$ is related to the much higher level of sulphur dioxide emissions in the eastern provinces and in the adjacent areas of the United States.

The presence of fine PM in a particular area is affected not only by local sources of precursor gases but also by regional circulation/airflow patterns that transport these gases or particles from sources in other areas. In the summer especially, southern parts of the eastern provinces are exposed to a southwesterly airflow that transports pollutants from heavily urbanized and industrialized areas of the U.S. such as the Ohio Valley and the Boston-New York-Washington corridor. Because the precursor gases from these areas have had time to undergo reactions before they arrive in Canada, the incoming air tends to carry a substantial load of particles as well as precursor gases that can contribute to further particle formation. Figure 3 shows the origins of air masses that contributed to major $PM_{2.5}$ episodes at four locations in Canada from 1992 - 1995.

What factors affect $PM_{2.5}$ formation and concentration?

Because most fine PM is of secondary origin, it is important to know more about the factors that affect its formation and influence its concentration and transport in the atmosphere. The processes by which precursor gases like sulphur dioxide, nitric oxides, ammonia, and different kinds of VOCs form $PM_{2.5}$ are many and complex and involve numerous chemical reactions and many alternative reaction pathways. These reaction pathways are shown in a simplified manner in Figure 4. They depend not only on the presence of precursor gases but also on weather conditions and on the availability of other reactive compounds in the atmosphere, especially oxidants such as ozone and a highly reactive molecular fragment known as the hydroxyl radical (OH).

Sulphate particles result from a process where sulphur dioxide reacts with the hydroxyl radical (OH) to form sulphuric acid. The sulphuric acid may then form particles directly through either physical or chemical processes or it may react with ammonium ions in the atmosphere to produce fine ammonium sulphate particles. Figure 5 illustrates the strong link between airborne sulphur dioxide and particle sulphate concentrations at

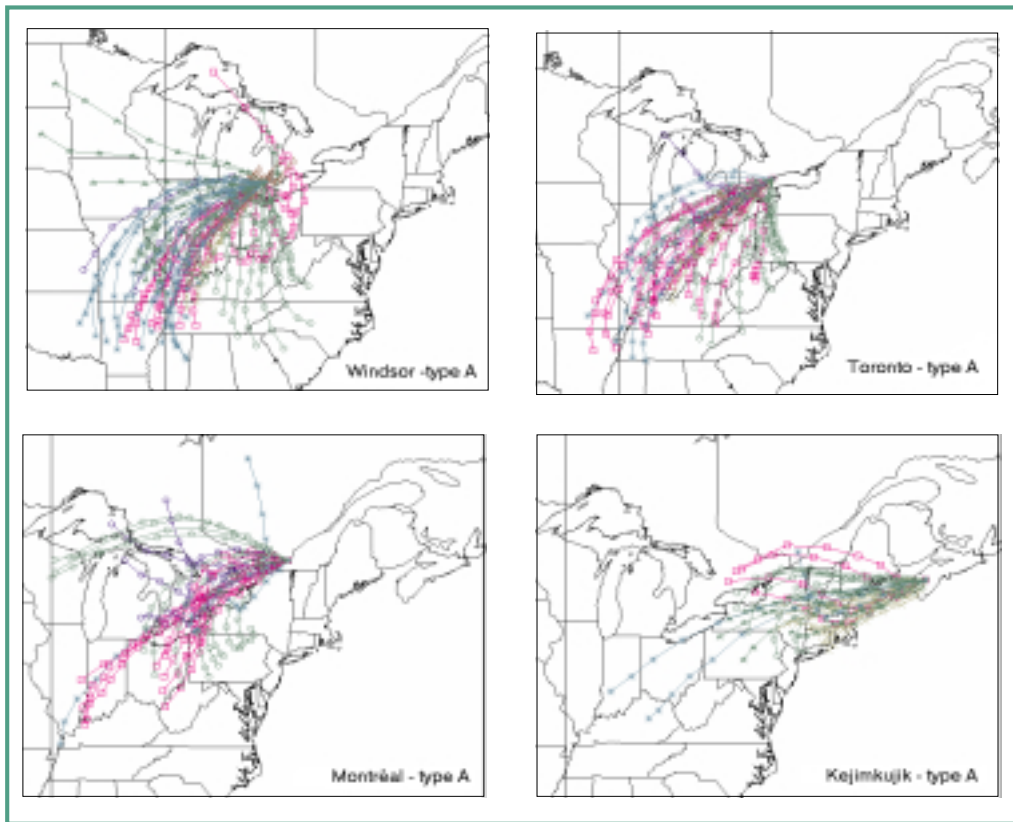


Figure 3: Back trajectories of air masses contributing to major $PM_{2.5}$ episodes at Windsor, Toronto, Montreal, and Kejimikujik National Park, 1992-1995. Prolonged $PM_{2.5}$ episodes covering broad geographical areas are typically associated with air masses that have travelled over areas where sulphur dioxide and NO_x emissions are high. For Windsor and Toronto, the most important of these source areas is the U.S. Midwest. For Montreal, they are the U.S. Midwest and southern Ontario. For Kejimikujik, New York and the New England states are the principal source regions.

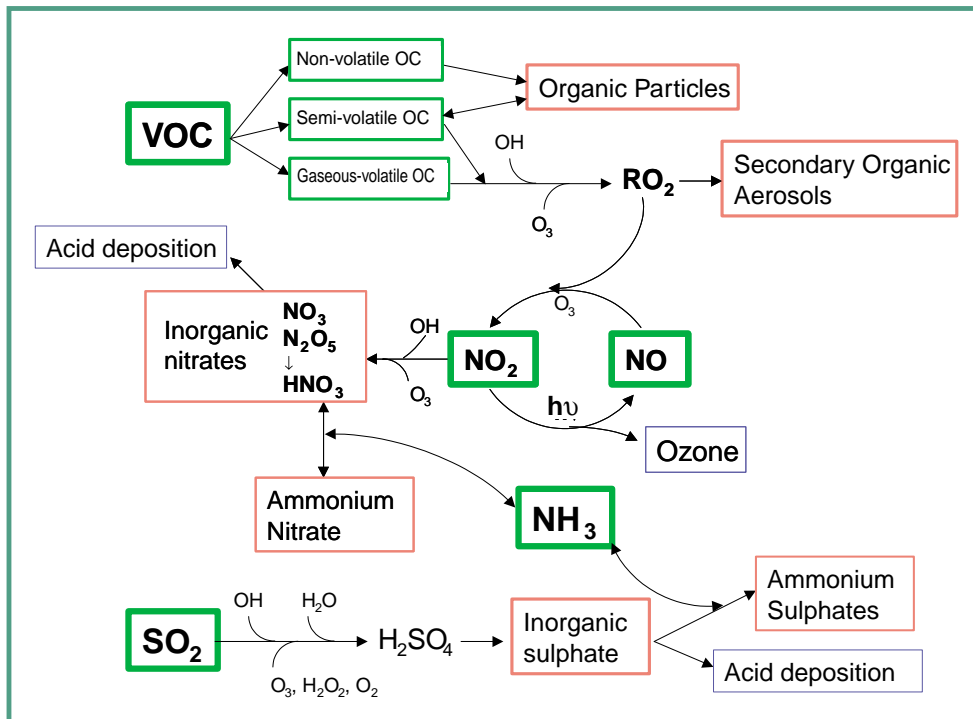


Figure 4: The many complex reactions by which precursor gases (green boxes) form particles (red boxes) are schematized here in a highly simplified form. Oxidizing agents like the hydroxyl radical (OH) and ozone (O_3) play a significant role in many of these reactions. It can also be seen that particle formation is closely linked to the processes that produce acid rain and ground-level ozone.

regional sites across Canada.

The formation of **nitrate particles** follows a series of reactions where NO_x is converted to nitric acid, which then reacts with ammonia in the air to form ammonium nitrate particles. These chemical reactions involving NO_x are the ultimate source of the oxidizing agents (OH and O_3) that are needed to transform sulphur dioxide into sulphuric acid and to convert various VOCs into oxidized organic compounds that tend to form particles.

Ammonium is formed when emitted ammonia gas reacts with water. Ammonium contributes to the formation of particulate matter when it reacts with either sulphate or nitrate.

VOCs can form particles in a number of ways. Some VOCs may alternate between gas and solid or liquid phases, depending largely on the temperature of the surround-

ing or ambient air. These are referred to as semi-volatile organic compounds or SVOCs. Most VOCs, however, remain in the gas phase within the normal range of ambient air temperatures. When VOCs react with oxidizing agents in the atmosphere they may be converted to products that are more likely to exist as particles at ambient temperatures or that change from the gas phase to particles at cooler temperatures.

Meteorological Influences: Temperature has an important influence on the formation of particles. Most chemical reactions that result in particulate matter formation proceed faster at higher temperatures, but some particle forming processes, such as condensation favour cooler temperatures. The presence or absence of strong sunlight also affects the availability of oxidizing agents since they are produced by photochemical reactions that require energy from the sun to take place.

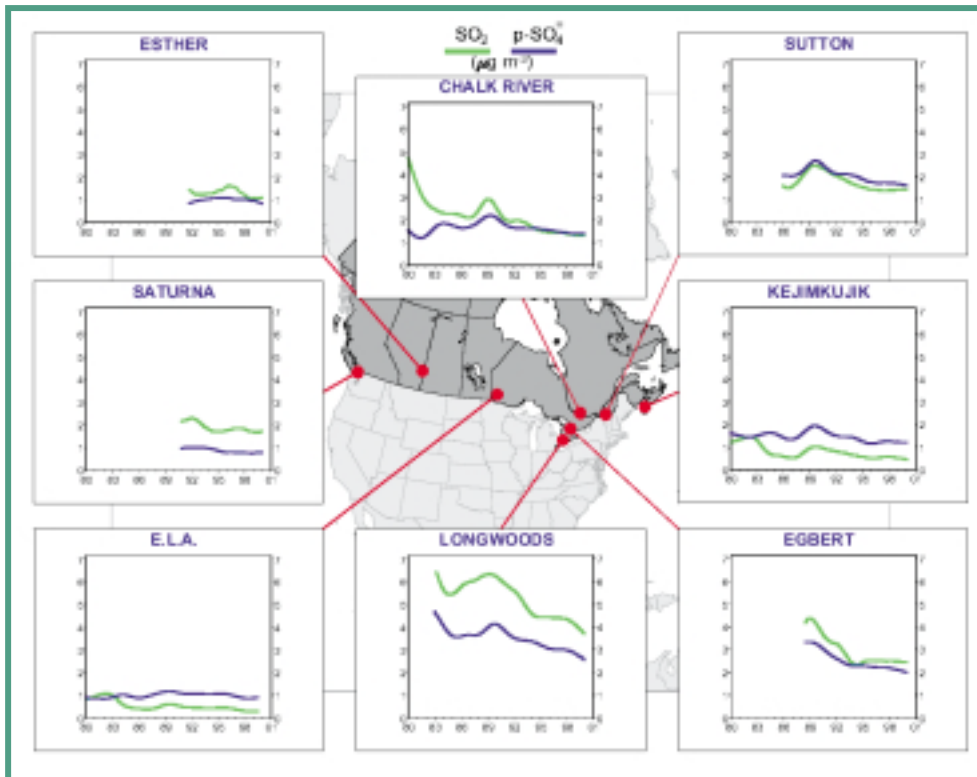


Figure 5: Long-term trends of SO_2 and sulphate concentrations at rural/remote CAPMoN (Canadian Air and Precipitation Monitoring Network) sites across Canada.

Atmospheric moisture is another factor that affects particle formation. Precipitation can wash air pollutants out of the air, but small water droplets in clouds or fog can increase the particle formation rate. Sulphur dioxide, for example, is converted to sulphate much more quickly under foggy conditions, leaving higher particle concentrations in the air after the fog has evaporated.

Different meteorological influences are at play in the particle formation throughout the year and thus **PM is a year round air quality problem**. The trends we see in PM have strong seasonal patterns. Figure 6 shows the seasonal variation in the monthly concentrations of PM_{2.5} at four sites across Canada.

Meteorological influences also cause definite seasonal patterns in the makeup or composition of PM. Sulphate, for example, tends to be more dominant in the summer. There are a variety of possible reasons why this is so, but one of the more important is that warm temperatures and bright summer sunshine favour the formation of the oxidizing agents needed to produce sulphuric acid from sulphur dioxide. Nitrate, on the other hand, is more abundant in

winter. Many of the particle-forming reactions involving ammonia and nitric acid are favoured by cool weather. Also, sulphate production is diminished in the cooler months, leaving more ammonia available to take part in particle-forming reactions with nitric acid. Figure 7 shows how the percentage of PM_{2.5} mass components at Egbert, Ontario is different during a wintertime episode from a summertime episode. Emissions of sulphate and NO_x do not show enough seasonal variation to account for these patterns. Therefore, the most likely cause of these seasonal and episodic differences in sulphate and nitrate particle formation is the effect of temperature and other seasonal weather factors on secondary particle formation processes.

Large-Scale PM_{2.5} Episodes

From time to time, PM_{2.5} concentrations may rise to episodically high concentrations greater than 30 µg/m³ and persist for several days. These PM episodes happen more frequently in southern Ontario and eastern Canada than in the Prairie Provinces and British Columbia. They may occur any time of the year, but in Ontario they are most

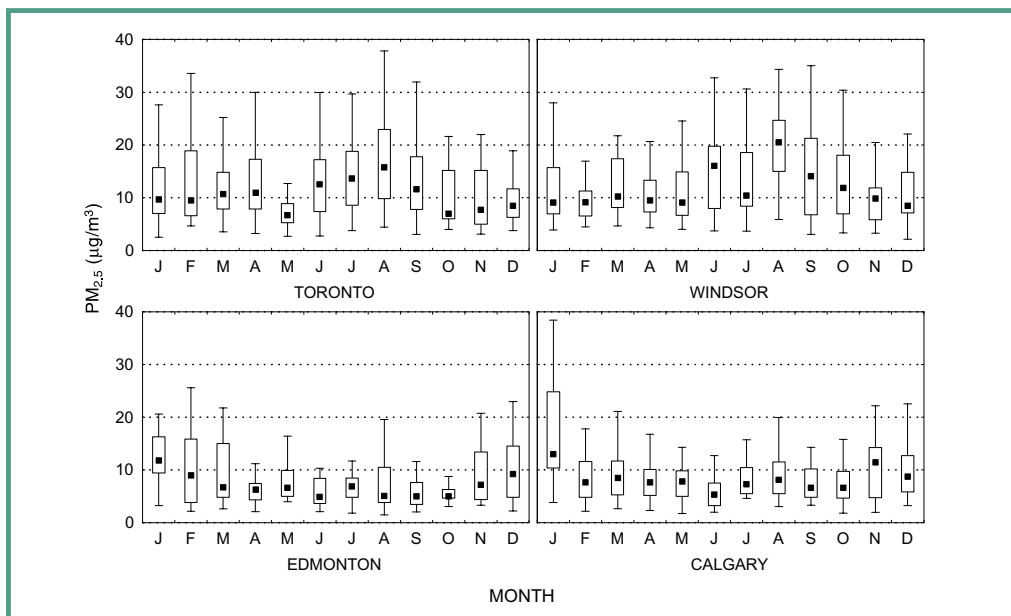


Figure 6: Monthly variation in PM_{2.5} concentrations in µg/m³ for Ontario and Alberta sites – 1994 to 1998, based on 24-hour dichotomous sampler results measured every 6th day.

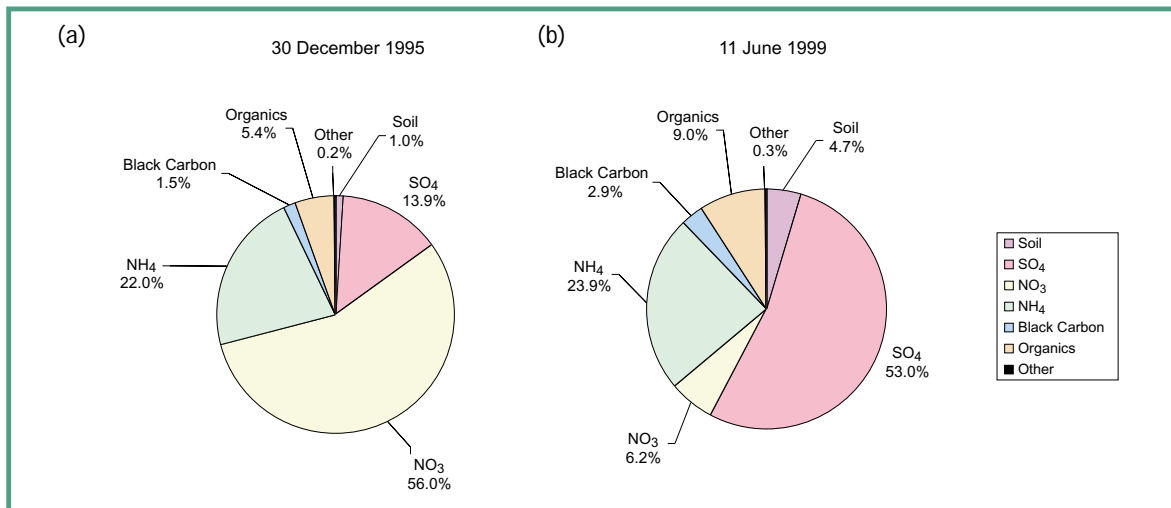


Figure 7: The relative composition (%) of PM_{2.5} mass at Egbert, Ontario, during (a) the wintertime PM_{2.5} episode of December 30, 1995, and (b) the summertime episode of June 11, 1999. The composition of PM_{2.5} in winter episodes is radically different from that in summer episodes. At Egbert, sulphates dominate in summer episodes while nitrates dominate in winter. The difference is not a result of changes in emissions but rather of the differing temperature dependence of the reactions that lead to the formation of sulphate and nitrate particles.

frequent in the summer. In the West episodes may occur throughout the whole year.

PM_{2.5} episodes are associated with weather conditions that lead to the buildup of precursor gases and particles in an air mass, and with weather conditions that transport pollutants from upwind source areas. Episodes usually occur when slow-moving high pressure weather systems with light winds and vertically stable air move into an area. Such conditions keep pollutants near their sources and close to the ground, as do conditions in which a temperature inversion exists. Under a temperature inversion, a layer of warm air forms above cooler air below and stops the upward movement of air. High pressure systems that cause a flow of air from regions like the Ohio valley are also linked to high concentrations of PM_{2.5} because they transport precursors to an area where they subsequently react to form PM_{2.5} in the air. In fact, **PM_{2.5} episodes that cover large geographic areas tend to be caused more by particles and precursors transported from distant source regions than by local emissions.**

Although atmospheric concentrations of both natural and human-related VOCs increase during the summer because of higher evaporation rates, organic compounds do

not seem to play a significant role in PM_{2.5} episodes. In fact, the proportion of organic carbon in the overall PM_{2.5} mix usually diminishes when PM_{2.5} concentrations rise to high values. This is because of a disproportionate increase in the amount of inorganic particles that is characteristic of episodes rather than an actual decline in organic carbon concentrations. Analysis of PM composition under varied episode conditions is required to gain more knowledge about the many possible ways that VOCs can contribute to particle formation.

Managing PM

Average PM_{2.5} concentrations in Canadian cities have generally shown a declining trend since the mid-1980s. [Figure 8: Composite PM_{2.5} trend for 11 Canadian cities, 1986–1998] The reasons behind this decrease have not been extensively studied, but it is thought that it is linked to the substantial reductions in sulphur dioxide emissions that have taken place in eastern North America during that period, as a result of efforts to reduce acid rain. In spite of these important reductions, however, PM_{2.5} remains a serious threat to public health, as concentrations in most parts of southern Canada still regularly exceed

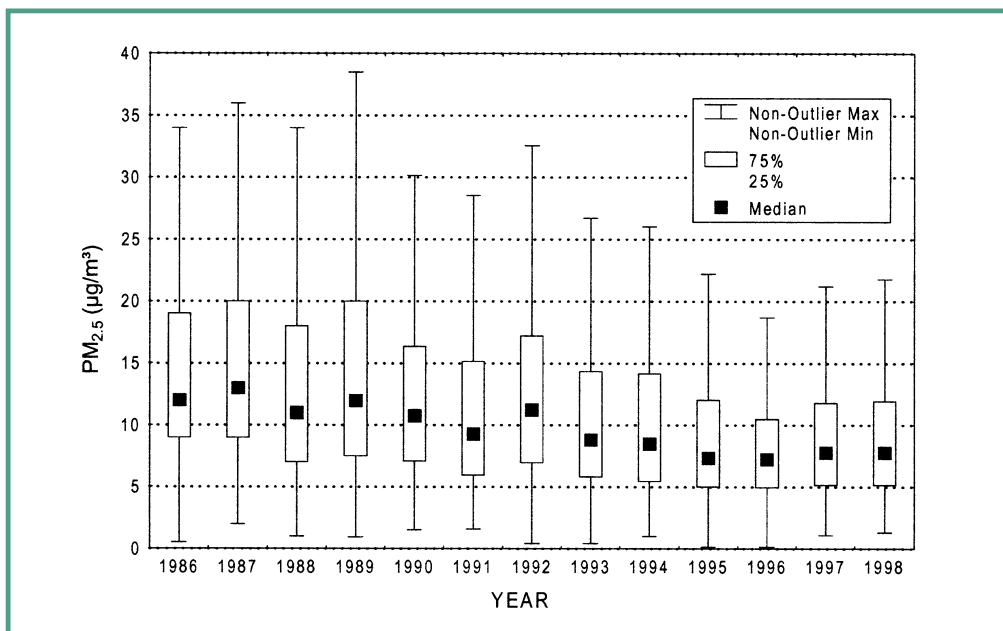


Figure 8: Composite PM_{2.5} concentrations for 11 Canadian cities, 1986–1998. From 1992 to 1996 the average PM_{2.5} concentrations for these 11 cities (as shown by the black squares) declined by about 40%, although concentrations increased again in 1997 and 1998. Maximum values have also decreased substantially. Decreases in sulphur dioxide emissions in eastern Canada and the northeastern U.S. are thought to be the principal reason for the decline.

levels associated with adverse effects on human health. Consequently, Canada's federal, provincial, and territorial governments have all agreed that further reductions in PM_{2.5} concentrations are necessary.

PM₁₀ (which also includes PM_{2.5}) was recently listed as a toxic substance under the Canadian Environmental Protection Act. A Canada-Wide Standard has also been set for PM_{2.5}. This requires actions to be taken so that average daily PM_{2.5} concentrations do not exceed 30 µg/m³ more than 2% of the time over a three-year period. The federal, provincial, and territorial governments have agreed upon a set of initial actions to begin to address the PM problem. These initial actions include initiatives to reduce emissions from transportation and woodburning as well as consultations with various industries and other stakeholder groups about the development of multi-pollutant emission reduction strategies for a number of industrial sectors. In addition, current commitments under the Canada–United States Air Quality Agreement that were put into place to reduce emissions of ozone-forming nitric oxides (NO_x)

and VOCs may also be extended to include other PM precursors. This would be an important step towards reducing the impact of particles and precursors from U.S. sources.

Since most fine particulate matter is formed from precursor gases, it would seem that any reduction in emissions of these gases would lead to corresponding reductions in PM_{2.5} concentrations. For a variety of reasons, however, the solution to the problem is not that straightforward. The many different reactions that can lead to fine particle formation depend on many factors, such as weather and the presence and levels of other chemical constituents in the atmosphere. Therefore, there is not necessarily a one-to-one correspondence between changes in precursor concentrations and changes in the total amount of PM in the air. In fact, the relationship between changes in precursor concentrations and PM_{2.5} abundance is often highly nonlinear. As an example, a decrease in sulphur dioxide emissions may result in temporary increases in total PM_{2.5}, especially in the colder months. This is possible because a decline in sulphate concentrations would leave more ammonia free to

react with nitric acid and lead to the formation of ammonium nitrate particles.

Some other complicating factors that also have to be taken into account to effectively manage PM are:

- PM_{2.5} composition and concentrations and the frequency of PM_{2.5} episodes can vary considerably from one locality to another because of differences in local sources, climate, topography, and contributions of transported pollutants.
- The frequency of PM_{2.5} episodes and the composition and concentration of PM_{2.5} vary seasonally.
- Meteorological factors are primarily responsible for the occurrence of large-scale PM_{2.5} episodes that are characterized not only by much higher concentrations of PM_{2.5} but also by a change in its composition, with sulphates dominating the particle mass in summer and nitrates in winter (at least in eastern Canada). **As a result, managing PM_{2.5} episodes and managing the overall distribution of PM_{2.5} in non-episodic situations are two very different problems.**
- PM_{2.5} is intimately connected with other issues such as acid rain and ground-level ozone. Therefore, some actions that may help alleviate PM_{2.5} problems may affect these other problems. While ammonia, for example, contributes to particle formation, it also reduces the acidity of precipitation. Consequently, reducing ammonia emissions to control particle formation could increase the acidity of acid precipitation. On the other hand, some actions to reduce PM_{2.5} could also bring benefits in other areas. Lower emissions of NO_x and VOCs, for example, would not only lessen the formation of nitrate and organic particles but would also lead to reductions in ground-level ozone.
- VOCs are a special problem, because there are so many VOC species and there is still so much to learn about how most of them contribute to PM_{2.5}. Also, those species that are emitted in the greatest quantities do not necessarily make the greatest contribution to PM concentrations. Higher localized VOC emissions (such as in urban areas) may have a stronger impact on PM formation in populated areas than natural VOCs emitted from vegetation.

Given the existence of these many complexities, **it is clear that no one solution will be effective for all loca-**

tions and situations. Emission reduction strategies that work well in some areas and seasons might have little or no impact in others. **A flexible overall strategy is needed that will combine many precursor reduction approaches that will take into account seasons, and be tailored to the needs of different regions.** Also, limiting the severity of PM_{2.5} episodes may require approaches that differ from those used to reduce average everyday concentrations.

We do not yet have all the scientific knowledge needed to devise such a sophisticated and multifaceted response. **One of the top priorities of the atmospheric science community, therefore, is closing the many knowledge gaps that still limit our understanding of the characteristics and evolution of our various local and regional PM_{2.5} problems.**

One of the most important gaps concerns the contribution of VOCs to total PM_{2.5} concentrations. Which of the many classes of VOCs contribute most to particle formation? Do primary emissions of VOCs contribute more to total particle concentrations than secondary particles formed from VOCs? Do the more reactive VOCs that contribute to ground-level ozone also make a significant contribution to PM_{2.5}? To answer these and other questions, researchers need to acquire considerably more data about VOC emissions and the detailed composition of the organic component of PM_{2.5} under both field and laboratory conditions. This information should make it possible to target reductions in those VOCs that will provide the biggest payoff in PM_{2.5} reductions.

Researchers also need considerably more data on ammonia concentrations in outdoor air. These have not been measured on a regular basis in the past, but such information is essential if we are to gain more insight into the role of ammonia in secondary particle formation and its significance regionally. In addition, measurements of PM_{2.5} concentrations need to be taken more frequently and at more locations to get a better picture of when and where PM_{2.5} episodes occur. With more information about these concentrations, it will also be easier to understand how PM_{2.5} episodes are affected by local precursor emissions, regional weather conditions, and the transport of particles and precursor gases from distant sources. Getting this and other vital information will require an expansion of our air quality monitoring capacity to measure more pollutants, more often and at more places.

Urban and regional air quality models that include state-of-the-art understanding of the atmospheric processes of PM formation are beginning to be applied to build up a more detailed and accurate picture of how emissions, weather conditions, and atmospheric chemistry interact to form airborne PM_{2.5}. Using these models – which are essentially sophisticated computer programs that simulate chemical and physical processes in the atmosphere – researchers are also exploring how different approaches to reducing emissions of PM_{2.5} precursors are likely to affect related atmospheric issues like acid rain and ground-level ozone.

While we wait for the results of this research, there are still important actions that can be taken to address the PM_{2.5} issue. Reductions in both SO₂ and NO_x emissions appear to be the most promising initial strategy, as they would contribute to PM_{2.5} reductions in both summer and winter and would also help to reduce average PM_{2.5} concentrations as well as moderate the high concentrations that

occur during PM episodes. These reductions would also have a beneficial effect on acid rain and, depending on how local and regional NO_x and VOC concentrations change could also help to reduce ground-level ozone and smog.

A variety of initiatives that will contribute to achieving these reductions, such as adopting lower sulphur limits for motor fuels and enforcing tighter emission standards for motor vehicles, are already in place. Discussions with various industry representatives and other stakeholders are also under way to identify further measures for reducing sulphur dioxide and NO_x emissions. These are just the first steps, however. Later, as the benefits of further research become available, it will be possible to develop a broader range of targeted emission reductions that will respond much more effectively to the regional and seasonal complexities of the issue. This kind of tailored response will provide communities everywhere in the country with improved air quality.

Current Federal-Provincial Actions to Reduce Smog

Sectors included in the initial joint actions have been selected because based on current emission inventories, they are significant emitters of the precursor pollutants that cause PM and ozone; they are common to most jurisdictions and affect many communities across Canada; effective action requires a multi-jurisdictional approach, and; effective action can be initiated in the near-term. Some of these initiatives will build upon programs currently under way, such as the Strategic Options Processes (SOPs) under the *Canadian Environmental Protection Act* for reducing toxic substance releases from certain industrial sectors, and sectoral greenhouse gas reduction measures. Specifically, the joint initial actions that Environment Ministers agree to undertake are to:

- Provide more thorough and timely air quality information to governments, industry and the public;
- Establish new initiatives to reduce emissions from transportation;
- Participate in new initiatives to reduce emissions from residential wood burning appliances;
- Identify and develop, in consultation with industry and other stakeholders, national multi-pollutant emission reduction strategies for key industry sectors including pulp and paper, lumber and allied wood products, electric power, iron and steel, base metals smelting, concrete batch mix and asphalt mix plants.
- Compile, in consultation with industry and other stakeholders, model emission management measures or codes of practice for use by all Canadian jurisdictions as appropriate, applicable to the construction and demolition sector;
- Assemble a model alternative energy program to aid all jurisdictions in promoting energy alternatives;
- Enhance the mechanisms for the coordination of science activities related to PM and ozone.

Clean Air

Canada's Plan of Action on Clean Air, announced in February 2001, includes a number of initiatives to reduce emissions of sulphur dioxide, NO_x, and VOCs – gases that are important contributors to acid rain and ground-level ozone as well as PM_{2.5}. The plan also contains measures that will improve our scientific capacity to develop effective control measures. These initiatives include:

- A NO_x emission cap for fossil-fuelled power plants in central and southern Ontario and southern Quebec. In Ontario, power plant emissions of nitrogen dioxide will be cut in half by 2007.
- Implementation of new emission standards for cars, vans, pick-up trucks, and sports utility vehicles as well as for heavy trucks and buses, beginning with the 2004 model year. The new standards will reduce NO_x emissions by approximately 88% from passenger cars and by up to 95% from light trucks and SUVs. Engines in off-road equipment (e.g., lawn mowers, snow blowers, chain saws, string trimmers, leaf blowers, construction and agricultural equipment, portable generators, and outboard motors) will also have to meet higher emission standards.
- Implementation of a 10-year plan to reduce emissions of VOCs from paints, degreasing agents, solvents, and other products.
- The addition of up to 10 new monitoring stations as well as the refurbishing of 50 stations in the existing network and the upgrading of equipment in several others.
- Expansion of the National Pollutant Release Inventory to provide more comprehensive reporting of PM and ground-level ozone and precursors.

Under the Canada–U.S. Air Quality Agreement, the United States is also committed to making extensive reductions in emissions of sulphur dioxide, NO_x, and VOCs. The Canadian government also wants to negotiate an annex to the agreement that would deal specifically with particulate matter and the role of transboundary sources of precursor gases.

This brochure is based upon the report *Precursor Contributions to Ambient Fine Particulate Matter in Canada*, published by the Meteorological Service of Canada in May 2001. It is available online at <http://msc-smc.ec.gc.ca/saib/> or it can be obtained in hard copy by calling (416) 739-4645.