Integrated Program on Urban, Regional, and Global Air Pollution

Project for the
Design of an Integrated Strategy
for the Air Quality Mangament
in the Valley of Mexico
2001-2010

Second Phase:

Design, Evaluation and Preparation for the Implementation Mechanisms of the Strategies to Improve the Air Quality in the Metropolitan Area of the Valley of Mexico

EXECUTIVE SUMMARY

Coordinated by:

Mario J. Molina and Luisa T. Molina

Prepared for:

Metropolitan Environmental Commission
Government of the State of Mexico
Government of the Federal District
Secretariat of the Environment and Natural Resources
Secretariat of Health

JUNE 2004

Massachusetts Institute of Technology

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EXECUTIVE SUMMARY

1. INTRODUCTION

Degraded air quality is now widely recognized as a serious threat to both human health and ecological viability. Unfortunately, very poor air quality is often associated with the world's megacities, particularly in rapidly developing nations, where pollutant and pollutant precursor emissions from high-density populations are both concentrated and persistent.

In the Mexico City Metropolitan Area (MCMA) maintaining acceptable air quality is particularly challenging, since the mountains surrounding the Valley of Mexico tend to trap the daily emissions of over 18 million residents, 3.5 millions vehicles, 35,000 industries, while the city's high altitude exposes it to much higher than usual fluxes of ultraviolet solar radiation that can drive photochemical smog. This has resulted in a serious and sustained air quality problem that has persisted for decades.

Recognizing that the citizens of Mexico City deserve to breathe clean air and the ecology of the Valley of Mexico needs to be protected from excessive pollutant deposition, the Integrated Program on Urban, Regional and Global Air Pollution at the Massachusetts Institute of Technology together with colleagues in the USA, Europe, and Mexico, have teamed with the MCMA's Comisión Ambiental Metropolitana (CAM) to characterize the city's air pollution problems and to develop strategies to restore its air quality. However, as important as clean air is to the health and well being of the MCMA's citizens, they also require warm housing, a productive commercial and industrial base, convenient access to work, shopping, educational and cultural institutions, and recreational facilities within the MCMA, and efficient transport throughout the region and beyond. Balancing the energy consumption and monetary investments required to meet these societal needs and still improve air quality is a tremendous challenge, requiring a highly integrated approach to housing, transportation, industrial, commercial, educational and health care activities. The interactive nature of the problem is explored in Molina and Molina (2002).

The first phase of the Project was carried out during the year 2000. In March 2000, the Environmental Trust Fund of the Valley of Mexico approved the Project for the Design of an Integrated Strategy for Air quality Management in the Valley of Mexico 2001-2010. The Project was awarded to the Massachusetts Institute of Technology, through the Integrated Program on Urban, Regional and Global Air Pollution whose principal investigator is Professor Mario Molina. This is a collaborative program for research and education to contribute to the understanding of the complex and severe environmental problems that are characteristic of developing countries, and to develop the capacity of those countries to solve their problems. Mexico City serves as the Program's case study. It involves the participation of a multidisciplinary group of researchers from several Mexican institutions working in close collaboration with a multidisciplinary team of faculty, students and research scientists at MIT, Harvard University, and other US and international institutions. In addition, the Project involves active collaboration with Mexican government officials and decision-makers.

The objectives of the first phase were: a) to evaluate the current status and the air pollution trends in the Mexico City Metropolitan Area (MCMA); b) to identify control strategies; and c) to review the available analysis and decision-making tools. The objectives of the first phase of the Project were completed, and led to an updated diagnosis of the problem of air quality and with a wide range of options for their control, which were used by the Metropolitan Environmental Commission (CAM) for the design of the "Program to Improve the Air quality in the Valley of Mexico 2002-2010." Also, the Project identified the steps to continue to improve the scientific foundations and the administrative tools of air quality management available in the MCMA, with the objectives to increase the effectiveness of the pertinent programs and to make better use of the scarce resources available.

The final report of the Project was presented by MIT to the Environmental Trust Fund of the Valley of Mexico in October of 2000. The results were presented to the public in November of that same year in Mexico City. The report of the study is available via Internet: (http://eaps.mit.edu/megacities/Reports.html). It has since been updated and published as a book entitled "Air Quality in the Mexico Megacity: An Integrated Assessment" by the Kluwer Academic Publishers.

At the recommendation of CAM, on August 14, 2001, the Environmental Trust Fund of the Valley of Mexico City approved the allocation of resources to elaborate the research project "Design of an Integrated Strategy for Air Quality Management in the Valley of Mexico: Second Phase." The project was assigned to the Massachusetts Institute of Technology (MIT), with Dr. Mario J. Molina as principal investigator leading a research team comprising of Mexican and US institutions and researchers. The contract was signed between MIT and Metropolitan Environmental Commission (CAM) at the end of December 2001, and the Project activities officially started in January 2002.

This second phase focused on the systematic development, implementation and transfer to CAM of scientific information, evaluation methodologies, simulation tools and indicators in the following areas: a) the causes that determine the generation of pollutants in the MCMA and the activities that lead to their emissions (transportation, production of goods and services, degradation of the natural environment, etc.); b) the dispersion processes and the movement of the pollutants emitted to the atmosphere, as well as their transformation into other pollutants (with focus particularly on ozone and particles); c) the evaluation of risks and the effects of the pollutants on the population; d) the evaluation of costs of the contamination and benefits of their control; e) an integrated evaluation of policy options and priorities for the control of atmospheric contamination; f) strategies for capacity building and professional development in all the relevant institutional sectors and at all levels.

In the following sections, we presented the summaries of the key findings and recommendations.

2. INTEGRATED SCENARIO ANALYSIS

One of the key goals for the integrated scenario analysis was to identify portfolios of options (strategies) which could result in "substantial and sustained" reduction in pollutants, so that as the MCMA grows and evolves, air quality and its associated health and ecosystem benefits improves. With this in mind, three alternative growth and evolutionary paths for the MCMA were formulated that encompassed varying degrees of economic prosperity and purchasing power, population growth and household size, and urban growth and density. Also included in the crafting of these scenarios or "future stories" of MCMA's development were the availability and cost of future technologies, the ability of government institutions to implement complex emissions reduction programs, and the willing of the citizens to accept or adopt the emissions reduction measures as intended.

Areas covered by the MIT integrated scenarios analysis team included emissions from transportation, large stationary sources (point sources), and small stationary sources (area sources). Transportation was divided into personal transport (autos), road based public transport (buses, colectivos and taxis), the metro, and freight for mobile emissions. For stationary area and point sources, the residential, commercial (formal and informal), industry, and power generation sectors were covered. Emissions reduction measures from past and current air quality programs emphasize emissions reductions from transportation, and to some degree point sources. The number of measures reducing emissions from households and small business has been few even though these represent a substantial proportion of non-methane hydrocarbon (NMHC) emissions, as shown in Figure 1.

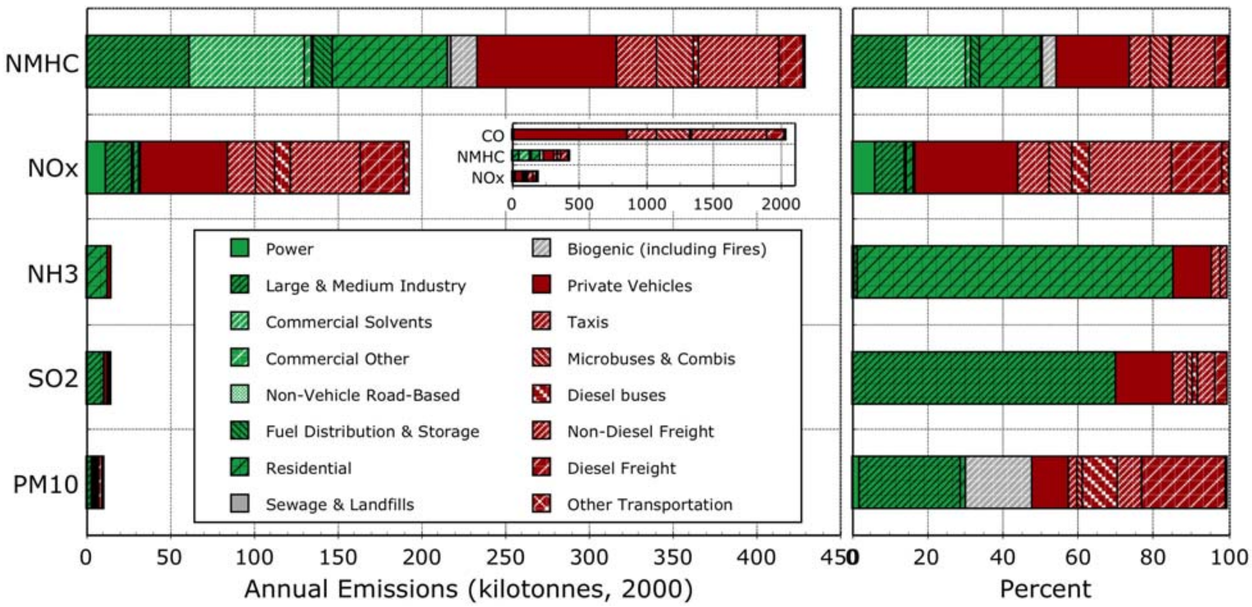


Figure 1: Sources of Emissions in the MCMA – 2000 (CAM, 2004)

This is not to say that the number of measures directed at the transportation sector is too large, but that the number of measures directed at non-transportation sources may be too small. Non-mobile emissions sources (except for carbon monoxide) are of equivalent magnitude to those from transportation. From an exposure and health effects viewpoint they may also be large as residents of the MCMA are generally at home, at work, or in-between, where direct exposure to pollutants can often be substantially higher than ambient concentrations. Furthermore, the number and diversity of informal businesses, from road side food stands, to small paint and printing shops, to metal works and brick making, make these sources of emission hard to quantify, which means they may be under represented in emissions inventories.

This diversity of emissions sources, the balance of emissions reduction measures, and uncertainties surrounding the evolution of the MCMA over the next several decades, highlights the need for a very integrated and coordinated approach to the design and implementation of economically responsible, environmentally effective air quality programs. This challenge of long-term emissions reductions must first overcome the need for emissions reductions in some sectors (private autos, diesel vehicles) to *overcome increases* from other areas (e.g. overall urban growth, formal and informal commercial activities, increased road congestion). Only then can the challenge of achieving *substantial and sustained emissions reductions* and improvements in air quality be addressed. The recommendations from each of economic-activity sectors below are presented with these dynamics in mind.

Working from the "future story" descriptions, seven emissions generating activity categories were targeted for detailed investigation of how to achieve substantial emissions reductions. For the transportation of people, these included private vehicles, road based public transport (RBPT: taxis, colectivos, diesel buses), and the metro. Also in the transportation category was local and regional freight. Non-transportation emissions came from the residential sector (households), the commercial sector (both formal and informal), and from industry and power generation. Table 1 shows how these activity categories map to the various criteria pollutants based upon the 2000 emissions inventory, and based upon whether their emissions fall into 5-10%, 10-20%, or greater than 20% of annual MCMA emissions. Also listed is the principal fuel-energy source for the category.

Table 1: Principal Activity Categories and Emissions Sources Evaluated by the MIT Integrated Scenario Analysis Team

	NMHC	NOx	SO2	PM10	CO	Primary Fuel
Mobile Sources						
Private Vehicles	• •	• • •	• •	•	• • •	Gasoline
RBPT Taxis	•	•			• •	Gasoline
Microbuses & Combis	•	•			• •	Gasoline
Diesel Buses				•		Diesel
Frieight Non-Diesel	• •	• • •		•	• • •	Gasoline
Diesel		• •		• • •	•	Diesel
Non-Mobile Sources						
Residential	• •					LPG
Commercial	• •					LPG, Nat.Gas
Industry & Power	• •	• •	• • •	• • •		Nat.Gas, Oil
	••• > 20%, •• > 10%, • >5%					

2.1. Recommendations by Principal Activity Categories

2.1.1. Personal Transport – Private Automobiles

The principal emissions from the predominantly gasoline fueled private vehicle fleet are CO, NO_x, and NMHC.

Over the long term, motorization rates, and therefore the number of personal autos on MCMA roads, will increase. The number of personal cars, and the distance and amount of drive time will be influence by how many people within the MCMA will be able to afford cars, where they live and work. Policies influence what types of cars are available, which ones people buy, and how they use them. The multi-option scenarios for personal auto fleets encompassed continued personal automobile driving restriction days (*Hoy No Circula*), vehicle emissions retrofits and vehicle scrappage for existing autos, and stricter emissions standards and improved fuel economy for new vehicles.

The scenarios for the private auto fleet show that efforts to improve the performance of vehicles entering the fleet reduced emissions over the long-term much more than strategies focused on cleaning up the existing vehicle fleet. Short term reductions were achieved from options aimed at existing vehicles, however in the context of the twenty-five year analysis period (2000-2025) these vehicles exit the operating fleet anyway, and if the inspection and maintenance program works as intended, high emitting vehicles are dealt with. Reductions were greatest for NO_x and NMHC, with CO emissions held in check.

Confounding efforts to reduce emissions from private vehicles will be the availability of low emissions vehicles for purchase, the affordability of these vehicles, both of which may inhibit the displacement of older vehicles from the fleet. Of equal, or perhaps even greater importance, is the continued decentralization of the MCMA leading to increased vehicle use (vehicle kilometers traveled), and drive times (increased traffic and congestion). Over the long-term, vehicles with low stop-and-go traffic emissions, such as hybrid cars, may mitigate some of the emissions due to increased congestion, but it is unlikely that these will represent a large portion of the private vehicle fleet for some time to come. A well integrated, inexpensive, and safe public transport system may also reduce private vehicle use, and therefore reduce emissions from this sector.

2.1.2. Public Transportation

The principal emissions from predominantly gasoline fueled colectivos and taxis are CO, NOx, and NMHC, with diesel buses contributing to particulate and NOx emissions. The Metro runs on electricity, and changes in metro usage will have negligible effect on the emissions from power plants located in the MCMA. Emissions reductions (or increases) from road-based public transport (RBPT) need to be evaluated in the context of the use of RBPT versus private auto. An increase in RBPT emissions may be a net reduction of emissions within the MCMA if the public transport system, including RBPT and metro integration, bus rapid transit, and transit oriented development reduces the growth and use of private vehicles.

Scenarios focused on reducing emissions from the RBPT fleet included options which scrapped old vehicles, converted vehicles to compressed natural gas, or retrofitted taxis and colectivos with three-way catalysts, and diesel buses with PM-NOx traps. Other options included improved emissions standards and fuel efficiency for taxis and colectivos (including hybrids), improved inspection and maintenance of public transportation fleets, and the introduction of hybrid buses. Beyond technologies, the introduction of bus rapid transit, and route and fare integration were also evaluated.

Since the longevity of diesel buses, colectivos, and taxis is much greater than that of private autos, strategies that cleaned up or retired old vehicles, as well as required cleaner, more efficient vehicles were more cost effective if they could be successfully implemented. A conclusion shared with that of private vehicles is that strategies that promoted cleaner and more fuel efficient vehicles were considerably cheaper, as the savings from reduced fuel purchases were often greater than the incremental cost of better vehicles. Strategies focused on fleet turnover alone, or the conversion to CNG vehicles did not achieve substantial and sustained reductions in NO_x and NMHC. Integrated transport and fare integration options also performed well. However, these options need to be analyzed in greater detail and need to be implemented in ways that address the concerns of current transportation operators, and maximize high demand travel corridors and under-utilized metro lines, all within the context of transit oriented development and reduced urban sprawl.

2.1.3. Freight Transportation

Local and regional freight transportation is an important contributor to air pollution in the MCMA. Light duty (gasoline) trucks are large contributors to overall CO, NOx and NMHC emissions. Diesel freight, both local and regional, contributes to particulates and NOx emissions.

Like public transportation, vehicle lifetimes can be very long, especially for diesel trucks. The demand for freight transport increases with economic activity and urban population, with a substantial portion of freight vehicle deliveries crossing into, out of, or through the MCMA. Better emissions reduction options look similar in form to those of public transport, with the need to retire older-dirtier vehicles, introduce improved vehicle technologies, and integrate the transfer of freight from high volume, longer distance modes to more suitable local delivery modes (tractor trailers analogous to bus rapid transit, rail transport analogous to the metro, transshipment centers like colectivo/bus/metro hubs). These options offer significant challenges to the structure of the freight industry (common carriers versus corporate fleets). More subtle benefits of these improvements include increases in economic productivity, and the reduction of exceedingly high particulate emissions of diesel truck emissions caught in city traffic. Reduced (local) road congestion plays a role here as well. If congestion persists, delivery companies will have to use more delivery vans (further exacerbating congestion), as the number of deliveries a vehicle can make in any given day will be reduced.

2.1.4. Residential Sector

The 2000 emissions inventory identifies NMHC as the primary pollutant from the residential sector. This is due to a mix of LPG leakage and solvent use, with toxic exposure, indoor air quality as well as metropolitan air quality considerations. In poorer neighborhoods there is the generally unaccounted for emissions from trash burning, or the use of waste fuels for cooking and hot water. Measures previously considered to reduce household emissions include replacing LPG burner tips and valves to reduce leakage, and the greater availability of natural gas as a household fuel. Higher efficiency appliances to reduce electricity consumption also has substantial greenhouse gas and household cost benefits, but limited local and regional air quality benefits.

Inhibiting the transition to improved fuels and appliances in the residential sector is general economic development. If economic progress is slow within the MCMA, and that progress fails to reach lower income households, then their ability to avail themselves of better energy sources and more efficient end-uses will be low. Low household wages will also promote continued urban sprawl (in the absence of a redensifying low income housing program), reducing the likelihood of access to residential natural gas distribution networks, centralized waste collection, and sewage interconnects, as well as the inability to implement the more coordinated, high occupancy, cleaner public transportation options mentioned above.

2.1.5. Commercial Sector – Formal and Informal

The commercial sector is comprised by a diverse set of small and medium sized enterprises including food, retail, business-to-business, and light manufacturing, some of which are formal (licensed) business while others are not. Included are such activities as gas stations, LPG recharging and delivery, road side food stalls, paint shops, metal and brick and other fabrication, custodial services, landscaping, etc. The vintage and use of technologies, processes, and practices by these businesses is broad. Combined, the commercial sector is a large source of employment, and the balance of formal to informal commerce depends in part on the health of the economy. Therefore emissions from the commercial sector will grow not only with economic activity in general, but the distribution of formal to informal businesses.

Options suggested the commercial sector have included vapor recovery equipment for gas stations, technological shifts for dry cleaning establishments and substitute fuels for select industries (e.g., brick kilns). While beneficial for the targeted end-use, there is little opportunity to "scale-up" these measures to the sector as whole. However, improved characterization of these activities and their associated emissions will allow for the consolidation of future options to achieve broader emissions reductions, but implementation will be a challenge. The largest opportunity for emissions reduction will be product substitution of cleaning and other solvents. This will extend to products used by households as well.

2.1.6. Industry and Power

Unlike the commercial sector, industrial point sources are well known, provide emissions reports to government agencies, and are subject to emissions regulations, including shutdowns during air quality contingencies. Ensuring compliance by these businesses, in a cost-effective manner, will help eliminate or mitigate emissions from these "high volume" facilities.

Over the past decade of so, the MCMA has seen a shift of its industrial sector as some businesses moved, or chose to expand their operations outside the MCMA (e.g. US-Mexico border). Therefore the changing mix and vintage of MCMA industries must be taken into account when refining measures to manage the emissions from MCMA based industrial facilities. One shift that may have adverse emissions consequences is the outsourcing of manufacturing sub-processes to facilities within the less well regulated commercial sector.

Continued expansion of natural gas as the fuel of choice for industries requires that attention be paid to the development of a robust natural gas supply, transmission, and delivery infrastructure, insulated from price swings that might discourage the switch to natural gas. The same can be said for making natural gas a broadly available fuel for the commercial, residential, and transportation end-uses.

2.2. Cross-Cutting Insights and Recommendations

The challenge of "substantial and sustained" emissions reductions within the MCMA over the next several decades is a large one. Emissions reductions themselves are a surrogate metric for overall air quality improvement, personal exposure, and health impacts. The overview of results and recommendations from the integrated scenario analysis show that significant reductions in emissions are possible from private auto, and public transportation fleets, even as those fleets grow in number and use over time. Of particular note is the balance between higher emissions, older technologies and their persistence in the various "fleets," and the environmental performance of new cars, trucks, buses, etc. entering the fleet either to meet increasing demand, or replace vehicles exiting the fleet. Emissions from freight transport are also important, and as this fleet tends to turn over more slowly than the passenger fleet, it is an area for more worthwhile, detailed study, and the design of emissions reduction options aimed at both the technical aspects of freight vehicles and the coordination and integration of freight transportation incorporating intermodal and trans-shipment organizational improvements.

While emissions reductions from vehicles, due to technological improvements and fleet turnover dynamics are promising, emissions from other sectors generally increase, or at best decrease only slightly. Growing populations and economic output threaten aggregate reductions in emissions, as growth in these areas, and their associated emissions, may eclipse the reductions gained in transportation sectors. Continued urban sprawl, and its association with poverty exacerbate these trends. *The management of urban growth, and its influence on the demand for both personnel and freight, is a major element of any long-term emissions reduction plan.*

Much more work is needed to better characterize the activities and associated emissions from poorly understood sectors, namely the commercial sector, especially informal commercial activities. Industrial emissions, in particular the impacts of structural change of industry encompassing both the product mix and de-centralization of manufacturing industries, will inform environmental regulators not only about long-term trends, but also the effectiveness and ease of implementation of command-and-control versus market-based approaches to emissions control. In the more dispersed sectors, especially the residential and informal commercial sectors, product substitution approaches appeared promising, especially for solvent related NMHC emissions, but fuel switching appears more problematic as it highly dependent on government action to extend the natural gas distribution systems to smaller consumers, many of whom are located on the outer edges of the city.

The general conclusion from the integrated scenario analysis is that significant emissions reduction options exist in the short term, but if the longer-term, urban growth and urban form drivers are not included into the design of successive air quality, transportation and other programs, then it will be difficult to improve and sustain air quality improvements over the long-term.

3. THE HEALTH IMPACTS OF POOR AIR QUALITY

Poor air quality imposes a significant health burden on residents of Mexico City. Epidemiologic evidence indicates that of the best-studied air pollutants (*e.g.,* particulate matter, ozone, CO, NO_2, and SO_2), particulate matter, followed by ozone, causes the most severe health impacts.

Researchers now believe that fine particulate matter ($PM_{2.5}$, particulate matter with an aerodynamic diameter of 2.5 μm or less) contains the most toxic components. Increases in daily $PM_{2.5}$ concentrations have consistently been linked to increases in daily mortality. Most of the deaths caused by $PM_{2.5}$ are from cardiovascular causes and occur among the elderly. However, recent evidence indicates that infants may also be particularly sensitive to fine particulate matter.

Particulate matter is also believed to cause chronic bronchitis, and to lead to increased rates of hospital admissions for respiratory and cardiovascular disease, increased emergency room visits for treatment of respiratory symptoms and asthma attacks, and to increased absenteeism from work and school (i.e., restricted activity days).

Ozone has a smaller effect than particulate matter on mortality. However, ozone has strong and obvious effects on respiratory function, respiratory symptoms (such as eye irritation and cough), and on hospital admissions for asthma and other respiratory conditions.

A rough estimate of the magnitude of health benefits that could be achieved by a reduction in air pollution in the MCMA can be obtained by considering only the benefits of mortality reduction caused by decreasing ambient $PM_{2.5}$ levels. In the first phase of the Program, we estimated that a 10% reduction of ambient $PM_{2.5}$ in Mexico City would prevent approximately 1000 deaths each year, and perhaps several times this many. Given the amount that residents of Mexico City are willing to pay for reducing mortality risks, we estimate the economic value of these health benefits to be on the order of 650 million U.S. dollars for every 1000 deaths attributed to particulate matter air pollution.

3.1. Quantifying Health Benefits

While the health impacts of poor air quality are significant, the Mexican government must choose among many pressing social and environmental needs when deciding which policies to pursue. By quantifying the health benefits of improving air quality and comparing them with the costs of reducing emissions, researchers can help government decision-makers to make more informed choices among diverse policies. Therefore, during the second phase of the Program, we improved our ability to quantify the benefits of improved air quality, and compared the benefits and costs of two policies that aim to improve air quality.

3.1.1. Improving the Basis for Quantifying Health Benefits of Improving Air Quality

To quantify the health benefits of reducing emissions, analysts must quantify three highly uncertain variables. First, reductions in human exposure to harmful pollutants are calculated from the emissions reduction. Second, the reductions in health impacts (such as reduced rates of mortality or chronic bronchitis) due to reduced exposure are calculated using information from epidemiological studies (*i.e.*, the concentration-response coefficient) and supporting evidence from toxicology. Finally, the health benefits are monetized using information on citizens' willingness to pay to reduce health risks. We conducted original research to characterize two of these variables for Mexico City: the concentration-response coefficient, and the willingness to pay for eliminating risks to health.

Concentration-Response Coefficient

Estimates of the reduction in mortality due to a reduction in pollution generally rely on coefficients from long-term and short-term epidemiologic studies conducted in settings around the world. While these studies have provided regulators and analysts with useful information regarding pollution and health effects, many uncertainties about the complex mortality-pollution relationship remain. Key uncertainties include – (1) whether long-term health impacts found in studies outside of Mexico occur at the same rate in Mexico City, (2) whether the particulate matter in Mexico City has a higher, similar or lower toxicity than that found in other cities, and (3) whether the deaths which occur due to air pollution involve primarily the elderly and susceptible (and therefore lead to only small losses of life expectancy) or whether they may include deaths of young healthy individuals (with correspondingly larger losses of life expectancy).

In the first phase of this work, we qualitatively described these sources of uncertainty but did not provide a quantitative sense of their impact on estimates of health benefits of improvements in air quality. In the second phase of this work, we conducted a structured elicitation of air pollution experts in Mexico and Europe in which they were asked to evaluate the uncertainty about the concentration-response coefficient. While this study is not yet complete, the preliminary results suggest that all of the experts assigned higher values to the dose-response coefficient than those commonly used in regulatory analysis (which provided the basis for our initial estimate of the mortality benefits of a 10% improvement in air quality in Mexico City. Further (as might be expected) preliminary analysis indicates that experts ascribed much broader ranges of uncertainty to concentration-response coefficients than those that would be derived directly from the statistical confidence intervals reported in the underlying studies. For example, when asked to characterize the impact of a 1 ug/m3 permanent reduction in $PM_{2.5}$ the experts gave 90% confidence intervals which varied from a factor of 8 below their median estimate to a factor of 4.5 above their median estimate. The experts noted that, among the many sources of uncertainty, they were particularly concerned with differences between the Mexican population and the epidemiologic study populations, the relationship between ambient air quality and personal exposure to $PM_{2.5}$, and composition of the particulate matter in Mexico City.

Willingness to pay

It is not possible to know whose health is affected by a change in air quality. Therefore, instead of placing a monetary value on preventing individual deaths from air pollution, it is more relevant to value individuals' willingness to pay for small reductions in risk of death. Willingness to pay for a risk reduction is then aggregated over individuals to obtain the value of a statistical life, i.e., the amount that a community would pay to reduce the expected number of deaths from air pollution by one. A standard method for estimating willingness to pay to reduce mortality risk is to estimate the additional wages that workers receive in compensation for holding jobs with higher levels of occupational risk. In the first phase of the Program, we converted the value of a statistical life used by US EPA for the United States by comparing the ratio of Mexico and US per capita gross national products, since direct estimates for Mexico City were not available. This approach produced a central value of $650,000 (with an uncertainty interval of $100,000 to $2 million) which was used in our early benefits estimates. In the second phase of the Program, we obtained estimates of the monetary value of reducing mortality risk by surveying workers in Mexico City about their wages and fatal and non-fatal occupational risk. Wages were compared with both actuarial and perceived risk, yielding estimates of the value per statistical life ranging from $230,000 to $320,000, toward the lower end of the uncertainty interval for the estimates derived by extrapolating from the US to Mexico.

3.1.2. Quantifying the Benefits of Reducing Diesel Emissions

Our research evaluated two interventions that are expected to result in significant health benefits. We chose to focus on interventions that mitigate the impact of diesel emissions because these contribute heavily to primary particulate matter, and to the precursors that form secondary particulate matter and ozone in the atmosphere. In addition, emissions reductions efforts in the past have concentrated on point sources (such as factories) and gasoline vehicles. Therefore, policies that reduce emissions from diesel vehicles are expected to have a greater impact on health at a smaller cost than other types of emissions-reduction policies. We analyzed two policies that would diminish diesel emissions, through (1) retrofit of existing vehicles with improved emissions control technology, and (2) gradual improvement of the diesel fleet emissions profile by tightening standards for new diesel vehicles.

Dealing with Diesel on the Road: The Benefits of a Retrofit Policy

We quantified the social costs and health benefits of retrofitting diesel vehicles in Mexico City with catalyzed diesel particulate filters, actively regenerating diesel particulate filters, or diesel oxidation catalysts, either immediately or in 2008 (when capital costs are expected to be lower). Diesel particulate filters are more effective, but are also more costly, than oxidation catalysts. Retrofits with diesel particulate filters or oxidation catalysts are expected to provide net benefits to society whether they begin immediately or in 2008. For example, retrofitting an average new bus with a catalyzed particulate filter is expected to provide annual net benefits of $800 per vehicle, and retrofit with an oxidation catalyst $300 per vehicle. Retrofitting vehicles in 2008, after capital costs have declined, increases annual net benefits to $2000 per bus for a catalyzed particulate filter, and $600 per bus for an oxidation catalyst. Although retrofit with particulate filters provides greater net benefits, retrofit with oxidation catalysts provides greater health benefits per dollar spent than retrofit with particulate filters. Finally, retrofit of older, dirtier vehicles provides higher net benefits than retrofit of newer, cleaner vehicles. Because this study was conducted prior to the expert elicitation project, the concentration-response coefficients used in this assessment are based largely on values used in the first phase of our work. If the larger estimates provided by experts in the elicitation study had been applied, benefits would have increased by a factor of two or more.

Ensuring a Cleaner Diesel Fleet: The Benefits of Tighter Diesel Emissions Standards

Advanced technologies, including particulate filters, are available to reduce diesel emissions in new diesel vehicles. These technologies reduce emissions of particulate matter from new vehicles by 90%, and emissions of oxides of nitrogen by 80%. However, the government must first reduce the sulfur levels in the general diesel supply. Therefore, the Mexican government has decided to reduce sulfur levels in Mexican diesel from 500 ppm to 15 ppm by September 2008. In order to evaluate the government's decision, we quantified and compared the costs and benefits of reducing sulfur in diesel fuel and requiring stricter emissions standards (equivalent to U.S. EPA's 2007 standards) for new diesel vehicles. By requiring that new vehicles comply with these emissions standards beginning in 2009, 1,500 deaths per year can be prevented by the year 2020. This policy is expected to have net present benefits of about $8 billion over a status quo baseline.

3.2. Recommendations

The recommendations are grouped in two categories, those that are related to regulations and air pollution control in Mexico City, and those related to research and assessment exercises.

3.2.1. Air Pollution Control Strategies

Strategies that use advanced emissions control technologies to reduce emissions of particulate matter from diesel vehicles, such a diesel retrofit technologies and strict emissions standards for new diesel vehicles, provide benefits to society. These strategies represent cost-effective and practical methods for reducing exposure to fine particulate matter and to ozone. We recommend that the Mexican government adopt policies to encourage or require the adoption of advanced diesel control technologies.

We recommend that the government continue to evaluate policies that aim to improve air quality through formal benefit-cost analysis. Quantitative analysis can help decision makers identify policies that will provide the largest gains in air quality and health while minimizing costs and other burdens on the population. In addition to policies designed for the U.S. and other countries, attention should be given to policies that may be more appropriate to conditions in Mexico City. For example, we suggest that decision makers investigate the potential of policies that aim to reduce emissions by improving the relative cost, convenience, and safety of using public transportation. In addition to reducing vehicular emissions, these types of policies can provide other benefits to society, such as reductions in roadway congestion and improvements in roadway safety, particularly for pedestrians.

3.2.2. Opportunities for future research

Improving Estimates of Exposure

Benefits estimates and, in turn, decision-making about air pollution policy rely heavily on estimates of how population exposure to fine particulate matter and other pollutants would change in response to changes in emissions. Future policy evaluations could be substantially improved by better estimates of the relationship between emissions from specific classes of fixed and mobile sources and population exposure, based on refinement of exposure modeling techniques and estimates. Results of the field measurements completed in the second phase of the program and the improved characterization of atmospheric chemistry can be harnessed for improving exposure models and the estimates used for policy evaluations in Mexico and the MCMA.

Improving Characterization of Mortality Response to Air Pollution

Current estimates of mortality due to air pollution rely on a small number of epidemiologic studies based in Mexico, supplemented with studies from settings around the world. Thus, characterization of mortality response to air pollution in Mexico can be improved by conducting more studies in Mexico for direct characterization of air pollution effects within Mexican populations, particularly those examining long-term exposure. Such studies can provide helpful input to research and decision-making; however, they are potentially expensive and their results will take several years to be realized. In the interim, understanding how exposure and population characteristics in Mexico compare with those in epidemiologic studies around the world would help reduce uncertainty in the use of these studies for health effect estimates in Mexico. Similarly, increased analysis of epidemiologic results (such as in the expert elicitation described above) and their application to risk assessment and policy decision-making in Mexico would maximize the value of existing studies for policy and research prioritization.

4. AIR POLLUTION SCIENCE

While an integrated strategy will be required to achieve and sustain improvements in the level of air pollutants in the MCMA, air quality management strategies must be based on a solid understanding of the pollutant and pollutant precursor emissions and atmospheric processes that lead to polluted air. The required level of understanding can only be achieved by comprehensive atmospheric measurements followed by a coordinated atmospheric modeling program. An innovative, two phase atmospheric measurement program, with exploratory measurements in February 2002 and extensive measurements from late March through early May of 2003, was designed to be a key feature of the MIT/CAM collaboration. Measurements of reactive photochemical intermediates were made in the ambient air for the first time; measurements which will help in the understanding of the causes of air pollution in Mexico City, and lead to suggestions for improvement.

The extensive data sets from the 2002 and 2003 measurement programs are still being analyzed and prepared for publication; however, our preliminary analysis efforts have yielded important insights into the nature and extent of air pollution in the MCMA. These preliminary results are presented below and provide context for defining initial policy options and recommendations that form the core of this report.

Preliminary analyses of data from our 2002 and 2003 atmospheric measurement program confirm many the conclusions of presented in our initial review of MCMA's air quality (Molina and Molina, 2002). In addition, our atmospheric measurements and computer modeling have revealed unexpected large emission sources for some key pollutants, uncovered important correlations in the evolution of secondary pollutants produced in the atmosphere, and produced new insights about the coupling of pollution and air movement in the Valley of Mexico.

A major product of this project is the availability of a sophisticated atmospheric photochemical model whose performance is being verified with the measurements conducted during the extensive field measurement campaigns. The model can be used as a reliable tool to assess the efficiency of various emission control strategies.

4.1. Key Findings Supported by Atmospheric Measurements

Relative to typical U.S. and European cities:

1. The MCMA atmosphere contains very high levels of highly reactive volatile organic compounds (VOCs). These highly reactive VOC levels are important because they are key contributors to the formation of both ozone and secondary fine aerosol particles.
2. The MCMA atmosphere contains very high levels of reactive nitrogen oxides (NO + NO2 = NOx). These compounds are also contributors to the formation of ozone and secondary fine aerosol particles.
3. The MCMA atmosphere contains surprising high levels of ammonia (NH3), which contributes to the formation of secondary fine aerosol particles.
4. The MCMA atmosphere receives high levels of solar ultraviolet (UV) radiation, although large concentrations of fine secondary aerosol particles often attenuate the level of ground level UV radiation.
5. Large concentrations of secondary fine particulate matter (PM) composed primarily of oxidized organic species, ammonium nitrate, and ammonium sulfate are correlated with atmospheric oxidant production.

6. The MCMA atmosphere can develop unhealthful levels of ozone and related oxidants surprisingly early (before noon), even on days when solar radiation is partially attenuated by clouds.
7. The MCMA atmosphere contains surprisingly high levels of toxic air pollutants, including formaldehyde, acetaldehyde, benzene and toluene.
8. MCMA motor vehicles are the major source of NOx emissions.
9. MCMA motor vehicles emit surprisingly high levels of formaldehyde and acetaldehyde.
10. Newer MCMA gasoline powered light duty motor vehicles are a source of ammonia emissions.

4.2. Top Level Air Quality Management Recommendations

The atmospheric measurement-based findings listed above lead directly to several top level air quality management recommendations. These include:

1. The close correlation between photochemical oxidant (ozone) and secondary fine particle (PM2.5) production and their common precursor species (NOx, reactive VOCs) requires that these critical pollutants be addressed in a combined management strategy.
2. Many high concentration toxic air pollutants are reactive VOCs; controlling their levels will not only reduce air toxic exposures, but also contribute to a reduction in photochemical oxidants and secondary organic aerosol particles.
3. MCMA motor vehicles are major sources of primary fine PM, ozone and secondary fine PM precursors, and toxic air pollutants, these emissions will need to be reduced to achieve acceptable air quality.

4.3. Classes of Pollutant/Precursor Emissions Requiring Control

Initial analyses of MCMA photochemical and PM formation chemistry indicate that emissions control should focus on the following chemical classes:

1. Primary fine PM (soot)
2. Reactive nitrogen oxides (NOx)
3. Reactive VOCs – aldehydes, olefins, aromatics
4. Ammonia (NH_3)

4.4. Policy Options to Reduce Emissions

1. Improve emission control on all vehicles; introduce new catalyst technology; improve fuel quality by reducing sulfur levels in both diesel and gasoline; cause vehicles with substandard emission controls to be repaired, retro-fitted, or removed.
2. Reduce aromatic emissions from industrial and commercial processes.

3. Reduce VOC emissions from food cooking processes
4. Reduce emissions from sewer vents and open sewage canals
5. Reduce smoke emissions from refuse fires, rendering facilities, and other uncontrolled combustion facilities

5. TRANSPORTATION SECTOR

The linkage between air quality in Mexico City and transportation has been well established in several years of research. The challenge that we face is assuring the mobility of people and goods and services around the MCMA, while lessening the negative air quality impacts of various transportation activities. Retaining mobility is central to the economic growth agenda of Mexico City; yet if air quality continues to deteriorate, this will be a drag on human health, productivity and, indeed, economic growth itself.

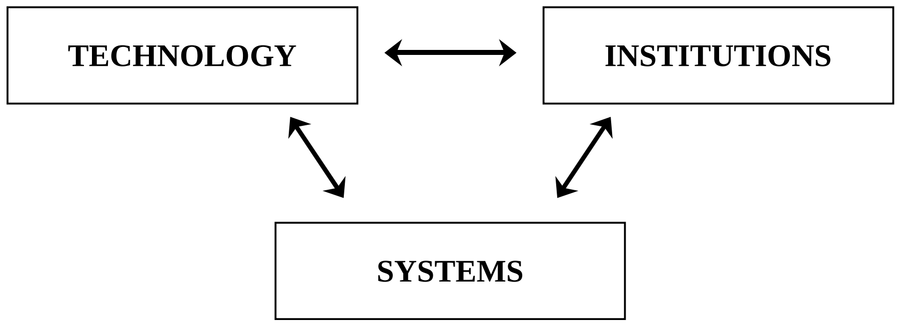
Over the past several years, we have considered a number of aspects of the transportation system of the MCMA, with an eye to understanding transportation impacts on air quality and developing various strategic options that could be used to minimize negative externalities on the environment. Among the areas we have studied are those below.

- The Metro system and associated land-use changes
- Freight transportation and especially operation and management of trucks in the MCMA
- Transportation network performance and its implications on air quality -- the relationship between emissions and congestion
- Emissions from surface-based public transportation modes -- buses, taxis, colectivos (i.e., all public transportation except the Metro)
- Road-based transportation and how mobility needs relate to environmental impacts
- New technological approaches to transportation and air quality issues – using Intelligent Transportation Systems
- Institutional factors in the development of transportation/air quality policies.
- The role of stakeholders in representing the Mexico City transportation system and in developing strategic options for enhancing mobility and improving air quality
- Innovation in regional strategic transportation planning

These areas, taken collectively, consider the triplet of *technology, systems and institutions*, wherein we examine

1. **Technological** possibilities for enhancing the performance of transportation systems relative to air quality (e.g., catalytic converters) and mobility (e.g. Intelligent Transportation Systems);
2. **Systems** issues, which involve understanding the interrelationship among transportation, the environment, economic development, land use, human health and so forth; and

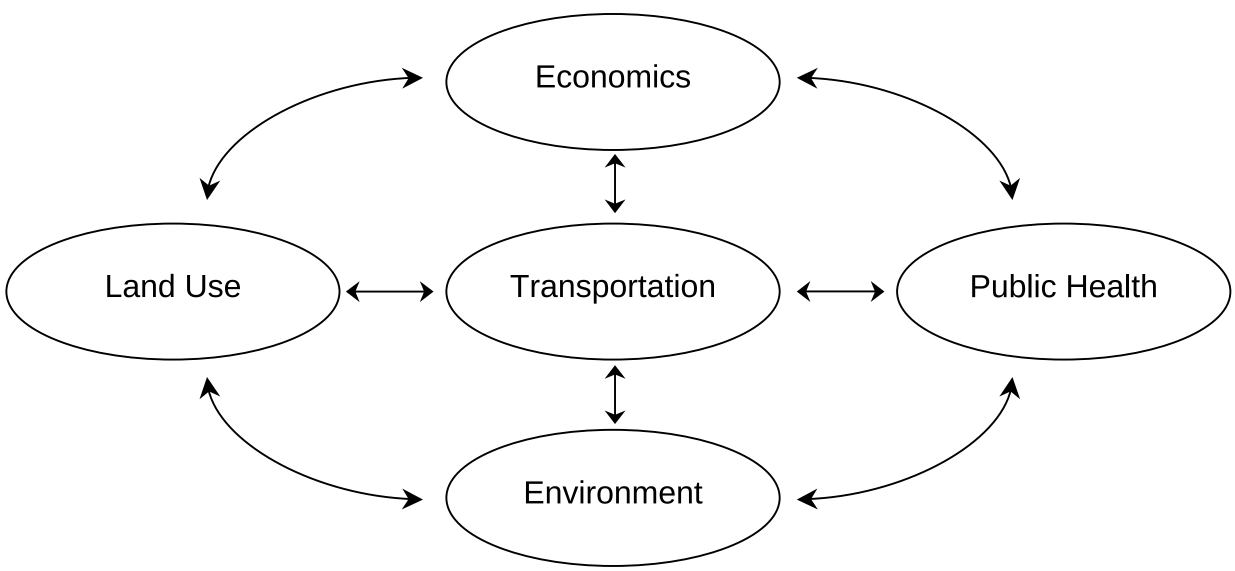
3. **Institutional** factors, the relationships among various government agencies as well as private-sector organizations and stakeholders and how they must come together to provide for a better air quality system in the MCMA without draconian cutbacks in mobility.



From these studies and considerable interactions with colleagues in Mexico, especially through a series of air quality workshops at various venues in Mexico and in the US, we have developed a series of overarching recommendations for CAM as it proceeds toward its long term goal of improving air quality in the MCMA while providing mobility for people and for freight.

We recognize Mexico City faces a daunting problem in the realm of transportation and air quality. Only through a broad-based ***systems*** approach, recognizing subtle interactions between various societal subsystems -- are we likely to make long-range progress. Hence, our recommendations have the theme of *integrated thinking* on several dimensions including:

Domains — considering transportation, environment, economics, land use and public health issues as inter-related.



Geographical — considering the MCMA region as a whole

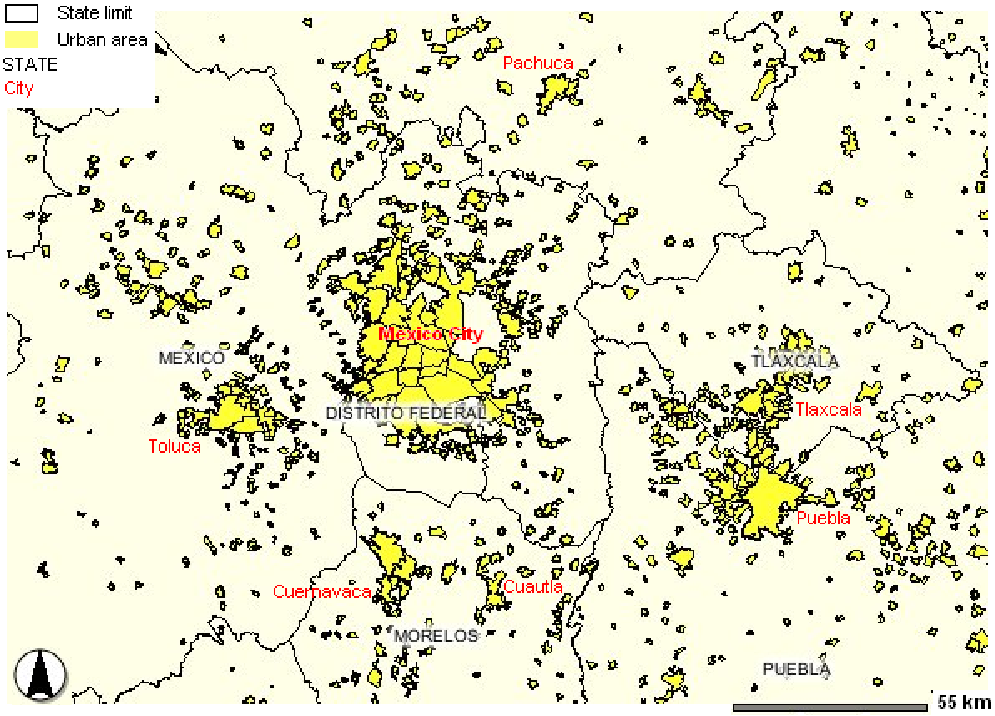


Figure 2. The Megalopolis: Mexico City Metropolitan Area and the "Corona Cities"
Source: INEGI, 2004. See http://galileo.inegi.gob.mx/website/mexico/viewer.htm

Modal — considering the modes not as independent that rather as an integrated multimodal system and including both travelers and freight.

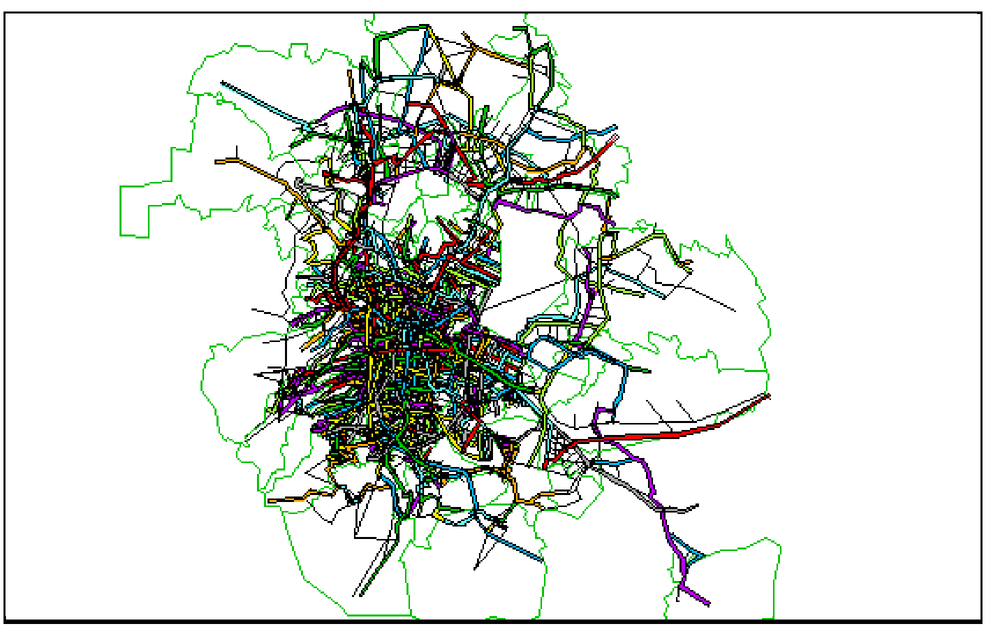


Figure 3. Public Transportation Network for the MCMA.
Source: MIT MC Urban Transportation Model, 2004.

Institutional — recognizing that restructuring organizations with different missions and constituencies, representing different political entities (eg the DF and EM) is a legitimate path for improvement.

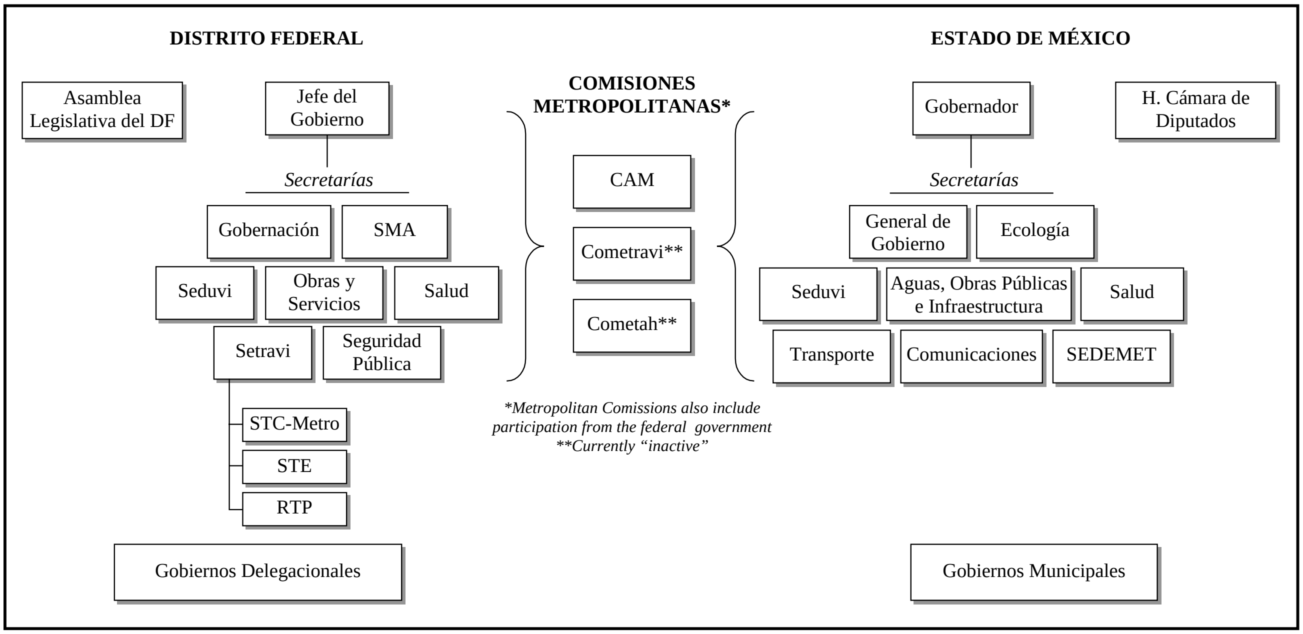


Figure 4. Institutional Structure: Transportation and Air Quality Management in the MCMA

We speak below of *strategic options* for the MCMA. The reader should recognize that strategic options are available across domains in technology, systems and institutions, but *that integrated thinking about strategic options is a precondition for success.* Further we understand that these strategic options must be considered under conditions of uncertainty as we project out 20 or more years into the future. Therefore, we have developed three future scenarios; strategic options are studied under each of the three with the goal of finding strategic options that are robust across various futures. Where possible, we have produced quantitative estimates of costs and benefits of these options over time and these have guided our recommendations.

5.1. Recommendations

We organize our recommendations under seven headings: guiding principles; institutional restructuring; technology; resources and capabilities; (modal) fare integration; transportation and land use integration; and freight.

5.1.1 Guiding Principles

The following recommendations apply to all decisions concerning transportation and land use in the MCMA.

There is no single approach in considering how to improve air quality and mobility in the MCMA. Improvement will require many coordinated strategic options involving both new policies and actions.

Strategic options must be integrated for synergistic effect and to avoid unforeseen, negative side effects. Especially, recognize the interaction of strategic options in transportation, environment, economics, land use and human health (personal exposure) in formulating an integrated approach.

Transportation should be considered as an integrated, multimodal network for travelers and freight. This is a vital overarching principle for rethinking transportation in the MCMA.

Long-term plans to improve air quality and mobility must recognize that transportation demand (in terms of vehicle-km traveled) will continue to grow because of both population growth, growth in automobile ownership and growth in the economy. The strategic options developed must be robust over time in the face of these virtually assured trends.

Sustainability is a vital overarching design principle for whatever is done in the MCMA. Strategic options to achieve this should be developed in the full context of environmental, economic, and socially equitable and fair sustainability parameters.

Undertake consensus building to deal with governmental, private sector and stakeholder conflict, seeking opportunities for cooperation across domains (see above), modes, geographical entities and institutions.

Where possible, use economic incentives to promote socially effective transportation outcomes. Congestion pricing and emissions permits trading are examples worth pursuing.

5.1.2. Institutional Restructuring

Our research and conversations with Mexican colleagues indicate that the current configuration of government institutions with jurisdictions in the areas of transportation and land use is poorly suited to seeking integrated solutions to air quality and mobility problems.

Institutional restructuring is a strategic option of great importance and leverage, given the need for systemic change. We understand the difficulties in achieving institutional change, but the situation is such that we can **not** afford to ignore it. Specifically, rethink the role of the federal government in transportation and air quality issues and the inter-relationships between the DF and EM.

Effective restructuring can be achieved either by a building a new set of agencies or by developing institutions for cooperative decision making among existing agencies. Metropolitan Planning Organizations (MPOs) in the US, which provide a framework for coordinated decision-making by diverse agencies, are a reasonably successful example of the latter. Simply encouraging agencies to work together will probably not be adequate; there needs to be a framework. An MPO-type approach to cooperative decision making would require action on the part of the federal government, in terms of defining the legal framework, as well as the creation the appropriate incentives, financial or otherwise, to guarantee continuous cooperation.

The geographic span of planning and policy should be the full region surrounding the metropolitan area. Focusing on the needs of the DF or the EM in isolation, while institutionally convenient, has proven decidedly suboptimal in outcomes.

Strategic transportation planning must be integrated with *strategic* environmental management.

- Recent legislative requirements for the member states of the European Union (EU Directive 2001/42/EC) are leading to the implementation of Strategic Environmental Assessments (SEA) of transportation plans and projects. Evidence shows that many states in the US are also adopting legislation with similar strategic and systemic approaches to evaluating the environment impact of entire transportation plans and programs. These approaches should be seriously considered for use in the Mexico City Metropolitan Area, as a form of more strategic and system-wide planning for a sustainable transportation system.
- Implementation of this type of environmental assessment could provide the basis for important changes in inter-organizational relationships (in particular, between transportation planners and environmental agencies), as agencies work together in a more structured review process of transportation plans and programs.

5.1.3. Technology

New technologies provide enormous scope for reducing emissions and congestion; thus choosing the *right* technologies is one of the most important policy tasks facing the MCMA.

Scan new technologies to select opportunities for both the short and long term consistent with societal goals. Although some suggest technology is "*the* answer," it is *not* a "stand-alone" tool. Technology will be most effective *within* a set of integrated strategic options. To do this effectively, the MCMA should do technology forward-planning to be able to anticipate opportunities.

Our models show that incremental improvements in technology will not yield much benefit over the long-term, as population, automobile ownership and economic activity grow. Aggressive steps using the best available technologies (such as hybrid vehicles and advanced combined NOX/PM filters) constitute the only technological way to achieve reductions in the long term. Their costs, normalized for the emissions reductions they achieve, are justifiable.

Our models show that despite higher front-up costs, advanced technologies such as hybrid vehicles and aggressive supply/demand management strategies are cheaper to operate in the long-run than "business as usual" due to immense fuel savings.
Consider Intelligent Transportation Systems (ITS) for technological and management concepts and techniques to improve the effectiveness of existing, conventional infrastructure. ITS has shown itself to be a cost effective alternative to simply adding conventional highway infrastructure.

- Traffic speed, starts and stops, and idling time are important determinants of emissions levels from traffic flows. The use of ITS to "smooth" traffic flows, without having to undertake additional capacity expansions, is becoming an increasingly popular option in many cities with high levels of congestion.
- For dense road networks, Advanced Traffic Signal Control strategies are often a highly effective method for managing traffic flow. In particular, where traffic conditions are highly variable, Adaptive Signal Control, which responds to "real time" traffic conditions, may be the best option. However, the resources for personnel training and maintenance of hardware, such as loop inductors, must be provided for on a consistent basis, to ensure the efficacy of these complex systems. In many areas, such advanced signal control is not as necessary, and significant gains could be made with more simple actions, such as signal coordination across political jurisdictions. This type of action could be a mechanism for fostering better collaboration between the DF and the State of Mexico, as well as between the municipalities and delegations along the DF and State of Mexico border.
- There is a growing consensus among traffic and transportation engineers that, indeed, "you can't build your way out of congestion." However, there is often considerable political and social pressure to ease congestion along what are considered to be the "critical" roadways to move around a city. Many cities, upon finding that building additional capacity only solved the problem for a year or so before congestion reached former levels, have opted instead for ITS-based technologies such as Ramp Metering – a form of controlling access to limited access freeways/highways. By controlling the flow of vehicles that enter the freeway, the flow of traffic along these critical routes can be preserved at more acceptable levels of congestion. However, given that this type of ramp metering is not common in Mexico, and given the high incidence of "red light running," ITS-based enforcement might also be needed to ensure the effectiveness of a ramp-metering strategy.
- Providing improved information to travelers regarding traffic conditions, is another method for improving traffic flow, and potentially leading to better trip making decisions (trip chaining, change in routes or departure times to avoid congested conditions or incidents, or even avoidance of unnecessary trips). These strategies are relatively low cost, however, and may require additional coordination between the various government agencies, as well as with the media (radio, on-line newspapers) to consolidate real-time traffic information from various sources, and provide detailed instructions and information to drivers, via dedicated traffic telephone "hotlines", variable message signs, and non-ITS technologies, such as the radio. For online traffic information, an appropriate visual interface should be used, preferably a map-based interface, representing the traffic network (primary routes) as well as the public transportation network.

Detailed analysis of the traffic/congestion impacts of the BRT system, in particular the benefits and costs of implementing Transit Signal Priority along the BRT corridors, needs to be undertaken.

- Currently, there is increased surveillance by traffic police along the avenues where the first BRT corridors will be put into place, in order to ease the flow of traffic along those routes, for example, by prohibiting left turns. While these actions may improve performance of the BRT, experience in other cities with BRT show that Transit Signal Priority can significantly enhance BRT performance along corridors without fully separated busways. The potential impacts of Transit Signal Priority on (1) bus operations, (2) general traffic along the same routes, and (3) cross-traffic, should be investigated. Research has shown that TSP can have substantial benefits for travel-time and reliability of public transport, and in highly congested conditions, "conditional" signal priority (conditional upon factors such as whether the bus is behind schedule, or the vehicle occupancy, etc.), can be used to minimize the impacts on general traffic flow both within and crossing the BRT corridor.

- Given that Adaptive Signal Control (ACS) is already in the process of being implemented at intersections within many delegations in the DF, there needs to be additional research regarding the use of Transit Signal Priorities with SCATS (the Adaptive Signal Control systems being used in the DF). Consultation and collaboration with other cities using ACS along with Transit Signal Priority, may be one manner of approaching this issue.

Examine possibilities for congestion (value) pricing as a instrument to improve mobility and air quality within an overall package of strategic options. In particular, consider the integration of BRT and the provision of High Occupancy Toll (HOT) lanes through ITS technology.

- Integrated BRT and HOT lanes involve the use of lanes reserved only for BRT bus operations and for drivers willing to pay a toll to drive in that lane. The toll prices are set to provide the buses and drivers in the lane with a substantial travel time advantage. In areas where infrastructure expansion is highly constrained, the BRT/HOT lane combination can be an effective means of augmenting capacity without necessarily building additional lanes. The integration of BRT with the HOT lane concept can also address potential equity concerns, if revenues from the HOT lanes are used to support high-quality BRT operations, while maintaining fares at a "equitable" level. Major radial routes into and out of the city, where public transit options often have insufficient capacity, or entail extremely long travel times for their users, could benefit from the implementation of this type of system. ITS, in the form of electronic payment for private vehicles, is a critical component of monitoring and operating BRT/HOT lanes.

5.1.4. Resources and Capabilities

Creating and maintaining a rational and more integrated transportation and land use system in the MCMA will require the development of analytical and managerial resources.

Emphasize professional human resource development that considers the need for handling contemporary complex transportation planning and management issues.

Create an information-base for transportation planning including a mobility survey of a representative sample of households and knowledgebase to support best planning practices.

Improve travel demand network models (such as the Mexico City Urban Transportation Model---MCUTM) in ways that enable more rational and targeted approaches to transportation and air quality policy questions.

Traveler
Based on the mobility survey mentioned above, the MCUTM can be enhanced to represent how policy decisions regarding infrastructure, pricing, operations and modal integration can influence individual travel decisions in the direction of more sustainable alternatives.

Freight
Augmenting the current modeling work and analysis of the trucks can help us understand how they interact with the other vehicles in the MCMA and provide insight into how best to minimize related externalities. Current modeling work is focused on the strategies that provide the most benefit for the MCMA, including zoning and land use, terminals and modal exchange, and pricing.

5.1.5. Modes and Integration

All policy decisions related to individual modes must recognize and promote modal integration and system wide sustainability.

Integrating Informal Modes
Rationalize and integrate the participation of the informal transportation providers—colectivos-- into the formal transportation system. Consider a changed role for the colectivos as feeders as a vital component of an *intermodal public transportation system*.

Colectivos are currently the most important form of personal transportation in MCMA and will continue to be for some time; getting rid of them entirely is simply not realistic. Indeed, given low labor costs and the highly dispersed pattern of development they are more economically efficient than a conventional bus system in some instances. Colectivos need to be better regulated, better integrated into a multimodal system and have their emissions cut by subsidized retrofit and stock turnover. Intransigent colectivo organizations may make this difficult but bringing the colectivos into an integrated public transportation system is a goal worth pursuing.

Developing an Integrated BRT Network
Undertake Bus Rapid Transit (BRT), but integrated with other transportation modes in an approach to accessibility. Our models suggest that BRT strategies are very cost-effective in the long-run and experiences in other Latin American cities have been positive.

The success of BRT will be limited without appropriate feeder systems, and this will involve integrating colectivos into the more formal system as noted above. Since colectivos will likely see BRT as a threat, some form of incentive such as a subsidy for routes that intersect with the BRT line, is a useful option to explore.

Furthermore, the BRT must be designed, in the long-term, as a metropolitan-level network. Currently, there are two corridors in the planning stages, with several other possible corridors identified within the DF. In the State of Mexico, they are also considering the development of a BRT line along an important route in the northern section of the MCMA. Given that number of trips between the State of Mexico and the

DF likely will increase substantially, the creation of two disparate BRT systems will undermine its potential as an integrated and metropolitan service.

The institutional relationship of the BRT with the colectivo owners and drivers must be clearly defined, both along the corridors where the colectivos will be “phased-out” of services, as well as along corridors which will serve as important feeder routes for the BRT.

Finally, the public space and non-motorized modes of access to the BRT system need to be given high consideration. Ideally, these issues should be analyzed in a context of broad public consultation, in order to ensure that the land use component is in harmony with the goals of the BRT. An inability to comfortably access the BRT system (in particular, when compared to the current colectivo practice of stopping anywhere to pick up and drop off passengers, which is very comfortable from the passengers point of view) will limit the system’s ability to attract passengers.

Fare Integration
System and fare integration in public transportation has recently made important progress; this should be a continued emphasis. The value of “smart cards” in this application is clear from their use in other cities and should be seriously considered in Mexico City.

The deployment of Smart Cards could be an important step in moving toward a more intermodal public transit system, allowing more diverse, differentiated fare policies, including discounts and transfers (between the Metro, Light Rail, Trolleybuses, RTP buses, future BRT corridors, and colectivos).

Smart cards can also an important component of the image of a public transit system. The BRT system, for which image and marketing is often an important factor in increasing ridership and passenger satisfaction, should be used to leverage the introduction of Smart Cards for all public transit modes.

Finally, the data from Smart Cards could be a rich source of information on passenger flows within the public transportation system. This data can be used for future modeling and planning purposes. While in some cities, Smart Cards have personal information linked to their users, in order to avoid any privacy issues, the cards could be anonymous, while still providing important information on trip origins and destinations, particularly if the Smart Card is deployed across all modes.

5.1.6. Transportation and Land Use Integration

The effectiveness of transportation policy will be limited in the absence of complementary land use policy, especially in the long run.

Consider an ideal urban form for the MCMA achievable through coordination of transportation and land use. The goal is to preserve the importance of the downtown area and channel development outside that area into corridors served by the Metro, light rail or suburban rail for maximum accessibility by people of all income levels.

Consider expansion of the Metro, but only in the context of a broad package of strategic options for enhancing accessibility and further in the context of land use policies such as transit oriented development (TOD) to achieve a transit-oriented urban form for Mexico City.

Government commitment to building affordable housing, and locating most or all of it near Metro, light rail or suburban rail stations could lead to a significant increase in Metro ridership. If this housing is located near underutilized Metro lines, it could increase ridership on those lines and perhaps help alleviate congestion on the saturated ones.

Some development will probably happen along the suburban rail alignment, for example in the Buenavista terminal in the DF. However, metropolitan coordination in the form of a joint DF-EM suburban rail corridor plan can significantly increase the potential for the development of a high-density, mixed-use transit-oriented corridor along the suburban rail alignment.

The addition to the Metro Master Plan of a detailed study of real estate opportunities in Metro stations, together with aggressive marketing of these opportunities for transit oriented development (TOD), can improve the chances of their development, bring money to the STC (the DF-owned company that operates the Metro) and reduce its dependence on subsidies from the DF government.

If more people can be concentrated near Metro stations through an expansion of the system and a policy of locating housing and other developments near it, the equity and environmental effects can be considerable. People who have the option of using the Metro without a colectivo feeder trip have significantly lower transportation expenses. They are not affected by road congestion, and can reach their destination more quickly and predictably. This could increase their job opportunities. In short, TOD can be a great force for equity in the developing world. Mexico City's extensive Metro system positions it to take full advantage of this concept.

On the environmental side, TOD can significantly reduce colectivo-related emissions by eliminating and/or shortening colectivo trips. However, the most significant environmental effect of TOD is indirect and long-term – creating a transit-oriented urban form, where people will continue using high-capacity transit (at least for the trip to work) even after they can afford an automobile, thereby mitigating the increase in pollution that accompanies motorization. As part of a policy of transit-oriented affordable housing, Mexico City can include limitations on parking supply before the residents can afford automobiles, thereby averting some of the political backlash.

Coordination of transportation and land uses is of course, a long-term policy shift and cannot be expected to deliver immediate results. But a series of changes to the planning culture in the MCMA could help sow the seeds for a transit-oriented urban form that would be both socially and environmentally more sustainable.

5.1.7. Freight

Improvements in freight transportation are of vital importance for both economic development and air quality management, but decision-makers must consider freight and traveler transportation as an integrated whole.

Freight vehicle technology and fuel quality improvement options incorporated into PROAIRE have good potential as identified in our modeling. Monitoring existing technology and fuel improvement programs, securing funding for maintaining these programs and ensuring that these best policies are operating as intended should be a high priority while considering freight policy implementation options.

Fleet operation and utilization improvement strategies are categorized among inter-regional trips, and intra-regional trips. The first two measures below are primarily directed toward the inter-regional trips, whereas the third measure is intended for freight movements that take place entirely within the MCMA. All should be carefully considered.

- Fleet transfer centers (intended to keep primarily heavy-duty freight vehicles out of the region by provided a transfer center for light-duty vehicles to pick up the goods for delivery within the MCMA);
- Increase railroad utilization (for delivery of inner-city goods to eliminate heavy-duty trucks within the MCMA, especially in conjunction with the above transfer centers, assuming that freight rail lines were incorporated as well); and
- Increase the role of logistics companies (for intra-city deliveries, in order to reduce the number of private fleet vehicles that often travel empty, or underutilized).

6. INDUSTRIAL SECTOR

With the exception of uncontrolled solvent use, air pollution is usually directly proportional to the energy consumption and the fuel-mix of a sector. The economic growth of the MCMA region would mean an increased demand for goods and services, resulting in higher production and activity in the industrial, commercial and informal sector.

Apart from growth in the demand for goods and services, the structure of the industry, and energy intensity are important variables affecting the energy demand and air pollution from the industrial sources in the MCMA. The structure of the industry sector, represented by the relative share of various sub-sectors of the economy of the region, holds the key to shift in energy demand by the manufacturing sector. The three prominent sub-sectors in the MCMA industrial output are, the chemical industry, the metal products industry, and the food and beverages industry. Energy intensity of the chemical industry is higher than that of the metal products industry. Therefore, if the structure of the manufacturing industry in the MCMA were to change in such a way that the relative dominance of the chemical industry continues, this would effect the energy demand by the manufacturing industry as a whole. The rate of change of energy intensity is another important variable that would affect the magnitude of the energy demand in the MCMA. The International Energy Agency (IEA) has reported energy intensity of the manufacturing intensity of its member states to be decreasing at a rate of 0.5% per annum, as compared to the earlier rate of change of 3.7% per annum (from 1974-1986). The rate of change of energy intensity, moderate or fast, would significantly affect the energy demand from the manufacturing sector.

The manufacturing sector in the MCMA consists of economic units located in the Federal District (DF) and in 37 municipalities in the State of Mexico (EM). In the recent past few years, the manufacturing sector has witnessed a structural shift. The chemical sector has witnessed a growth in its share of output in the DF industrial output. In the DF, the chemical industry has a dominant share in the output, followed by the metal products industry; in the EM the metal-products sub-sector contributes highest share to the total output of state. Roughly, 72% of the total output of the EM is included in the industrial output of the MCMA. In the MCMA, the chemical sub-sector retains its dominance, and the metal products sub-sector closely follows.

The MCMA industry sector fuel energy (natural gas, diesel, and LPG) demand was pegged at 104.6PJ in 1998. Electric energy demand by the manufacturing sector was estimated to be 54PJ for the year 1998.

In the business as usual (BAU) scenario, the fuel-energy demand by the manufacturing sector in the MCMA grows to 128PJ (a 21% increase from the current levels) in 2025. Most of the scenarios show an increase in the fuel-energy demand for the manufacturing sector. The "GU-Const-Chem" scenario shows highest increase in the energy demand. GU refers to the future story, Const, refers to no change in energy intensity, and Chem indicates the continued dominance of the chemical sub-sector in the industry structure of the MCMA. Energy demand in this scenario is expected to grow to a whopping 339 PJ; over 200% increase in energy demand from current levels. Only a few scenarios show significant reduction in energy demand, namely those for which aggressive energy intensity reduction (at a rate of 2% per annum) is combined with a structural shift toward the metal products sub-sector. The scenario DC-Agres-Metal, shows 35% reduction in energy demand in 2025, from the current levels.

Assuming that the output of the sector is solely determined by the supply-demand situation, as governed by the regional, national, and international, macro-economic indicators, there are very few policy options to pursue to reduce energy demand and air pollution from the manufacturing sector. Reducing energy demand by introducing policy options to affect the structure of the industry toward less energy intensive structure, aggressive energy intensity reduction, modernizing manufacturing processes, and changing the product-mix, by promoting the turn-over of the capital stock, hold the key for reducing energy demand and air pollution from the industrial sector.

6.1. Recommendations

- Aggressive reduction in energy intensity, to aim at reducing energy at a rate of about 3%, could pave the way to contain energy demand and air pollution from the manufacturing sector in the MCMA.
- Designing programs and incentives to measure, monitor, and reduce output-based energy intensity.
- Providing incentives for maintaining a less energy-intensive structure of the manufacturing sector in the MCMA.
- Providing incentives to the entrepreneurs for setting up of industries such as electronics component assembly, which are high value added and low energy intensive sub-sectors.
- In 1998, natural gas and LPG supplied 78 percent of the total fuel energy demand by the manufacturing sector. Identifying industries to switch fuels to further increase in the clean fuel ratio.
- End-of-the-pipe pollution control equipments can help reduce certain pollutants. Exploring the use of market-based-instruments (such as Cap-and-Trade, or Emission Taxes) can pave the way for least-cost options to reduce emissions.

- Analysis of the air pollution abatement indicates a substantial cost advantage of using market-based instruments to reduce air pollution from the industrial sources, which requires identifying sub-sectors to participate in the emissions trading program, and creating a market-place.

7. COMMERCIAL AND INFORMAL SECTORS

The commercial and informal sector plays a key role in meeting the demand for goods and services and by providing jobs to a large section of population in the MCMA. However, due to a lack of clear definition of the informal sector, its energy demand, and contribution to the air pollution is difficult to track. Baseline emission inventory for the commercial and informal activities is incomplete. In general, in the short term, the most relevant emissions would increase, almost in parallel, for the three reference cases, no matter what the future story is. Further, in the medium and long term, the trends followed by the emissions under different reference cases and future stories, would diverge, in some cases significantly.

Non-methane hydrocarbon (NMHC) and SO2 emissions from the commercial and informal sector are especially relevant due to their large contribution to the emissions inventory. PM_{10} emissions are also believed relevant for the informal sector, even though they are currently underestimated, we expect annual growth in emissions for both the formal commercial and the informal sectors, resulting in the increase in emissions from about 40 to 80%, by the year 2025.

Several specific policy options to reduce emissions from the informal and commercial sector can be pursued, which can result in significant reduction in air pollution from this sector. For example, the installation of vapor capture (and solvent recovery) systems in dry-cleaners, printing shops, auto-painting shops, and bakeries, seems to be effective for reducing as much as 30% NMHC emissions from these activities, with a potential to achieve reductions of as much as 75% from the current levels. For the abatement of SO_2 emissions, the most effective policy seems to be the substitution of fuels, both for boilers and burners, in both commercial and informal activities. The switching from gas-oil to LPG is the most cost-effective way of abating SO_2 emissions, although it would imply an increase in NOx and NMHC. For PM_{10}, some significant reductions in emissions could be achieved at the sub-sector level, for example, in construction and brick production, through the enclosing of facilities.

7.1. Recommendations

- Include the informal sector explicitly in the emissions inventories and air quality programs of the MCMA, by making a clear distinction between formal and informal commercial activities.
- To improve emission estimates and to develop more effective policies, it is necessary to gather data on informal activities, and to develop specific emission factors for informal activities as well.
- For reducing commercial NMHC emissions, the installation of vapor capture (and solvent recovery) systems in dry-cleaners, printing shops, auto-painting shops, and bakeries, seems to be effective for reducing as much as 30% NMHC emissions from these activities, with a potential to achieve reductions of as much as 75% in NMHC

emissions from particular processes, as it also lowers some costs due to reduced solvent consumption.

- The reformulation of products containing solvents is another effective measure to reduce NMHC emissions, since most commercial emissions are due to solvent use.
- For the abatement of SO_2 emissions, the most effective policy seems to be the substitution of fuels, both for boilers and burners, in both commercial and informal activities. The switching from gas-oil to LPG seems to be the most cost-effective way of abating SO_2 emissions.
- For PM_{10}, construction and brick production presents significant opportunity to reduce emissions by enclosing of facilities.
- For the reduction of greenhouse gases, and particularly of CO_2, the most effective policies are the switching to solar boilers and the improvements to energy efficiency for buildings and equipment.
- Substituting lower quality fuels such as used oils, wood and garbage by cleaner, commercial fuels, such as diesel or LPG.

8. INSTITUTIONAL REFORM

Further improvement in air quality in Mexico City – or in any other metropolitan region for that matter – will be best achieved when all the governmental institutions involved are (1) clear about the policy objectives they are trying to achieve, and (2) can agree upon an allocation of responsibility, not only among the levels and units of government, but also among the public sector, the private sector and civil society for achieving specific objectives. Generating such agreement on policy will require a carefully planned multi-stakeholder dialogue of a sort that has not occurred before in Mexico. The key to such a dialogue is an expanded level of public involvement.

After many years of discussing scientific and policy solutions to the problem of air pollution in Mexico City, it has become increasingly clear that there are significant institutional and political barriers that inhibit the implementation of effective and integrated air pollution control policies. Addressing air pollution in a metropolitan conglomeration requires analyzing the forces that contribute to the problem from an environmental as well as a political and institutional perspective. Politically, the MCMA is divided into different jurisdictions each with its own needs and concerns. From an environmental perspective, to be able to manage air pollution there need to be coordinated reforms to transportation, land-use, environmental, and industrial policies at the metropolitan level. Difficult trade-offs are unavoidable.

It is our belief that the situation in the MCMA is ripe for what is called a Conflict Assessment to help identify areas of agreement and disagreement among the different policy actors. Such an Assessment will indicate whether the carefully planned multi-stakeholder dialogue necessary to reach agreement on the most important trade-offs will be possible.

8.1. Recommendation to Conduct a Conflict Assessment:

A specific Conflict Assessment procedure has been planned during the spring and summer 2004, and is summarized here.

8.1.1. Assessment Objectives:

- Produce an understanding of the range of stakeholders' views on the adequacy of the existing institutional arrangements to deal with environmental, transportation, and land-use management in the MCMA.
- Provide an understanding of the range of stakeholder views about the likely benefits and costs associated with implementing stricter environmental regulations in the MCMA to reduce air pollution.
- Assess whether or not direct negotiations among the relevant stakeholders and regulators will have a good chance of leading to a constructive resolution of metropolitan and environmental management issues in the MCMA

8.1.2. Assessment Products:

The Assessment will produce a written report based on confidential interviews with each major stakeholder group likely to be affected by a change in air quality management policy and related regulations and investments. The Assessment will analyze the issues, stakeholders, their interests, and gauge their willingness and capacity to participate in sustained face-to-face negotiations. Along with these findings, the Assessment will offer recommendations as to whether and how to proceed with a national consensus building effort. The Assessment can also produce changes in the way stakeholders view the conflict. The interview process gives them an opportunity to express their views, to raise issues important to them, and to directly shape any negotiations that follow. It will also force them to clarify their priorities and encourage them to test their arguments "out loud" in front of a neutral party. By neutral we mean that the Assessment team does not favor the concerns or interests of one particular stakeholder group over another or advocate specific outcomes.

8.1.3. Steps of the Assessment:

Thus far, the Assessment team has:

- Developed an interview protocol and identified more than 50 key stakeholders to interview, including leaders from the national government, regional government, local government, existing environmental and metropolitan commissions, local activists, business interests, university leaders, environmental health specialists, members of the transportation sector and other non-government groups interested in reducing air pollution in the region;
- Begun conducting face-to-face confidential interviews with all relevant stakeholders;
- Begun summarizing the concerns of members of each stakeholder group on key issues, without attribution by name, title, or organization;

- Begun analyzing these findings and assessing the opportunities for and obstacles to reaching a multi-stakeholder agreement on how best to combat air quality problems in the region.

Once the Assessment is completed, we will recommend, if appropriate, key elements of a consensus building process (e.g. draft mission statement, ground rules and organizational protocols, a draft agenda of issues to be discussed, and options for a proposed schedule of meetings).

8.1.4. Importance of Neutral Convener:

One of the key challenges in preparing an Assessment is to ensure that the process has legitimacy. If some stakeholders think that a particular group, with a vested interest in a particular outcome, is driving the process, it is unlikely that those and other stakeholders will agree to participate in a constructive manner. It needs to be clear that the Assessment does not commit anyone to a particular set of policy changes. The participants need to feel comfortable sharing information with a neutral team of professionals who promise to ensure that what they say in confidence will not be used against them at a later point. A neutral convener signals that this will be a "safe" undertaking and that the goal is to find an outcome that addresses the concerns of all interests.

8.2. Recommendations to Replace the Existing Environmental Impact Assessment (EIA) Procedures in Mexico

Based on our year-long study of Environmental Impact Assessment (EIA) procedures in Mexico, we have identified a series of principles that should guide efforts to expand public involvement in the making of air quality management policy. More specifically, we have the following recommendations:

8.2.1 Be creative, flexible, and proactive in terms of public participation

The institutionalization of public participation in the EIA process in Mexico has tended to make EIA practitioners see public participation as a formal obligation rather than as an opportunity to improve the quality of the analysis and the legitimacy of the policies that ultimately emerge. The consensus building process we are suggesting will only work if it offered as a genuine opportunity for all groups in the country to participate in the actual formulation of a policy package. If it is used, instead, to "sell" a set of policies that have already been decided, it will backfire.

EIA in Mexico tends not to generate solutions. It is usually carried out too late and ends too soon. The Silva reservoir case demonstrates that it is possible in Mexico for environmental officials to go beyond mere process requirements to generate a creative and effective problem-solving dialogue. Simply providing more information to convince the public that the government's preferred alternative is best is not likely to address public concerns.

8.2.2. The sooner participation begins, the better the results will be.

The public is rarely consulted by EIA professionals in Mexico when they are planning major projects. In fact, during the initial scoping process of many important transportation projects, local citizens should have been invited to comment on the proposed project before EISs were prepared. They might have helped identify problems, which, in fact, became sources of conflict, or even to suggested solutions, which professionals would not have considered on their own.

In addition, earlier public participation provides excellent opportunities for constructive dispute resolution. Avoiding policy disputes is not possible, no matter what political strategy. So, it makes sense to pursue an efficient dispute resolution strategy. Those seeking redress will find ways to exert political pressure or use the judicial system, which ultimately may stall a project. In practice, according to the U.S. Forest Service, participation by informed citizens in more collaborative processes "substantially reduces the number of subsequent appeals and law suits".

8.2.3. Focus on substantive issues not just procedural concerns

The Mexican EIAs for roadways that we studied suggest that agency personnel have missed the substantive benefits of participation. The process of participation became a means of meeting procedural requirements rather than solving problems or resolving disputes. Participatory programs need to be structured in a way that raises and confronts substantive disagreements. This can be done through a process of Joint Fact Finding within the framework of a consensus building effort. In practice, learning is more likely to occur in situations where participants are active rather than passive. When people are given opportunities to "do," to participate in tasks, to speak from their experience, and to be "players," they are more likely to learn than when they only observe.

8.2.4. Information must be geographically and linguistically accessible

People often refused to read about proposed projects as they were described and analyzed in Environmental Impact Statements in Mexico, but then they complained vigorously about how the same project was described in the media. Assuming an EIS is prepared appropriately, newspaper stories will always be an inferior source of information. One of the reasons people are reluctant to be involved in an EIA process is because EISs are often difficult to read. Thus, whatever participatory process is selected to help engage the public in long-term air quality management, it is important that technical materials are understandable and support greater levels of public and stakeholder participation.

After several years of close study of the institutional arrangements in Mexico through which decisions are made about the linked systems of land use, transportation, public health and environmental protection, we are convinced that a new approach is required. Merely announcing a new allocation of responsibilities or a new set of policies is unlikely to work. An expanded level of stakeholder involvement in policy-making is called for. This should be preceded by a full-fledged Conflict Assessment to clarify the overlapping and conflicting interests of all key stakeholder groups on the cluster of issues surrounding possible efforts to improve air quality in the metropolitan area. Assuming the Assessment generates a clear "map" of the prevailing conflicts (and the scientific and technical input needed to clarify the relevant trade-offs), a consensus building process -- in which all key stakeholder groups participate directly in a sustained face-to-face problem-solving dialogue – should proceed. The Conflict Assessment will generate a detailed design for such a dialogue. It will be up to the political actors at every level to decide whether such a participatory process will go forward.

9. EDUCATION AND OUTREACH

The success and sustainability of the environmental policies depend in great measure on a high level of citizen awareness and of an active and informed stakeholders participation. To achieve this objective, it is necessary to develop an environmental culture and to elevate the education in all the levels in order to achieve a permanent change of attitudes and behaviors. Also, it is essential to continue capacity building of human resources responsible for the diagnosis of environmental problems, as well as the formulation, execution, pursuit and evaluation of the policies and programs directed to the reduction of atmospheric pollution, at governmental level as well as private sector, including the academic sector and the non government organizations.

9.1. Educational Activities

The educational activities developed in this Project include:

9.1.1. Professional Development Courses:

Two mid career courses were offered as part of the educational activities of the project. The main objective of the course was to train the participants in negotiation strategies to reach agreements and on the evaluation of health risk due to exposure to polluted air. More than 60 individuals from governmental agencies, the media, and non-governmental organizations from Mexico attended the courses. These were presented by leading experts in the field of risk analysis and on environmental negotiations from Harvard University and MIT.

9.1.2. Masters Program in Environmental and Health Management:

The Massachusetts Institute of Technology, the Harvard School of Public Health (HSPH) and the Mexican government have established an exciting new mid-career degree program, the Masters in Environmental and Health Management (MEHM) in June 2000. It is specially tailored to address the needs of those making decisions at the federal and local government level, as well as managers in the private sector and leaders of non-governmental organizations.

The MEHM represents a breakthrough in environmental management education, combining depth in environmental science training with a series of cross-disciplinary management tools such as integrated assessment, negotiation analysis, cost-benefit and cost-effectiveness analysis and comparative risk analysis.

The MS students interacted regularly with the students in the Mexico City Program; they participate in the seminars and the research activities. As part of their curriculum, the Mexico

City Program senior personnel designed a new course on Practicum in Environmental Management, which examines environmental management strategies and the role they can and should play in managing air quality in a megacity like the Mexico City metropolitan area. The class mixes lectures, case histories (presented by visiting lecturers), class discussion, and presentation of student papers. The new knowledge in atmospheric chemistry and modeling, urban planning, environmental health, etc., emerging from the Mexico City Program's research activities were used to augment the training materials and methods, thus enriching existing curricula.

9.1.3. Collaborative Research

The collaboration includes MIT, Harvard and Mexican investigators and students and other institutions in the US and Europe.

9.1.4. Exchange Program

Various Mexican senior researchers and students have visited MIT for as little as a week to as long as a year to work with MIT researchers. Researchers and students from MIT and other US partner institutions also visited Mexico to meet with Mexican collaborators and groups of selected stakeholders. Several students from MIT have completed their dissertations and are pursuing environmental related research activities in Mexico.

9.1.5. Workshops

One of the major components of this Project consists of: a) presentation of research progress, b) promotion of information exchange between the different sectors (academe, private sector, public sector, non-government organizations, etc.). Since the inception of the Mexico City Program, the Program has organized seven workshops on air quality attended by Program investigators, students and invited representatives from government and industries. Three annual joint US-Mexico workshops (January 2002, 2003 and 2004) were held during the Second Phase. The number of participants has increased from about 40 in the first workshop to over 250 in our last workshop. The workshop proceedings are posted on the Program website. In addition, the program has organized a Symposium on Emissions Inventory in February 2003 in Mexico City (with support from SEMARNAT and CEC); Special Workshop on "Reducing Transport-related Emissions" in collaboration with IUAPPA in January 2004 in Mexico City; several workshops on scenarios analysis and on field measurement campaigns, some in Mexico City and some at MIT. The summaries of the workshops are available in our website.

9.1.6. Metropolitan Air Pollution Negotiation Game

Inspired by the success of the "Negotiation and Conflict Resolution" course, the Program students designed a multi-party negotiation simulation game, "The Air Pollution Crisis in Varara." It asks participants to play a variety of roles and to simulate the kinds of political dialogue likely to emerge in response to the results of a hypothetical assessment of air quality management options. it was introduced in the January 2003 workshop and sixty-eight people from a wide range of governmental agencies, corporate entities, NGOs, and student organizations participated in the two-hour exercise. Many people requested simulation materials after the exercise. In response to those requests, the simulation game (bilingual) was posted on the Mexico City Program website so that people in Mexico and elsewhere can download it for use in classrooms or offices.

9.1.7. Program Website

The Mexico City Program has created a website at the following URL:
http://eaps.mit.edu/megacities/. Information related to the Program available at this website has been used heavily by international community.

9.1.8. Newletters

The Program has started the publication of bilingual, on-line newsletters posted on the Mexico City Program website at the following URL:
http://eaps.mit.edu/megacities/newsletter/index(e).html
Printed copies of the Newsletters were distributed at the workshops.

9.2. Recommendations on Education and Outreach

These educational and outreach activities should be continued as an important part of this Project. In addition, we recommend strong support for the ongoing educational activities of the Mexican Government aimed at raising environmental consciousness in the general public.

10. SUMMARY

Air pollution causes increased mortality and morbidity in the urban population. To improve people's health emissions, reductions are required.

Emissions reductions are needed from transportation and both the large and small industrial sectors. Transportation includes freight, private automobiles, and public transportation. Transportation contributes most of the NOx and fine particles and a considerable amount of the hydrocarbons in the MCMA.

In the short term existing vehicles will need to be addressed. For private automobiles strong inspection maintenance programs, with removal of vehicles that cannot be repaired, and use of restricted driving days for older vehicles will help. In the longer term, lower sulfur gasoline and much lower emitting vehicles, such as hybrids and Tier 2 automobiles will likely be required. Growth of the private vehicle fleet is expected in the MCMA since only a small fraction of the families own private automobiles and private automobile ownership results in increased convenience and status. Private vehicle fleet growth however will contribute to increased congestion resulting in increased emissions as well as causing direct economic loss. The use of intelligent transportation systems such as advanced signal control strategies will ameliorate the rate of congestion growth, but mode shifts to low-emitting public transport is a necessity.

To be attractive, public transport should be convenient, safe, and reliable. Construction and extension of bus rapid transit routes is a step in this direction. Integrated public transportation through the use of smart cards has been successful in increasing mode share in some cities. Improvement in the emission control systems of taxi and colectivo fleets is both a short term and long term necessity.

Diesel vehicles contribute a large percent of the fine particulate matter. Since diesel vehicles stay in use for long periods of time, the existing diesel fleet needs to be upgraded through retrofit programs. Reducing sulfur in diesel to 15 ppm is extremely important to enable particle traps for new and many existing diesel vehicles.

Transportation infrastructure improvements can contribute to emission reductions. In addition to intelligent transportation systems for private automobiles, staging freight delivery to reduce the need for large diesel vehicles to enter the city center and the creation of bypass roads for vehicles transiting Mexico City can significantly reduce diesel emission exposure. Ultimately land use planning to provide incentives for people to have residential, education, work, and medical facilities located near public transportation hubs will help increase public transport mode share and decrease private automobile use.

Improved monitoring and control at large industrial sources should continue. Emissions reduction can take place through fuel switching to natural gas. Of concern is the uncertainty in the amount of emissions coming from small industrial sources, especially in the unregulated sector. Research is needed to better understand the amount of pollution from these sources and innovative measures and incentives may be required to reduce their emissions.

Many of the hazardous pollutants are not emitted directly, but are formed through atmospheric chemistry. In order to select and prioritize technical solutions, high quality air monitoring and scientific studies are required. An exploratory and an intensive measurement campaigns were carried out for this purpose in the MCMA in 2002 and 2003; preliminary results are described in the report.

While technical solutions leading to emissions reductions can be designed, the creation of regulations that mandate these solutions, and their successful implementation are challenging tasks. These tasks are done more efficiently when a single metropolitan organization is charged to accomplish them and the organization has the authority, budget, and technical staff to do this successfully. Regulation is most effective when affected stakeholders and the public participate in the process. Interactions leading to effective participation are complex since the parties may perceive that they have conflicting objectives. A methodology for facilitating constructive interactions is described in the report.

Health effects and exposure studies in Mexico City are limited and should be expanded. These studies should be designed to help decision makers better understand the priority of improving air quality in the context of other opportunities to improve the health and welfare of the people in the MCMA and the limited financial resources available.