Integrated Program on Urban, Regional, and Global Air Pollution

Science Technology and Innovation Policy
Harvard University

December 5, 2003

Air Quality in Megacities
The Mexico City Case Study

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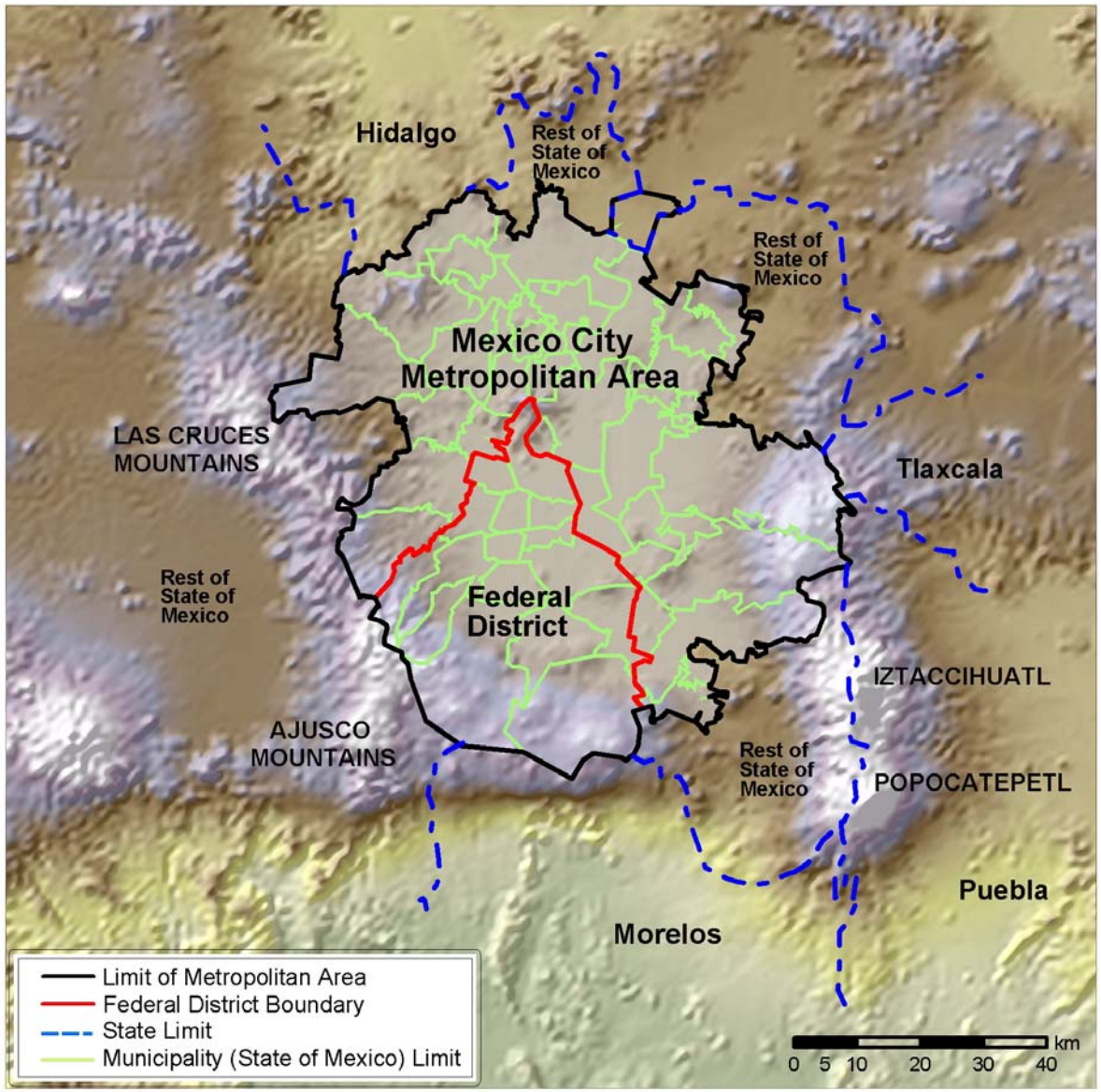
Massachusetts Institute of Technology

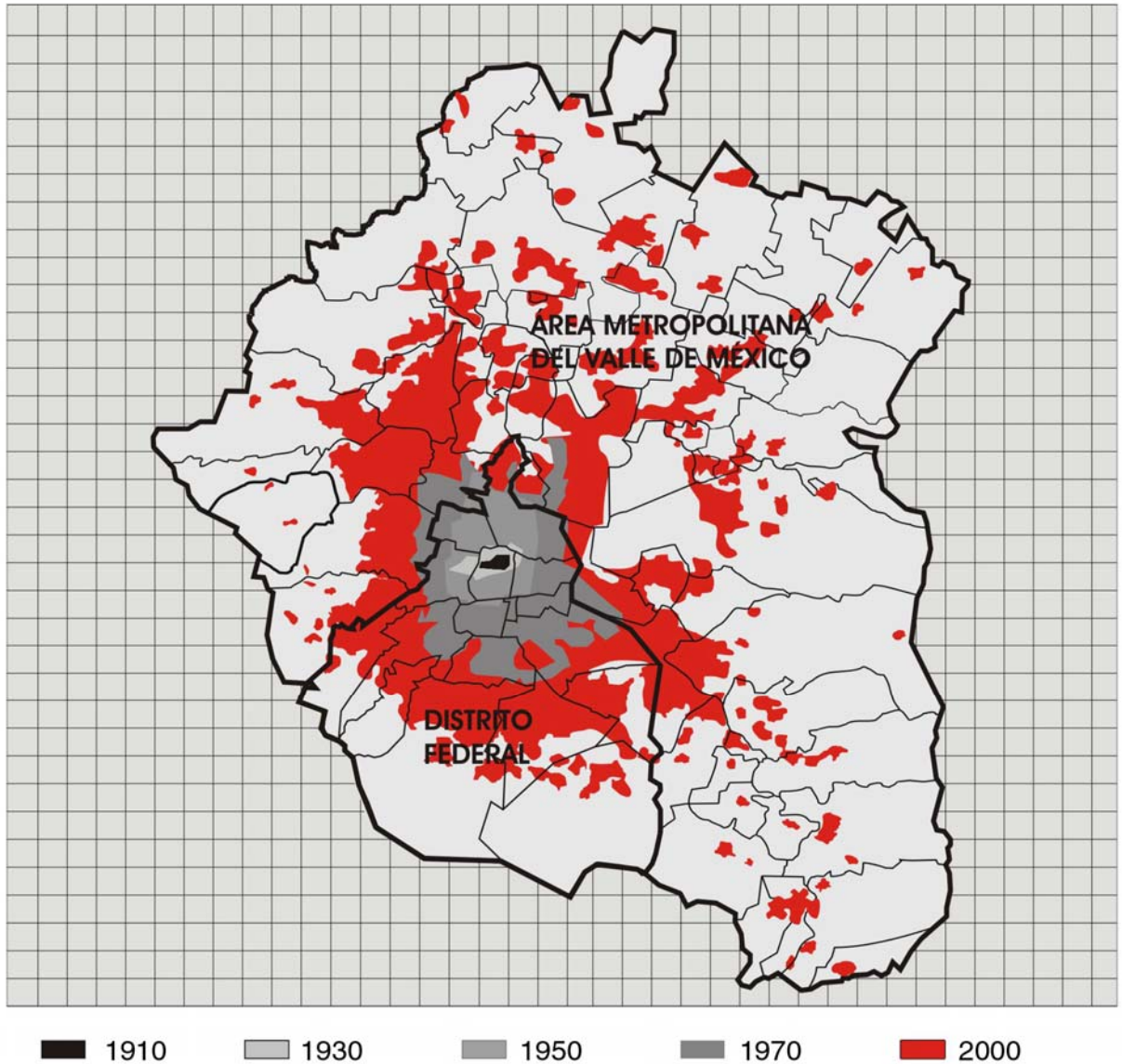
Mexico City Metropolitan Area (MCMA)

Topographical Map of the MCMA



- Population Growth
  - >17.5 million (1999): 20-fold increase since 1900
  - Growth projection to 25 million (2010)
- Urban Sprawl
  - >1500 km2 (1999): 10-fold increase since 1960
  - >Expansion to peripheral areas
- Geographic and Topographical Conditions
  - >High altitude (2240m): less efficient combustion processes
  - >Mountains are a physical barrier for winds
  - >2nd largest mega-city in the world
  - >Temperature inversions in the dry season
- Increases in Emissions Sources

Expansion of the MCMA



April 9, 2001

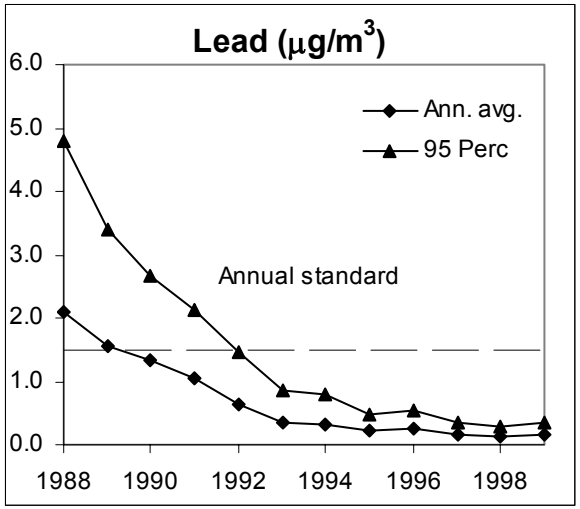
December 5, 2001

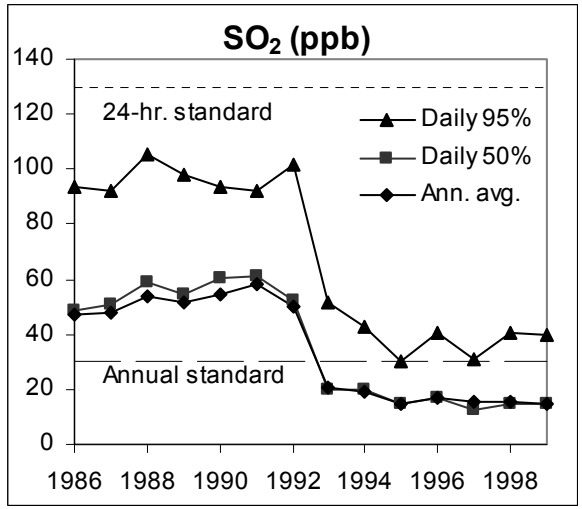
Comparison of selected statistics between the MCMA and the Los Angeles Air Basin

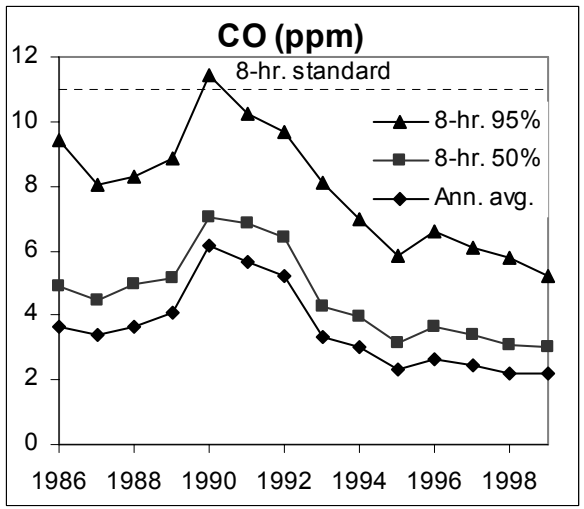
	Los Angeles Air Basin	MCMA
Population (2000)	15 million	18 million
Total area (km^2)	27,800	5,300
Urbanized area (km^2)	17,500	1,500
Population density (inhabitants/km^2)	840	12,000 (central area) 2,700 (periphery)
GDP per capita (2000) in US dollars	32,700	7,750
Energy consumption (petajoules)	4,100	720
Fuel consumption (gasoline) liters/day (1999)	76 million	18 million
Fuel consumption (diesel) liters/day (1999)	10 million	Total =5.3 million Automotive = 4.4 M
Vehicle fleet (1999)	9.3 million	3.2 million
Average Vehicle age (years)	~10	~10
Vehicle emission control technology (1998)		
Pre-control	1 %	50%
Early control	8%	22%
Tier 0	66%	28%
Tier 1	25%	~0
VKT (kilometers per day)	512 million	153 million
Peak ozone conc. (ppbV) in 1999	176	321
Peak PM_{10} conc. ($\mu g/m^3$) in 1999	139	202

Trends in criteria pollutant concentrations for the MCMA

(averages of data at five RAMA sites: TLA, XAL, MER, PED, and CES)







I/M PROGRAM

Trends in criteria pollutant concentrations for the MCMA

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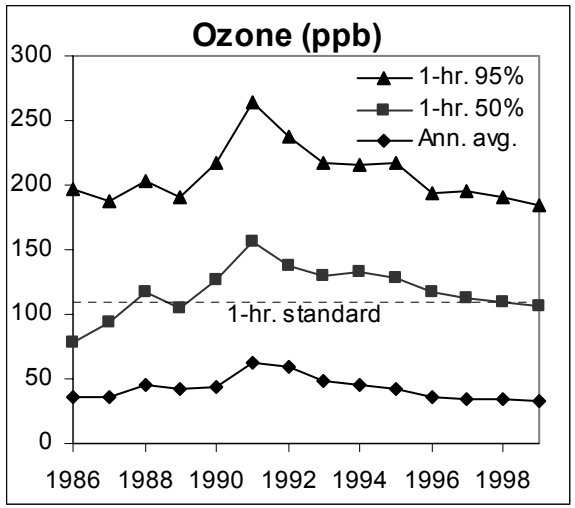
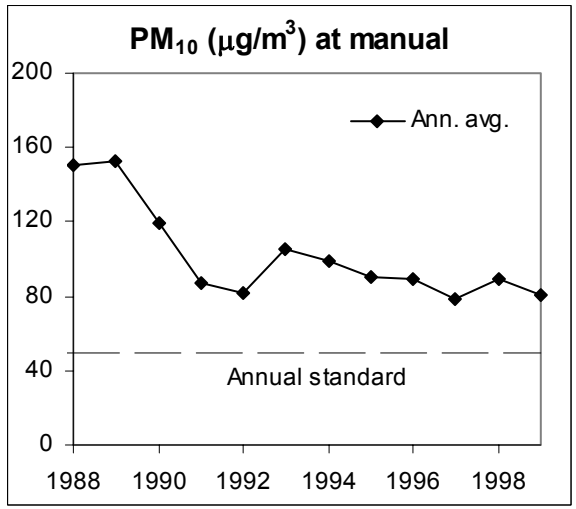
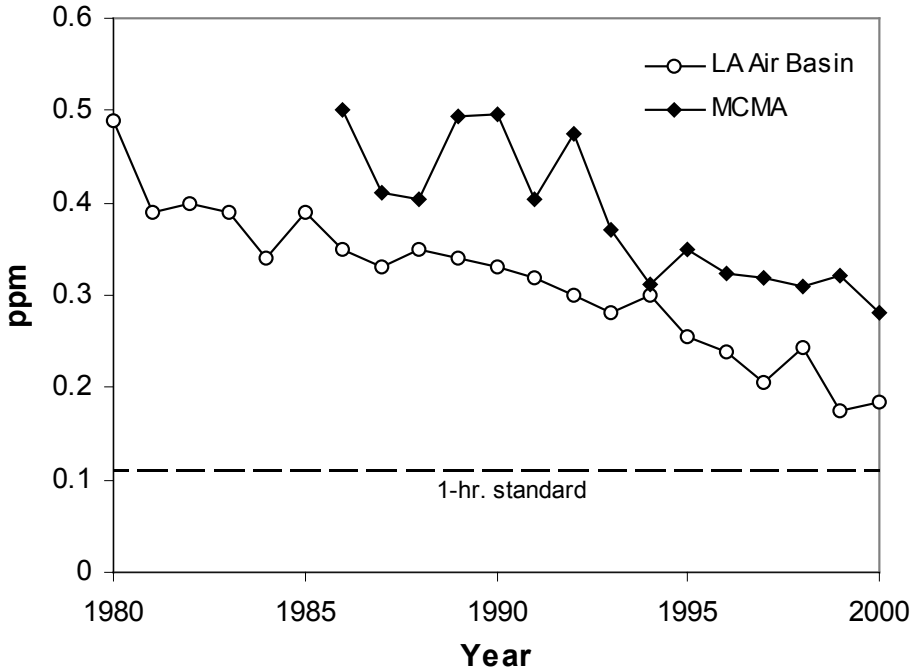
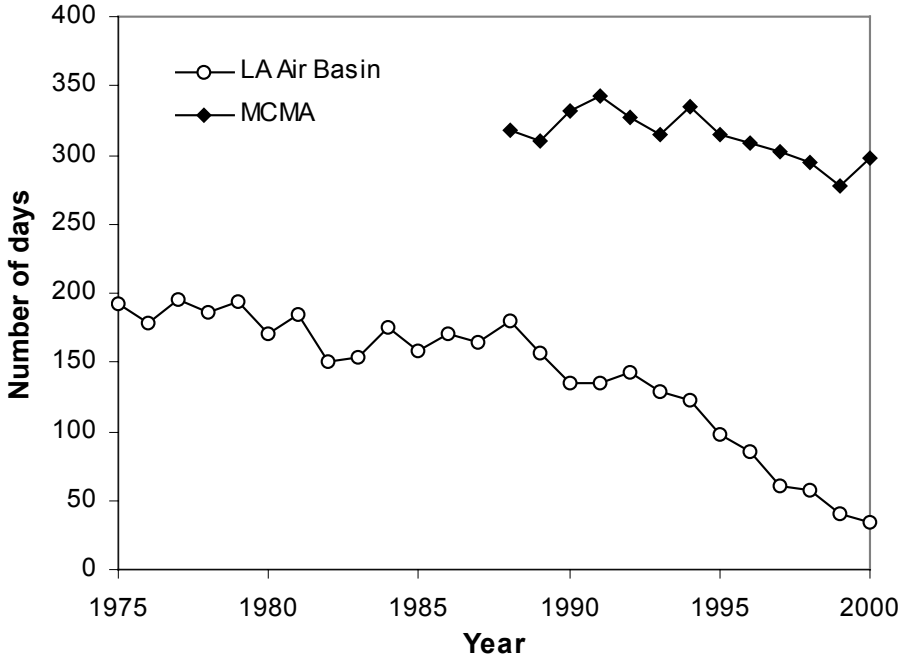




Comparison of the air quality in the MCMA and the Los Angeles Air Basin



Ozone trend (peak 1-hr concentrations) in the LA Air Basin and the MCMA



Number of days with ozone exceedences in the LA Air Basin and the MCMA

Mexico City Air Quality Trends

- **In the early 1990s´:**
  - **Air Quality Standards for all criteria pollutants frequently exceeded**
  - **Ozone standard exceeded 90% of the days**
  - **Peaks above 300 ppb 40-50 days a year**
- **In the late 1990s´:**
  - **Pb, SO_2 levels always within standard**
  - **CO and NO_2 standards rarely exceeded**
  - **Ozone peaks above 300 ppb only 3-4 days a year**
  - **Ozone still above standard 85% of days**
  - **PM10 exceeds standard on 20-30 % of days**

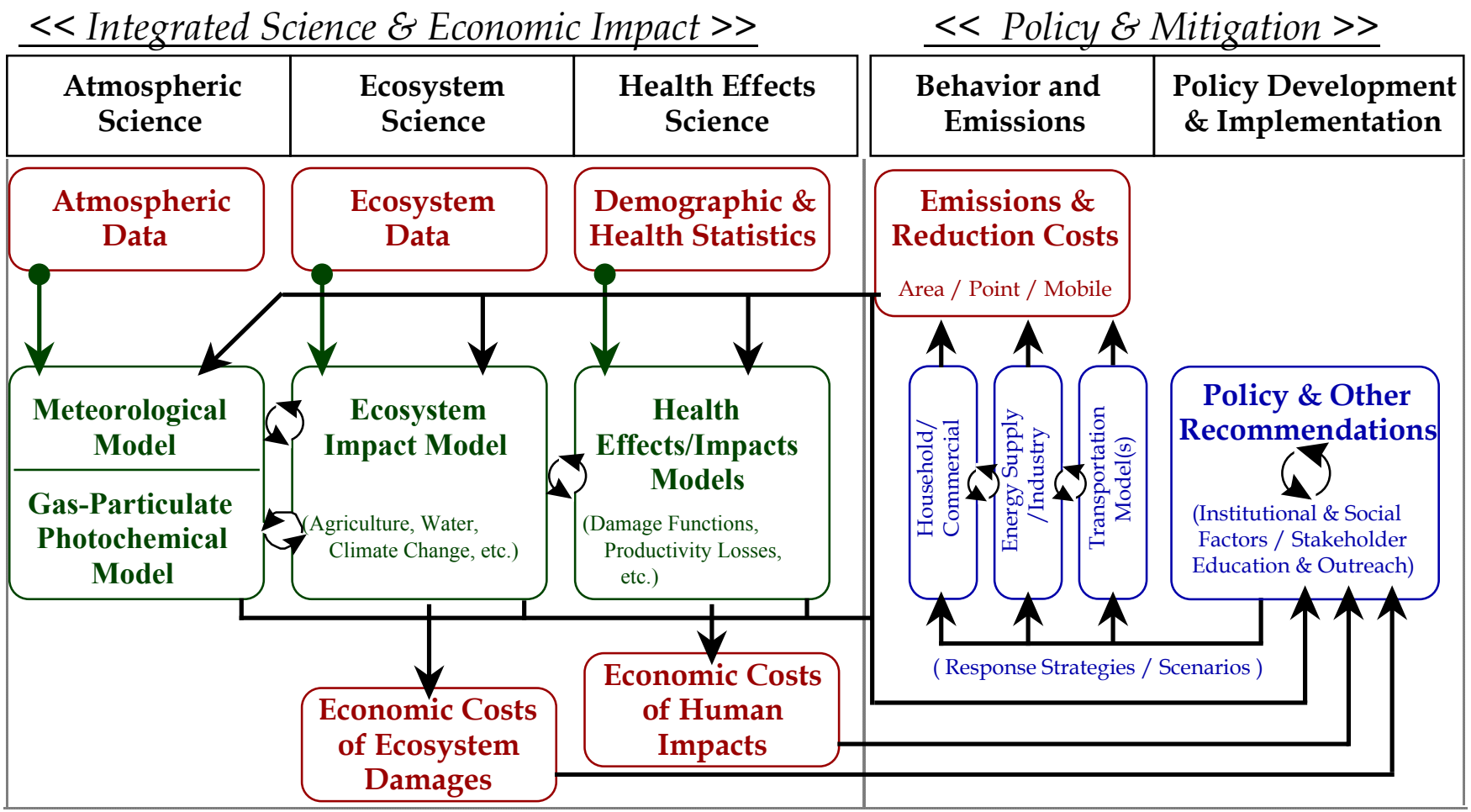
Integrated Program on Urban, Regional and Global Air Pollution: Mexico City Case Study (Mexico City Air Quality Program)

Objective:

Provide objective, balanced assessments of the causes and alternative cost-effective solutions to urban, regional and global air pollution problems through quality scientific, technological, social and economic analysis in the face of incomplete data and uncertainty

- Use Mexico City as the initial case study
- Develop an approach that applies globally
- Build on strong base of ongoing basic research

A Framework for Integrated Assessment



Collaborative Research and Education Program

Mexican Participants

Universidad Autónoma Metropolitana (UAM)
Instituto Mexicano del Petróleo (IMP)
Petroleos Mexicanos (PEMEX)
Universidad Nacional Autónoma de México (UNAM)
Universidad de las Americas, Puebla
Universidad Iberoamericana
Instituto Tecnológico de Estudios Superiores de Monterrey (ITESM)
Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT)
Instituto Nacional de Ecología (INE)
Centro Nacional de Investigación y Capacitación Ambiental (CENICA)
Gobierno del Distrito Federal; Red Automática de Monitoréo Atmosférico (RAMA),
Gobierno del Estado de México
Secretaría de Salud
Insituto Nacional de Salud Pública

US Participants

Massachusetts Institute of Technology
Harvard University
--School of Public Health, Kennedy School of Government, Medical School
Boston University
Washington State University
Montana State University
University of Colorado
Aerodyne Research Inc.
Department of Energy (National laboratories)

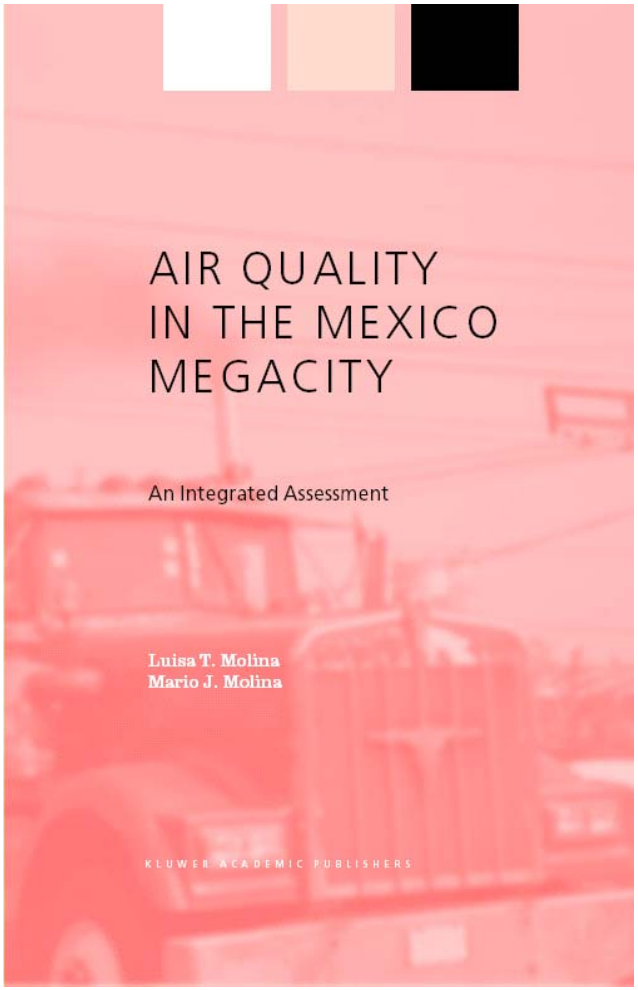
International Participants

ETH-Zurich
Ecole Polytechnique Federal de Lausanne
University of Heidelberg
Free University of Berlin

Environmental Education and Outreach

- Visiting Mexican scholars at MIT
- Workshops/symposia on air quality
- Professional development courses on air quality for mid-career personnel in the government, industry and academic sectors as well as non-governmental organizations and the media
- Masters Program in Environment and Health Management at MIT and Harvard School of Public Health (INE-MIT-Harvard joint program)
- Exchange program between MIT and Mexican institutions
- Establish the Research and Development Network on Air Quality in Large Cities in Mexico (communication forum for Mexican researchers)

Summary of the First Phase of the Mexico City Air Quality Program



Chapter 1. Air Quality Impacts: A Global and Local Concerns

Chapter 2. Cleaning the Air: A Comparative Overview

Chapter 3. Forces Driving Pollutant Emissions in the MCMA

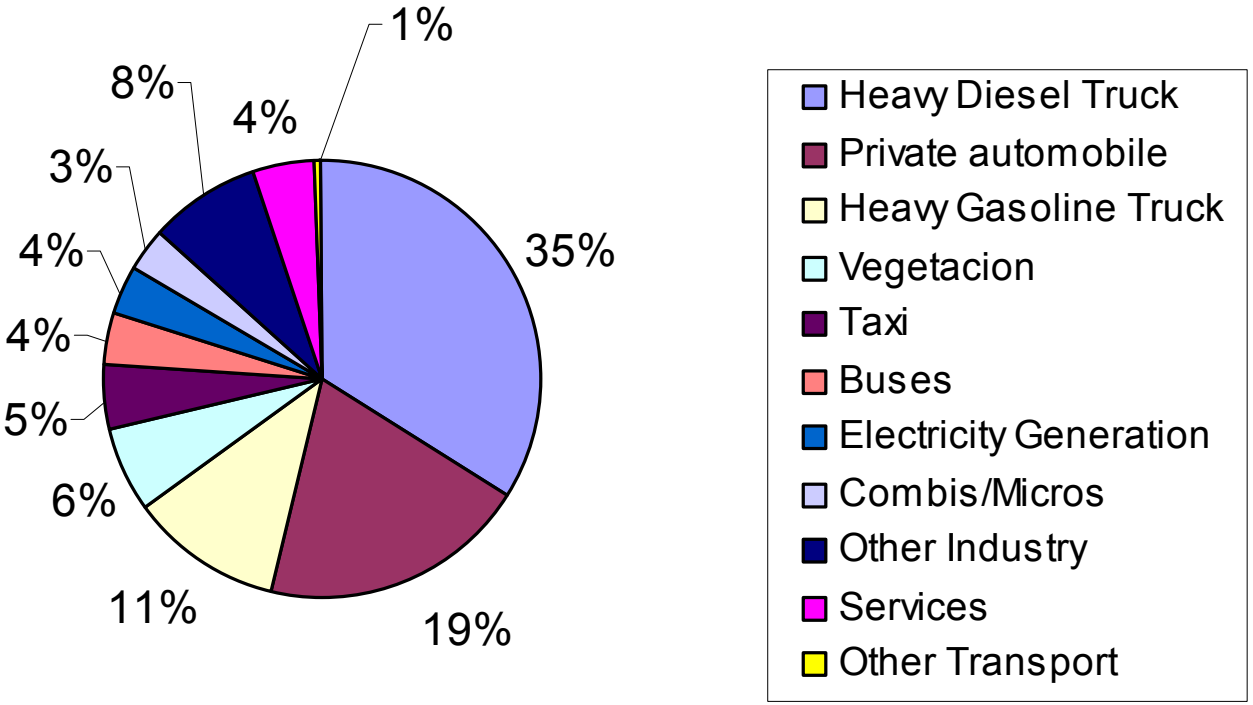
Chapter 4. Health Benefits of Air Pollution Control

Chapter 5. Air Pollution Science in the MCMA: Understanding Source-Receptor Relationships Through Emissions Inventories, Measurements and Modeling

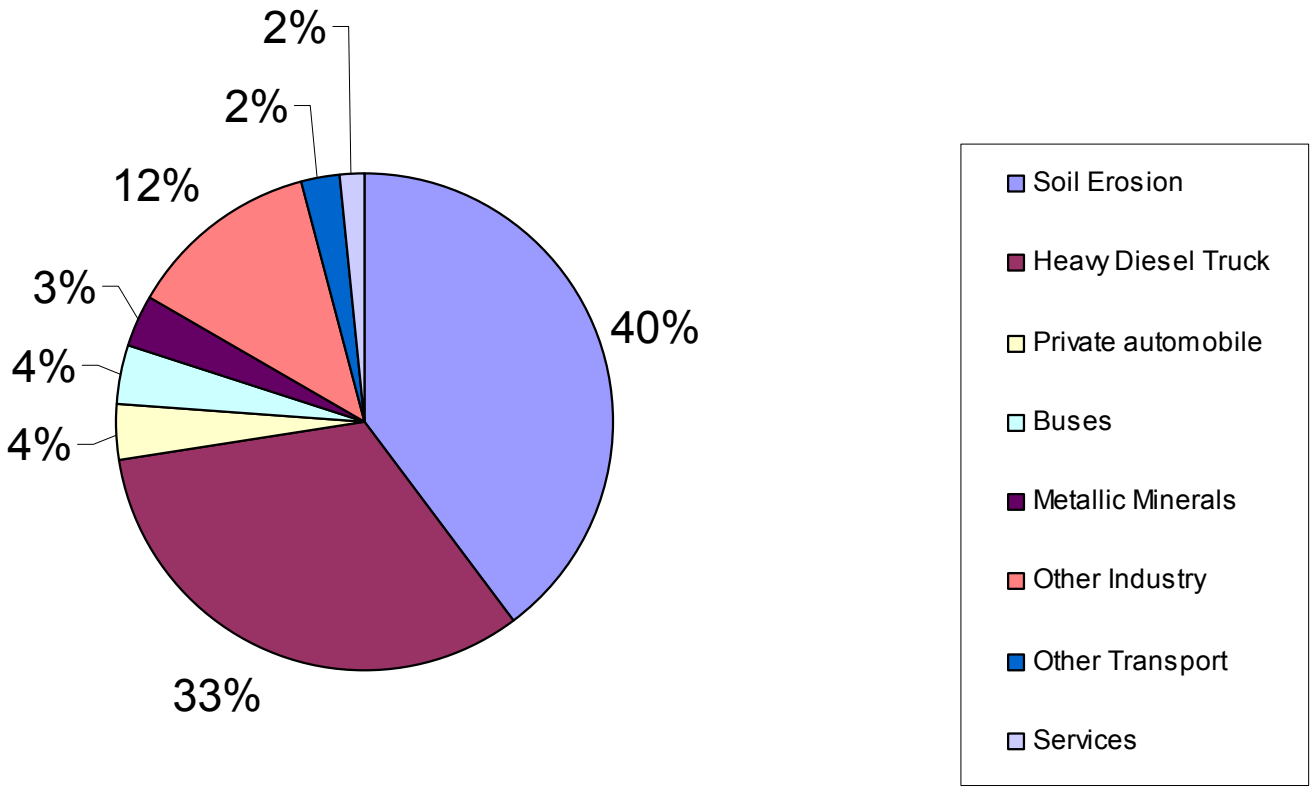
Chapter 6. The MCMA Transportation System: Mobility and Air Pollution

Chapter 7. Key Findings and Recommendations

NOx Emissions (1998)

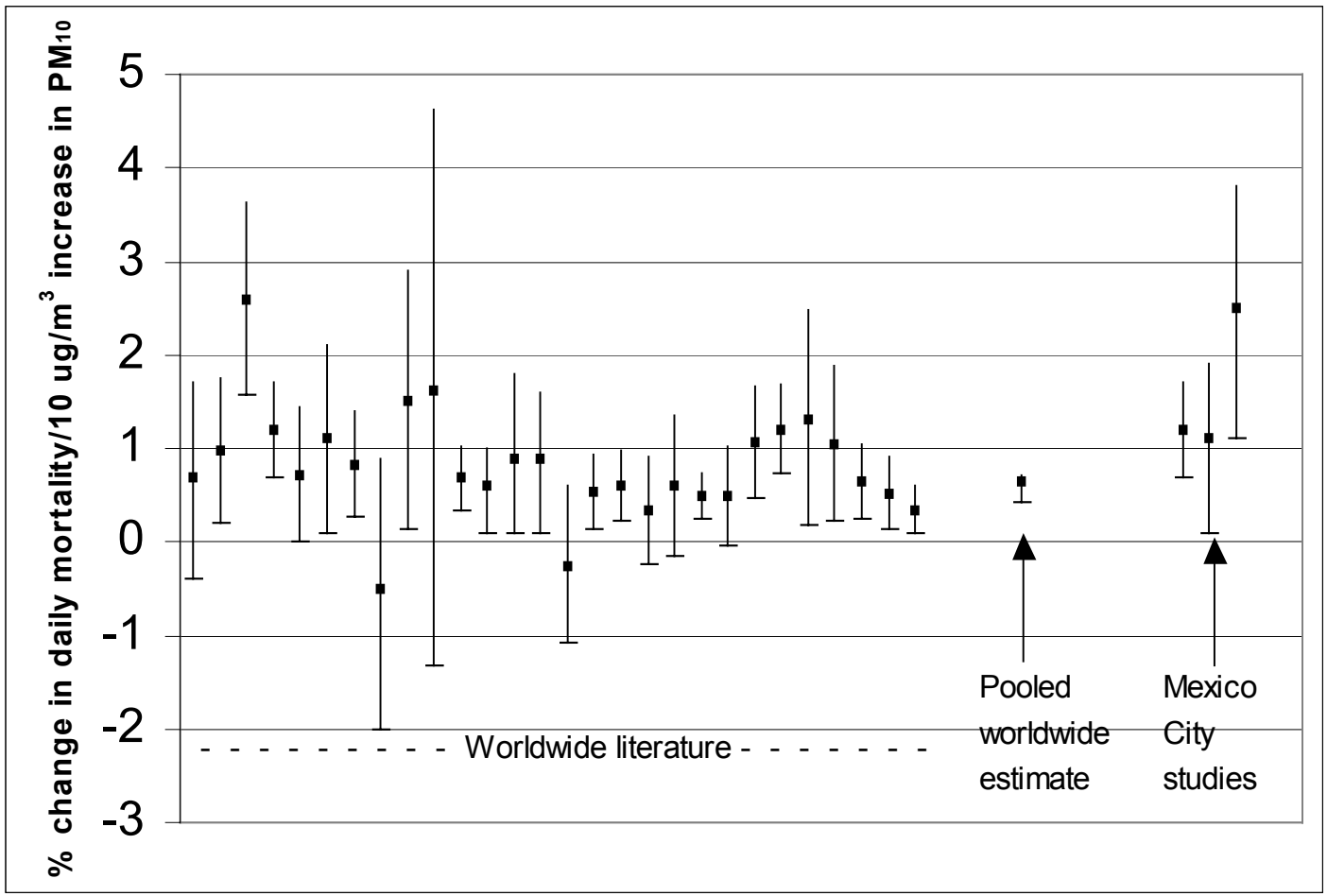


PM10 Emissions (1998)



TAXI

Estimates of mortality impacts from particulate matter, drawn from time-series studies worldwide and in Mexico City



Estimated Health Benefits of a 10% Reduction of Pollution Levels in the MCMA

PM10	Background Rate (case-persons-yr)	Risk Coefficient (% per 10µg/m3)	Risk Reduction (cases/yr)
Cohort Mortality	10/1000	3	2000
Time Series Mortality	5/1000	1	1000
Chronic Bronchitis	14/1000	10	10 000

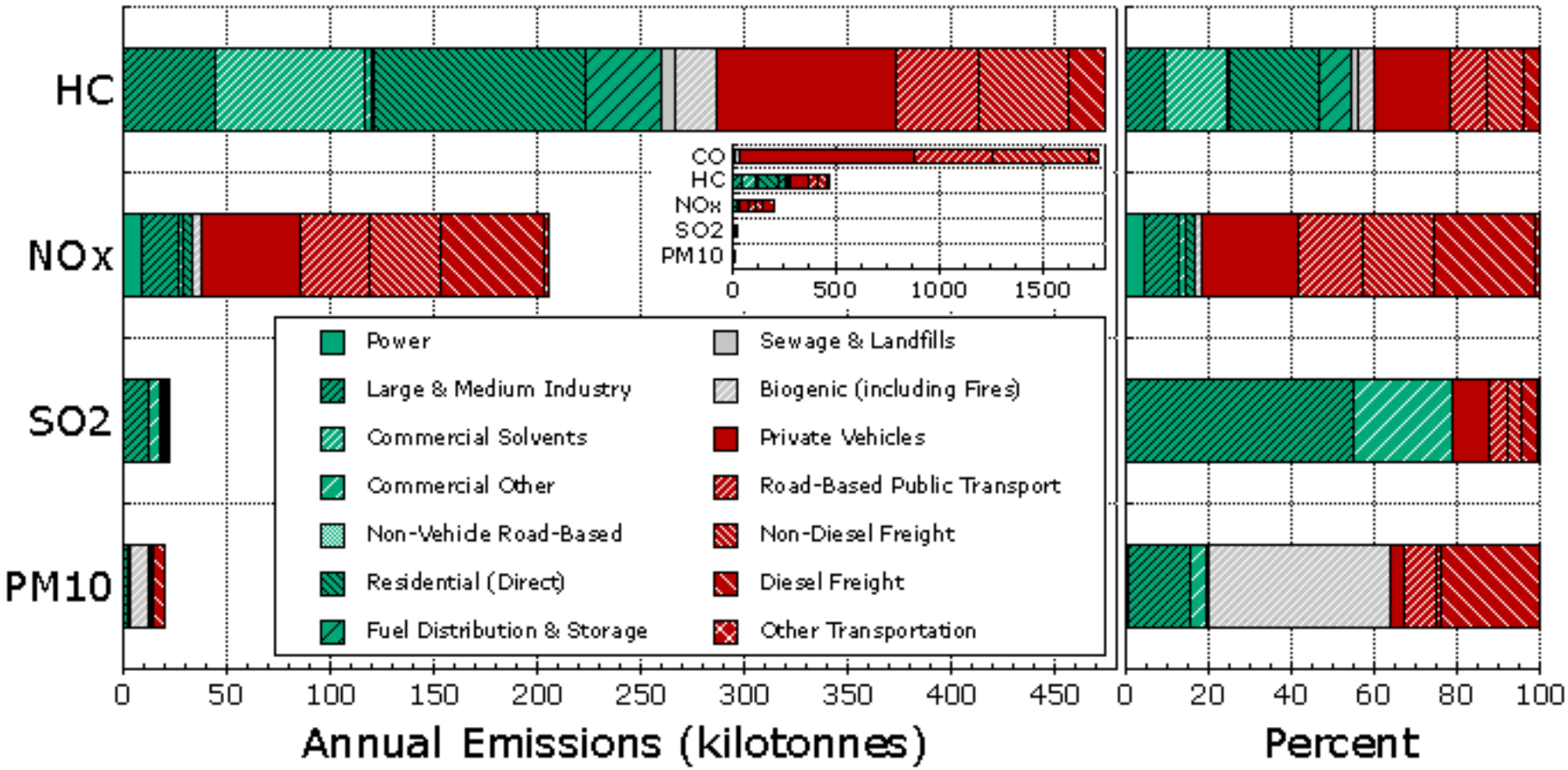
Ozone	Background Rate (case-persons-yr)	Risk Coefficient (% per 10µg/m3)	Risk Reduction (cases/yr)
Time Series Mortality	5/1000	0.5	300
Minor Restricted Activity Days	8000/1000	1.0	2,000,000

Focus of the Second Phase of the Mexico City Air Quality Program

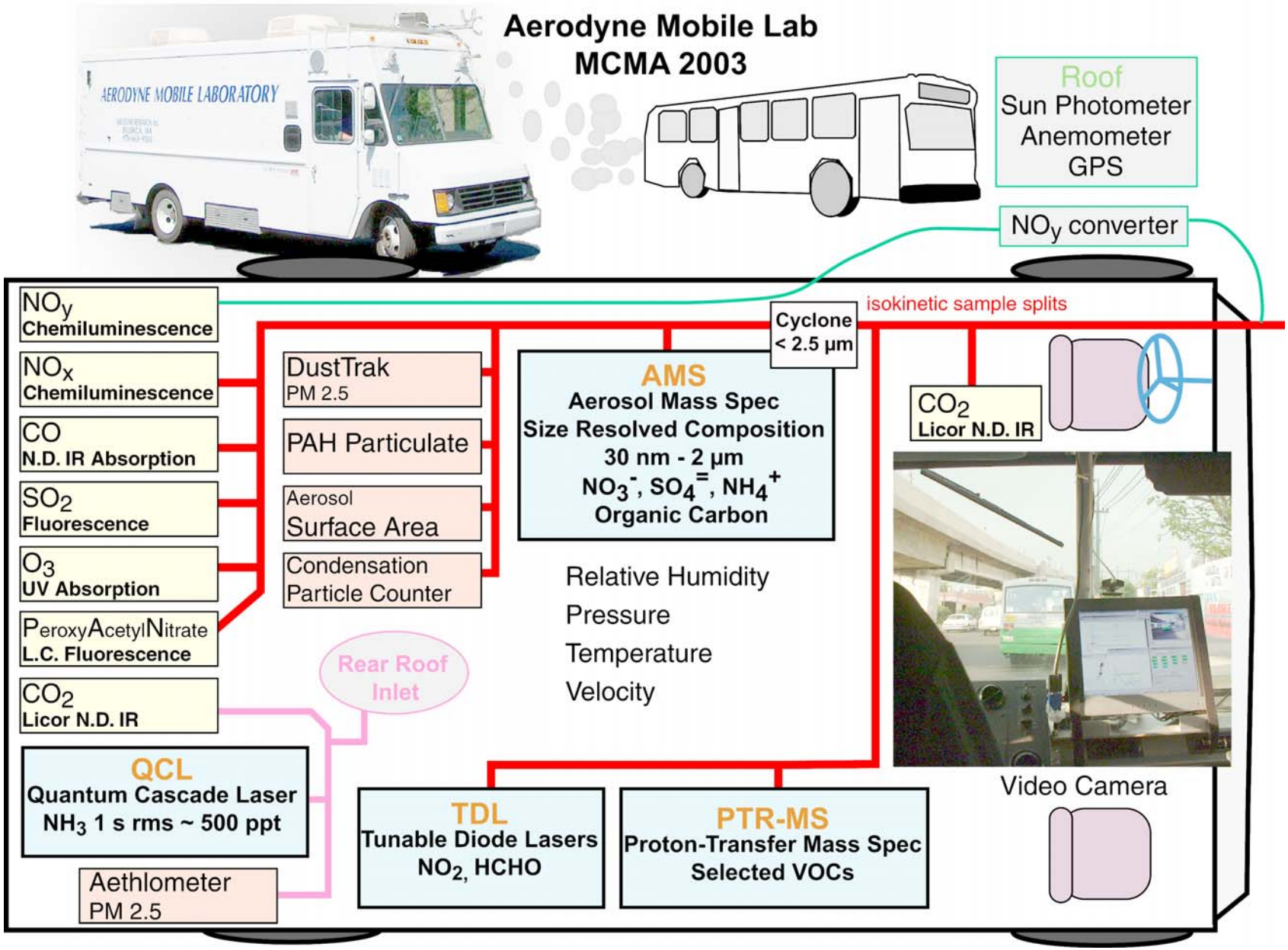
Systematic development of scientific information, evaluation methodologies and simulation tools in the following areas:

- activities that lead to the generation of pollutants in the MCMA (transportation, production of goods and services, degradation of the natural environment, etc.);
- dispersion and transformation of atmospheric pollutants (focus on ozone and particles);
- evaluation of risks and the effects of pollutants on the population;
- cost-benefit analysis of control strategies;
- integrated assessment of policy options and priorities for control strategies;
- strategies for capacity building.

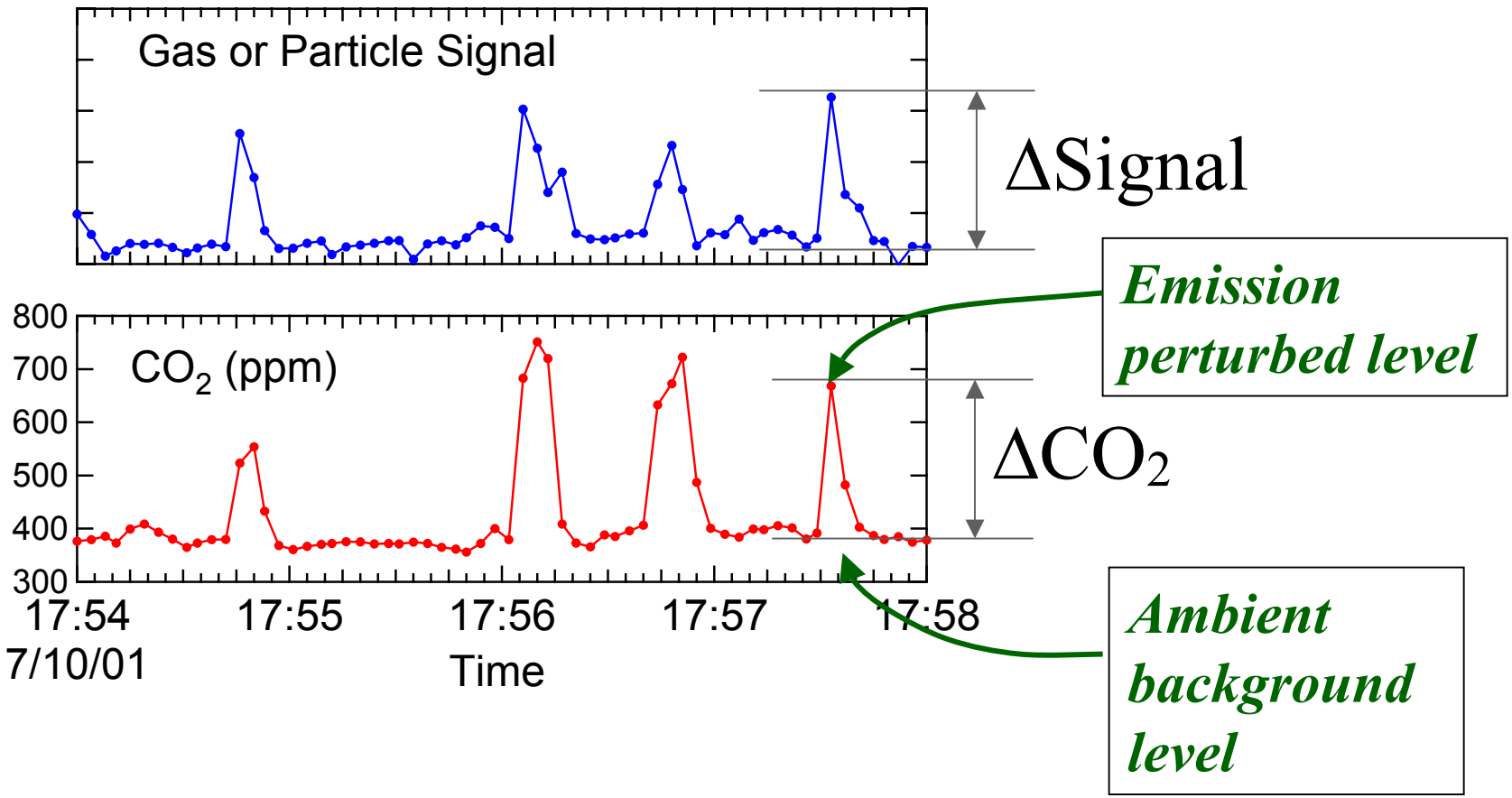
A Diverse Mix of Emissions/Sources



Source: CAM 1998 MCMA Emissions Inventory

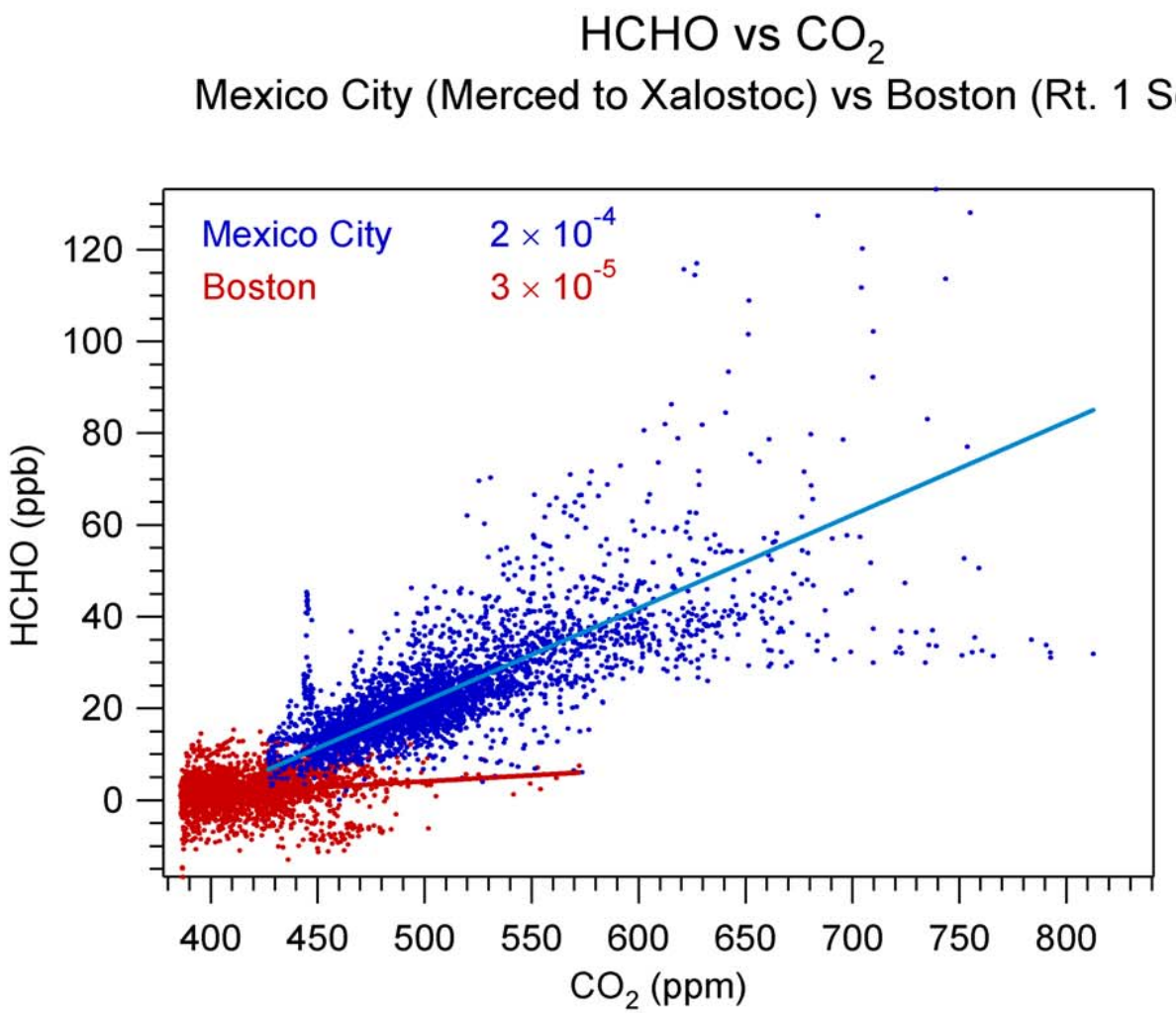

Aerodyne Mobile Lab
MCMA 2003
AERODYNE MOBILE LABORATORY
Roof
Sun Photometer
Anemometer
GPS
NO_y converter
isokinetic sample splits
NO_y
Chemiluminescence
NO_x
Chemiluminescence
CO
N.D. IR Absorption
SO_2
Fluorescence
O_3
UV Absorption
PeroxyAcetylNitrate
L.C. Fluorescence
CO_2
Licor N.D. IR
DustTrak
PM 2.5
PAH Particulate
Aerosol
Surface Area
Condensation
Particle Counter
Cyclone
< 2.5 µm
AMS
Aerosol Mass Spec
Size Resolved Composition
30 nm - 2 µm
NO_3^-, $SO_4^=$, NH_4^+
Organic Carbon
Relative Humidity
Pressure
Temperature
Velocity
CO_2
Licor N.D. IR
Rear Roof
Inlet
QCL
Quantum Cascade Laser
NH_3 1 s rms ~ 500 ppt
Aethlometer
PM 2.5
TDL
Tunable Diode Lasers
NO_2, HCHO
PTR-MS
Proton-Transfer Mass Spec
Selected VOCs
Video Camera

"*In-plume*" sampling indicated by *above-ambient* CO_2 levels

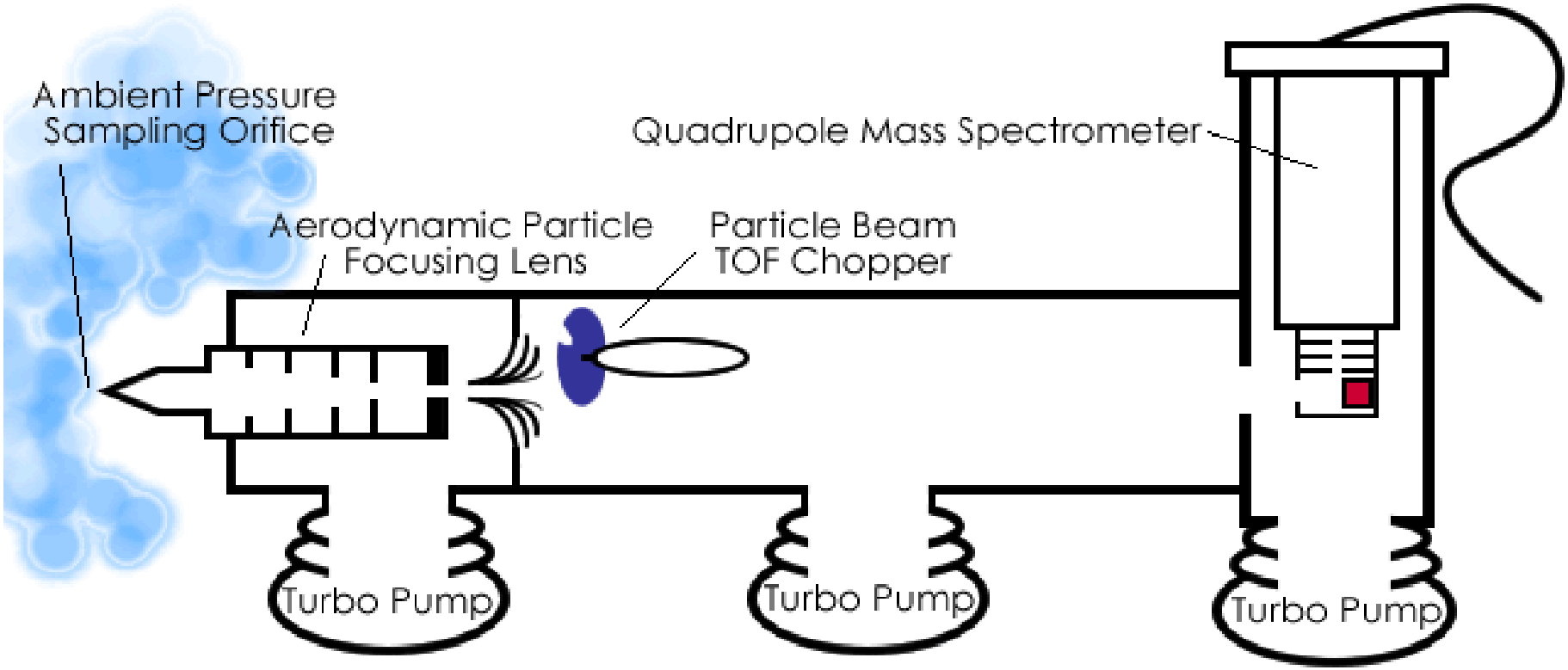


Emission Ratio = ΔSignal/ΔCO_2

Formaldehyde Measurements
February 2002

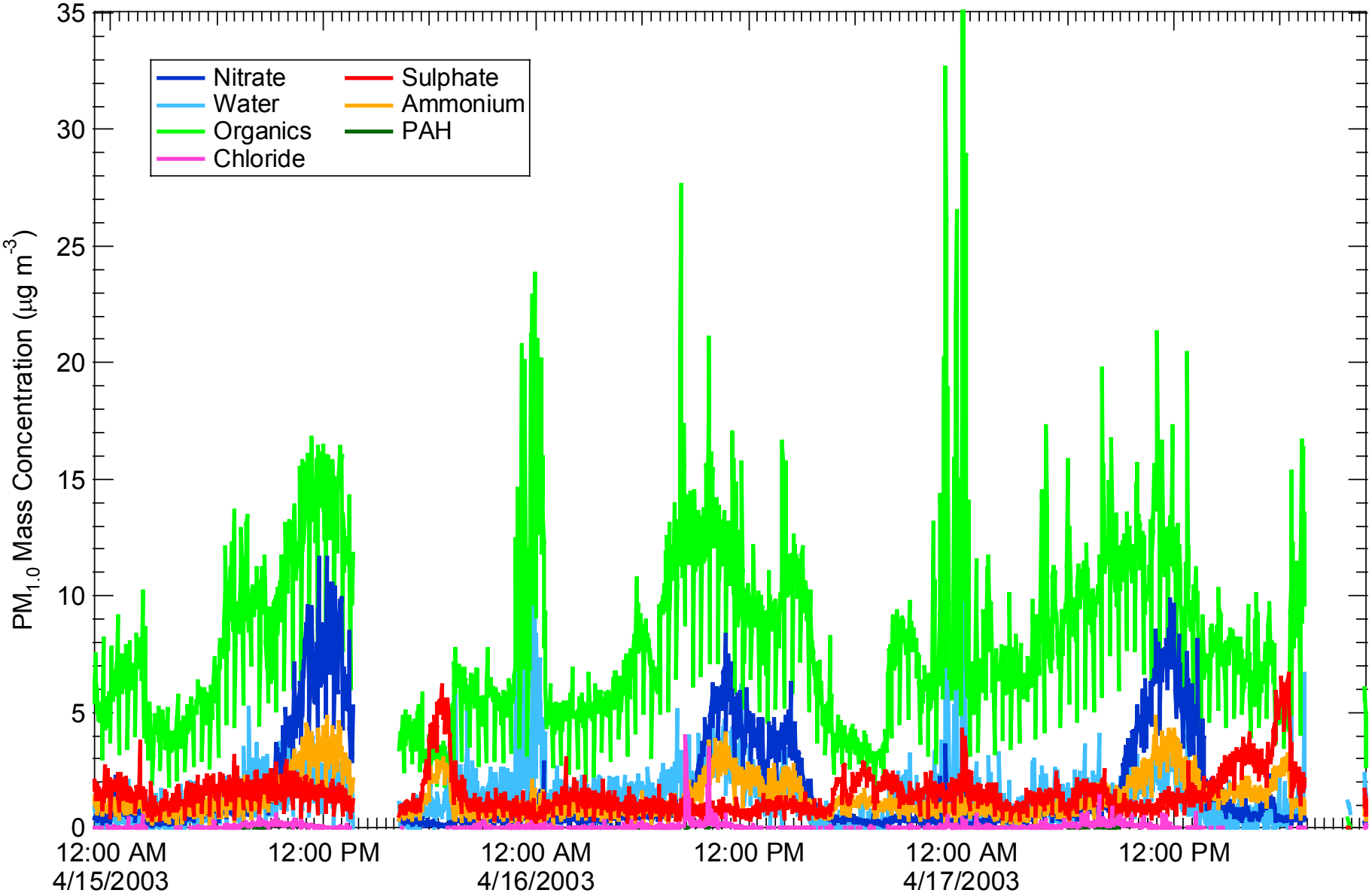


Aerosol Mass Spectrometer (AMS) at CENICA



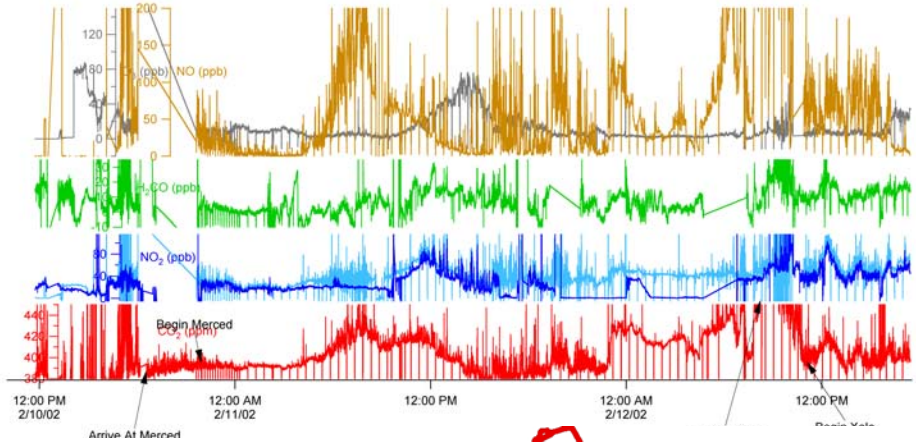
100% transmission (60-600 nm), aerodynamic sizing, linear mass signal.

Aerosol measurements (April 15-17, 2003)

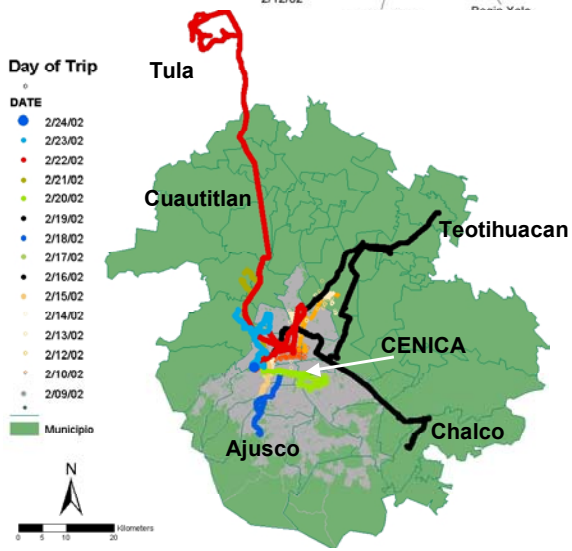


Mobile Laboratory Modes of Operation

Stationary Sampling
High time resolution point sampling
Quality Assurance for conventional air monitoring sites



Mobile Sampling/Mapping
Motor vehicle pollution emission ratios
Large source plume identification
Ambient background pollution distributions



Chase
Detailed mobile source emissions characterization
Plume tracer flux measurements

MCMA-2003 Field Campaign

Supersite Instrumentation

Supersite Location: CENICA (UAM-Ixtapalapa)

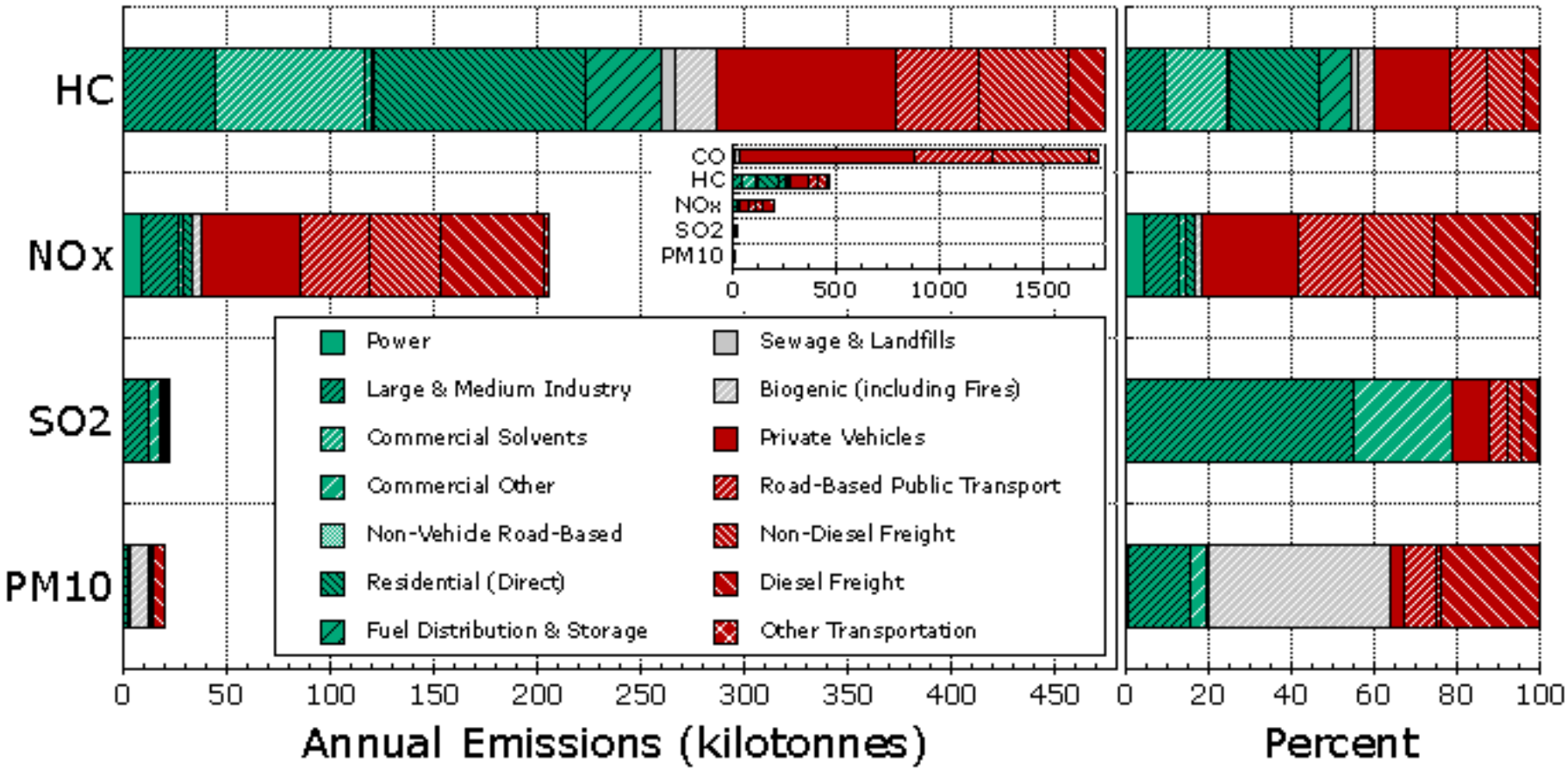
Instrumentation:

- CENICA - monitoring station, tethered balloon
- RAMA - monitoring station
- WSU – VOC sampling
- DOE/ PNNL – PTRMS, single particle sampler/analyzer, MFRSBR, RSR
- UCB/LBL – Particle sampling apparatus
- DOE/Argonne National Lab – PAN, black carbon, olefins, NH_3
- Colorado U. – AMS
- Penn State – OH and HO_2
- IMP – MINIVOLS and MOUDI , aldehyde cartridges
- MIT/U. Heidelberg - DOAS
- MIT/ Free U. Berlin – LIDAR
- MIT – PAHs
- UCR – nitro-PAHs, PAHs
- EPFL - LIDAR
- UNAM – FTIR
- Chalmers – FTIR, DOAS
- Plus others

MIT Scenario Analysis

- Integrating Bottom-Up and top-Down Analytic Approaches
- Three Feasibility "Screens"
  - *Technical Feasibility* (effective)
  - *Economic Feasibility* (affordable)
    - Pursued through quantitative analysis
  - *Political Feasibility* (implementable)
    - Pursued through qualitative dialogue
- "Feasibility" depends in part upon the "Future Story"
    - Allows us to identify more robust options

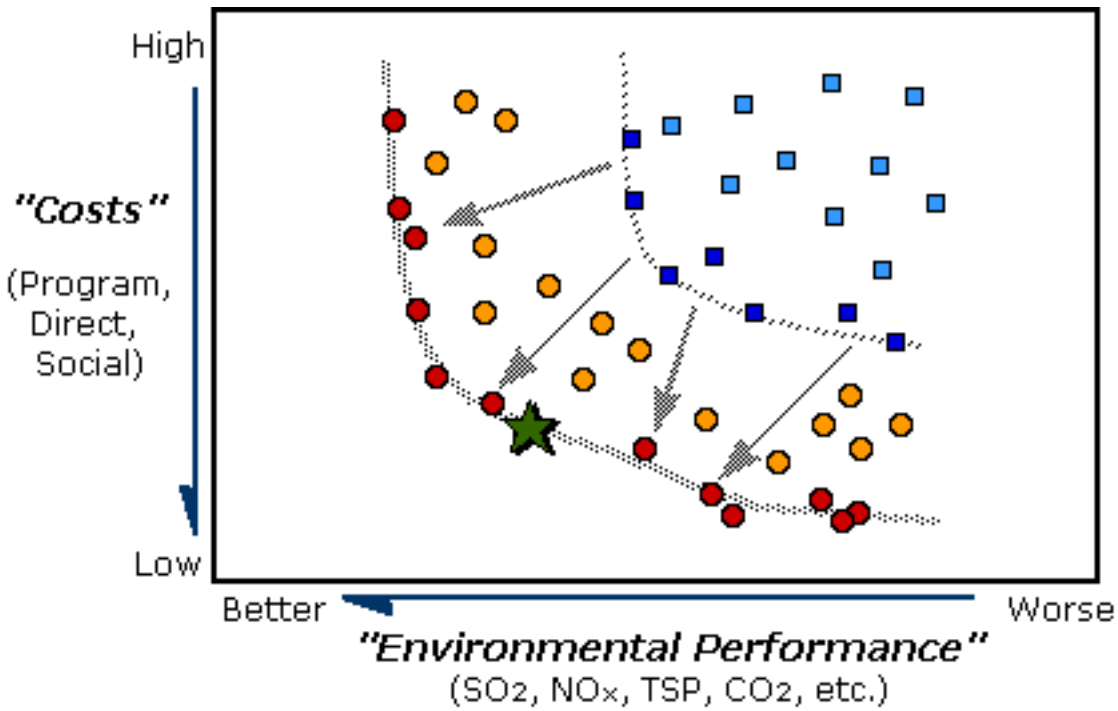
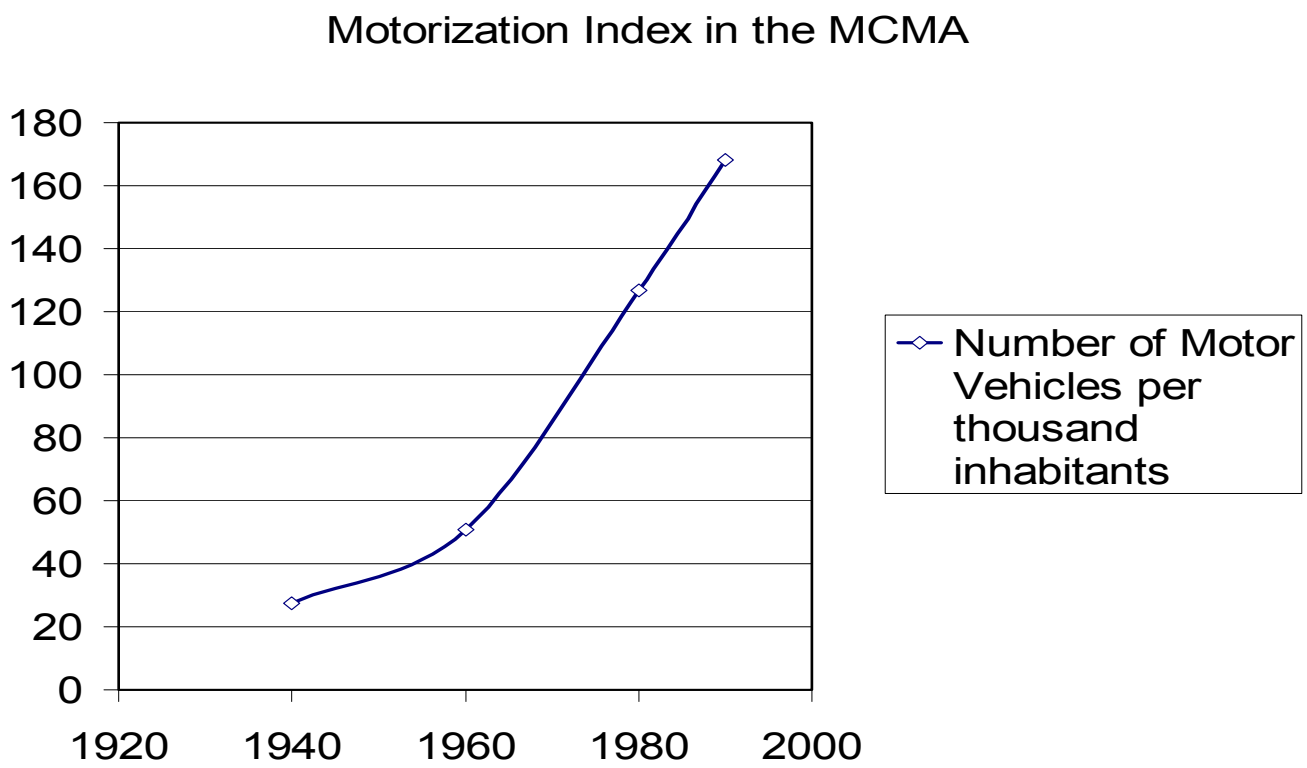
A Diverse Mix of Emissions/Sources



Source: CAM 1998 MCMA Emissions Inventory

Identifying Tradeoffs

- Combined Technical and Economic Feasibility



Increase in Automobiles per Capita in Mexico City