Chapter 4 - Air Quality Management Approaches and Evidence of Effectiveness

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KEY MESSAGES

- While North America, the European Community, and Asia have a unique set of air pollution problems – and approaches and capacities to deal with them – there is a clear portfolio of comprehensive management strategies common to successful programs. These include the establishment of ambient air quality standards that define clean air goals, strong public support leading to the political will to address these problems, technology-based and technology-forcing emission limits for all major contributing sources, and enforcement programs to ensure that the emission standards are met.
- Initially, many regions focused their air pollution control efforts on lead, ozone, and large particles (i.e., TSP, PM_{10}). However, newer epidemiological studies of premature death, primarily conducted in the U.S. with cohorts as large as half a million participants, have made it clear that long-term exposure to $PM_{2.5}$ is the major health risk from airborne pollutants. While WHO, US EPA, Environment Canada, and California Air Resources Board (CARB) rely on the same human health effects literature, there are striking differences, up to a factor of three, in the ambient air quality standards they set. In addition, how these standards are implemented (e.g., allowable exceedances, natural and exceptional event exceptions) can greatly reduce their stringency.
- Worldwide, command-and-control has been the primary regulatory mechanism to achieve emission reductions, although the European Community has successfully used tax incentives and voluntary agreements with industry. Over the past four decades, the California Air Resources Board set the bar for US EPA and European Union motor vehicle emission standards that are now being adopted in many developing countries, particularly in Asia.
- Since the emission standards are technology-based or technology-forcing, industry has been able to pursue the most cost-effective strategy to meeting the emission target. As a result, actual control costs are generally less than originally estimated. In the US, total air pollution control costs are about 0.1% of GDP, although this has not necessarily resulted in overall job and income loss because the air pollution control industry is about the same size. In addition, the US EPA estimated that each dollar currently spent on air pollution control results in about a $4 of reduced medical costs as well as the value assigned to avoided premature deaths
- A comprehensive enforcement program with mandatory reporting of emissions, sufficient resources for inspectors and equipment, and meaningful penalties for noncompliance ensures that emission standards are being met. While air quality management through standards for vehicles and fuels have resulted in measurable reductions in emissions, regulation of emissions for in-use vehicles through I/M programs poses greater technical challenges.
- An alternative to command-and-control regulations is market-based mechanisms that results in more efficient allocation of resources. The SO_2 cap and trade program in the US resulted in rapid

emissions reduction at lower cost than was initially anticipated. Efforts to extend the cap and trade system to SO_2, mercury and NO_X emissions in the Eastern US were less successful due to several issues related to heterogeneous emissions patterns which could worsen existing hot spots, allocation of emissions allowances, procedures for setting and revising the emissions cap, emissions increases following transition to a trading program, and compliance assurance.

- Emission reduction initiatives at the local level also play a critical role in air quality management. Local governments can contribute to cleaner air through emission reduction measures aimed at corporate fleets, energy conservation and efficiency measures in municipal buildings, public education to promote awareness and behaviour change, transportation and land use planning; and bylaws (anti-idling etc). Many large urban centres such as the City of Toronto are following the policy trend towards an integrated and harmonized approach to cleaner air and lower greenhouse gas emissions.
- An evidence-based public health approach in the assessment of health impacts of air pollution may not lead to essential policy changes. Environmental advocacy must develop more effective methods of risk communication to influence public demand for cleaner air and strengthen political will among decision-makers.
- Average daily visibility has been declining in Asia over two decades. Visibility provides a measure, with face validity, of environmental degradation and impaired quality of life; and a risk communication tool for pollution induced health problems, lost productivity, avoidable mortality and their collective costs.
- Although scarce, information from both planned and unintended air quality interventions provides strong evidence in support of temporal association and causality between pollution exposures and adverse health outcomes. Even modest interventions, such as reductions in fuel contaminants and short-term restrictions on traffic flows, are associated with marked reductions in emissions, ambient concentrations and health effects. Coal sales bans in Ireland and fuel sulfur restrictions in Hong Kong, successfully introduced in large urban areas within a 24-hour period, were economically and administratively feasible and acceptable, and effective in reducing cardiopulmonary mortality.
- While some air quality problems have been eliminated or greatly reduced (i.e., lead, NO_2, SO_2), particulate matter and ozone levels remain high in many large cities, resulting in hundreds of thousands of deaths per year and increased disease rates. Air quality management agencies are developing innovative approaches, including regulation of in-use emissions, reactivity-based VOC controls and exposure-based prioritization of PM controls. Several cooperative, multi-national efforts have begun to address transboundary issues. Newly recognized challenges also need to be integrated into air quality management programs, ranging from the microscale (e.g., air pollution “hotspots”, ultrafine particles, indoor air quality) to global scales (e.g., climate change mitigation, international goods movement).

4.1 Introduction

This chapter focuses on describing how air pollution problems are managed in North America, within the European Community (EC; former European Economic Community, EEC), and in Asia. Policy approaches are reviewed including mobile source, point source and area source emission reduction strategies; standard-setting approaches; market-based approaches; trans-boundary strategies; multi-pollutant strategies; as well as public education/behavioral approaches. Case studies of air quality management in large urban centres within each continent provide more detailed examples to illustrate the mix of strategies and their impact on air quality. The chapter concludes with evidence from intervention studies to illustrate the public health benefits associated with reductions in pollutant emissions.

4.2 Air Quality Management in North America

This section provides a perspective on air quality management in North America, focusing on the past and present situation in United States, Canada and Mexico. For each country, the historical development of clean air policies and programs is provided, as well as a brief description of major emissions sources, an overview of some of the main regulatory and non-regulatory air quality management initiatives, and trends in ambient air concentrations as an indicator of overall program effectiveness.

Within North America, each country sets separate ambient air quality standards (see Table 4.1). Within the United States, California has set its own standards, generally more stringent than those set by the U.S. Environmental Protection Agency.

Table 4.1: Ambient air quality standards for North America.

Pollutant	Averaging period	U.S.	California	Mexico	Canada
SO_2	1 hour	--	655 µg/m³	350 µg/m³	160 µg/m³
	1 day	365 µg/m³	105 µg/m³	80 µg/m³	30 µg/m³
NO_2	1 hour	--	470 µg/m³	400 µg/m³	--
	1 year	100 µg/m³	--	--	60 µg/m³
PM_{10}	1 day	150 µg/m³	50 µg/m³	150 µg/m³	50 µg/m³
	1 year	--	20 µg/m³	50 µg/m³	--
$PM_{2.5}$	1 day	35 µg/m³	--	--	30 µg/m³
	1 year	15 µg/m³	12 µg/m³	--	--
Ozone	1 hour	235 µg/m³	180 µg/m³	216 µg/m³	100 µg/m³
	8-hour	160 µg/m³	150 µg/m³	--	65 ppm (130 µg/m³)
CO	1 hour	40 mg/m³	23 mg/m³	--	34 mg/m³
	8-hour	10 mg/m³	10 mg/m³	13 mg/m³	--

Even though they rely on many of the same human exposure and epidemiological studies, these standards have striking differences. The use of allowable exceedances, spatial averaging of monitoring data, and natural (e.g., dust storms) and exceptional event (e.g., prescribed burn) exceptions can greatly reduce the stringency of these standards.

4.2.1 Air Quality Management in the United States[1]

Historical Perspective on Air Quality Management in the United States

Air quality control was first addressed by the US federal government in the 1955 Air Pollution Control Act and its 1959 extension, which provided money to state and local agencies for research and training on air quality. This was followed by a series of acts including the 1963 Clean Air Act. However, it was in 1970 that two fundamental events set the stage for subsequent air quality management approaches in the United States: the creation of the United States Environmental Protection Agency (EPA) by President Nixon, and significant amendments to the Clean Air Act (CAA).

The introduction to the CAA lists four overarching goals:

- To protect and enhance the quality of the Nation's air resources so as to promote the public health and welfare and the productive capacity of its population
- To initiate and accelerate a national research and development program to achieve the prevention and control of air pollution
- To provide technical and financial assistance to State and local governments in connection with the development and execution of their air pollution prevention and control programs
- To encourage and assist the development and operation of regional air pollution prevention and control programs

The 1970 CAA authorized the USEPA to set national ambient air quality standards (NAAQS) for criteria air pollutants, defined as those "in the ambient air resulting from numerous or diverse mobile or stationary sources." It also allowed for emissions standards for hazardous air pollutants, development of aircraft emissions standards, some automotive emissions standards, and motor vehicle emissions inspection and maintenance programs. The 1970 CAA also allowed individual states to take over responsibility for compliance with the CAA in return for funding. In order to receive the funding, states submitted state implementation plans (SIPs) describing plans to meet the EPA's requirements. SIPs affect mainly local areas where pollution levels exceed the standards, and usually include control of large industrial sources. States were also granted permission to adopt air quality guidelines that were more stringent than federal standards. Once a SIP receives approval from state and federal regulatory bodies it becomes legally enforceable at both levels.

In 1971, initial NAAQS were established for CO, NO_2, SO_2, TSP, hydrocarbons, and photochemical oxidants. The EPA was tasked with reviewing each of the NAAQS every five years. At the same time, a US ambient air quality monitoring program began. Over time the agents defined as criteria air contaminants have changed somewhat: lead was added in 1976, and in 1979, "photochemical oxidants" was replaced by ozone. Hydrocarbons were removed in 1983, and separate standards for PM_{10} and $PM_{2.5}$ have now replaced TSP.

The first prospective cohort studies to examine the relationship between air pollution and health, the Harvard Six Cities (Dockery et al., 1993) and the American Cancer Society studies (Pope et al., 1995), were initiated in the early 1970s. The publication of their results in the 1990s provided important evidence that there was a significant association between living in a polluted city and risk of premature death. In response, the American Lung Association sued the EPA, declaring that the agency had failed to

[1] Based largely on i) Cote, I., Samet, J., and Vandenberg, J. 2007. U.S. Air quality management: Local, regional and global approaches. *J. Toxicol. Environ. Health* (in press) and ii) National Research Council 2004. *Air Quality Management in the United States*, Washington, DC: The National Academies Press.

meet its obligation to review the NAAQS every five years, and that the new evidence obligated the EPA to conduct a new review. The result was a court order resulting in an accelerated but contentious review of the PM standards. Ultimately, the US EPA committed to a nationwide $PM_{2.5}$ monitoring network, Congress funded a new multifaceted research program, and the administration agreed not to implement the new standard until the next 5-year review was completed in 2002.

Efforts to meet the NAAQS have not always resulted in attainment, but they appear to have contributed substantially to reductions in pollutant emissions across the US. Limitations on continued improvement to achieve the NAAQS are imposed by growth in population, energy use, the number of sources, and vehicle miles traveled.

The initial regulations for HAPs under the 1970 CAA authorizations were mainly national standards which were applied to specific industries. Between 1970-1990, only the eight hazardous air pollutants with the strongest evidence for harm were regulated (asbestos, benzene, beryllium, coke oven emissions, inorganic arsenic, mercury, radionuclides, and vinyl chloride). Efforts to expand the regulations to other substances were hampered by legal and scientific arguments over risk assessment methods and assumptions, the amount of evidence required to justify regulations, the cost to industry, benefits to human health and the natural environment, and debates over "how safe is safe" (National Research Council, 2004).

This lack of progress on regulation at the federal level led agencies at all levels to turn to the individual states for implementation of AQM. During the 1980s, federal grants, training, and technology transfer facilitated expansion of regional programs, and almost all regulation of HAPs occurred at the state level. Although many of these programs continue to be strong, there is significant interstate variability in AQM approaches, likely due to the lack of national leadership during the 1980s.

In 1990, a new set of amendments to the CAA were adopted, largely in response to Congress' dissatisfaction with the lack of productive AQM for HAPs on a national scale. The amendments replaced the risk-based approach to managing the industrial sector with a technology-based approach. The amendments identified 189 HAPs for management, and defined sources where emissions standards should apply. The current list is intended to be periodically reviewed and amended as dictated by new scientific information. The amendments also addressed nonattainment areas, mobile sources, acid rain, permits, stratospheric ozone, and enforcement.

Beginning in the 1970s, acid rain, which results from the chemical conversion of SO_2 and NO_x to sulfuric and nitric acid in the atmosphere, became a national concern. SO_2 is emitted primarily by coal-fired power plants, and NO_x emissions are mainly a result of coal combustion in power plants and fuel combustion in vehicles. The site of acid deposition is typically distant from the point of emission because of the time it takes for atmospheric conversion of the gases to acid.

Pressure from states experiencing acid deposition and the Canadian government led to funds for research into the impacts of acid rain and recommendations on whether emissions control approaches were required to mitigate them. The 1990 CAA amendments addressed acid rain in a form of legislation which represented a significant departure from previous approaches to regulating criteria air contaminants and HAPs: "cap and trade." This program (described in more detail below) sets a maximum emissions level and assigned emissions allowances to individual emitters. They are then free to design their own compliance strategies, which may involve trade in emissions allowances.

In 2004, the National Academy of Science identified seven challenges facing US air quality management for the future:

- Achievement of standards – further reductions in emissions will be required in order to meet the 1998 standards for ozone and particulate matter as well as the 1999 regulations for regional haze
- Toxic air pollutants – further research is needed on the sources, atmospheric transport and distributions, and health effects of toxics

- Health effects at low pollution concentrations – there is increasing evidence that there is no level below which exposure to some pollutants has no potential health effects. This may have implications for how some pollutants are regulated
- Environmental justice – there are currently no programs under the CAA which address mitigating pollution that might be disproportionately born by minority and/or low-income groups in densely populated urban areas
- Protecting ecosystem health – protection of ecosystems affected by air pollution has received insufficient attention despite being mandated in the CAA
- Multistate, cross-border, and intercontinental transport – air quality in a particular area can be affected by pollutant transport across geographic areas including political boundaries
- AQM and climate change – AQM systems must ensure that pollution reduction strategies remain effective as the climate changes. Multipollutant approaches that include reducing emissions that contribute to both climate warming and air pollution may be desirable

Regulation of Air Pollutants in the United States

The Clean Air Act

In the US, air quality management is undertaken by local, tribal, state, and federal authorities, with responsibilities delegated to each jurisdiction by the CAA. The EPA coordinates the federal government's role, which is to ensure a basic level of environmental protection across the country through national uniformity in air quality standards and pollution mitigation approaches. The CAA also charges the EPA with overseeing actions carried out by agencies at all levels, which may include imposing federal sanctions or federally-developed pollution-control plans on delinquent areas. However, most of the responsibility for implementing federal rules and developing strategies and control measures to meet national air quality standards falls on state and local governments. An overview of air quality management activities is provided by Figure 4.1.

Federal rules promulgated under the CAA are subject to judicial review by the courts. Courts may set aside an agency rule if they find that it was not based on consideration of relevant factors, or if an error in judgment was made. However, the court may not substitute its judgment for the EPA's.

Five major goals are identified in the most recently amended CAA:

- Mitigating potentially harmful human and ecosystem exposure to six criteria air pollutants (CO, NO_2, SO_2, O_3, PM, and lead)
- Limiting sources and risks from exposure to hazardous air pollutants (HAPs, also called air toxics)
- Protecting and improving visibility impairment in wilderness areas and national parks
- Reducing the emissions of species that cause acid rain, specifically SO_2 and NO_x
- Curbing the use of chemicals that have the potential to deplete the stratospheric O_3 layer

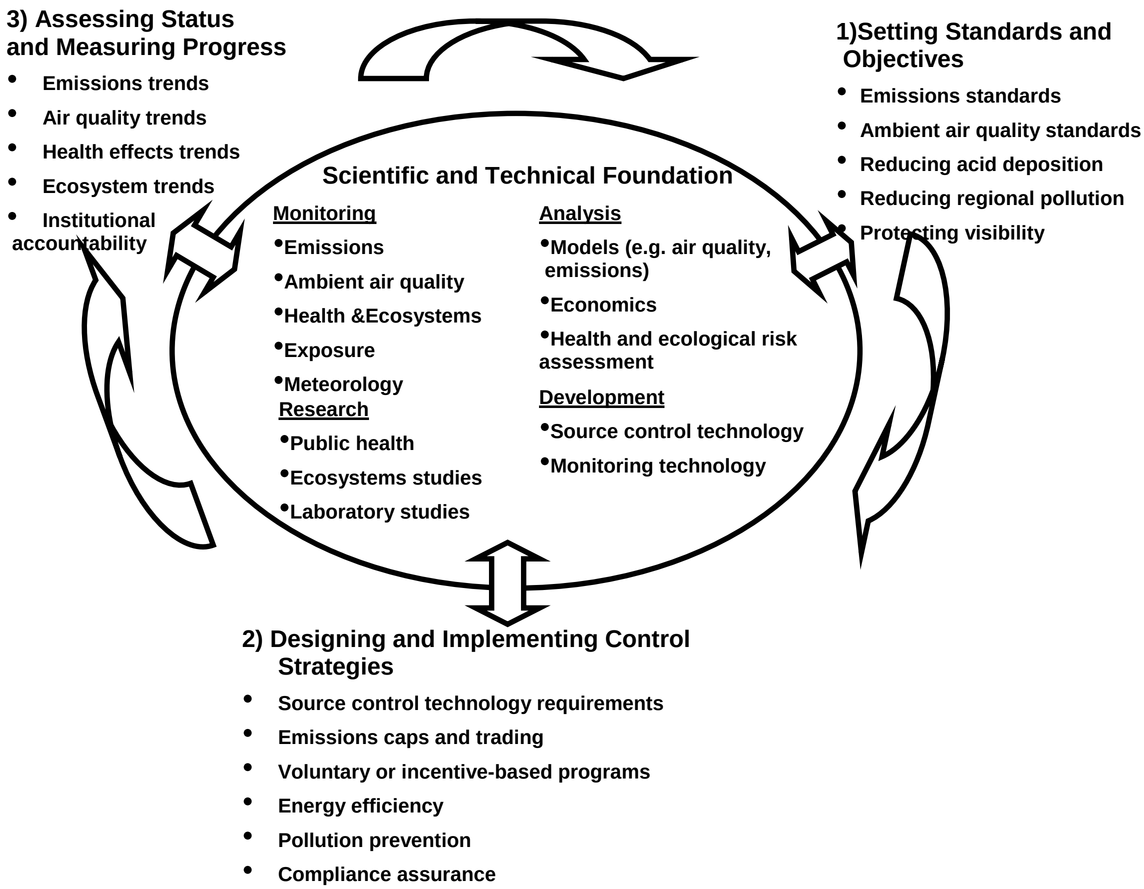


Figure 4.1: Schematic of U.S. Air Quality Management Activities. (Source: Cote and Samet, 2007).

Regulation of Criteria Air Contaminants and Hazardous Air Pollutants

There are fundamental differences in the way that criteria air contaminants and HAPs are regulated. The six pollutants regulated under NAAQS (the criteria air contaminants) are considered to originate from multiple sources and are characterized as being more ubiquitous and therefore having a greater impact on human health. These are regulated through ambient air concentration and time standards that define maximum allowable ambient concentration as well as monitoring and statistical methods to be used when determining if an area is in compliance. Two types of standards exist: primary standards, which are intended to protect the health of the most sensitive population subgroups with an adequate margin of safety, and secondary standards, which are intended to protect public welfare (by addressing issues such as visibility and ecosystem impacts). The CAA specifies the date by which primary standards must be met and gives the EPA authority to enforce compliance. Although reviews of the air quality data and NAAQS are ideally conducted every five years, the complexity of the review process combined with high research data output has resulted in more extended periods between reviews. The Supreme Court has determined that economic consequences should not be considered when setting a primary NAAQS, although costs are assessed during the NAAQS setting process.

The process for attaining NAAQS includes monitoring ambient concentrations, designation of nonattainment plans, and implementation of SIPs. Although most pollution reduction activities therefore take place on a local or regional scale, uniform national regulations have been adopted for some stationary and mobile criteria air contaminant sources in an effort to avoid placing an unfair economic burden on individual states.

In contrast to criteria air contaminants, HAPs are regulated at the point of emission for stationary sources and area sources. Standards for HAPs are developed based on threshold for health effects, accounting for a margin of safety. Facilities emitting large quantities of HAPs, i.e., 10 tonnes or more of any individual HAP or a combined total of 25 tonnes or more on an annual basis, are defined as "major emitters." 174 types of sources fall under this definition and these facilities are requires to implement maximum achievable control technologies (MACT) and work-based practices. Standards are also used to control area sources of HAPs, where standards must be imposed on a sufficient number of area sources so as to ensure that sources representing 90% of the area source emissions (excluding mobile sources) of the 30 (or more) HAPs that pose the greatest threat in the largest number of urban areas are subject to regulation. For these sources, the EPA administrator chooses whether MACT or GACT (generally available control technologies) are more appropriate.

In cases of major stationary or area sources, regulation is followed by assessment of residual risk. After this assessment, if no action was taken by Congress for two years, the EPA administrator should promulgate emissions standards to "provide an ample margin of safety to protect public health or to prevent, taking into consideration costs, energy, safety, and other relevant factors, an adverse environmental effect" (National Research Council, 2004). However, because of the difficulties in assessing residual risk, this process has not yet been completed.

SIPs are state implementation plans which must be devised by each state under the CAA. These are dynamic plans which must evolve to meet new federal or state requirements, changes in status of NAAQS attainment, or address other new information. They must be submitted within three years of a new NAAQS being promulgated, and provide "implementation, maintenance, and enforcement" of the standard. The specific requirements for each SIP depend on the state's air quality, which is determined by its compliance with NAAQS for criteria air pollutants:

- Nonattainment – any area (such as an urban centre) which does not meet a primary or secondary NAAQS. O_3 nonattainment areas are further classified as being marginal, moderate, serious, severe, or extreme.
- Attainment – any area that meets the primary and secondary NAAQS and does not contribute to the violation of a primary or secondary NAAQS in a nearby area
- Unclassifiable – any area that cannot be classified on the basis of available information.

Specific procedures are designated for determining attainment status and for setting requirements for nonattainment areas. Actions to be carried out in nonattainment areas include providing a plan for implementing reasonably available control technologies (RACT), meeting primary NAAQS, offsetting emissions from any new or modified major sources, and for installing MACT, comprehensive emissions inventories, and implementing new-source reviews before construction.

Data from national air quality monitoring networks suggests that SIPs have contributed substantially towards air quality improvement. Drawbacks of the process include its overly bureaucratic nature, an overemphasis on attainment demonstrations, and the single-pollutant focus. Another weakness of the SIP AQM approach is its inability to deal with pollutants crossing jurisdictional boundaries. One method that has been used to approach the problem is "Cap and Trade," an approach that originated as a method of reducing acid deposition.

Cap and Trade

Initially, the most cost-effective way to reduce the local impact of SO_2 and NO_x emissions from stationary sources was to install taller stacks; an approach which significantly reduced local concentrations of the pollutants and helped urban areas attain the NAAQS. However, it resulted in long-range dispersion of the pollutants, contributing to the acid rain problem. Cap and Trade is a market-based strategy for emissions reduction whereby an aggregate emissions cap for a particular pollutant is set by an agency such as the EPA, but discrete amounts of the pollutant are traded among sources.

In 1990, Congress implemented a Cap and Trade program on SO_2 in response to the acid deposition issue, allocating an annual emissions allowance to each electricity-generating facility. The allowance is determined based on historical resource consumption and entitles the holder to emit a defined amount of SO_2 each year. If the facility's emissions exceed the allocated emissions amount, the facility can either reduce its emissions to achieve the allowance, or purchase allowances from other facilities which have a surplus. The facilities must report their emissions regularly, and the EPA manages an allowance tracking system and ensures compliance.

The overall cap set by Congress represented a 50% reduction in emissions nationwide, which was believed to be sufficient to ensure that trading would not create regions of unacceptably high emissions. The EPA believes that the SO_2 cap-and-trade program has resulted in rapid emissions reductions at lower cost than was initially anticipated. Features believed to be associated with its success include its simplicity, the availability of CEM (source continuous emissions monitor) systems, transparency, certainty of penalties, and the opportunity for banking emissions allowances.

An effort was made to extend the cap-and-trade system to SO_2, mercury, and NO_x emissions in the Eastern US, but this program was somewhat less successful. Some of the issues that complicate cap-and-trade programs include spatial redistribution of emissions, where potential exists for heterogeneous emissions patterns which could worsen existing "hot spots," banking emissions allowances for the future, fairness in allocating emissions allowances, procedures for setting and revising the emissions cap, implicit emission increases following transition to a trading program, and compliance assurance.

In 2005, the Clean Air Interstate Rule (CAIR) was promulgated. It caps SO_2 and NO_x emissions in 28 Eastern States and the District of Columbia, mandating the largest pollution reductions since those set by the acid rain program. States can achieve the emissions reductions by either (a) requiring power plants to participate in an interstate cap-and-trade system that will be administered by the EPA and cap emissions in two stages, or (b) meeting an individual state air emission limit through some measure chosen by the state. In 2005, the United States also promulgated the Clean Air Mercury Rule, which will permanently cap and reduce mercury emissions from coal-fired power plants.

Management of mobile source emissions

Several approaches exist to reducing emissions from mobile sources. One is new-source certification programs which specify emissions standards that apply to new vehicles and motors. The 1970 CAA amendments required vehicle manufacturers to reduce light duty vehicle (LDV) and light-duty truck (LDT) emissions by 90%. Although the CAA amendments in 1977 extended the deadlines after the manufacturing industry claimed that the timescale for implementation was too short, the approach reflected an important new "technology-promoting" approach by Congress. Over time, the development of the technology was refined and installed on new vehicles and by the end of the 1980s, emissions control devices were widespread throughout the US automotive fleet. Despite the success of the technologies, the increase in vehicle miles traveled and the discovery that some evaporative emissions were not being controlled continued to contribute to nonattainment for ozone across the US. In 1990, amendments to the CAA mandated emissions reductions referred to as Tier 1 controls for LDVs. These called for further reductions in NO_x and VOCs and tightening controls on evaporative emissions, including during refueling. Since then, Tier 2 standards have been promulgated, which tighten NO_x and VOC emissions standards even further, limit sulphur content in fuel, and place regulations on medium-duty passenger vehicles.

A series of negotiations between concerned states, car manufacturers, environmental groups and the EPA has resulted in a voluntary national low-emission vehicle (NLEV) program. Although the EPA sets regulations for the program, they come into effect only if and when states and auto manufacturers opt into it.

Heavy-duty vehicles (HDV) were regulated beginning in the 1980s and in 2001 the US adopted new regulations that require reductions in fuel sulphur content and tightening of emission certification standards. Nonroad engines, which encompass a wide variety of engines, including land-based diesel engines, spark ignition engines, marine engines, and diesel locomotive engines, have generally not been subject to emissions regulations in the US. However, in 2004, the EPA finalized a national program to reduce emission from nonroad diesel engines through a combination of fuel and engine controls. The proposed standards would take effect as early as 2008 and are expected to reduce emissions by more than 90%.

Regulations on mobile sources also include in-use technological measures and controls, which includes specifications on fuel properties, vehicle inspection and maintenance programs, and retrofits to existing vehicles. Inspection and maintenance programs for LDVs and LDTs were enhanced after the 1990 CAA amendments but remain a controversial issue politically. This is partly a result of the EPA’s use of a particular model (MOBILE) for estimating emission-reduction benefits from inspection and maintenance (I/M) programs. Although most states have implemented some form of I/M, many have not yet met all of the EPA’s requirements, and the model discounted programs which did not meet the EPA’s criteria. In 1995 Congress responded by allowing more flexibility. Technical controversies also hamper I/M programs, with recent allegations that the programs are not as effective at identifying faulty or non-compliant emissions in vehicles as originally thought.

Regulating in-use emissions of HDVs has also been difficult. The vehicles are typically sturdier and remain in use longer, meaning that older, more inefficient engines remain in operation much longer than for LDVs. As well, it is technically challenging to conduct accurate in-use emissions testing.

Beginning in the late 1980s, a strategy that combined vehicle performance with fuel quality was adopted. The phase-out of lead was highly successful, and the introduction of reformulated gasoline resulted in important reductions in benzene emissions. The federal reformulated gasoline program included performance requirements and content reductions. Implementation of sulphur-reduction regulations is ongoing.

Behavioral and societal strategies also constitute a method of reducing mobile source emissions. Although the 1970 CAA required states to develop transportation control plans (TCPs) for their metropolitan areas, the policies that would be required to attain the NAAQS by 1975 were severe and highly unpopular. Many states refused to submit TCPs, and over time, regulations on motor vehicle use in the states have continued to be politically unfeasible. Efforts to link air quality legislation to transportation planning and investment has met similar institutional resistance and difficulties. In 1990, the CAA amendments required tighter integration of clean air and transportation planning. This affected mainly metropolitan planning organizations (MPOs), the agencies which conduct transportation planning under federal law. If conformity is not maintained, federal funding for transportation can be cut off. If forecasted emissions result in an exceedance of permissible levels as defined by the SIP, the MPO must either alter its transportation plan or promulgate additional mobile or stationary source controls. This has had the greatest impact on rapidly growing urban areas where there is economic and political pressure to expand the transportation infrastructure.

Case Study: Air Quality Management in California[2]

The Role of the California Air Resources Board

California's air pollution control program began in 1959, when the California legislature created the California Motor Vehicle Pollution Control Board, to certify emission control devices for vehicles. Subsequently, under the Federal Air Quality Act of 1967, California was granted a waiver to adopt and enforce its own emission standards for new vehicles, in recognition of its unique air quality and need to set more stringent emission control requirements compared to the rest of the nation. In 1967, the California Air Resources Board (CARB) was formed through the Mulford-Carrel Air Resources Act, signed into law by Governor Ronald Reagen. The Act created CARB by merging the California Motor Vehicle Pollution Control Board and the Bureau of Air Sanitation. CARB has the ability to set mobile source emission standards more stringently than the U.S. Environmental Protection Agency, except sources involved in interstate commerce: trains, planes, ships, and interstate trucking. Other states, like many in the Northeast U.S., have taken advantage of their option to adopt California's mobile source emission standards.

CARB also sets regulations for consumer products, paints and solvents, and identifies and controls toxic air contaminants. It coordinates the efforts of federal, state and local authorities to meet ambient air quality standards, while minimizing the impacts on the economy. While local air quality management districts have the primary authority to control emissions from stationary and areas sources, CARB can assume this authority if local agencies do not develop or implement their air quality plans. Californians support and want air pollution control – 65% support environmental protection over economic growth (although California has accomplished both), and this has created a supportive Legislature. For example, the California Legislature recently passed a bill (signed by Governor Arnold Schwarzenegger) to give CARB the authority to regulate greenhouse gas emissions 1990 levels by 2020, a 25% reduction from business as usual.

The governor of California, with the consent of the State Senate, appoints the 11 members of CARB, five of which are from local air quality management districts. It is an independent board when making regulatory decisions. The Board is required to have a medical doctor and an engineer as members. The first chairman was a respected atmospheric scientist (Professor Arie Haagen-Smit) who discovered how urban smog was created and the latest (Dr. Robert Sawyer) was formerly a mechanical engineering professor at the University of California, Berkeley. Except for the Chairman, the Board only works once per month and relies on its staff for technical input. The Board oversees a $150 million budget and a staff of over 1,100 employees located in northern and Southern California. In addition, the board provides financial and technical support to the 35 local districts. CARB is funded by vehicle registration fees and fees on stationary sources and consumer products. It also receives up to $166 million per year in incentive funds from fees on vehicle registration and new tire sales. This goes to diesel engine retrofits, car scrappage, and agricultural, port and locomotive projects.

California has 4,000 air quality professionals at the State and local levels. Most of CARB's workforce are engineers and scientists, and about 20% have Ph.D.'s and Master's degrees. CARB conducts its own vehicle testing programs and funds extramural research at a level of $5 million per year, taking advantage of the strong academic community in California and other states. It also funds a technology demonstration and commercialization program, and the development of state-of-the-art emission, air quality and macroeconomic models. The technology research demonstrates that reduced emissions are feasible, but the use of performance-based standards allows industry to come up with more cost-effective approaches. Enforcement and monitoring programs ensure that the emission standards are met. CARB has a requirement that the scientific underpinnings of all its regulations undergo scientific peer review. This is normally done by the University of

[2] Adapted from O'Connor, S., and Cross, R. 2006. California's achievements in mobile source emission control, *EM J. Air Waste Manage*, July 2006.

California. Underlying this science-based approach is the willingness to move ahead in the face of some uncertainties.

Air Quality Management Plans and Programs in California

In the post-World War II boom period, California developed severe air quality problems. By the mid-1960s, total oxidant (ozone plus NO_2) levels approached 800 ppb in Los Angeles, and 24-hour-average PM_{10} concentrations exceeded 1800 $\mu g/m^3$ in desert areas and 600 $\mu g/m^3$ in Los Angeles. Although California made significant progress by attaining air quality standards for lead, SO_2, sulfates, and NO_2, and reducing peak ozone levels and PM, there are still many days of unacceptable ozone and particle levels across most of the State. In fact, over 90% of Californians continue to breathe unhealthy air at times.

Mobile sources such as gasoline-fueled vehicles (24 million cars and light trucks for 34.5 million people) and diesel-powered vehicles (1.25 million trucks and buses) play a major role in California's air quality problems. Because of California's proximity to the Pacific Ocean and geography, the meteorology is particularly conductive to generating poor air quality. Los Angeles' pollutant formation potential is the worst in the U.S. due to its unique combination of recirculation patterns, stagnation, inversions, and topography. The Los Angeles Air Basin's carrying capacity (an estimate of the maximum atmospheric burden a region can have and still attain air quality standards) per capita is five times less than Houston's (36 versus 181 lbs VOC and NOx/person/year), which has similar ozone peaks. As a result of the State's poor air quality and large population, California residents receive more than 40% of the nation's population-weighted exposure to ozone values above the national 8-hour standard of 0.08 ppm, and more than 60% of the population-weighted exposure to $PM_{2.5}$ values above the annual standard of 15 $\mu g/m^3$.

California's $PM_{2.5}$ nonattainment areas are dominated by ammonium nitrate and carbonaceous species, derived primarily from mobile sources. Unlike the East Coast of the U.S. and Eastern Canada, California has greatly reduced sulfate levels. This is due to essentially removing sulfur from diesel fuel and gasoline, and the use of natural gas for electrical generation.

PM is California's greatest challenge, as it is responsible for over 6500 premature deaths per year (about 10 times greater than ozone and 20 times greater than cancer cases from know toxic air contaminants). Air pollution is estimated to cost Californians \$51 billion per year – \$4 billion per year in direct medical costs, with the remainder the value assigned to premature death. CARB calculates that California gains \$3 in health benefits for every \$1 it currently invests in air pollution control.

The concept of environmental justice (EJ), which is the recognition that people of all races and incomes need equal protection from the detrimental effects of pollution, has emerged as an important issue in California over the past five years. The debate focuses on the need for community controls in addition to statewide measures.[3] In California, people who live near busy roads are disproportionately Hispanic, Asian, and black, and from low-income families. Several Dutch studies found reduced lung function and higher asthma, hayfever, and wheezing rates for children living near heavy truck traffic (Brunekreef et al., 1997; Janssen et al., 2003). A study by Ralph Delfino found that Hispanic children with asthma symptoms had higher breath levels of benzene, a marker for traffic (Delfino et al., 2003).

California is also concerned about indoor sources of air pollution. Kirk Smith of the University of California, Berkeley has calculated that a typical pollutant release is a thousand time more likely to go down someone's throat if it occurs indoors rather than outdoors because people are usually indoors, near the sources (Smith, 1988). While the sources and risk reduction measures are known, CARB and other agencies have very little authority in this area.

California has adopted many emission standards more stringent than the U.S. standards.

[3] Refer to Chapter 6 for further information on addressing Environmental Justice in air quality risk management.

This includes light- and medium-duty vehicles – exhaust and evaporative standards, handheld and non-handheld small off-road equipment, personal watercraft, in-board motors for boats, and portable engines. Planned regulations for light-duty vehicles include a parts replacement program and improvements to the Smog Check program (i.e., more vehicles to test only, loaded mode testing for gasoline trucks, evaporative emission control test to detect liquid leakers). For forklifts and other large spark-ignited equipment, CARB is working on lower emission standards for new equipment as well as in-use reductions through catalyst retrofits. For heavy-duty vehicles, CARB has a broad range of controls to reduce emissions from both new and in-use vehicles (i.e., OBD, reduced idling, chip reflash, gasoline tanker vapor recovery, in-use inspections in EJ areas) and must go beyond those strategies to get additional reductions. For off-road compression ignition equipment, although California is preempted from controlling a significant (~80%) of this equipment, it is a huge source of emissions and large reductions are needed. California will work with the U.S. EPA to establish more stringent nationwide standards for HC, NOx, and PM from off-road compression ignition engines, and implement in-use strategies to get additional reductions. For marine engines, California plans to get reductions from existing harbor craft through cleaner engines and fuels. For the ports, reductions from land-based port emissions are planned, including cargo handling equipment and locomotives, heavy trucks, and dredges. CARB will set standards for additives to control engine deposits.

California has a goal of reducing diesel PM by 75% during this decade and 85% by 2020. This is being achieved with new emission standards, cleaner fuels, retrofits of existing engines, and enforcement programs. CARB and the U.S. EPA have adopted new vehicle standards that reduce emissions by 90% beginning in 2007. CARB will require aftertreatment on every diesel source where it is technically feasible. Low-sulfur fuel is required, as well as cleaner fuels like CNG (compressed natural gas) and measures to reduce or eliminate idling. Enforcement programs are used to minimize the effects of tampering and wear, especially in environmental justice communities.

California considers greenhouse gases to be ozone and particle precursors and recognizes that climate change can affect urban air pollution. In 2004, CARB adopted regulations that reduce greenhouse gases emitted by passenger vehicles and light trucks, although this measure is being litigated by the automotive industry. Reductions in greenhouse gases on the order of 30% can be achieved for all vehicle types using technologies already deployed in production vehicles. The costs are on the order of a few hundred to a thousand dollars and are more than offset by reduced operating costs of up to $5000. Gas-electric hybrid vehicles and other technologies can achieve greater reductions.

California set the bar for U.S. EPA and European Union emission standards that are now being adopted by many developing countries, particularly in Asia. Most of the world's population benefits from the fact that over 70% of the vehicles worldwide must comply with cleaner emissions standards. These policies have resulted in significant emission reductions and air quality improvements over the years. At least 50% reductions have been achieved in both the stationary and mobile source emission categories over the past 20 years, and will continue their downward trend (see Figure 4.2). These emission reductions have been achieved despite a doubling in vehicle miles traveled and a 50% increase in population. California's economy grew by 75% despite the $10 billion cost per year for air pollution measures adopted since 1990.

Air pollution levels have improved dramatically. The health-based standards for lead, NO_2, SO_2, and sulfates have all been attained, CO is very close, and peak ozone levels have dropped 75% relative to levels in the mid-1960s. California has also had success with PM_{10} and air toxics.

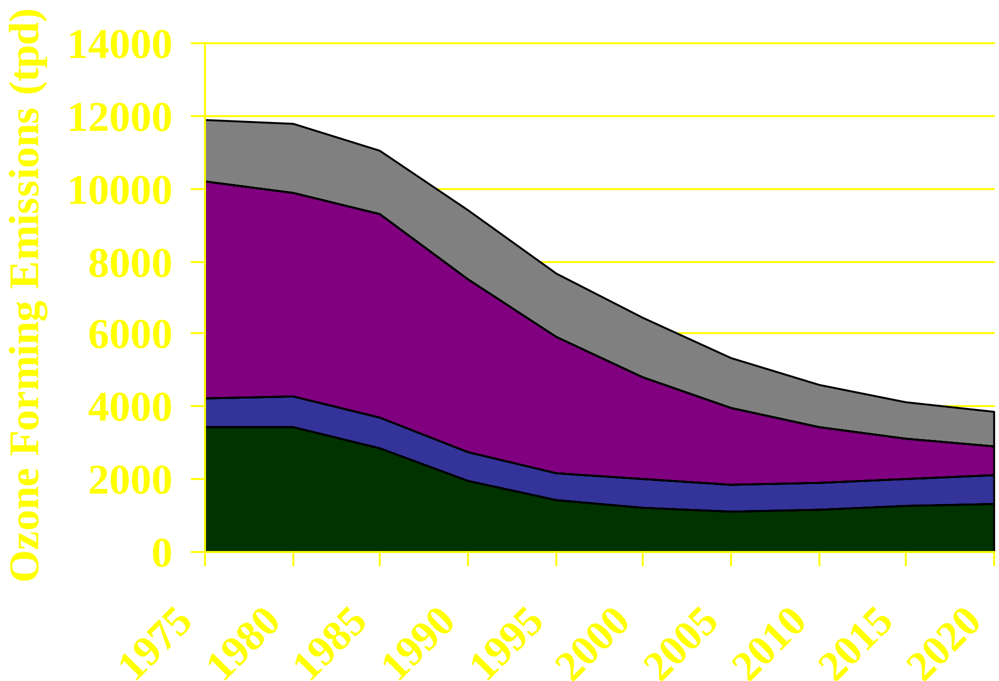


Figure 4.2: Emissions reductions in both the stationary and mobile source emission categories over the past 20 years. (Source: CARB, 2002)

CARB's technology-forcing emission standards have resulted in major advancements in emission control technologies. Today's cleanest passenger car emits less than one percent of ozone precursor emissions compared to the emissions from a car produced in 1960. California's successful introduction of many emission control programs has served as the basis for many similar U.S. programs. Through decades of emission control success, these programs have significantly improved California's air quality, despite more than doubling the number of people and tripling the number of vehicles over the last four decades.

Two of the keys to CARB's success are the technical evaluations that go into its regulation development and the transparent regulatory process. CARB develops new emission test methods, and in some cases, proves that more stringent emission standards are achievable by funding or conducting technology demonstrations. It encourages participation by all stakeholders, including the public, industry and communities that may be impacted by air pollution disproportionately from others. CARB meets with many stakeholders to hear concerns and to provide a mechanism for addressing their issues. It holds workshops that solicit suggestions and comments on initial issues. The technical data and assumptions are published in advance of the workshops. Regulations are first proposed in an initial report and additional workshops are held for public comment. CARB changes its proposal if significant issues are raised that warrant a revision. Once the regulation is adopted, it issues a formal response to all issues raised. The public has a chance to air their concerns directly to our Board members who are appointed by the Governor and represent different professions and regions in California. The Board reviews the technology and enforceability of regulations when necessary to make sure that the regulations meet the expectation held at the time of adoption.

Figure 4.3 shows a 29-year timeline of the cost-effectiveness of various vehicle and fuel regulations, in dollars per pound of ozone precursor. Most measures have cost less than $2 per pound, which is considered to be quite reasonable in comparison to a benchmark of $5 per pound for stationary and area source control measures. Due to technology advancements, these costs have stayed fairly steady. CARB considers economic impacts of its regulations on California businesses and individuals, and regulations do not advantage or disadvantage California manufactured products over products manufactured elsewhere in the U.S. or in the world.

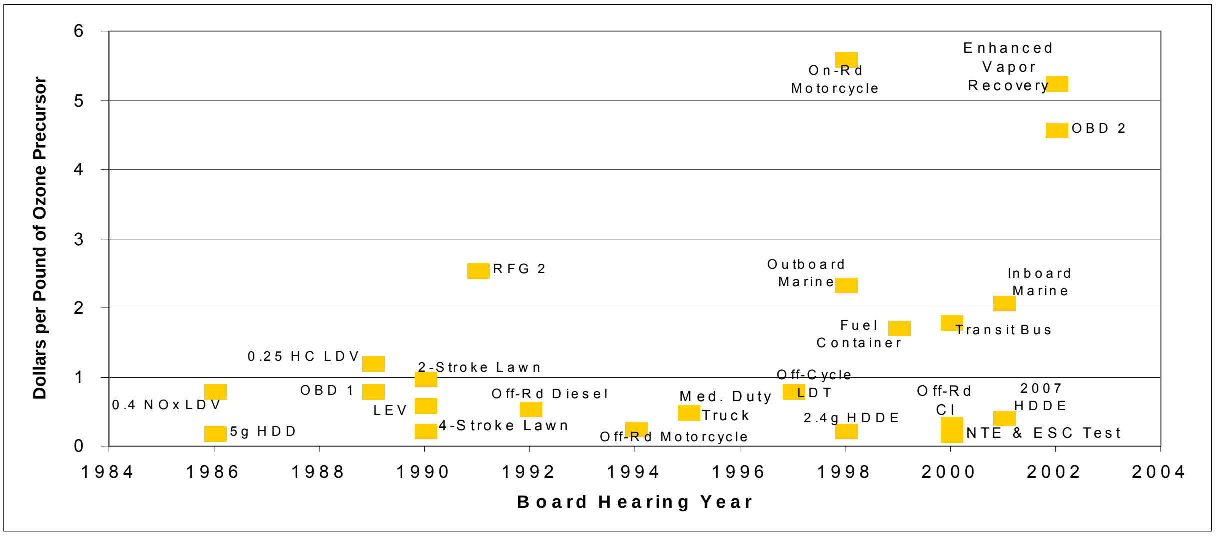


Figure 4.3: Cost-effectiveness of various vehicle and fuel regulations, in dollars per pound of ozone precursor. (Source: Reza Mahdavi, personal communication).

A recent study by EBI concluded that the air pollution control industry in California generated $6.2 billion in revenues and employed 32,000 people in 2001. The U.S. figures are $27 billion in revenues and employment of 178,000 people.

4.2.2 Air Quality Management in Canada

Historical Perspective on Air Quality Management in Canada

In Canada, environmental management is an area of shared constitutional authority, with 14 governments (provincial, territorial, and federal) participating in air quality management activities. However, the main responsibility for controlling air pollution falls under provincial jurisdiction.

The federal and provincial governments first collaborated on air quality issues with the establishment of NAPS, the National Air Pollution Surveillance Network, in 1969, although the Canadian department of the Environment wasn't created until 1971. The first federal regulation to address air quality was the Canadian Clean Air Act (CAA) in 1970, which limited release of chlor-alkali mercury releases from point sources beginning in the mid-1970s. The CAA Secondary Lead Smelter National Emission Standards Regulations soon followed, which restricted emissions of lead from secondary lead smelters.

In the mid-1970s, the first National Ambient Air Quality Objectives (NAAQOs) were developed by the federal government. These guidelines were non-binding objectives, available for adoption by provinces as binding standards. Around the same time, vehicle emissions were regulated for the first time under the *Motor Vehicle Safety Act*. However, there was no further federal legislation covering air pollution until 1988.

In 1988, Canada passed the Canadian Environmental Protection Act (CEPA), which declared that "the protection of the environment is essential to the well-being of Canada." The Act defined pollution control as a priority approach for AQM and included several provisions which address air quality:

- Provisions to control the life cycle of toxic substances including development, manufacturing, storage, transportation, use, and disposal
- Regulation of fuels and components of fuels
- Regulation of emissions from federal departments, boards, agencies, and crown corporations
- Provisions to create guidelines and environmentally safe codes of practice
- Provisions to control sources of air pollution in Canada where a violation of international agreements would otherwise occur

In March 2005, CEPA 1999 was published after a five year review process. The focus of CEPA 1999, which contains many amendments to the original Act, is pollution prevention and the protection of the environment and human health in order to contribute to sustainable development. The updated Act signified a departure from pollution control as a priority approach, setting deadlines for taking action to prevent pollution from toxic substances, and including the power to require prevention planning for toxic substances. CEPA 1999 also expanded the government's authority over fuels and engines, provided additional mechanisms for Canada to meet international obligations, and improved enforcement.

The development of AQM for smog in Canada began in 1990, when the federal and provincial governments committed to a national NO_x/VOC management program in what was intended to be the first of a three-phase plan. Designed to help Canada meet the Canadian maximum acceptable one-hour air quality objective for ozone of 82 parts per billion by the year 2005, it included over 60 initiatives with work shared between federal, provincial and municipal governments. In 1993, the federal and provincial ministers of the environment and ministers of energy signed a *Comprehensive Air Quality Management Plan*, which was intended to coordinate federal and provincial initiatives on air quality. However, in 1997, they failed to reach consensus on phase two of the smog action plan, and the federal government developed its own Phase 2 Federal Smog Management Plan. The plan included several new initiatives for reducing NO_x and VOCs, and identified PM and a contributor to smog. In the meantime, PM_{10} limits were set by several provinces: Newfoundland, BC, and Ontario.

One approach to fostering intergovernmental cooperation on interjurisdictional issues such as air quality is through The Canadian Council of Ministers of the Environment (CCME). The CCME is an intergovernmental council composed of the 14 ministers of the environment for the federal, provincial and territorial governments in Canada. The ministers meet twice a year to try and develop nationally consistent approaches to environmental management issues. However, the CCME does not have the power to enforce legislation; members of the council retain legislative authority for their own jurisdictions.

Initially, the CCME focused on individual areas of environmental protection but in 1993, efforts to harmonize environmental programs and policies became a priority. In January 1998, the Canadian Environment Ministers (with the exception of Quebec) signed the Canada-Wide Accord on Environmental Harmonization. The objectives of harmonization are to i) enhance environmental protection; ii) promote sustainable development; and iii) achieve greater effectiveness, efficiency, accountability, predictability and clarity of environmental management for issues of Canada-wide interest.

Harmonization was intended to encourage cooperation among the provincial governments in development of consistent environmental measures such as policies, standards, objectives, legislation, and regulation across federal and provincial jurisdictions. The Accord delineated the roles and responsibilities of Federal, Provincial, and Territorial governments within a management partnership, so as to prevent overlapping activities and inter-jurisdictional disputes. A series of principles underlies the Accord, including (i) polluter pays, (ii) precautionary principle, (iii) pollution prevention as a preferred approach, (iv) performance, results, and science-based environmental measures, (v) transparency and participation, (vi) cooperation with Aboriginal people, (vii) flexible implementation, and (viii) consensus-based decision-making. The individual governments retain legislative authority and are not prevented from legislating stricter standards than those determined under harmonization.

One element of the Accord was development of Canada Wide Standards (CWS), intended to provide an alternative regulatory tool for the management of environmental issues of national interest. In 2000, federal and provincial governments (except for Quebec) endorsed CWS for ozone and PM with implementation target dates of 2010. Risk Management approaches to air quality under CEPA now integrate both NAAQOs and CWS.

Transboundary cooperation[4]

Canada and the US are large countries separated by an international border that runs more than 8000 km, but they share airsheds and air quality issues. Much of Canada's population lives close to the international border with the US, especially in southwestern Ontario. The prevailing airflow in this area brings air from the industrial areas in the American Midwest to Eastern Canada, and on smoggy summer days, can account for the majority of air pollution in Ontario and Nova Scotia.

In the 1980s, both countries began to experience the impacts of acid rain, which causes a cascade of damaging effects to lakes, streams, soils, aquatic wildlife, and vegetation. Areas experiencing acid deposition included the northeastern States and parts of Ontario, Quebec, and the eastern Canadian provinces. In 1980, the two countries signed a memorandum of intent on transboundary air pollution, and in 1991, the *Canada-United States Air Quality Agreement* became the first agreement on transboundary air pollution. Its *Acid Rain Annex* committed each country to specific emissions reductions: 10 million tonnes of SO_2 emissions nationally, including caps for power generation and industrial sources and 2 million tonnes of NO_x reduction from power generation and vehicles in the US, and in Canada, staged caps on SO_x both nationally and in the eastern provinces plus reduction in stationary source NO_x emissions and implementation of a NO_x control program for mobile sources. The agreement included a notification and consulting mechanism, compliance monitoring, and prevention of air quality deterioration and visibility protection. Although it was negotiated specifically for acid rain, it provided a useful framework for technical and scientific cooperation in general and required regular review, assessment, and public progress reports.

In 2000, Canada and the United States signed an *Ozone Annex* to the Canada-United States Air Quality Agreement, extending its scope to include transport of ground-level ozone between the two countries. The Annex commits each country to reducing NO_x and VOC emissions, precursors to ground level ozone and smog formation, with the US focusing on summertime caps on industrial boiler NO_x emissions, mobile source controls, and new source standards for NO_x and VOC, while Canada focuses on an annual NO_2 power plant cap by 2007, improved fuel and engine regulations, and emissions from solvents, paints, and consumer products.

Cooperation between the two countries has resulted in significant reductions in acidic deposition, acid rain monitoring and ecological assessment programs, development of shared emissions inventories, and production of a joint transboundary ozone assessment report in 1999 and a joint transboundary PM science assessment report in 2004.

In 2003, Canada began working in cooperation with the United States to develop a Border Air Quality Strategy. Three pilot projects were undertaken to investigate approaches towards cooperative transboundary AQM:

1. The Great Lakes Basin Airshed Management Framework was undertaken in Southwestern Ontario/Southeast Michigan, an area where air quality standards for $PM_{2.5}$ and O_3 are routinely exceeded on both sides of the border. The goal of the project was to improve air quality coordination and information exchange between the two countries. The project increased understanding of the technical tools and information used in each country for assessing air quality, completed quality assurance for air quality on each side of the

[4] Based on McLean, B. and Barton, J. (2006). "U.S.-Canada Cooperation: The U.S.-Canada Air Quality Agreement", *Journal of Environmental Epidemiology and Toxicology* (in press),

border, initiated research into health impacts of the area's air quality, and identified improved mechanisms for responding to cross-border complaints. The conclusions from the project were that coordinated AQM of an airshed spanning an international border is both feasible and desirable.

2. The Georgia Basin-Puget Sound International Airshed Project was undertaken in Western Canada, in an area where past local AQM and public support have helped maintain a clean area where air quality standards are usually met. The goal of the project was to increase information exchange and knowledge of regional air quality issues which might have transboundary effects, and to explore policy options for better collaboration and management. Health research on effects of PM is underway, and ongoing collaboration is continuing to identify air pollution causes and solutions, and implement regional measures to reduce emissions from mobile sources, marine vessels, agricultural activities and woodstoves.
3. The Emission Trading Feasibility Study was undertaken to investigate the possibility of developing a cross-border trading of capped NO_x and SO_x emissions. Environment Canada and the EPA reviewed the US cap and trade program and modeled the environmental and economic benefits of cross-border trading, focusing mainly on electricity generators that burn fossil fuels and emit NO_X and SO_2. The study was completed in 2006 and concluded that acid rain, smog, and regional haze are problems in both Canada and the US, and would improve if caps comparable to US levels were implemented in both countries. It also concluded that cross-border trading would not change the overall emissions reductions or the expected benefits to air quality and the environment, and that it would be cheaper to comply with the caps with trading than without trading. To be successful, cross-border trading would require that Canada have enforceable emissions caps for SO_2 and NO_2 with rigorous emissions monitoring and public reporting requirements, and that both countries make legislative and regulatory changes to give the allowances equivalency across the border, and a commitment to pursue implementation of the program.

The impacts of Canada's AQM strategies have been variable. Decreases of 27%, 6% and 15% were observed for emissions of SO_2, NO_x and VOCs between 1990 and 2000, but Canada's per capita emissions of VOCs remained high. $PM_{2.5}$ levels have dropped since the 1980s, but exposure to ground level ozone increased between 1990 and 2003. In 2003, Environment Canada estimated that about 50% of the Canadian population resided in areas where ozone levels exceeded the 3-year standard, and about 33% lived in areas where either $PM_{2.5}$ or both $PM_{2.5}$ and ozone were above the three year standards.

Efforts to develop a health-effects based air quality index (AQI) are underway, with a pilot project being launched in 2005.

Recently, the federal Conservative party tabled the 2006 Clean Air Act, which is described by the party as an integrated, nationally consistent approach to management of air pollutants and greenhouse gases. At the time of writing, it was under review by a special committee of the House of Commons.

Regulation of Air Pollutants in Canada[5]

The regulation of pollutants in Canada occurs at the federal, provincial, and municipal levels. Although the federal government can sign international treaties on air quality, it must have permission from the provinces to take action.

Canadian Environmental Protection Act (CEPA)

Under CEPA, the Minister of Health and the Minister of the Environment are responsible for developing a list of substances considered "toxic," and proposing at least one instrument to prevent or control those substances. These

[5] This section is drawn from Raizenne, M. 2003. Science and Regulation - U.S. and Canadian Overview. *J. Toxicol. Environ. Health, Part A*, 66:1503–1506.

instruments may include regulations, pollution prevention plans, environmental emergency plans or environmental codes of practice. In 2001, the federal government declared PM_{10} to be toxic, with an emphasis on the finer fraction $PM_{2.5}$. In 2003, ozone and the primary precursor pollutants to the secondary formation of smog, including SO_2, NO_x, some VOCs, and NH_3, were also declared to be toxic on the basis of their contribution to smog.

Under CEPA, the federal government also sets NAAQOs (National Ambient Air Quality Objectives). These are national targets intended to protect public health, the environment, and aesthetic properties of the environment. They take a long-term risk reduction approach to protecting the environment and public health while recognizing economic and technical limits. The targets, which were developed for SO_2, NO_2, CO, O_3, and TSP are intended to provide background information, a uniform scale for assessing air quality in Canada and to provide guidance to governments. Provincial governments are responsible for implementing air quality standards, but are free to design their own implementation plans – this may include adopting NAAQOs as enforceable standards. The targets were originally developed as a 3-tier system, where three ranges of air quality (maximum desirable, acceptable, and tolerable) were identified. However, a 1992 review of the NAAQOs recognized evidence that many of the pollutants did not have identified effect thresholds, which is problematic for establishing scientifically defensible threshold values for air quality management. In response, the new design for NAAQOs was a 2-tier system. It included a reference level, above which there are demonstrated effects on the health and/or the environment, and an air quality objective (AQO), a concentration that reflects a specified level of protection while acknowledging technical feasibility issues. In all cases the NAAQOs are to be effects-based values developed after an extensive scientific review of the evidence. Individual provinces are free to adopt the values as objectives or as an enforceable standard.

The 2-tier system has not yet been formalized for the NAAQOs (although CWS have been developed for both $PM_{2.5}$ and O_3). As of 2001, annual publications by NAPS reporting on current air quality compare ambient levels of SO_2, NO_2, CO, O_3 to the NAAQS (National Ambient Air Quality Standards) which were adopted in the US.

The Canadian federal government, in consultation with provincial ministers of the environment, recently developed a set of ambient air quality standards known as Canada-wide standards (CWS). The CWS establish numeric targets for ambient $PM_{2.5}$ (30µg/m^3 using a 24-hour averaging time) and O_3 concentrations (65 ppb over an 8-hour averaging time) that should be met by 2010. The federal, provincial, and territorial governments must publish implementation plans and support strategies of pollution prevention, continuous improvement, and keeping clean areas clean in areas where ambient concentrations are below the CWS. Jurisdictions commit to establishing and maintaining ozone and PM monitoring networks, and designing management plans. Additionally, they commit to providing regular reports on progress and participation in reviews of the standards. Under the CWS, the federal government agrees to aggressively pursue reductions in transboundary flow of pollutants and precursors in areas where jurisdictional action alone will not be sufficient to meet the CWS. The federal government is also responsible for preparing PM and ozone guidance documents, reviewing jurisdictional implementation plans, and overseeing joint initial actions (i.e. multi-pollutant emissions reduction strategies, alternative transportation, and health and science updates).

The CWS recognizes that in many areas of Canada, ambient levels are already below the numerical targets, and provides for AQM in these areas through the principles of "Keeping Clean Areas Clean" – which recognizes that polluting "up to a limit" is not acceptable, and encourages pollution prevention and best management practices, and "Continuous Improvements" – which suggests that all jurisdictions should take remedial and preventive action to reduce emissions where practical, even if they are meeting the numerical CWS target.

In 2004, the Canadian government released the *Federal Agenda on the Reduction of Emissions of Volatile Organic Compounds from Consumer and Commercial Products*, which describes actions to be implemented between 2004-2010 and setting VOC emissions standards for products such as consumer products, automobile refinish coatings, architectural and industrial maintenance coatings, and pesticide products.

Emissions Regulations

The Canadian federal government has responsibility for setting new equipment emission standards; however, provinces are free to set their own more stringent standards.

Up until 2000, emissions limits for Canada's on-road vehicles were promulgated under the *Motor Vehicle Safety Act*; however in 2000, this authority was transferred to CEPA. Under CEPA 1999, the *On-road Vehicle and Engine Emission Regulations* were promulgated. The regulations came into effect on January 1, 2004 and continued previous approaches towards harmonizing Canada's vehicle emissions standards with those of the US. Vehicle and engine certification requirements are now aligned with those of the US federal EPA requirements, including the US Tier 2 program for new light-duty vehicles, light-duty trucks, and medium-duty passenger vehicles as well as the US Phase 1 and Phase 2 programs for new heavy-duty vehicles and engines. Vehicles and engines meeting the more stringent requirements will be phased in over the 2004-2010 model year period, with exact phase-in dates depending on the specific vehicle class. More stringent exhaust emissions standards for LDVs affect NO_x, non-methane organic gases, CO, formaldehyde, and PM. The standards apply equally to all weight categories within the LDV category. Phased emissions standards for HDVs affect mainly NO_x and non-methane hydrocarbons.

No regulations were in place to control emissions from off-road engines until December 2000, when the Ozone Annex to the 1991 Canada-United States Air Quality Agreement was promulgated. Canada committed to establishing regulations under CEPA 1999 that would align with federal EPA regulations. In 2000, before promulgation of the regulations, Canada signed MOUs with 13 engine manufacturers who agreed to supply engines that would meet EPA's Tier 1 standards. In 2005, the Off-Road Compression-Ignition Engine Emission Regulations were promulgated, introducing emissions standards for model year 2006 and later for diesel engines used in off-road applications. The regulations currently follow the EPA's Tier 2 and Tier 3 process with some minor differences, and it is anticipated that they will aligned with Tier 4 regulations in the future.

Cleaner Fuels Regulations

Sulphur in Gasoline Regulations published under CEPA in 1999 limit sulphur in gasoline to an average level of 30 mg/kg with a never-to-be-exceeded maximum of 80 mg/kg. They prescribed the phase-in of low sulphur in Canada in two stages: by July 1, 2002, a limit of 150 mg/kg was imposed, and by January 1 2005, a limit of 30 mg/kg was in effect. The Regulations also include never-to-be-exceeded limits of 300 mg/kg during 2004 and 80 mg/kg thereafter.

Sulphur in Diesel Fuel Regulations were passed in 2002 and stipulate strict new emissions standards. The maximum allowable limit for sulphur for on-road diesel was reduced to 15 ppm in June 2006. Beginning in 2007, off-road diesel fuel will transition to less than 500 mg/kg, and must reach a limit of 15 mg/kg by 2010. Locomotive and marine diesel fuels will be required to have less than 500 mg/kg of sulfur starting in 2007 but will have until 2012 before dropping further to less than 15 mg/kg.

Other fuels regulations limit the concentration of benzene in gasoline to 1.0% by volume and the concentration of lead in gasoline to 5 mg/L (30 mg/L for leaded gasoline). Use of leaded gasoline in motor vehicles has been prohibited in Canada since 1990.

In 1969, Canada established the NAPS Network, the National Air Pollution Surveillance Network as a joint action of the federal and provincial governments. It has expanded to include monitoring of SO_2, CO, NO_2, O_3, and particulate at over 152 monitoring stations in 55 urban centres. Additional monitoring of VOCs, NO_x and rural O_3 is carried out in support of the federal smog plan.

Individual provinces develop their own approaches to AQM, and may impose stricter regulation than what is required federally. For example, Ontario has its own anti-smog action plan, a collaborative effort initiated in 1995, as well as a provincial "drive clean" vehicle emissions testing program. The province is implementing new regulations to apply NO_x and SO_2 limits in five new sectors: iron and steel, cement, petroleum refining, pulp and paper, and carbon black. The limits (which already exist for the power generation and non-ferrous smelting sectors) will become progressively stricter over time. New standards are being introduced for 29 pollutants, several of which have not previously been subject to standards, and air dispersion models are being updated.

Many industries are also taking voluntary steps to reduce emissions, while the non-governmental organizations continue to lobby government, industry and the public to adopt practices that will reduce emissions levels. Many Canadian municipalities have also taken on a diverse array of local air quality management initiatives.

Air Quality Management Plans and Programs: Toronto Case Study

The City of Toronto is located on the North Shore of Lake Ontario in the province of Ontario. It is Canada's largest city and one of the fastest-growing metropolitan areas in North America. The city itself has a population of ~2.5 million, and an average population density of ~4000 inhabitants/km^2. It is situated at the heart of the Greater Toronto Area (GTA), which encompasses 25 separate municipalities in an area of just over 7000 km^2. Ontario is Canada's most populated province, and in general, the population density in Ontario is highest along its Southern border, where the climate is mildest. Toronto is one of a string of municipalities extending from Windsor, in Southwest Ontario, to East of Kingston, and the population density across the region is much higher than in the province (or country) generally. The area is subject to wide variations in meteorology, which is affected by the nearby Great Lakes. In spring and summer, the cooler water in the lakes helps keep temperatures down, while in the fall and winter, moisture from the lakes increases precipitation and the latent heat of the lakes protects the region from cold.

Toronto is also vulnerable to long-range transport of pollutants from the US. Monitoring data suggests that on average, only about 35-40% of PM in Toronto originates in the city (although higher relative contributions exist in some local areas), suggesting that 55-70% of PM may be transported into the city. Additionally, on days when smog levels are high in Toronto, about half of the ozone in the city is estimated to originate from outside Ontario. The other main contributor to air pollution in Toronto is the transportation sector. Recent modeling suggests that in Toronto, motor vehicles contributed about 20% of the PM in the city (Brook, 2006). More broadly, the transportation sector was responsible for 50% of the $PM_{2.5}$, 63% of the NO_x, and 85% of the CO emitted in Ontario in 2001.

The acid rain issue initiated Ontario's first actions on air quality. In the 1980s, the Government of Ontario and the base metals sector negotiated significant reductions in sulphur dioxide emissions. In 1985, the government introduced its "Countdown Acid Rain" program, which placed an annual SO_2 emission cap of 885 kilotonnes on Ontario, a reduction of 67%, to be attained by 1994. Regulations required specific reductions from four major emitters: Ontario Hydro fossil fuel power plants, the Inco nickel/copper smelter in Sudbury, the Falcon-bridge nickel/copper smelter in Sudbury, and the Algoma iron ore sintering plant in Wawa. The emissions reductions began in 1986 and in the case of Ontario power facilities, affected NO emissions as well. In 1997, the four individual regulations were consolidated into a single regulation which outlined the current requirements at the time. Most SO_2 in the province still originates from metallurgical industries such as copper smelters and iron and steel mills, as well as the coal-fired power generation facilities, petroleum refineries, and pulp and paper mills. The highest SO_2 concentrations are usually recorded in the vicinity of these industrial facilities.

Provincial actions on acid rain were complimented by actions at the federal level, including the 1991 signing of the Canada-US Air Quality Agreement and its Acid Rain Annex, which imposed reductions on SO_2 and NO_x emissions in both countries. The results of these activities on air quality in Toronto was significant: overall concentrations of SO_x and PM have declined in the city since the 1970s, as shown in Figure 4.4 and Figure 4.5. In Canada, emissions have dropped by 40% from 3.8 million metric tonnes to 2.3 million metric tonnes over the past 25 years.

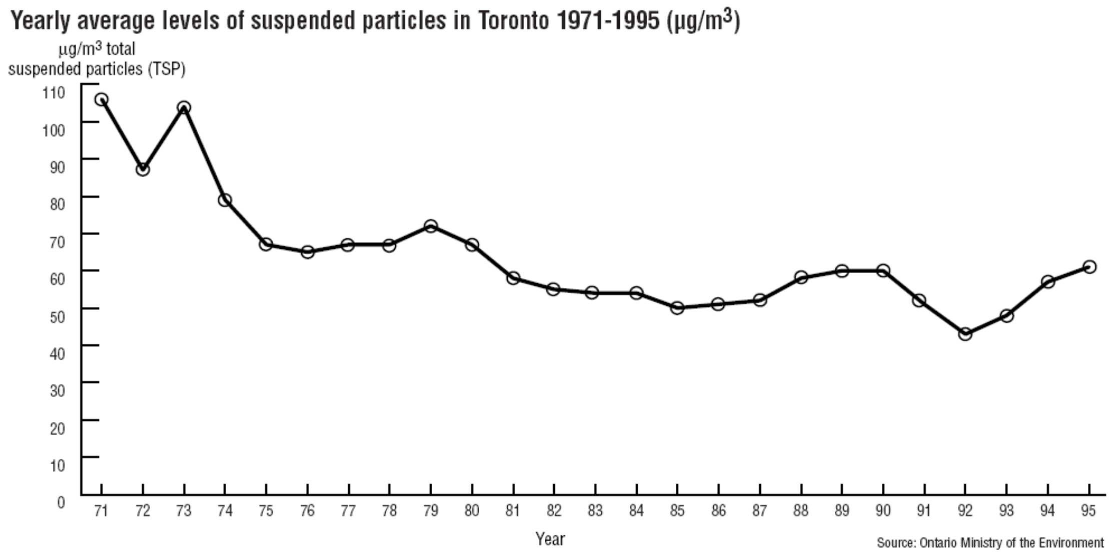


Figure 4.4: Yearly average levels of suspended particles in Toronto 1971-1995 (From: Macfarlane et al., 2000).

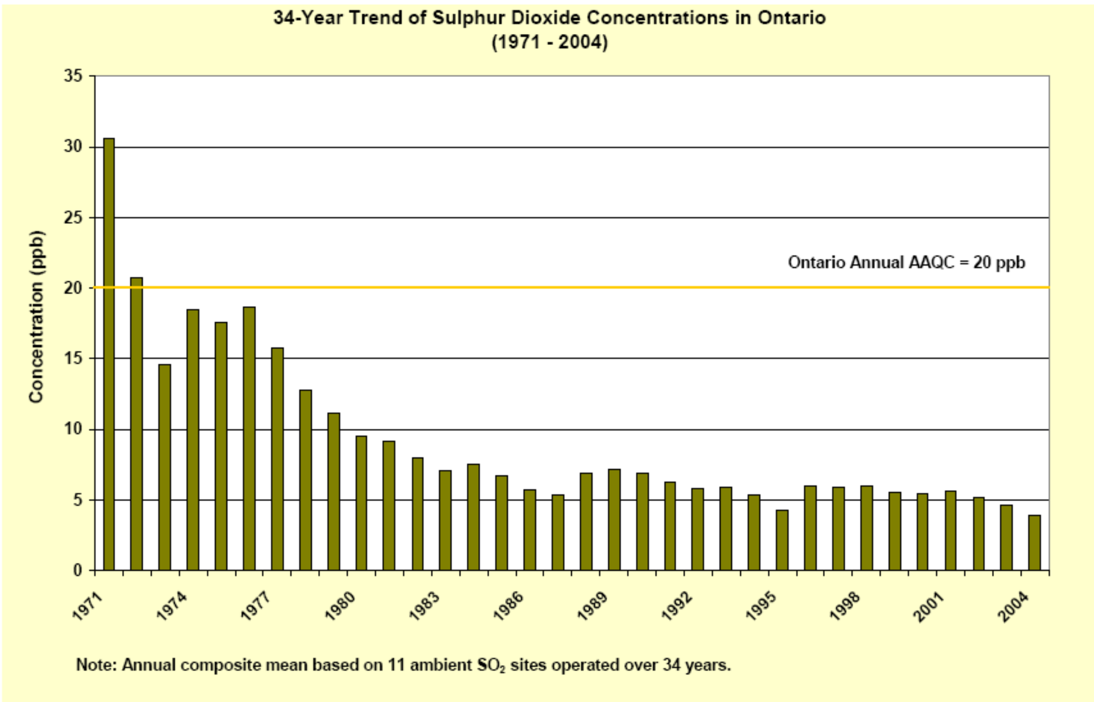


Figure 4.5 34-year trend of sulphur dioxide concentrations in Ontario.

Source: Environmental Monitoring and Reporting Branch, 2004

Actions on ozone have not resulted in the same remarkable improvements (see Figure 4.6). Like particles and acid rain precursors, ozone is subject to long-range transport. Up to 50% of the ozone in Toronto on smoggy days originates in the US. However, ozone generated in Ontario affects other regions, traveling onwards to Quebec, the Maritimes, New York and New England. Between 1979 and 1997, average ozone concentrations in Ontario increased by 19%, with some regions experiencing maximum 1-hour average concentrations as high as 140 ppb in 1998. However, there appears to be a decreasing trend in the province for maximum ozone concentrations of about 13% between 1980 and 2004 (Environmental Monitoring and Reporting Branch, 2004).

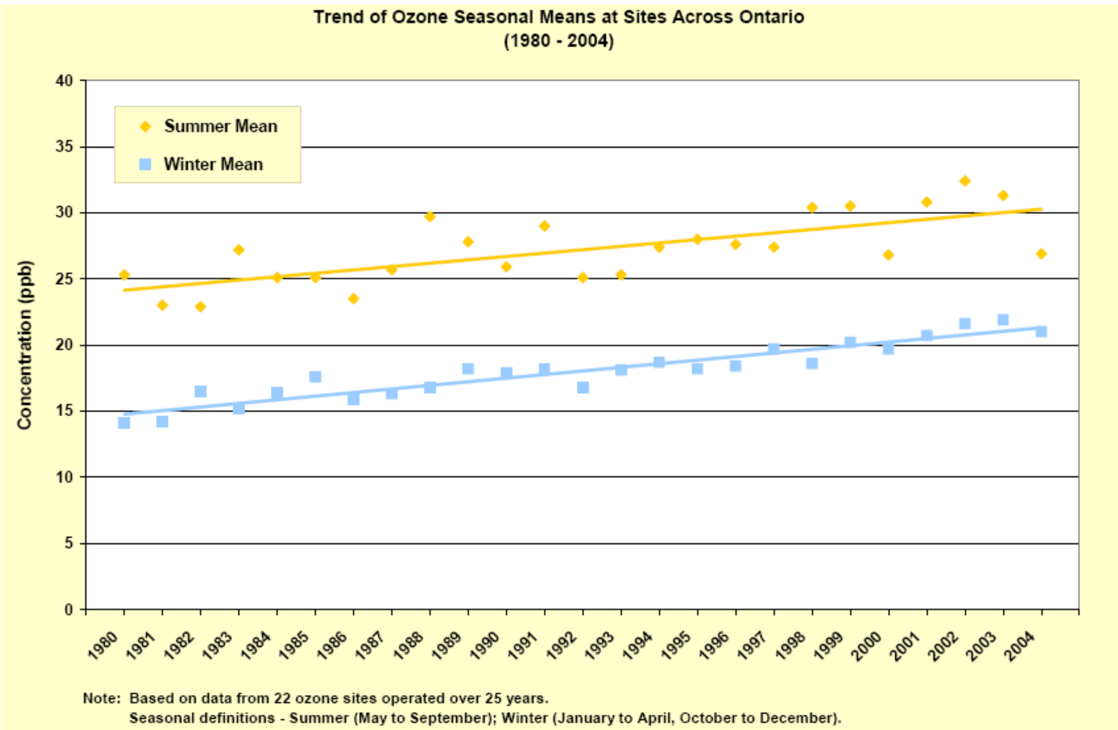


Figure 4.6: Trend of ozone seasonal means at sites across Ontario (1980-2004)
(Source: Environmental Monitoring and Reporting Branch, 2004).

Beginning in 1993, the provincial ministry issued air quality advisories when air quality was poor. In 2000, the Smog Alert Program, operated jointly by the Ontario Ministry of the Environment and Environment Canada, was initiated. Warnings are issued to the public when smog levels are predicted to be persistent and widespread within the next 24 hours, or when high levels of unexpected smog occur. The program operated for health regions in Southern, Eastern, and Central Ontario, and issues a separate air quality index and forecast for larger municipalities such as the City of Toronto. In 2001-2003, there were 75 ozone exceedances in the City of Toronto.

In 2000, Canada and the US added the Ozone Annex to the Canada-US Air Quality Agreement, committing both countries to specific objectives for volatile organic compounds and nitrogen oxides which will reduce transboundary flows of tropospheric ozone and its precursors. The Ozone Annex established a Pollutant Emission Management Area (PEMA), which includes central and southern Ontario, southern Quebec, 18 U.S. states, and the District of Columbia. The provinces and states within the PEMA region are the areas of primary concern for the impact of transboundary ozone. In 2002, Canada and the US met the first requirement of the Annex, which was collection of monitoring data for ozone, NO_x, and VOCs from stations within 500 km of the international border.

Both NO_x and VOC emissions contribute to smog formation. In Ontario, most VOC emissions originate with the transportation sector or from general solvent use. Most NO_x originates with the transportation sector. Recently, studies have shown that concentrations of NO_2 in the city are highest close to major highways and in the downtown core (Jerrett et al., 2003). Traffic density, proximity to highways and industry were all correlated to NO_2 in the city. Additionally, exposure to traffic appears to be correlated with increased rates of circulatory disease hospitalization and mortality in the city (Finkelstein et al., 2004). Concentrations of NO_x have not changed dramatically since the 1970s (Figure 4.7).

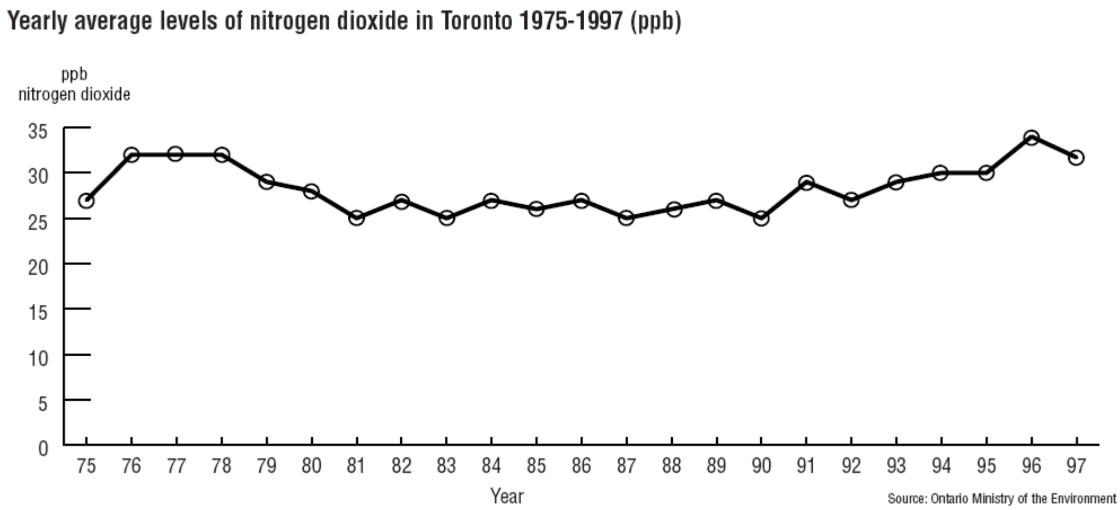


Figure 4.7: Yearly average levels of nitrogen dioxide in Toronto 1975-1997 (ppb) (From: Macfarlane et al., 2000).

In 1998, the city passed an anti-idling bylaw that limits idling to no more than three minutes out of every hour. The same year, the city initiated a corporate smog response plan, where activities such as reduced air conditioning use, evening refueling of vehicles, suspension of non-essential vehicle use, gas-powered lawn-mowing equipment, and use of oil-based products are curtailed on smog alert days.

In 2001, the provincial government introduced an emissions trading program for NO and SO_2, setting limits on the amounts permitted to be released from fossil-fuel-generating stations. However, critics of the emissions trading program suggest that because the government has committed to closing the power plants, which are the major source of the pollutants, the emissions trading system may not be an efficient way of addressing air quality issues.

The provincial government initially committed to closing its coal-fired power plants by 2007. These plants provide about 25% of the electricity used in Ontario, and will be replaced by a combination of several measures: reduced energy consumption through energy efficiency and conservation, investment in renewable sources, construction of new natural gas plants, and restarting of nuclear facilities that were closed in 1997. The initial phase-out date has been extended several times and now stands at 2014. The first plant to close was the Lakeview plant in 2005, which was previously the greatest source of air pollution in the GTA. Another coal-fired power plant, the Nanticoke generating station, has been labeled as Canada's worst polluter and is a major contributor to air pollution in Toronto.

Burden of Illness Report and Subsequent Initiatives

In 2000, the first Toronto Burden of Illness (BOI) report was published (Toronto Public Health, 2000), predicting that 1000 premature deaths and 5500 hospitalizations were caused in Toronto each year as a result of poor air quality. The report suggested that the impacts were preventable, and that air pollution increases severity or frequency of common medical conditions and illnesses. A follow-up BOI report published in 2004 predicted that 1700 premature deaths and 6000 result from air pollution in the city each year (Pengelly and Sommerfreund, 2004). The study was based on the health risk associated with acute exposures to ozone, nitrogen dioxide, carbon monoxide and sulphur dioxide, as well as the health risk associated with chronic exposure to $PM_{2.5}$. The study also notes that air pollution affects thousands of people with less serious chronic illnesses such as chronic bronchitis and asthma.

The first Burden of Illness report garnered significant public attention and concern; it prompted Toronto's first smog summit in 2000, gathering representatives from each of the municipalities in the GTA, and the provincial and federal governments to discuss air quality in the region. The summit is now an annual event at which each of the governments can report on local actions to improve air quality, express concerns, and describe major barriers to improving air quality. The summit has become an opportunity to increase knowledge and exchange ideas.

The BOI report also triggered the creation of *20/20 The Way to Clean Air*, a social marketing campaign designed and run by the public health units of York, Peel, Halton, Durham and Toronto through the Clean Air Partnership (CAP). The program emphasizes individual and collective actions that improve air quality and health in the city, setting a goal of a 20% reduction in energy consumption at home and on the road.

The report also instigated low-sulphur fuel purchases by the city, increased participation in policy discussions, and facilitated NGOs in advocating for clean air. Finally, it promoted further research, giving rise to another report: *Condition Critical: Fixing our Smog Alert Warning System* (Toronto Public Health, 2001.). This report suggested that the AQI (air quality index) in use did not adequately represent the risk to health from air pollution in the city, and did not appropriately warn the public about risks to their health. The AQI did not include particles, was based on air quality standards which are out of date, and was driven by the single pollutant with the highest concentration relative to its standard. Environment Canada is currently developing a new AQI which addresses these concerns, and which has recently undergone pilot testing.

Emission reduction initiatives at the local level play a critical role in air quality management. Municipal governments can contribute to cleaner air through emission reduction measures aimed at corporate fleets, energy conservation and efficiency measures in municipal buildings, public education to promote awareness and behaviour change, transportation and land use planning, and bylaws (anti-idling etc). The Greater Toronto Clean Air Council has developed a resource to assist municipal governments in the development of an integrated approach to reducing air pollution in their communities. A Model Clean Air Plan for the Living City (www.cleanairpartnership.org/gtacac/pdf/clean_air_plan.pdf) provides a menu of options for measures that can be taken as part of a clean air plan and best practice case studies of municipal clean air initiatives and lessons learned in their implementation. This Model Clean Air Plan seeks to reduce the quantity of fossil fuel that local governments and their communities use by reducing consumption, switching to cleaner fuels, improving energy efficiency, and reducing or phasing out activities or products that contribute to smog and climate change. It divides actions into five policy areas (transportation; energy; business, industry and government; natural and built environment; education and outreach). The document notes that in general, many municipalities have found energy efficiency retrofits and improved energy management programs for their buildings, along with cleaner fuels procurement for their fleets, to be cost-effective ways to quickly reduce their smog-causing emissions, but municipalities will have to determine for themselves what is best for their particular situation.

The City of Toronto has been recognized as a leader in reducing greenhouse gas emissions and have recently released a new Framework for an integrated climate change and clean air action plan (www.toronto.ca/changeisintheair/change.htm) to reach greenhouse gas and NOx and PM_{10} emission reduction targets. The plan follows the policy trend in Canada and internationally towards an integrated and harmonized approach to cleaner air and lower greenhouse gas emissions. Twenty-seven proposed initiatives that residents, businesses, industry and the Toronto government can take to reduce greenhouse gas emissions and create a sustainable urban environment are clustered according to four major energy sources that contribute to greenhouse gas emissions and poor air quality - natural gas, gasoline, diesel and electricity. Some examples of proposed initiatives under each source are provided below:

i) Natural Gas: energy efficiency retrofits for family homes, small businesses and high-rise dwellings; mandatory green building standards for new buildings, development of renewable energy systems on city-owned properties
ii) Gasoline: improved city transit plans, expand bikeway networks
iii) Diesel: convert city fleet to biodiesel, identify opportunities to replace food imports with locally produced goods
iv) Electricity: expand energy conservation and renewable energy conservation programs offered by local utilities, ban incandescent bulbs in city owned buildings, convert street lighting to LED, expand deep lake water cooling

While there are many areas of critical need, climate change experts who provided guidance on the plan agreed that the transportation sector and the energy efficiency of residential and commercial buildings are crucial areas of opportunity.

4.2.3 Air Quality Management in Mexico[6]

The Mexican air quality situation is dominated by the Mexico City Metropolitan Area (MCMA), home to 20 million people, 3.5 million vehicles and 35,000 industries. The MCMA is thus the region of highest pollution in Mexico and the focus for air quality management activities. The activities initiated in the MCMA are beginning to spread to other metropolitan areas, and many of the policies adopted to address air quality problems in the city are national in scope.

Historical Perspective on Air Quality Management in Mexico

General Environmental Policy Development

Mexico’s first attempts to create national regulations promoting appropriate use of natural resources occurred with the “Air and Water Conservation Act of 1940.” In 1972, the Government created the Subsecretariat for Environmental Improvement in the Secretariat of Health and Care (*Secretaría de Salubridad y Asistencia*), acknowledging that health problems were arising from environmental pollution. Various laws were created to address environmental policy at a national level but there was little overall control of pollution and waste. It wasn’t until creation of SEMARNAP (The Ministry of Environment, Natural Resources, and Fisheries) in 1994 that the regulations were coordinated by a single administrative body, as the need for a comprehensive plan that included economic, social and environmental considerations was acknowledged.

In 1995, a newly elected Mexican government paid special attention to environmental concerns for the first time. The two main objectives of its National Development Plan were to maintain economic growth and achieve sustainable development. A specific environmental strategy was developed with five focal areas:

- Link political instruments to the promotion and generation of employment and income.

[6] Based largely on Molina, L.T., and Molina., L.T. 2002. A*ir Quality in the Mexico Megacity: An Integrated Assessment* Cambridge, MA: Kluwer Academic Publishers.

- Ensure equitable distribution of costs and benefits, with the objective of fighting poverty.
- Reinforce preventive measures.
- Encourage social participation in policy design through mechanisms of consensus between social authorities and citizen groups.
- Actively participate in international forums and agreements

In 2000, the Ministry responsible for environmental legislation changed names and became SEMARNAT (*Secretaría del Medio Ambiente y Recursos Naturales*), the Secretariat of Environment and Natural Resources, with a mandate to "create a State environmental protection policy reversing the tendencies of ecological deterioration and establishing the basis for sustainable development in the country." It set six main goals around which to structure its activities:

- Integrality
- Commitment with all economic sectors
- New environmental management
- Assessment of natural resources
- Observance of law and fight against environmental impunity, and
- Social involvement and accountability

Although SEMARNAT has principle responsibility for Mexico's environmental policy, some important enforcement duties are the responsibility of state and municipal governments.

MCMA Environmental Policy Development

In the MCMA, a variety of air quality management plans have been implemented over the past few decades. Because air pollution from the city crosses jurisdictional boundaries, there has often been involvement from various levels of government. Construction of high capacity roads and the expansion of the Collective Metro Transportation during 1978-1986 helped address congestion and air pollution to some extent, but initial air quality management plans such as PCMCA (*Programa Coordinado para Mejorar la Calidad del Aire en el Valle de México*), established in 1979, were largely unsuccessful.

A General Law passed in 1988 which assigned jurisdictional responsibility for environmental regulation encouraged development of new policy tools, and during the period from mid 1980s -1990, several important air pollution reduction measures were initiated, including

- conversion of roughly 2000 state-owned buses to new, low-emissions engines
- extending urban electric transit
- implementing no-driving day
- mandating a vehicle verification program
- developing and enforcement of a contingency plan for high-pollution days
- reduction of lead in gasoline sold in the MCMA
- gradual substitution of fuel oil with natural gas in the *Valle de México* power plant
- plans to move high-pollution industries out of the city

At the end of the decade, the first comprehensive air quality management plan was developed for Mexico City. This was achieved as part of an extensive technical collaboration between the Federal District authorities, the World Bank and the German Cooperation Agency.

Until the mid 1990s, environmental problems in Mexico and particularly in the MCMA were addressed through a "command and control" approach. This included use of official Mexican standards, and Environmental Licenses and reports of emissions from industrial facilities. More recently, an integrated approach including prevention, stakeholder input, training, technology transfer, and information dissemination has been favoured. Since 1995, self-regulation instrument such as agreements between enterprise and government, voluntary standards, and environmental audits have also been adopted. Implementation of economic incentives such as taxes and subsidies is still rare.

The Comprehensive Program to Combat Atmospheric Pollution (PICCA) (*Programa Integral contra la Contaminación Atmosférica en la Zona Metropolitana de la Cuidad México*) was implemented in the MCMA from 1990-1995. Its goals were to reduce lead, SO_2, particulate, and NO_x emissions, and the program oversaw a shift towards natural gas for industrial and power sectors as well as reduction of lead in gasoline and sulfur content of diesel and fuel oils, introduction of two-way catalytic converters, the establishment of vehicle standards, and a no-driving program. The program was hampered by inefficiency and a lack of coordination among participating institutions.

PICCA was followed by a series of PROAIRE (*Programa para Mejorar la Calidad del Aire en el Valle de México*) programs –air quality management programs for large urban centres in Mexico formulated with input from government, private, and public stakeholders. Their development and implementation is spearheaded by the INE (National Ecology Institute) with support from state and municipal authorities, academic institutions, NGOs, and the private sector. PROAIRE was first implemented in the MCMA, but has now been expanded to other regions of Mexico including the Guadalajara Metropolitan Area (1997-2001), the Monterrey Metropolitan Area (1997-2000), the Toluca Valley Metropolitan Area (1997-2000), Cd. Juárez (1998-2000), Tijuana-Rosarito (2000-2005), Mexicali (2000-2005), and Salamanca (2003-2006). These programs were implemented with funding from the USEPA and the Western Governor's Association, with investigative support from MIT.

The goals of PROAIRE I included reduction of hydrocarbons, NO_x, particle emissions, and reduction of ozone peak and average concentrations in an effort to achieve greater compliance with guidelines. PROAIRE achieved introduction of MTBE into fuels, further reductions in sulphur content of fuels, reductions of aromatic content of gasoline, and implementation of Tier 1 vehicle emissions standards. Barriers to effective implementation of the program included lack of participation by all sectors, lack of coordination among the various participating institutions, and inadequate administrative and financial support.

The original PROAIRE was followed by a longer, more ambitious program, PROAIRE 2002-2010, which focuses on reduction of ozone and particulates. It includes a series of 89 individual measures targeting mobile, point, and area sources, and specifically addresses transportation and renewal of the automotive fleet. It is designed to improve the links between control options for urban air pollution and greenhouse gas emissions.

The PROAIRE program is intended to be a long-term policy initiative, but is subject to biennial reviews in which resources allocated to groups of policy measures are assessed, and new information is used to determine whether new measures should be added or existing measures abandoned.

Although emission inventories have been developed for the MCMA since 1986, the VOC to NO_x ratios derived from the inventories do not reflect the ratios observed in ambient air, suggesting that the emissions models used were inaccurate. More recently, more reliable emissions inventories have been under development: between 1997-2000, the first emissions inventories were coordinated for the cities of Guadalajara, Monterrey, Ciudad Juarez, Tijuana, and Mexicali. As part of PROAIRE 2002-2010, the National Ecology Institute (INE) and SEMARNAT began developing a nation-wide emissions inventory which includes point, area, biogenic, and mobile sources. The base year for the inventory is 1999, and it covers NO_x, SO_x, VOCs, CO, NH_3, PM_{10}, and $PM_{2.5}$. On September 18, 2006 Mexico released its first National Emissions Inventory (NEI), a tool which will inform ongoing institutional efforts to manage air quality.

Significant improvements in monitoring and evaluation of air quality have occurred in Mexico over time. Visibility range was the main indicator of air quality in Mexico from 1940 up until 1970. In 1940, the average visibility range was 4-10 km, in the 1950s it was 2-4 km, and it is now 1-2 km. In 1967, the Pan-American Network of Standardized Sampling was introduced, collecting SO_2 and TSP data at 14 stations, and in the 1970s Mexican authorities added an additional 22 manual SO_2 and TSP stations in collaboration with UNEP. In 1985, the USEPA assisted with the installation of an automatic monitoring network, known as RAMA (*Red Automática de Monitoreo Atmosférico*). By 1999 there were 37 stations collecting data on NO_x, TSP, CO, and O_3 as well as data on SO_2 and Pb. In August 2003, the city government inaugurated a six-station $PM_{2.5}$ monitoring network now integrated by CENICA in a real-time system.

In the summer of 2006, the Registro de Emisiones y Transferencia de Contaminantes (RETC), Mexico's first mandatory pollutant release and transfer register (PTRER) was published, providing public access to detailed information about the release and transfer of 104 toxic chemicals.

Regulation of Air Pollutants in Mexico[7]

Air quality was recognized as a social and environmental problem in Mexico beginning in the 1960s. The first law addressing air quality specifically, the Federal Law for Prevention and Control of Environmental Pollution, was passed in 1971, and in 1978, an Interministerial Commission for Environment was established to oversee the implementation of its regulations. A second national environmental legislation was the Federal Law of Environmental Protection, enacted in 1982 and amended in 1984 to include an air quality monitoring system. However, the new law had little effect since air quality guidelines and enforcement procedures were unaltered. As well, financial crises in the early part of the decade and the Mexico City earthquake of 1985 diverted attention and resources from the issue.

The primary legal mandate for air pollution prevention in Mexico at the national level is the 1988 General Law of Ecological Balance and Environmental Protection. The law assigns environmental responsibilities at various jurisdictional levels. The federal government has several responsibilities:

1. Issuing standards for air quality. This includes ambient air quality standards, maximum allowable emissions releases for industrial facilities, and emissions limits for vehicles. The current ambient air quality standards were adopted.
2. Permits for industrial facilities under federal jurisdiction (which includes most heavy industry, such as chemicals, energy, metals, cement, paper, cars, and transport). The government requires these facilities to install air pollution control equipment, monitor emissions, and compile and submit emissions inventories.
3. Enforcement. The government may delegate some enforcement activities in agreement with state and municipal governments.
4. Air quality issues that affect multiple states.

The State and local governments are responsible for regulating light industry, vehicle use, including vehicle inspection and maintenance programs and driving policies, zoning, and measures to be taken under air quality "emergencies." They must also carry out air quality monitoring, and are responsible for developing transit plans.

The governance of the MCMA is split primarily between the Federal District (Distrito Federal or DF) and the State of Mexico (*Estado de Mexico* or EM). One of the major obstacles to the implementation of anti-pollution measures in the MCMA is the lack of a powerful metropolitan institutional structure. The Metropolitan Environmental Commission (*Comision Ambiental Metropolitana*, or CAM) was created in 1996 to coordinate the policies and programs that are implemented in the metropolitan area. Permanent members of CAM consist of the federal Secretariat of Environment and Natural Resources, the federal Secretariat of Health, the Chief of Government of the Federal District, and the Governor of the State of Mexico.

Every two years, the responsibility to preside over CAM changes between the DF and the EM governments. Any decision on how to organize the Commission as well as the responsibility for operating costs would go to the jurisdiction in office at the time. Frequently, the side presiding over CAM has to use its own financial resources to manage the commission and its own environmental officials also serve as CAM officials. The local government that is not presiding over CAM, as well as the federal government, contributes human resources and other support to CAM operations, mainly for the

[7] From Molina, M.J. and Molina L.T. 2004a. Critical Review: Megacities and Atmospheric Pollution. *J. Air Waste Manage. Assoc.* 54:644–680 and Molina, L. T.et al. 2004b. *2004 Critical Review Online Version: Air Quality in Selected Megacities*, http://www.awma.org.

specific tasks of its working groups.

The Environmental Trust Fund for the Valley of Mexico (*Fideicomiso Ambiental del Valle de Mexico*) was created exclusively to support CAM projects. Between 1995 and 1997, the Trust Fund received money collected from the application of a surcharge on gasoline sold in the MCMA. The annual renewal of the surcharge required the approval by the Finance Ministry, which did not happen in 1998. Since then, the surcharge has not been reactivated. The Trust Fund has its own organization and rules of operation, and it is managed through an Executive Committee headed by the Finance Ministry. One representative each from CAM, governments of the DF and the State of Mexico and SEMARNAT are included. However, without income, the Trust Fund has been depleted. Other sources of funding for CAM projects include international environmental agencies, national and international financial institutions, international and national academic institutions and foreign governments.

There are serious concerns over its current operation: one of the most important issues is that CAM does not have a specific budget for its own operation, nor does it have a defined operative organizational structure as well as lack of continuity. The Technical Secretariat is appointed by the presiding government, which rotates every two years; in addition, local and federal representatives change in response to political events. These deficiencies in institutional memory cloud an integrated long-term vision of the policy requirements.

The Metropolitan Commission for Transport and Roadways (*Comision Metropolitana de Transporte y Vialidad*, or COMETRAVI) has a mandate similar to that of CAM, but it also lacks financial resources and has no executive or regulatory powers. In 1999, COMETRAVI developed a proposal for the adoption of comprehensive integrated strategies for transportation and air quality in the MCMA. This strategy has not been incorporated into the official programs.

The lack of integration of environmental policies with transportation, urban development and land use planning is one of the most important barriers preventing sustainable environmental improvements. Another important barrier is the incomplete harmonization of environmental policies among the Federal Government, the State of Mexico and the Federal District, which results in unfair practices and inefficiency. Also, at present neither local nor federal environmental agencies have sufficient human and financial resources to efficiently carry out their environmental management activities. Furthermore, the continuing dispersion and growth in the size of the MCMA drive the need for vehicle-miles traveled still higher. The almost totally unregulated establishment of communities on the periphery creates both mobility and environmental problems. The development of a regional planning commission with strong enforcement capability is fundamental to creating a sustainable transportation/ environmental system in the MCMA.

As a large source of emissions, the MCMA has the potential to influence air quality over a much wider region than the Valley of Mexico thus exposing larger populations in nearby cities and also affecting forests and crops. Pollutants emitted outside of the MCMA likewise may influence air quality within the Valley of Mexico. Therefore in addition to metropolitan coordination, there is an urgent need for regional coordination and planning. To ensure continuity in the implementation of long-term strategies, it is essential that the CAM be significantly restructured and be empowered to carry out the planning, integration and implementation of metropolitan environmental policies.

AQ Indices

Air quality for criteria air pollutants in the MCMA are reported as IMECA units (*Indice Metropolitano de Calidad del Aire*), or Metropolitan Index of Air Quality. They are derived from dividing the measured concentration of the pollutant by its concentration guideline. If the value of the ratio is less than 100 the air quality is considered satisfactory. Between 101-200 and the air quality is considered unsatisfactory. Values between 201-300 indicate “bad” air quality, and 301-500 IMECA units indicates “very bad” air quality. If the IMECA units exceed a certain threshold (currently 240 for ozone, which is equivalent to 280 ppb), certain mitigation and adaptation measured are triggered: activity of polluting industries is restricted, vehicle use is restricted, and outdoor activities at primary schools are curtailed.

The IMECA ozone threshold is higher than similar thresholds in the US (about 205 ppb) and elsewhere.

Case Study: Air Quality Management in Mexico City[8]

The severity of the air quality problem in Mexico City has spurred large amounts of research and action, making it an ideal case study for learning about challenges facing those who undertake air quality research, management, and policy. Indeed, Mexico City serves as the case study for MIT's Integrated Program on Urban, Regional and Global Air Pollution[9] which was initiated in 1999, which has as its goal to "provide objective, balanced assessments of the causes and alternative cost-effective solutions to urban, regional and global air pollution problems through quality scientific, technological, social and economic analysis in the face of incomplete data and uncertainty" and will serve as a great resource for air quality management generally.

The Mexico City Metropolitan Area (MCMA) is one of the largest cities in the world and continues to expand rapidly. In 1950, the population hovered around 3 million and occupied about 120 km^2. Today, as a result of migration from other parts of the country and a rapidly industrializing economy, the city has swelled to almost 20 million inhabitants occupying 1500 km^2. An estimated 40 million litres of fuel is consumed per day in the MCMA (Molina and Molina, 2004a), generating smog precursors and pollutants. Located in an elevated basin at 2240 metres above sea level and surrounded by mountain ridges on three sides, the city is prone to thermal inversions that trap pollutants in the MCMA basin. Pollution tends to be worst in the winter, when there is less rain and the inversions are more frequent; the high elevation and intense sunlight promote photochemical ozone formation year-round.

In 1992, the United Nations described Mexico City as the most polluted city on the planet. Between 1995 and 1999, the city's population was consistently exposed to PM_{10} concentrations above 50 $\mu g/m^3$ (the annual standard in Mexico), and two million MCMA residents experiences concentrations of 75 $\mu g/m^3$ or more. The daily maximum one-hour standard for ozone was exceeded 300 times a year or more (The Mexico Air Quality Management Team, 2002).

Throughout the 1990s, successful reductions in concentrations of air pollutants such as lead, carbon monoxide, and sulphur dioxide were achieved as comprehensive air quality programs were developed and implemented, and monitoring and evaluation of air pollution improved.

In 1990, unleaded gasoline was introduced to Mexico City, and by 1997 was the only type of gasoline available in the MCMA. This has lead to a dramatic improvement in ambient lead levels (See Figure 4.8), with the guideline for lead not being exceeded since 1993. Additionally, blood lead levels in the MCMA population have declined.

[8] Based on Molina, L.T. and Molina, M.J. 2004c. Improving air quality in megacities: Mexico case study. *Ann. N.Y. Acad. Sci.* 1023:142-158. Supporting evidence from MIT's Laboratory For Energy and the Environment (2002), *Air Quality Management in the Mexico City Metropolitan Area: An Interview with Mario Molina and Luisa Molina*. Initiatives in Energy and the Environment - a quarterly publication of MIT's Laboratory For Energy and the Environment.4 (2) pp. 8-9 http://lfee.mit.edu/public/LFEEnews_4.2.pdf

[9] For more information, visit http://mce2.org/airpollution/introduction.html

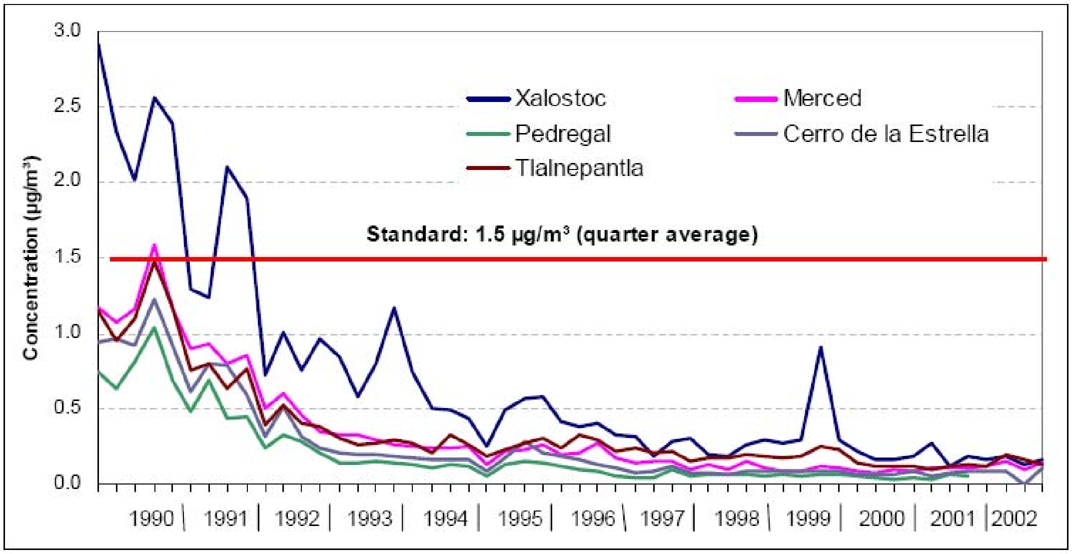


Figure 4.8: Lead concentrations measured at five monitoring stations in the MCMA 1990-2002. Source: (Bremauntz, 2007).

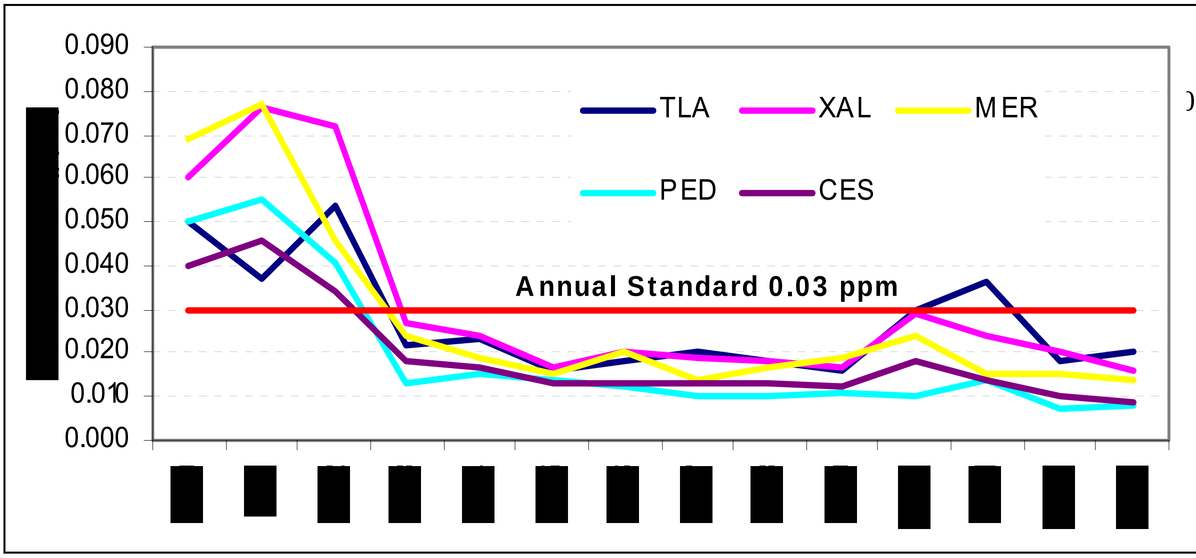
Sulphur dioxide levels improved as heavy fuel oil and high sulphur diesel was replaced by natural gas in industry and the power sector in the early 1990s. By the middle of the decade, heavy fuel oil use was completely phased out in the MCMA. In 1995, PEMEX, the state-owned oil company, replaced its high-sulfur diesel with a new variety containing 500 ppm sulfur.

Figure 4.9 shows the dramatic decline in SO_2 concentrations across the MCMA in the mid 1990s. Emissions controls including membranes and floating roofs were installed in fuel storage tanks, and vapor recovery systems (phase 0, I, II) were incorporated into the gasoline system. Self-regulation schemes were promoted and fiscal incentives and duty tax exemptions were established to encourage cleaner technologies. Relocation of major industrial plants outside the valley and the 1990 closure of a large oil refinery near the MCMA also helped to improve air quality.

In recent years, a slight increase in sulphur concentrations has been observed, and is thought to be a function of illegal use of fuel oil by some industries in response to high natural gas prices.

Transportation

The transportation sector is a major contributor to Mexico City's air quality problems, contributing more than 99% of the CO, ~80% of nitrogen oxides (NO_x), 45% of the VOCs, and 80% of the $PM_{2.5}$. As the population has grown, it has also decentralized. Official estimates suggest that in 2020, a projected 37 million "trip segments" will be made in the MCMA daily, up from an estimated 29.1 million in 1994. In the past years, the percentage of trips made by fixed-route buses and on the Metro system has declined. The existing transit system has not adequately adapted to the changing population distribution and travel patterns, and low-income housing and new commercial developments have been built without adequate concomitant roadway construction or access to mass transit. This may be partly responsible for the shift towards increased vehicle ownership of about 6% per year. Use of *colectivos*, minibuses which follow a set route and stop frequently to pick up and drop off passengers along the way, has also increased. Emissions control equipment on these vehicles is usually not well-maintained, and thousands of these minibuses compete for passengers in the city, increasing congestion. Taxis, many of which are older, inefficient vehicles, tend to have poorly maintained emissions control equipment, and contribute to congestion by driving around looking for passengers. Uncontrolled growth of both the *colectivo* and the taxi fleets pose difficult policy challenges.



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The ageing freight fleet is also an important source of emissions in the MCMA as goods are shipped to and around the city by truck, contributing to congestion and emissions. Due to a lack of routes that circumnavigate the MCMA, intracity freight often travels through the city.

Catalytic converters were first put into Mexican vehicles beginning in 1990, and by model year 1993, all cars were equipped with three-way catalytic converters. Stricter emissions limits were established, including adoption of US Tier 1 standards in 1999, encouraging use of more advanced control technologies. At the same time, fuel quality was improving. As a result, emissions in the MCMA have decreased despite an increase in vehicle miles traveled. In 2000, the Mexican authorities reached an agreement with vehicle manufacturers for continuous improvement such that the Mexican standards attain equivalency with US Tier 2 standards with a delay of 2 years or less. At the same time, PEMEX has continued fuel improvement efforts and in 2006, introduced 50 ppm sulphur gasoline for the Tier 2 vehicles and 300-ppm vehicles for the rest.

In 1989, the government adopted the *Hoy no Circula*, or “no driving day” program, which imposed a rotating ban on personal vehicle use. Cars were prohibited from driving one day a week based on the last digit of their license plate number. The program, which grew out of a grassroots initiative was initially successful, and decreases in both pollution and congestion were observed. In the long-term however, it proved difficult to enforce: many families bought a second car – often an older and more polluting vehicle. Ultimately, the program had the unintended effect of increasing driving by families which purchased a second vehicle and of drawing older, more polluting cars into the city from other regions of the country.

Beginning in 1993, the government strengthened and began to enforce the vehicle inspection program, which requires car owners to have their vehicles certified every six months, and harmonized procedures at Federal District and State inspection centres. In 1996, the inspection and maintenance was updated to act as an incentive to replace older, more pollution cars. Cars aged 1993 or newer with catalytic converters are no longer subject to driving restrictions of any kind. Cars with electronic fuel injection systems but no catalytic converter (usually cars aged late 1980s to 1992) are banned from driving one day a week, but may be driven during pollution episodes which fall on permitted driving days. Cars with a carburetor and without a catalytic converter are subject to two restrictions: they cannot operate one day of each week or during any declared pollution episode.

Low-interest loans are being provided for vehicle substitution for *colectivos* and taxis made before 1992, and roadways and other infrastructure aimed at reducing congestion are being built. The government has created incentives to persuade companies to invest in cleaner vehicles, and has used subsidies to encouraged manufacturers to furnish gasoline-powered delivery trucks with cleaner liquefied petroleum gas.

As a result of air quality management activities, the concentrations of CO, NO_x, and SO_2 (see Figure 4.9, 4.10 and 4.11) have also decreased and now rarely exceed the air quality guidelines. The most significant impacts are attributed to introduction of catalytic converters and improvement in fuel quality, and to a lesser extent, implementation of stricter industrial regulations and conversion to natural gas by the power plants. However, the ozone levels (see Figure 4.12) and PM levels still remain unacceptably high.

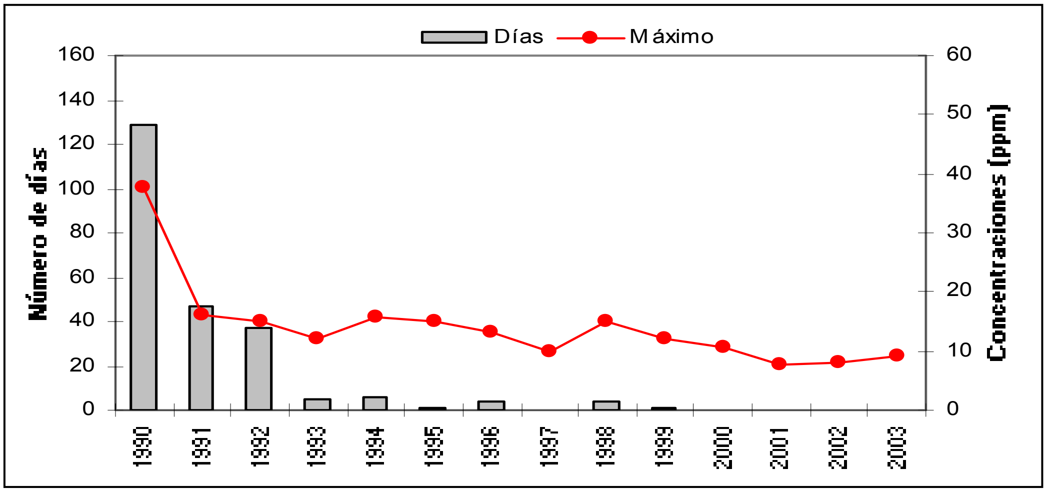

Figure 4.10: Carbon Monoxide concentrations measured at five monitoring stations in the MCMA 1990-2003 (Source: Bremauntz, 2007).

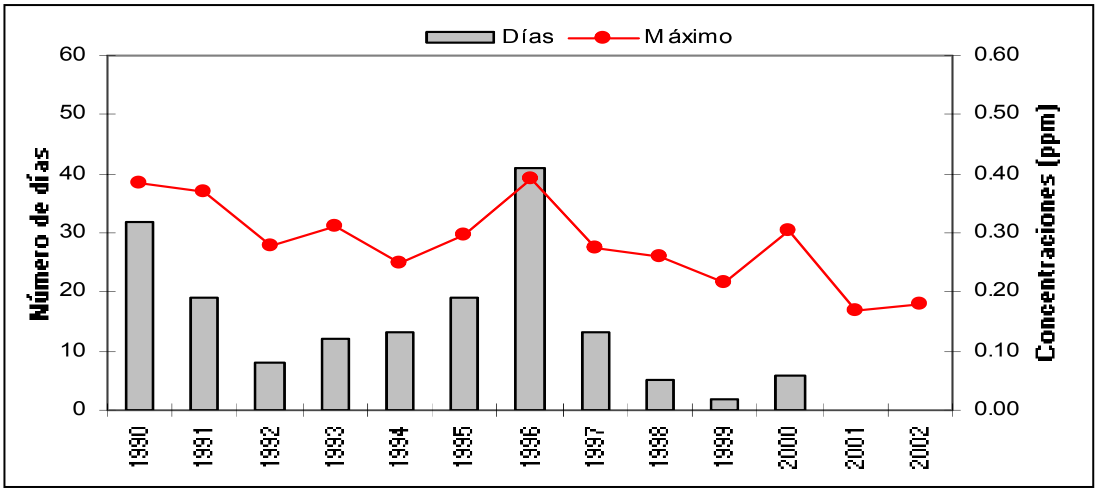

Figure 4.11: Nitrogen dioxide concentrations measured in Mexico City: days above 1 hour standard (0.21 ppm) and 1 hr maximum concentrations. Data from 5 representative monitoring stations. (Source: Bremauntz, 2007).

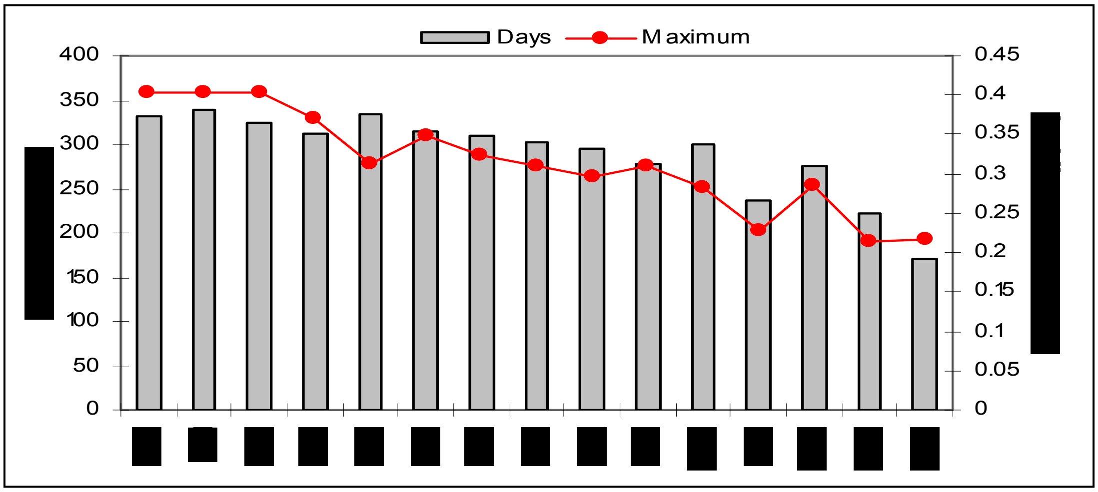

Figure 4.12: Ozone concentrations measured in Mexico City: days above 1 hour standard (0.11 ppm) and 1 hr maximum concentrations. Data from 5 representative monitoring stations. (Source: Bremauntz, 2007).

In response to increased vehicle traffic, the government is extending the metro lines and introducing bus rapid transit. They are making efforts to improve service quality, facilitate transfers between modes of transportation, and improve personal security.

In 2002, Mexico City's environment secretary signed an agreement with the World Resources Institute (WRI) to create the Center for Sustainable Transport in Mexico City (CSTMC). The broad mission of the CSTMC is to devise a sustainable transport network for the city of 20 million, and its initial goals were to focus on bus rapid transit, engine/fuel combinations for the high capacity buses and retrofitting existing diesel vehicles (Samaniego and Figueres, 2002). In June 2005, a Bus Rapid Transit system was launched, with designated bus lanes running along 14 km of the central transport artery Insurgentes Avenue. A recent pilot project to retrofit Mexico City's diesel buses with catalytic converters and diesel particulate filters, using ultra-low-sulfur diesel (ULSD) fuel imported from the US showed that particulate matter (soot) emissions could be reduced from older buses by 20-30% and from newer buses by up to 90%. Partly because of these findings, PEMEX will accelerate its plan to produce ultra-low sulphur diesel, making it available by 2007.

Mexico has also instituted land use planning for both urban development and rural areas, ecological restoration, including rural and urban reforestation, human settlement control in rural areas, and environmental education and research including establishment of an Epidemiological Surveillance System and increase in air quality research activities.

Various other initiatives which have been introduced for learning purposes include the pilot use of solar water heaters, introduction of efficient lighting on a massive scale, testing of electric vehicles, and a carbon sequestration project in the south of the Federal District.

Benefits

The impact of poor air quality on health is discussed more fully elsewhere in this document. However, the issue is particularly important for residents of the MCMA, where the higher altitude and concomitant decrease in oxygen means that more air (and pollutants) may be inhaled overall by residents in order to obtain sufficient oxygen. In 2002, Evans (Evans et al., 2002) estimating the benefits of a 10% reduction in PM and ozone at $760, 000-2, 200 000 US dollars. In 2004, Molina and Molina reached a similar conclusion, estimating that a 10% reduction in PM and a 10% reduction in ozone would be associated with benefits of $1,950,000

USD, related to 3,000 fewer deaths (due to PM reduction), and 300 fewer deaths annually (due to ozone reduction) (Molina & Molina, 2004a).

Conclusions

As a result of air quality management activities, the concentrations of CO, NO_x, and SO_2, have decreased and now rarely exceed the air quality guidelines. The most significant impacts are attributed to introduction of catalytic converters and improvement in fuel quality, and to a lesser extent, implementation of stricter industrial regulations and conversion to natural gas by the power plants.

However, decreases in PM, ozone, and NO_2 are inadequate. The PM standard is violated on ~40% of days, and the ozone standard is violated on ~80% of days. Barriers to implementing air quality control measures include lack of financial resources, lack of information, and inadequate follow-up.

The benefits of improving air quality have been established and the government, with assistance from a variety of international organizations, is continuing to address air quality in Mexico, and specifically in the MCMA.

4.3 Air Quality Management in the European Community

Historical Development of Air Quality Management in the European Community

European Union legislation on environmental issues and air pollution

An important starting point for the development of environmental policy was the first United Nations Conference on the Environment in Stockholm in 1972. In 1972 the European Council made a commitment to establish a Community environmental policy. The first so called Environmental Action Programme (EAP[10]) was decided in November 1973, which laid down principles for the environmental policy in the Community. It emphasized inter alia that economic development, prosperity and the protection of the environment are mutually interdependent.

However, environmental considerations were also always linked to other considerations relevant for policy development within the Community, e.g., the setting of uniform emissions standards to avoid distortions to industry competitiveness. Product regulations had to be harmonised in order to avoid non-tariff barriers originating from different national product norms. On the other hand, the economic benefits, especially the positive employment effects to be gained from environmental policies were stressed.

Environment policy was built into the Treaty by the Single European Act of 1987 and its scope was extended by the Treaty on European Union on 1992. This allowed the use of majority voting on environmental legislation. The general objectives formulated now in the Treaty are to:

- Preserve, protect and improve the quality of the environment,
- Protect human health, and
- Utilize natural resources in a prudent and rational way.

For achieving these environmental objectives the Treaty explicitly lists the precautionary principle, the principle of preventive action, the principle of rectifying damage at the source and the polluter pays principle.

In 1992, the EC set itself the objective for achieving sustainable development. The long-term goal, to transform the European economy into one whose development would be sustainable for generations to come, was set out in the 5th Environmental Action Programme 'Towards Sustainability'[11]. In addition, the 5th Environment Action Programme calls for the effective protection of all people against recognized health risks and demands that the guideline values of the Word Health Organization (WHO, 2000) should become mandatory at the European Union (EU) level.

The 6th Environmental Action Programme (covering the period from 2001 to 2010) identifies four environmental areas for priority actions:

- Climate Change.

[10] http://ec.europa.eu/environment/env-act5/envirpr.htm

[11] http://ec.europa.eu/environment/actionpr.htm

- Nature and Biodiversity.
- Environment and Health and Quality of Life.
- Natural Resources and Waste.

The main avenues for action include:

- Effective implementation and enforcement of environmental legislation: necessary to set a common baseline for all EU countries.
- Integration of environmental concerns: environmental problems have to be tackled were their source is and this is frequently in (?) other policies.
- Use of a blend of different approaches: all types of instruments have to be considered, not just legislation. The essential criteria being optimal efficiency and effectiveness.
- Promoting of participation and involvement across society – business, citizens, NGOs and social partners – through better access to quality information on the environment and co-operating to devise solutions.

In addition, the EAP requires the European Commission to prepare Thematic Strategies covering seven areas including air pollution.

Environmental legislation leaves plenty of scope for national action and allows Member States to take tougher protection measures than those agreed at the EC level. The situation is different for legislation affecting the free movement of goods (e.g., product regulations). Stricter regulations may only be applied in special cases.

Development of air quality legislation in the European Community

The first so-called Directive of the European Community on air quality entered into force in 1980 (Directive 80/779/EEC). This Directive set air quality limit values and guide values for sulphur dioxide and suspended particulates. The Directive specified a date by which the limit values had to be attained, but also allowed for a prolonged period of noncompliance in zones if a Member State could show that plans for the progressive improvement of the quality of the air in those zones were developed. From today's perspective, the limit values were rather high. In 1982 and 1985, new Directives on lead and nitrogen dioxide, respectively, entered into force. These Directives also contained limit values.

In 1992, an ozone Directive was decided. This Directive did include certain thresholds for the assessment of air pollution and for the warning of the population, but did not request emission reductions in the case of exceedances of these assessment thresholds.

In 1996, the Environment Council adopted an **Air Quality Framework Directive (FWD) 96/62/EC** on ambient air quality assessment and management. This Directive covers the revision of previously existing legislation, the introduction of new air quality standards for previously unregulated air pollutants and setting the timetable for the development of daughter directives on a range of pollutants. The list of atmospheric pollutants to be considered includes sulphur dioxide, nitrogen dioxide, particulate matter, lead and ozone – pollutants governed by already existing ambient air quality objectives – and benzene, carbon monoxide, polycyclic aromatic hydrocarbons, cadmium, arsenic, nickel and mercury. The so-called daughter directives to the Air Quality FWD are described in more detail in section 3.2.2.

The Air Quality FWD and its daughter directives are only one pillar of the EU air quality legislation. A number of other directives had considerable (and partly larger than the air quality directives) impact on air quality, notably those setting emission standards for mobile and stationary sources. In addition, some directives regulate product standards, a few of them are also particularly important for air quality (such as the Directives on fuel quality, solvents, etc.).

The most important EC Directives which impact air quality include:

- The **EURO standards** have established emission limit values for different pollutants for cars (differentiated between diesel and gasoline fueled), light- and heavy-duty vehicles. As an example, the development of emission limit values (ELV) for cars (NOx and PM) is given in Figure 4.13[12].

[12] However, it has to be noted that real life emissions can be considerable higher than the ELV.

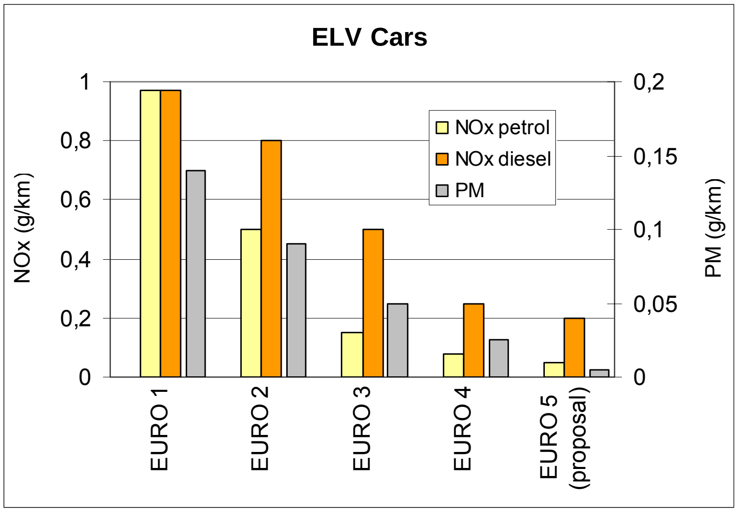

Figure 4.13: Development of emission limit values (ELV) for cars in the EU for NOx and PM.

- The directive on **Large Combustion Plants** (LCP, 2001/80/EC) sets more or less stringent emission limit values for large installations in the power generation sector.
- The Directive concerning **Integrated Pollution Prevention and Control** (IPPC, 1996/61/EC) requires the implementation of the Best Available Technology (BAT) concept to a large number of industrial activities (energy industries, production and processing of metals, mineral and chemical industries, waste management, etc.), for which it lays down general rules for the national permitting systems. The Directive covers both new and existing installations. The basic concept is that operators should go as far as they reasonably can to optimize their environmental performance by applying the best available techniques. Environmental performance is eventually to be measured against meeting the existing environmental quality standards, e.g., for air pollution to comply with the air quality standards of Community legislation. Measures going beyond BAT may be requested if this is necessary to achieve EC environmental objectives. The IPPC Directive covers only larger installations (> 50 MW). However, there is no comparable EU legislation for small (including the domestic sector) and medium installations, even though these source categories may contribute significant to excess air pollution.
- The Directive on **National Emission Ceilings** (NEC, 2001/81/EC**).** This Directive sets national emission ceilings for the pollutants SO_2, NOx, NMVOC and NH_3.
- The Directive on Volatile Organic Compounds Emissions from Storage and Distribution of Petrol (94/63/EC).
- The Directive on Solvents Use in Industry (99/13/EC).
- The Directive on Sulphur Content of Liquid Fuels.
- The Directive on Emissions from Engines to be Installed in Non-Road Mobile Machinery.
- The Directive on the Quality of Petrol and Diesel Fuels.
- The Directive on emission of VOCs due to use of organic solvent.
- The Directive on the incineration of waste.

4.3.1 Trends in Emissions in the European Union

Even though there was continued economic growth in the past decades, emissions in general stabilized or decreased. As an example, the aggregated emission of PM (primary and precursors for secondary PM) are shown in Figure 4.14.

This decoupling was triggered by stringent legislation, but also by other factors including fuel switching (which was partly influenced by economic considerations).

This is illustrated for the power sector and SO_2 emissions in Figure 4.15.

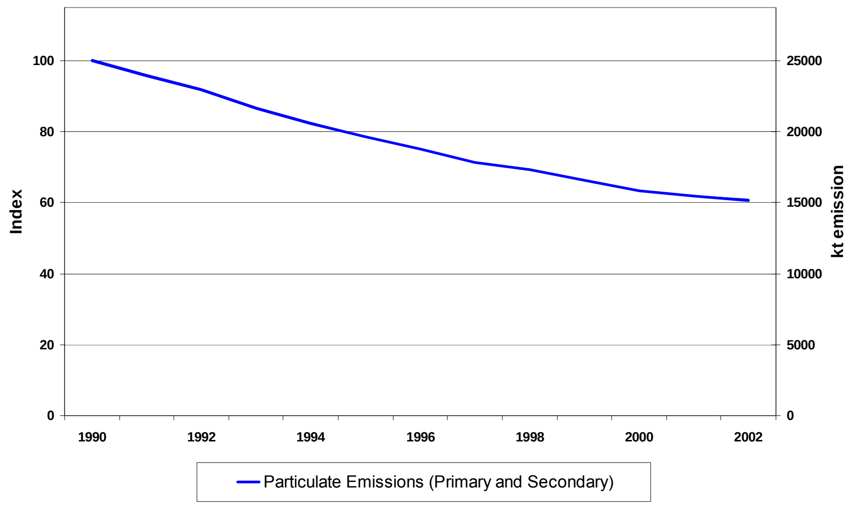

Figure 4.14: Emissions of primary and secondary fine particles (EU-15), 1990-2002. (Source: EEA, 2006).

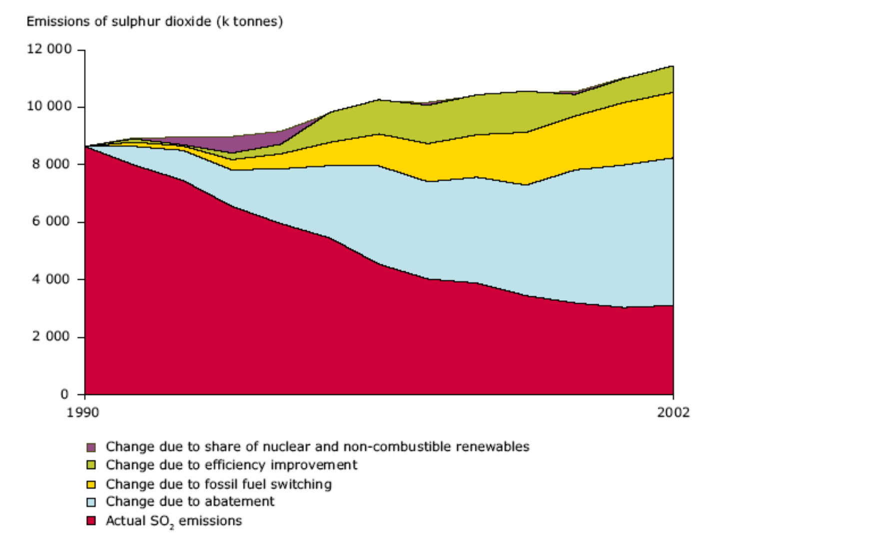

Figure 4.15: Development of SO_2 emissions from the power generation sector in the EU 15. Source: EEA, 2006

4.3.2 Regulation of Air Pollutants in the European Union

Numerical limit and target values as well as threshold values were set in four so-called daughter directives (DD) to the air quality FWD. The limit values from the first and second DD are listed in Table 4.2 (the third and fourth DD do only contain target values). The table also contains information on the basis for setting standards. As requested in the 5th EAP, many numerical values are identical to WHO AQG levels as contained on the Air Quality Guidelines for Europe (AQG, WHO, 2000). For some pollutants, the WHO AQG do not contain a numerical level (such as PM and benzene). The respective limit values were based on recommendations from technical working groups.

There are some important specifics about the limit value concept of EU legislation. The most important include:

- The LV have to be attained within a given period and not to be exceeded once attained. This definition implies that the limit values are not a weak environmental objective, but a strict requirement (which in principle also constitutes individual rights for citizens).
- The limit values apply in principle everywhere (including hot spot locations) except at workplaces (in reality, compliance monitoring and therefore compliance assessment includes hot spots, but usually focuses on those hot spots where exposure can occur).

Table 4.2: Numerical values of air quality limit values in the EU.

Pollutant	Averaging period	Limit value	Basis for setting standard	Exceedances allowed
SO_2	1 hour	350 µg/m³	Based on WHO AQG level[13]	24
	1 day	125 µg/m³	WHO AQG level	3
NO_2	1 hour	200 µg/m³	WHO AQG level	18
	1 year	40 µg/m³	WHO AQG level	-
PM10	1 day	50 µg/m³	Risk assessment in combination with an assessment of feasibility	35
	1 year	40 µg/m³	Risk assessment in combination with an assessment of feasibility	-
Benzene	1 year	5 µg/m³	Risk assessment in combination with an assessment of feasibility	-
Lead	1 year	0,5 µg/m³	WHO AQG level	-
CO	8 hour	10 mg/m³	WHO AQG level	-

[13] WHO AQG for SO2 is 500 µg/m^3 as 10-minute average.

Strategies for enforcement of regulatory measures

In general, the European Community has a relatively strict system to enforce implementation of Community legislation.

EU legislation has to be transposed and implemented in EU Member States. Transposition and implementation is scrutinized by the European Commission, the 'safeguard' of the Treaty (and secondary legislation). If legislation is not implemented sufficiently, the European Commission may start a so called infringement procedures, which has several steps. At the end, there is the possibility that Member States are condemned by the European Court of Justice, which can also result in considerable fines (which have to be paid by the Member State).

Non-compliance with limit values has also lead to national court cases in different Member States. In Austria, there has been a ruling by an appealing court implying that the authorities might be liable to damages compensation if there is health damage due to access air pollution.

In addition, licensing of new (usually quite clean) plants in areas with air quality in the range or above limit values is usually only possible, if this installations have small contributions to air pollution or if there emissions are compensated by other measures. Therefore, there is often a clear interest by industry to promote emission reductions in other sectors in order to avoid non technical barriers in licensing of new plants.

4.3.3 Air Quality Management Plans and Programs in the European Union

Stringent ambient air quality standards by themselves do not provide protection. The main tools to achieve the limit values are so called plans and programmes (if the sum of the limit value and a so called margin of tolerance is exceeded) and, after the attainment date, action plans, which have to be implemented if there is a danger of exceeding limit values. The limit values for PM_{10} and NO_2 are rather stringent, and exceedances are frequent in some parts of Europe. This triggered the development and implementation of air quality plans to reduce pollution. These plans also have to be reported to the European Commission. The plans are currently scrutinized in a project funded by the European Commission. Figure 4.16 provides an overview of the pollutants covered by the plans and those sources which have been identified as main source of this pollutant.

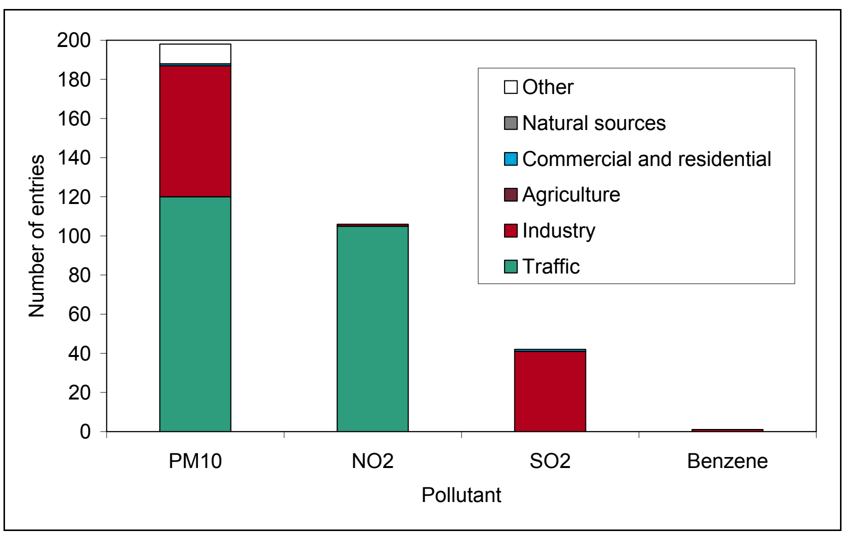

Figure 4.16: Main sources listed for different pollutants in plans and programmes reported to the European Commission for exceedances of limit values between 2001 and 2003.

There is some flexibility concerning the implementation in Member States, e.g. concerning responsibilities. There are large differences concerning the responsible authorities; in some Member States, local authorities are responsible for air quality assessment and management, while there are also examples where the responsibility lies with regional or national authorities. There is no simple answer to the question which model is most effective.

Exposure reduction target (ERT)

Experience has shown that for non-threshold pollutants, single limit values or standards may not on their own be the most appropriate way of managing air quality, particularly in areas where existing air quality management systems are mature. This has encouraged the European Commission to propose a new, additional concept, the exposure reduction target (ERT) (which has not entered into force yet, even though the concept is in principle supported by the Council and the European Parliament). The following short description of the basics of the concept is derived from a non-paper issued by the European Commission.

The existing legal framework of the Air Quality FWD and its Daughter Directives require complete compliance meaning that limit values must be met everywhere continuously. As such, a conventional air quality management strategy would implement measures according to their cost-effectiveness so as to reduce the areas of exceedance of these limits. Such a strategy would deliver increasingly smaller areas above the limit values. In the remaining areas, it may well be that reaching complete compliance is very difficult and costly. In addition, there would be little incentive to improve air quality where limit values are already respected.

For pollutants with no effect threshold, such as $PM_{2.5}$, it will generally be more beneficial for public health to reduce pollutant concentrations across the whole of an urban area as benefits would accrue from reductions in pollution levels even in relatively "clean" areas.

Therefore, an ERT was proposed for fine particulate matter $PM_{2.5}$. $PM_{2.5}$ is responsible for significant negative impacts on human health. Further, there is as yet no identifiable threshold below which $PM_{2.5}$ would not pose a risk. Advice from the WHO suggests that it is justified to assume a linear response linking exposure to $PM_{2.5}$ to adverse effects. This advice should apply both in "clean" as well as in "polluted" areas. The exposure reduction concept entails a reduction in the exposure of a larger part of the population compared to the limit value approach which affects (as we approach complete compliance) a smaller number of people. As such, the overall improvement in public health comes at a higher cost with limit values. A Commission Working Group has looked at this issue and concluded that exposure reduction would be a more cost-effective way of reducing air pollution. [14]

However, there is also an issue of environmental justice. Therefore, the European Commission stressed that it is necessary to limit the absolute maximum individual risk for European citizens. This is why the Commission proposes to keep a limit value in addition to the ERT. The new approach combines:

- A relative target for the reduction of ambient concentrations averaged over a wide geographical area. The extent of this reduction could be determined by the balance of costs and benefits. Intuitively higher reductions should be required in more polluted areas, without putting disproportional pressure on these areas and taking into account transboundary aspects. Thus, a percentage reduction would seem appropriate.
- A limit value.

The exposure-reduction approach, including any initiative aimed at improving the accuracy of the exposure-response function, embodies a form of environmental justice, although of a different kind from the ambient air quality standards. As long as there are sources of emission in an urban area, then there will always be differences in exposures due to dilution and

[14] See chapter 9 of CAFE Scenario Analysis Report Nr. 4 Target Setting Approaches for Cost-effective Reductions of Population Exposure to Fine Particulate Matter in Europe available at http://europa.eu.int/comm/environment/air/cafe/activities/pdf/cafe_scenario_report_4.pdf.

dispersion, even if there is uniformity in compliance with ambient standards. If the exposure reduction approach is adopted, and if the reduction amount is required to be the same everywhere, then there will be uniformity in the improvement in exposure, in percentage terms, if not in absolute amounts. In addition, when coupled with a concentration "cap" citizens are guaranteed an absolute minimum standard of air quality to protect them against unduly high risks.

The ERT would provide a better air quality management system than one relying solely on ambient air quality standards. The following benefits (in addition to those already mentioned above) have been identified:

- Source-related emissions reductions would contribute more effectively and not just in areas where there are exceedences of limit values.
- No need to modify the ambient air quality standard as time elapses as the emphasis is on reducing overall exposure thus saving administrative resources.
- Proposed approach would complement and "fine tune" overall emission ceilings for a Member State or region, which, if implemented, alone would not have the necessary focus on the improvement of public health; i.e. the total emission ceilings might be achieved with a disproportionately small improvement in public health, depending on the spatial relationship between the emission reductions and the populations exposed.

At this stage, no experience with the ERT is available.

Emission reductions

Emissions are generally spoken a function of the underlying emission generating activity and an emission factor, which depends on the applied technology (including any relevant abatement technology). Emission reductions may aim at the reduction of the activity or may be directed to decrease the specific emissions (often through end of pipe technologies).

Due to the uneven distribution of emission sources, pollutants show spatial gradients. These gradients vary also as a function of the atmospheric lifetime of pollutants. There are therefore considerable differences in the scale of relevant sources. Broadly spoken, for pollutants with short atmospheric lifetimes such as ultrafine particles, NO and NO_2, local sources may dominate the ambient levels. Longer lived species such as $PM_{2.5}$ and CO may have considerable regional and even continental and hemispheric background levels. This has important implications for control options. The contributions from emissions at different scales are shown schematically in Figure 4.17 for fine PM_{10}. The figure illustrates that reduction strategies at a local scale have only a limited scope.

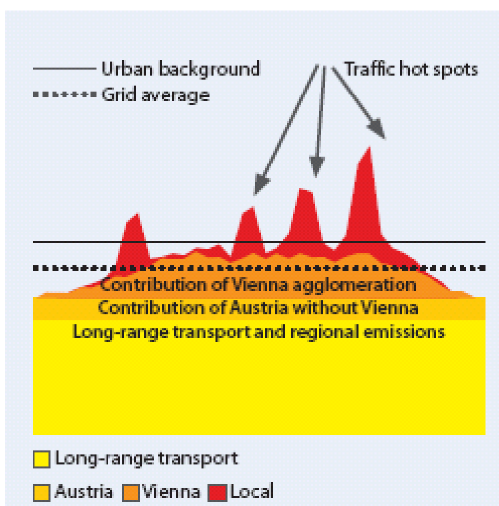

Figure 4.17: Schematic illustration of different PM_{10}levels in different locations for Vienna (Source: WHO, 2006).

Transboundary/hemispheric approaches

It has been recognized decades ago that some of the environmental problems linked to air pollution have a strong transboundary component. These problems include acidification (caused by the deposition of oxidized sulfur and nitrogen compounds), eutrophication and ground level ozone. Also fine PM may have a significant transboundary component. This has important consequences for abatement strategies. Since sources and receptors are often located in different countries, multilateral agreements are necessary to combat these effects effectively.

In Europe, the UN ECE Convention on Long Range Transboundary Air Pollution (CLRTAP) provides a framework for emission reduction agreements. Eight Protocols have been signed and entered into force in the last decades. Notably, the CLRTAP played also an important role in promoting research to investigate the sources, transboundary transport and effects of air pollution. The prime objective of these activities was to substantiate cost effective emission reduction strategies on a European scale. The most recent Protocol, the Gothenburg Protocol, set national emission ceilings for four pollutants (SO_2, NOx, NMVOC and NH_3) to combat acidification, eutrophication and ground level ozone (all this substances are also precursors for secondary PM). While in the past, concrete obligations for controlling emissions were derived solely based on technical and economic aspects or equal emission reduction percentages, this Protocol attempts to quantify specific reduction requirements for the Parties with the aim of achieving certain targets for acidification, eutrophication and ground level ozone. The starting point for negotiating emission ceilings were results form a so called integrated assessment model, which was used to investigate cost effective emission reductions. The first step was to construct a baseline scenario (including the effect of already decided emissions reduction measures) based on the projected development of emission generating activities. The emissions are translated into ambient concentrations (using the results of a European dispersion model) and effects in the same modeling framework. In a second step, cost effective emission reduction strategies (expressed e.g. as national emission totals in a specific year) can be identified to achieve different environmental improvements. However, the agreed ceilings were in case of the Gothenburg Protocol the result of subsequent political negotiations and did not necessarily reflect cost effective emission reductions from a European perspective.

In the European Community, the Directive on National Emission Ceilings (NEC) has similar objectives and was based on the same integrated assessment model which was also used for the Gothenburg Protocol. The NEC Directive itself does not contain any concrete requirements for sources. It is up to the Member States do identify those sectors where cost effective measures should contribute to achieving the ceilings.

Regional and national level approaches

Some measures are usually most effective at a regional or national level. These include many of the source related regulations listed in Table 4.3 (such as limit values for installations, national speed limits, etc.). In addition, taxes are usually applied on a national level. This includes fuel taxes or a specific tax on NOx, which e.g. is applied in Sweden for stationary sources (see below). These instruments have the potential to affect both the emission generating activities (e.g., mileage of road transport) and the introduction of abatement technologies. Changes in activity usually has ancillary effects (e.g., for road traffic emissions of GHG and noise).

Within the European Community, there is a minimum fuel tax for diesel and petrol. However, the real taxes are often higher and differ by Member States (see Figure 4.18).

For Austria, the effects of economic instruments for road transport has been assessed and compared to technical measures (such as retrofitting programmes; speed limits; traffic restrictions for high emitting vehicles) to reduce NOx and PM. Notably, a general road pricing scheme for cars and an increase of fuel taxes were among those measures which brought the largest emission reductions.

Table 4.3: Categories of measures reported from Member States within plans and programmes.

Category: Traffic	
Sub-category	**Measures**
Technical	Emission reduction of cars, buses, trucks, motorcycles, railways, ships, airplanes
Traffic management	Traffic flow management, parking charges, congestion charges, improved cargo logistics, airport traffic management
Public transport	Improvement and promotion of public transport, promotion of bicycle and pedestrian traffic
Traffic restrictions	Measures which restrict traffic in certain areas
Road construction	Construction of by-pass roads, constructive measures which improve traffic flow
Speed reduction	Area or road specific speed limits
Street cleaning	Improved street cleaning, alternative winter sanding
Other	alternative traffic concept, bicycle sharing, car sharing, car pooling, efficient driving training, labelling of low emission vehicles, low emission road surface, promotion of methane fuel stations, mobility planning, promotion of railway cargo transport, restrictions to maintain engines running, restrictions to studded tyres, truck toll, tunnel exhaust cleaning
Category: Stationary sources	
Sub-category	**Measures**
Agriculture	Measures in the area of manure handling and feeding
Construction	Measures to reduce emissions on construction sites
Heating	Improvement of heaters, building insulation, district heat
Industrial	Measures to reduce industrial and power plant emissions
Other	Restriction of open fires, removal of sand surfaces
Category: Regulation and information	
Sub-category	**Measures**
Financial incentives	Fiscal stimulation, emission certificates, financial support of low-emission technology
Information of the public	Information and awareness of employees, pupils and the general public
Change to emission standards	Improvement of emission standards on the European level
Other	---
Category: Other measures	
Sub-category	**Measures**
Energy	Support of alternative energy production, measures to reduce energy consumption
Fuel improvement	Propagation of low-sulphur and low-VOC fuels
Urban planning	Integration of mobility and air quality aspects in urban planning.
Other	Combination of information, incentives and traffic restrictions; procedure of regularly taking and evaluating new measures. reduction of transboundary pollution; planting of trees; construction of a protective wall.
Category: Other activities	
Sub-category	**Measures**
Air quality monitoring	Monitoring of pollutant concentrations
Studies	Emission inventory, emission monitoring, emission study, energy consumption research, exposure study, research program, study on regional transport
Not specified	Measures with unspecified emission reduction, measures which are in the stage of planning
Other	Definition of plans to reduce emissions, resettlement of population.

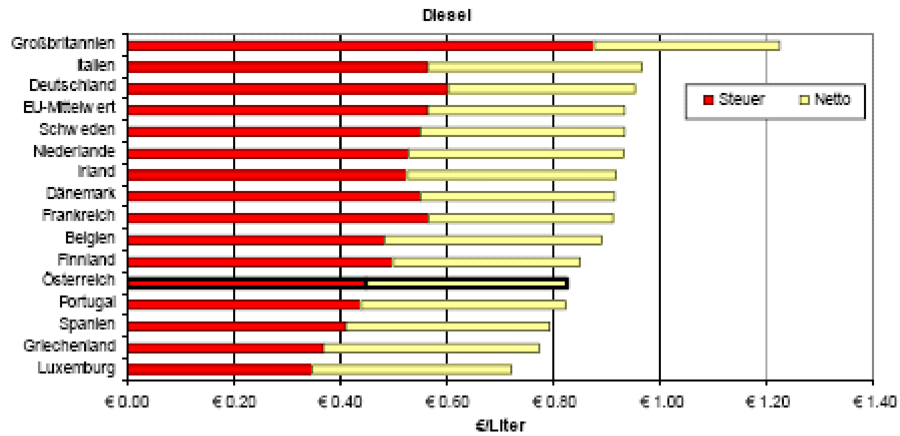

Figure 4.18: Fuel prices and taxes in different EC Member States; data from autumn 2004.

There are some other successful examples for the application of economic instruments within the European Community. For example, Sweden has implemented a charge on NOx emissions in order to reduce these emissions cost effectively. According to the NOx Act the charge is paid for emissions of NOx from boilers, stationary combustion engines and gas turbines with a useful energy production with at least 25 GWh per annum. The charge is based on actual recorded emissions and is imposed irrespective of fuel used. It is levied at a rate of SEK 40 (about € 4,3) per kg of emitted NOx. To avoid distorting the pattern of competition between those plants which are subject to the NOx charge and those that are not, the system is designed so that all revenue except the cost of administration is returned to the participating plants, in proportion to their production of useful energy. Boilers with high emissions relative to their energy output are net payers to the system, and sources with low emissions relative to energy output are net recipients. This feature of the system encourages the targeted plants to reduce their emissions of nitrogen oxides per unit of energy to the lowest possible level. Since the Swedish Parliament passed legislation introducing the NOx charge in June 1990 the specific emissions have dropped from an average of about 160 milligrams of NOX per megajoule (mg/MJ) of energy input to about 55 mg/MJ, equivalent to 65 per cent.

Local emission reduction approaches

Point sources and transportation sources

The most important source related regulations on the EC level (which have also a considerable impact on local air quality) are the continuous tightened EURO standards for mobile sources and the IPPC and LCP for power generation and industrial installations. However, the EURO standards and the LCP are applicable irrespective of air pollution levels. According to the IPPC Directive, measures going beyond BAT may be requested if this is necessary to achieve EC environmental objectives (such as limit values).

Measures to comply with limit values are usually in addition to these regulations. There are numerous possible additional measures for all relevant sectors. Databases containing lists of possible measures to reduce air pollution at a local scale are now available [reference]. These databases often contain estimates for reduction potentials and costs.

The measures reported in plans and programmes under the AQ FWD are summarized in Table 4.3 and Figure 4.19.

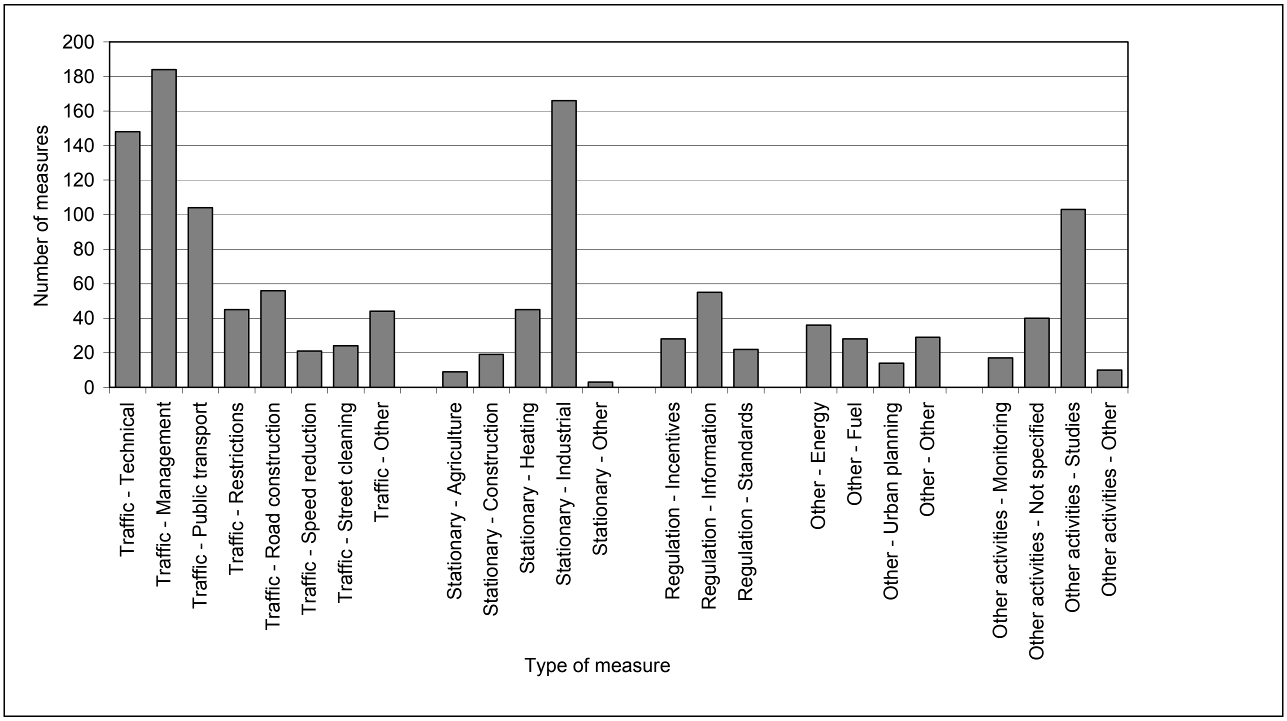

Figure 4.19:Categories of measures reported by all Member States.

Management of hot spots

As stated previously, limit values apply throughout the territory of Member States. Therefore, efforts to comply with limit values is often focused on hot spot locations (locations in the vicinity of emission sources with the highest pollution levels). As part of the information transmitted by Member States on plans and programmes under the air quality FWD, the authorities have to quantify the area of exceedance (and for traffic hot spots the length of roads). This information is shown in

Figure **4.20**, indicating that some plans aim at the reduction of pollution in rather limited areas.

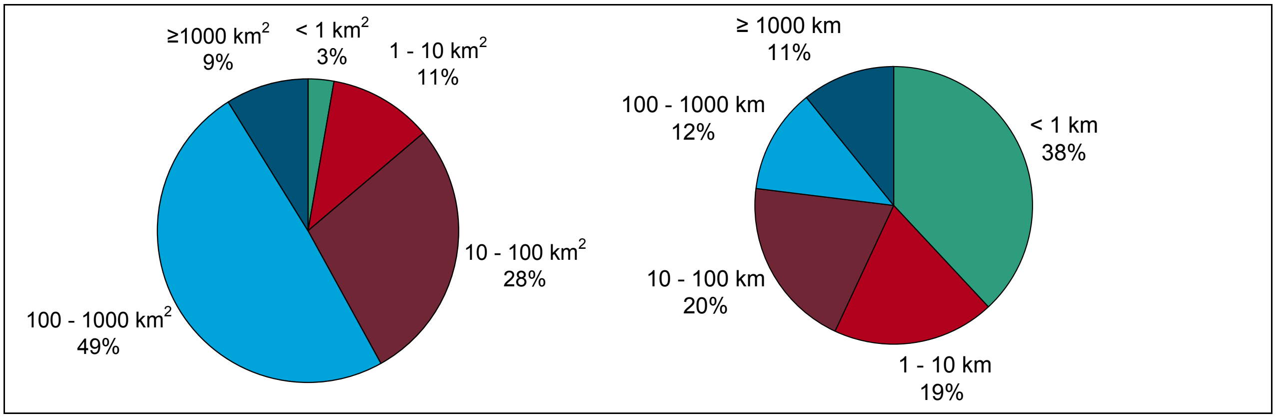

Figure 4.20: Estimate of the surface area where the level was above the limit value + margin of tolerance in the reference year. Right: Estimate of the length of road where the level was above the limit value + margin of tolerance in the reference year. For 27 % of exceedance situations, no surface area and no length of road was reported.

A recent study on the ex post evaluation of local measures in the EU concluded that

- Specifically targeted local measures do appear effective in terms of local emissions reductions, air quality improvement and progress towards legally binding air quality limit values, particularly when these schemes tend to be targeted at air quality hot spots (such as low emission zones; fuel bans; traffic flow controls). They also have good benefit to cost ratios, which are similar to or better than for the introduction of European level air quality policies. This provides some initial support for these measures as a complement to further European based legislation.
- The effectiveness of all local measures is very site-specific. It is not possible to simply transfer schemes between locations without consideration of local conditions. Location-specific characteristics of the following key factors determine this effectiveness: background pollutant levels, pollutant formation and transport mechanisms, cultural and economic factors influencing the scale and frequency of emissions from various sectors, legal and informational limitations on the ability of responsible authorities to act.
- The most effective schemes, in reducing emissions and reducing air quality hot spots appear to be those schemes directly focused on air quality improvements. This includes measures such as low emission zones, motorway flow management, smoky vehicles bans, etc in urban areas. Many traditional local transport schemes appear less effective in achieving emissions or air quality improvements, though this is not surprising when these schemes are aimed at other problems (e.g. congestion). However, these latter schemes have other benefits (e.g. travel time benefits, reduced accidents, etc) that are often their primary objective.

Public Education/behavioral/stakeholder engagement approaches

Emissions of air pollutants are often linked to the individual life style of citizens. This includes the choice of the transport mode, and also the use of energy. Many campaigns were launched to influence individual behavior of citizens. It is not easy to find published ex-post reviews of the effectiveness of such campaigns. A small survey among experts in Austria (mainly based on expert judgment) suggests that such campaigns are often limited in their effectiveness. However, there was also a consensus that public communication is an important element in increasing the acceptance of the public for new measures.

4.4 Air Quality Management in Hong Kong

4.4.1 Historical Perspective on Air Quality in Hong Kong

The Hong Kong Special Administrative Region (SAR) is a territory of 1,100 km2 comprising an archipelago of two major islands and many smaller outer islands, a peninsula and land adjacent to the mainland of the People’s Republic of China. Annual deaths total about 30,000 and age standardized total mortality (0.4%) is about 18% lower than in the West, with cardiovascular disease 47% lower and respiratory disease 40% higher. The annual GDP per capita is US$25,000 in a mostly service based economy. In recent years, the manufacturing sector has moved north of the boundary into the mainland and over 70,000 factories operate around the Pearl River Delta.

In 1990, by restricting fuel sulphur content to 0.5% by weight, the Hong Kong SAR demonstrated that even modest reductions in pollution led to significant health gains (Peters et al., 1996; Wong et al., 1998; Wong et al., 1999; Hedley et al., 2002). Since then air quality has been continuously degraded. Despite the progressive establishment of a large evidence base on air pollution health effects there has been a lack of recognition of the real community costs incurred by harm to health and lost productivity caused by air pollution; a lack of comprehensive approaches to improve urban air quality including cleaner fuels, transportation and infrastructure of urban environments; and a failure to implement a sufficiently comprehensive range of new laws and regulations on emissions, revise and enforce air quality and standards to update the 1987 Air Quality Objectives, or make significant progress in cross-boundary agreement with the mainland authorities and the business and power sectors in Hong Kong on pollution abatement. A large proportion of heavily polluting factories in the Pearl River Delta region are Hong Kong and foreign business investments. As a result, air quality in Hong Kong now compares unfavourably with the current situation in other world cities such as Auckland, Berlin, London, New York, Paris and Vancouver. Particulate levels are about 40% higher than in Los Angeles, the most polluted city in the USA (USEPA, 2003).

4.4.2 Visibility, Air Pollutants and Health

Watson (2002) cites the U.S. Environmental Protection Agency (EPA) as identifying impaired visibility as the "best understood of all environmental effects of air pollution." In addition to impairing quality of life, daily loss of visibility directly reflects the risk of injury by airborne pollutants on cardiovascular and pulmonary systems. The commonest manifestations of these health problems include serious cardiopulmonary events such as heart attacks, stroke, and respiratory illnesses including bronchitic symptoms of cough, phlegm and wheeze, acute and chronic bronchitis, pneumonia and attacks of asthma.

Effects of air pollution on visibility are apparent to everyone but the health effects may be silent and unobservable until they result in symptoms, illness episodes and death. Even then direct attribution of illness in an individual with daily air pollution is not possible in the same way as it would be with infectious disease. This uncertainty and lack of direct evidence is associated with lower perceptions of risk by some sections of the public who are potentially important drivers of policy and lack of political will by decision makers and it provides scope for arguments against interventions and air quality controls by vested interests.

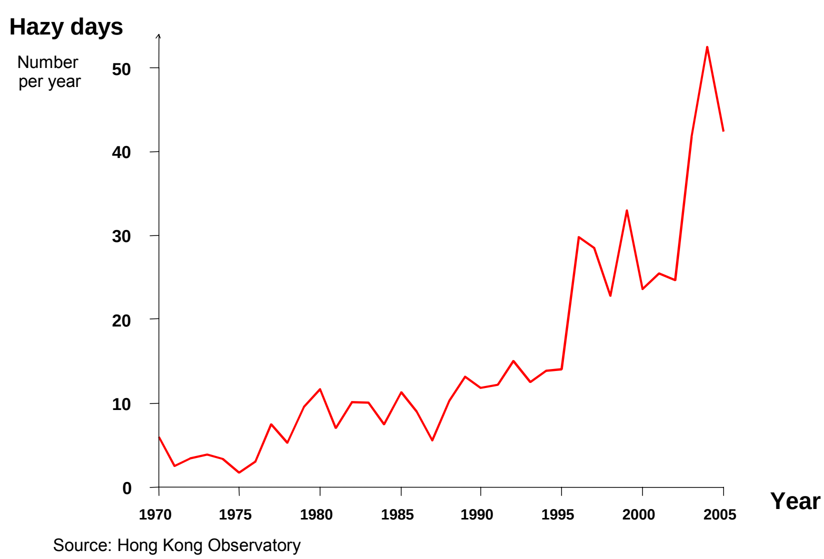

Figure 4.21. Deteriorating visibility (<8km) due to haze based on direct observation of landmarks by the Hong Kong Observatory 1970 – 2005.

Visibility has been deteriorating in Hong Kong for several years (Figure 4.21). This trend is now raising concern in the tourism and hospitality industry because of its impact on Hong Kong's attractiveness as a destination, and in the finance and foreign business sector because of increasing difficulties in recruiting overseas personnel. However, the threat of pollution to the health of the local community, demonstrated in many recent scientific reports, has not prompted the necessary radical action.

4.4.3 Case Study: Visibility as a Tool for Air Quality Management in Hong Kong (see Hedley et al., 2006)

The Hong Kong SAR and the mainland air quality objectives (AQO) are long outdated and provide no health protection from pollution. The Hong Kong AQO (Hong Kong Environmental Protection Department) date from 1987 and were based on the standards adopted by the US Environmental Protection Agency. None of the subsequent international revisions of air quality standards have been reflected in any changes to the HKSAR objectives. In addition they have come to be regarded as legal, safe and permissive levels in environmental impact assessments. Through that mechanism the AQO has become an instrument by which air pollution in different zones may actually be legally increased under the Environmental Impact Assessment Ordinance.

For some time, the local community in Hong Kong has raised concerns about levels of air pollution but the use of outdated standards as the basis for a daily air pollution index (Environmental Protection Department, 2006) has prevented communication of the true degree of hazard associated with current pollution levels. By using an easily understood and highly apparent indicator such as visibility and associating different levels of visibility with potential changes in costs incurred, our aim is to promote a better understanding of the impacts of air pollution.

As part of a programme of public accountability we used photographs on Poor and Better visibility days as representations of the relationships between visibility, air pollution, health effects and community costs for health care and lost productivity. We used coefficients from time series models and gazetted costs to estimate the health and economic impacts of different levels of pollution. In this population of 6.9 million, air quality improvement from the annual average to the lowest pollutant levels of Better visibility days, comparable to the World Health Organization air quality guidelines, would avoid 1,335 deaths, 60,587 hospital bed days and 6.7 million doctor visits for respiratory complaints each year. Direct costs and productivity losses avoided would be over US$246 million a year and US$2250 million for intangible costs. The dissemination of these findings led to increased demands for pollution controls from the public and legislators but denials of the need for urgent action from government, which has implemented its own review of the health effects of air pollution health effects will take more than two years to complete. The outcome demonstrates the need for more effective translation of the scientific evidence base into risk communication and public policy.

4.5 Evidence of Effectiveness of Air Quality Management Interventions

4.5.1 North America

Steel mill closure in Utah Valley

During the period of August 1986 to Sept 1987, a steel mill, which was the primary source of particulate pollution in Utah Valley, was closed for a 13 month period due to a workers' strike. The effects of the closure and subsequent re-opening of this mill on air quality and hospital admissions for respiratory diseases among children were investigated (Pope, 1989). The study period covered 12 months before and 12 months after the closure period. This study focused on the results from the winter seasons since PM_{10} levels are typically highest during the winter. The two winter seasons before closure and after re-opening experienced 13 and 10 exceedances, respectively, of the US federal 24-hour PM_{10} standard (150 µg/m^3). In contrast, during the closure period, the standard was not exceeded. When hospital admissions were analyzed for the same time periods, striking differences were observed.

During the 1986/87 winter season, when the mill was closed, hospital admissions for children were approximately 3 times lower than when it was open. Statistical analyses showed that this decrease was associated with the decrease in PM_{10} levels.

Traffic reduction in Atlanta during Olympic Games

During the 17 days of the summer Olympic Games in Atlanta, traffic patterns changed due to the alternative transportation strategy that was implemented to relieve traffic congestion. Researchers analyzed the effects of these changes on air quality and acute asthma events among children by examining the air quality and hospital records 4 weeks before and 4 weeks after the Games (Friedman et al., 2001).

Ambient ozone concentrations measured at three monitoring sites decreased by approximately 13% during the Games. Carbon monoxide (*1.26 vs 1.54 ppm, 19% decrease, p=0.02)* and PM_{10} (*30.8 vs 36.7 ug/m^3, 16% decrease, p=0.01)* concentrations also declined significantly, while the decline in NO_2 levels was not significant *(36.5 vs 39.2 ppb, 7% decrease, p=0.49)* and SO_2 levels increased (*4.29 vs 3.52, 22% increase, p=0.65).*

Correspondingly, there were fewer children admitted to the hospitals for acute asthma, an average of 2.5 cases per day during the Games compared to 4.2 cases per day in the baseline period (before and after the Games). The study determined that there were no significant changes in weather conditions or emissions from stationary sources. Also, hospital admissions for other causes among children did not change during this period.

California Children's Health Study

The Children's Health Study, which began in 1992, is a large, long-term, study of the effects of chronic air pollution exposures on the health of children living in Southern California. In one of the studies, investigators examined the health effects of relocating to areas of differing levels of air pollution (Avol et al., 2001). They followed 110 children from the larger Children's Health Study who moved to six western states at least one year before follow-up and to areas of either higher or lower pollution. They found that children moving to areas with lower PM_{10} levels experienced an increase in lung function growth rates. Conversely, moving to areas of higher PM_{10} resulted in a decrease in lung function growth rate. The results support the view that changes in ambient pollution levels (in this case, PM_{10}) may have measurable effects on longer-term lung function (and health) outcomes.

4.5.2 Europe

UK

A UK consultant investigated the effects of short term and local measures to reduce air pollution (AEAT, 2005). The study concluded that . *it is extremely difficult to find reliable and consistent data on the ex post costs, and the ex post benefits (particularly in relation to emissions and air quality), of local measures, they were able to draw some general conclusions*.

Probably it is even more difficult to assess and compare consistently the ex post costs, and the ex post benefits for local, regional and national measures. However, a few conclusions can be drawn.

- It is generally accepted that air quality management has been a success story in the EC. Member States of the European Union spend large sums for air quality protection, mainly triggered by source related legislation.
- The EURO standards are seen as an essential element of AQ protection which ensured that the continuously increasing road transport is emitting

less pollution than a few years ago even though the EURO standards proofed to be less efficient in practice than expected. However, there is still no legislation in force forcing external costs of road traffic to be internalized.
- The concept of integrated pollution prevention for industrial installations including the application of BAT for new and existing plants is also widely accepted. However, there is still a debate if legally binding emission limit values are warranted for those installations.
- Air quality limit values are one important element of air quality policy. The inherent focus on the most polluted sites has been discussed recently and lead to the proposal to supplement the limit value approach by an exposure reduction target (ERT), which sets objectives for relative improvements (more or less irrespective of absolute pollution levels) for urban background locations.
- Energy efficiency will become increasingly important (primarily due to concerns about energy prices, security of supply and climate change).

There is robust evidence indicating that air pollution still causes severe health and environmental damage. Since many measures to reduce air pollution are already in force, this leads to a situation where additional measures are getting increasingly expensive, while the reduction potentials get smaller and smaller. As a consequence, additional measures need to be well justified. This implies that any additional measures need to be based on robust science. This includes a profound knowledge on

- the sources of air pollution,
- the atmospheric dispersion,
- ambient levels,
- effects of air pollutants
- as well as costs and reduction potential for abatement measures,

Therefore, recent legislative proposals in the EC have been accompanied by impact assessments comparing the cost and benefits of these proposals.

Coal ban in Irish cities

On Sept 1, 1990, the Irish government banned the marketing, sales and distribution of soft coal within the city of Dublin. Clancy et al. (2002) examined the effect of this intervention on the association between ambient air quality and death rates. The ban on coal sales resulted in a substantial reduction in black smoke, which is a measure of fine particles. Overall, the average black smoke level fell by about 2/3 after the ban. Similarly, sulfur dioxide levels decreased by about 1/3 after the ban. The investigators analyzed data from 6 years prior and 6 years after the ban. After adjusting for factors known to influence mortality, which include temperature, relative humidity, respiratory epidemics, age and changes in personal habits such as smoking, the investigators found statistically significant decreases in death rates. They found a 6% decrease in non-trauma deaths. This decrease was primarily driven by an estimated 10% and 16% decrease in the rates of death from heart and lung diseases, respectively. This finding is consistent with our understanding of air pollution effects on the cardiovascular and respiratory systems. Moreover, the reduction in death rates was 2 to 3 times greater than had been predicted from previous PM mortality studies. These findings suggest that control of particulate air pollution can lead to immediate and significant reductions in death rates.

4.5.3 Asia

Cleaner fuel in Hong Kong

On July 1, 1990, all power plants and road vehicles in Hong Kong were restricted to use of fuel oil with a sulphur content of not more than 0.5% by weight. This intervention led to an immediate improvement in air quality as sulfur dioxide concentrations measured at multiple sites fell an average of 53% over the following year compared to the baseline levels measured 2 years prior (Hedley et al., 2002). In the 2 years following the intervention, a reduction of chronic bronchitic symptoms in children and adults (Peters et al., 1996) and improved lung function in primary school children (Wong et al., 1998) were shown. The impact of the regulation on mortality was assessed by examining death rates between two age groups for the period 1985 through 1995 -- which includes a 5-year period before and 5-year period after the restriction of sulfur content. In the 12 months following the restriction, seasonal deaths were substantially reduced, followed by a peak in cool-season death rate between 13 and 24 months, returning to the expected pattern during years 3-5. Compared with predictions, the intervention led to a significant decline in the average annual trend in deaths from all causes (2.1%; p=0.001), respiratory (3.9%; p=0.0014) and cardiovascular (2.0%; p=0.0214) diseases, but not from other causes. It was estimated that the regulations had resulted in a gain in the average life expectancy of 20 and 41 days in women and men, respectively, for every year of exposure to the lower levels of pollution (Hedley et al., 2002).

The Hong Kong intervention provides direct evidence that even modest reductions in sulphur dioxide air pollution following restrictions on sulphur-rich fuels leads to significant immediate and long-term health benefits.

4.6 Conclusions

This chapter described how air pollution problems are managed within North America, the European Community, and Asia by presenting both general policy approaches for each continent and detailed case studies for large urban centres. While each area has a unique set of problems – and approaches and capacities to deal with them – there is a clear portfolio of comprehensive management strategies common to successful programs. These include the establishment of ambient air quality standards that define clean air goals, strong public support leading to the political will to address these problems, technology-based and technology-forcing emission limits for all major contributing sources, and enforcement programs to ensure that the emission standards are met.

Initially, many regions focused their air pollution control efforts on lead, ozone, and large particles (i.e., TSP, PM_{10}). However, newer epidemiological studies of premature death, primarily conducted in the U.S. with cohorts as large as half a million participants, have made it clear that long-term exposure to $PM_{2.5}$ is the major health risk from airborne pollutants. While WHO, US EPA, Environment Canada, and California Air Resources Board (CARB) rely on the same human health effects literature, there are striking differences, up to a factor of three, in the ambient air quality standards they set. In addition, how these standards are implemented (e.g., allowable exceedances, natural and exceptional event exceptions) can greatly reduce their stringency. Now there is increasing evidence that there is no level below which exposure to some pollutants has no potential health effects. This will have implications for how some pollutants are regulated. Despite these issues, the ambient air quality standards and the regulatory authorities that result from public and political support have been the major driver of clean air progress.

Worldwide, command-and-control has been the primary regulatory mechanism to achieve emission reductions, although the European Community has successfully used tax incentives and voluntary agreements with industry. Over the past four decades, the California Air Resources Board set the bar for US EPA and European Union motor vehicle emission standards that are now being adopted in many developing countries, particularly in Asia. Emissions of VOC and CO (and to a lesser extent NO_X) from new passenger vehicles were reduced by a factor of a hundred in comparison to pre-control vehicles. The United States adopted emission standards for 2007 and subsequent model year heavy-duty engines that represent 90% reductions of NO_X and PM compared to 2004 model year emission standards. Implementation of reformulated gasoline and diesel fuels resulted in further reductions. Stationary source NO_X and SO_X emission standards were reduced by at least a factor of ten since 1980. Small off-road engines, architectural coatings, consumer products and solvents are also targeted for large emission reductions.

Since the emission standards are technology-based or technology-forcing, industry has been able to pursue the most cost-effective strategy to meeting the emission target. As a result, actual control costs are generally less than originally estimated. Over the past three decades, California's motor vehicle and fuel regulations have had a fairly uniform cost over time. In the US, total air pollution control costs are about 0.1% of GDP, although this has not necessarily resulted in overall job and income loss because the air pollution control industry is about the same size. In addition, the US EPA estimated that each dollar currently spent on air pollution control results in about a $4 of reduced medical costs as well as the value assigned to avoided premature deaths. In the past (1970-1990), when lead reductions and other major control programs were implemented, the benefit to cost ratio was $90 to $1.

An alternative to command-and-control regulations is market-based mechanisms that results in more efficient allocation of resources. The SO_2 cap and trade program in the US resulted in rapid emissions reduction at lower cost than was initially anticipated. Efforts to extend the cap and trade system to SO_2, mercury and NO_X emissions in the Eastern US were less successful due to several issues related to heterogeneous emissions patterns which could worsen existing hot spots, allocation of emissions allowances, procedures for setting and revising the emissions cap, emissions increases following transition to a trading program, and compliance assurance.

Emission reduction initiatives at the local level also play a critical role in air quality management. Local governments can contribute to cleaner air through emission reduction measures aimed at corporate fleets, energy conservation and efficiency measures in municipal buildings, public education to promote awareness and behaviour change, transportation and land use planning; and bylaws (anti-idling etc). Many large urban centres such as the City of Toronto are following the policy trend towards an integrated and harmonized approach to cleaner air and lower greenhouse gas emissions.

A comprehensive enforcement program with mandatory reporting of emissions, sufficient resources for inspectors and equipment, and meaningful penalties for noncompliance ensures that emission standards are being met. While air quality management through standards for vehicles and fuels have resulted in measurable reductions in emissions, regulation of emissions for in-use vehicles through I/M programs poses greater technical challenges.

An evidence-based public health approach in the assessment of health impacts of air pollution may not lead to essential policy changes. Environmental advocacy must develop more effective methods of risk communication to influence public demand for cleaner air and strengthen political will among decision-makers.

Average daily visibility has been declining in Asia over two decades. Visibility provides a measure, with face validity, of environmental degradation and impaired quality of life; and a risk communication tool for pollution induced health problems, lost productivity, avoidable mortality and their collective costs.

Although scarce, information from both planned and unintended air quality interventions provides strong evidence in support of temporal association and causality between pollution exposures and adverse health outcomes. Even modest interventions, such as reductions in fuel contaminants and short-term restrictions on traffic flows, are associated with marked reductions in emissions, ambient concentrations and health effects. Coal sales bans in Ireland and fuel sulfur restrictions in Hong Kong, successfully introduced in large urban areas within a 24-hour period, were economically and administratively feasible and acceptable, and effective in reducing cardiopulmonary mortality.

In response to severe air quality problems, many urban centres imposed comprehensive emission controls, but growth in population, energy demand, vehicle miles travelled, and industrial activity, and aging vehicle fleets, prevented attainment of all the health-based ambient air quality standards. While some air quality problems have been eliminated or greatly reduced (i.e., lead, NO_2, SO_2), particulate matter and ozone levels remain high in many large cities, resulting in hundreds of thousands of deaths per year and increased disease rates. In response, air quality management agencies are developing innovative approaches, including regulation of in-use emissions, reactivity-based VOC controls and exposure-based prioritization of PM controls. Several cooperative, multi-national efforts have begun to address transboundary issues. Newly recognized challenges also need to be integrated into air quality management programs, ranging from the microscale (e.g., air pollution "hotspots", ultrafine particles, indoor air quality) to global scales (e.g., climate change mitigation, international goods movement).

4.7 References

Avol, E.L., Gauderman, W.J., Tan, S.M., London, S.J., and Peters, J.M. 2001. Respiratory effects of relocating to areas of differing air pollution levels. *Am. J. Respir. Crit. Care Med*. 164:2067-2072

Bremauntz, A.F. 2007. Air quality management in Mexico. *J. Toxicol. Environ. Health* (in press).

Brook, J.R., Poiret, R.L., Dann. T.F., Lee, P.K.H., Lillyman, C.D., and Ip, T. 2006. Assessing sources of $PM_{2.5}$ in cities influenced by regional transport. *J. Toxicol. Environ. Health* (in press).

Brunekreef, B, Janssen, N.A., de Hartog, J., Harssema, H., Knape, M., and van Vliet, P. 1997. Air pollution from truck traffic and lung function in children living near motorways. *Epidemiology* 8:298–303.

CARB, 2002. The 2002 California Almanac of Emissions & Air Quality. California Air Resources Board, Planning and Technical Support Division, Sacramento, CA.

City of Toronto 2007. Change is in the air. Toronto's commitment to an environmentally sustainable future. Framework for public review and engagement. City of Toronto Environment Office. www.toronto.ca/changeisintheair/change.htm.

Clancy, L., Goodman, P., Sinclair, H., and Dockery, D. 2002. Effect of air-pollution control on death rates in Dublin, Ireland: an intervention study. *Lancet* 360:1210-1214.

Clean Air Partnership. 2005. A model clean air plan for the living city. A report prepared for GTA Clean Air Council. www.cleanairpartnership.org/gtacac/pdf/clean_air_plan.pdf.

Cote, I., Samet, J., and Vandenberg, J. 2007. U.S. Air quality management: Local, regional and global approaches. *J. Toxicol. Environ. Health* (in press).

Delfino, R.J., Gong, H. Jr, Linn, W.S., Pellizzari, E.D., and Hu, Y. 2003. Asthma symptoms in Hispanic children and daily ambient exposures to toxic and criteria air pollutants. *Environ Health Persp.* 111:647–656.

Dockery, D.W., Pope, C.A., Xu, X., Spengler, J.D., Ware, J.H., Fay, M., Ferris, B.G., and Speizer, F.E. 1993. An association between air pollution and mortality in Six U.S. Cities. *New Engl. J. Med.* 329:279-285.

Environmental Monitoring and Reporting Branch 2004. Ontario Ministry of the Environment, Toronto, pp. 136. www.ene.gov.on.ca/envision/techdocs/5383e.pdf.

Evans, J., Levy, J., Hammitt, J., Santos-Burgoa, C., Castillejos, M., Caballero-

Ramirez, M., Hernandez-Avila, M., Riojas-Rodriguez, H., Rojas-Bracho, L., Serrano-Trespalacios, P., Spengler, J.D., and Suh, H. 2002. Health benefits of air pollution control. In *Air Quality in the Mexico Megacity: An Integrated Assessment*, L.T. Molina and M.J. Molina (eds), pp. 384. Cambridge, MA: Kluwer Academic Publishers.

Finkelstein, M.M., Jerrett, M., and Sears, M.R. 2004. Traffic air pollution and mortality rate advancement periods. *Am. J. Epidemiol.* 160:173-177.

Friedman, M.S., Powell, K.E., Hutwagner, L., Graham, L.M., Teague, W.G. 2001. Impact of changes in transportation and commuting behaviors during the 1996 summer Olympic Games in Atlanta on air quality and childhood asthma. *JAMA* 285:897-905.

Hedley, A.J., McGhee, S.M., Barron, B., Chau, P., Chau, J., Thach, T.Q., Wong, T.-W., Loh, C., and Wong, C.-M. 2006. Air pollution in Hong Kong and the Pearl River Delta. Paper presented at the Network for Environmental Risk Assessment and Management (NERAM) Colloquium on Strategic Policy Directions for Air Quality Management. October 16-18, 2006. Vancouver, BC. www.irr-neram.ca/about/ Colloquium.html.

Hedley, A.J., Wong, C.M., Thach, T.Q., Ma., S. Lam, T.H., and Anderson, R. 2002. Cardiores-piratory and all-cause mortality after restrictions on sulphur content of fuel in Hong Kong: an intervention study. *Lancet* 360:1646-1652.

Janssen, N.A.J., Brunekreef, B., van Vliet, P., Aarts, F., Meliefste, K., Harssema, H., and Fischer, P. 2003. The relationship between air pollution from heavy traffic and allergic sensitization, bronchial hyperresponsiveness, and respiratory symptoms in Dutch schoolchildren, *Environ Health Persp.* 111:1512–1518.

Jerrett, M., Arain, M.A., Kanaroglou, P., Beckerman, B., Crouse, D., Gilbert, N.L., Brook, J.R., Finkelstein, N., and Finkelstein, M.M. 2007. Modelling the intra-urban variability of ambient traffic pollution in Toronto, Canada. *J. Toxicol. Environ. Health* (in press).

Macfarlane, R., Campbell, M., Fung, L., Li-Muller, A., Mee, C., Pengelly, D., Perotta, K., Ursitti, F., and Ying, J. 2000. Toronto Public Health, Health Promotion and Environmental Protection Office, Toronto, pp. 1-43. www.toronto.ca/health/hphe/pdf/airquality.pdf.

McLean, B., and Barton, J. 2007. U.S.-Canada Cooperation: The U.S.-Canada Air Quality Agreement. J. Toxicol.Environ. Health (in press).

MIT's Laboratory For Energy and the Environment 2002. In Initiatives in Energy and the Environment - A quarterly publication of MIT's Laboratory For Energy and the Environment 4:8-9.

Molina, L.T. and Molina., L.T. 2002. A*ir Quality in the Mexico Megacity: An Integrated Assessment* Cambridge, MA: Kluwer Academic Publishers.

Molina, M.J. and Molina, L.T. 2004a. Megacities and atmospheric pollution. *J. Air Waste Manage. Assoc.* 54:644-680.

Molina, L.T., M.J. Molina, R.S. Slott, C.E. Kolb, P.K. Gbor, F. Meng, R.B. Singh, O. Galvez, J.J. Sloan, W.P. Anderson, X.Y. Tang, M. Hu, S. Xie, M. Shao, T. Zhu, Y.H. Zhang, B.R. Gurjar, P.E. Artaxo, P. Oyola, E. Gramsch, D. Hidalgo and A.W. Gertler. 2004b. 2004 Critical Review Online Version: Air Quality in Selected Megacities, www.awma.org.

Molina, L.T., and Molina, M.J. 2004c. Improving air quality in megacities: Mexico case study. *Ann. N.Y. Acad. Sci.* 1023:142-158.

National Research Council 2004. Air Quality Management in the United States, Washington, DC: The National Academies Press.

O'Connor, S. and Cross, R. 2006. California's Achievements in Mobile Source Emission Control, *EM J. Air Waste Manage*. July 2006.

Pengelly, L.D., and Sommerfreund, J. 2004. Environmental Protection Office, Toronto

Public Health, Toronto, pp. 1-32.

Peters, J., Hedley, A.J., Wong, C.M., Lam, T.H., Ong, S.G., Liu, J., and Spiegelhalter, D.J. 1996. Effects of an ambient air pollution intervention and environmental tobacco smoke on children's respiratory health in Hong Kong, *Int. J. Epidemiol.* 25:821-828.

Pope, C.A. 1989. Respiratory disease associated with community air pollution and a steel mill, Utah Valley. *Am. J. Public Health* 79:623-628.

Pope, C.A., Thun, M.J., Namboodiri, M.M., Dockery, D.W., Evans, J.S., Speizer, F.E., and Heath, C.W. 1995. Particulate air pollution as a predictor of mortality and health, in a prospective study of U.S. adults. *Am. J. Respir. Crit. Care Med*. 151:669-674.

Raizenne, M. 2003. Science and Regulation - U.S. and Canadian Overview. *J. Toxicol. Environ. Health, Part A* 66:1503-1506.

Samaniego, J. and Figueres, C. 2002. Evolving to a Sector-Based Clean Development Mechanism. In Building on the Kyoto Protocol: Options for Protecting the Climate, K.A. Baumert, O. Blanchard, S. Llosa, and J. Perkaus (eds). Washington, DC: World Resources Institute.

Smith, K.R. 1988. Air pollution: Assessing total exposure in the United States. *Environment* 30:10.

The Mexico Air Quality Management Team 2002. World Bank Latin America and the Caribbean Region Environmentally and Socially Sustainable Development Sector Unit, Washington, DC, pp. 51. www.idrc.ca/IMAGES/ecohealth/100205-3.pdf.

Toronto Public Health 2000. Air Pollution Burden of Illness in Toronto. City of Toronto. www.toronto.ca/health/burdenof.pdf.

Toronto Public Health 2001. Condition Critical: Fixing Our Smog Warning System www.toronto.ca/health/hphe/pdf/report_condition_critical_technical.pdf.

Wong, C.M., Lam., T.H., Peters, J., Hedley, A.J., Ong, S.G., Tam, A.Y.C, Liu, J., and Spiegelhalter D.J. 1998. Comparison between two districts of the effects of an air pollution intervention on brochial responsiveness in primary school children in Hong Kong. *J. Epidemiol. Commun. Health* 52:571-578.