JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

NATIONAL INSTITUTE OF ECOLOGY
THE UNITED MEXICAN STATES

THE STUDY ON THE COMBUSTION TECHNOLOGIES FOR THE AIR POLLUTION CONTROL OF STATIONARY SOURCES IN THE METROPOLITAN AREA OF THE CITY OF MEXICO

Final Report

Main Report

SEPTEMBER 1995

PACIFIC CONSULTANTS INTERNATIONAL, TOKYO
In association with
JAPAN ENVIRONMENT ASSESSMENT CENTER CO., LTD., TOKYO

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

NATIONAL INSTITUTE OF ECOLOGY
THE UNITED MEXICAN STATES

THE STUDY ON THE COMBUSTION TECHNOLOGIES FOR THE AIR POLLUTION CONTROL OF STATIONARY SOURCES IN THE METROPOLITAN AREA OF THE CITY OF MEXICO

Final Report

Main Report

SEPTEMBER 1995

PACIFIC CONSULTANTS INTERNATIONAL, TOKYO
In association with
JAPAN ENVIRONMENT ASSESSMENT CENTER CO., LTD., TOKYO

In this report, project costs are estimated based on July 1995 prices with an exchange rate of 1 US$ = N$6.00 (= ¥90)

PREFACE

In response to a request from the Government of the United Mexican States, the Government of Japan decided to conduct the Study on the Combustion Technologies for the Air Pollution Control of Stationary Sources in the Metropolitan Area of the City of Mexico in the United Mexican States and entrusted the study to the Japan International Cooperation Agency (JICA).

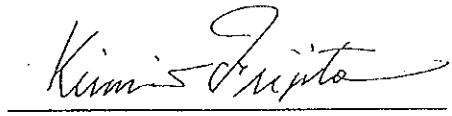
JICA sent a study team led by Dr. Akira Uchida of Pacific Consultants International (PCI) and organized by PCI and Japan Environment Assessment Center Co., Ltd. to the United Mexican States five times between June 1993 and August 1995.

The team held discussions with the officials concerned of the Government of the United Mexican States, and conducted field surveys. After returning to Japan, the team conducted further studies and compiled the final results in this report.

I hope that this report will contribute to the promotion of the plan and to the enhancement of friendly relations between our two countries.

I wish to express my sincere appreciation to the officials concerned of the Government of the United Mexican States for their close cooperation throughout the study.

September 1995



Kimio Fujita
President
Japan International Cooperation Agency

THE STUDY ON THE COMBUSTION TECHNOLOGIES FOR THE AIR POLLUTION CONTROL OF STATIONARY SOURCES IN THE METROPOLITAN AREA OF THE CITY OF MEXICO

September 1995

Mr. Kimio Fujita
President
Japan International Cooperation Agency

LETTER OF TRANSMITTAL

Dear Sir,

We are pleased to submit to you the final report entitled "The Study on the Combustion Technologies for the Air Pollution Control of Stationary Sources in the Metropolitan Area of the City of Mexico". This report has been prepared by the Study Team in accordance with the contract signed on 8 June 1993, 23 May 1994, and 8 May 1995 between Japan International Cooperation Agency and Pacific Consultants International.

The report examines the existing conditions concerning air pollution and stationary air pollution sources in the metropolitan area, analyzes the results of the combustion tests in the test plant, and proposes the combustion technologies for the air pollution control of stationary sources in the metropolitan area.

The report consists of the Summary, Main Report, Data Book, and Operation and Maintenance Manual for Combustion Test Plant. The Summary summarizes the results of all studies. The Main Report presents the results of the whole study including analysis of background conditions, evaluation of the present state of stationary air pollution sources, analysis of results of the combustion tests, proposals on improvement of combustion technology and institutional reinforcement for its dissemination. The Data Book contains detailed technical data. An Operation and Maintenance Manual for the combustion test plant has been also prepared.

All members of the Study Team wish to express grateful acknowledgments to the personnel of your Agency, Ministry of International Trade and Industry, Ministry of Foreign Affairs, and Embassy of Japan in Mexico, and also to officials of the Government of Mexico for their assistance extended to the Study Team. The Study Team sincerely hopes that the results of the study will contribute to the improvement of the air quality and the social development in the Metropolitan Area of the City of Mexico.

Yours faithfully,

内田顕

Akira Uchida
Team Leader

ACRONYMS

Administrative Areas

DF : Distrito Federal (Federal District)

EDOMEX : EM

EM : Estado de Mexico (State of Mexico)

MCEM : Municipios Conurbados del Estado de Mexico (17 cities of the State of Mexico within ZMCM)

ZMCM : Zona Metropolitana de la Ciudad de Mexico (Metropolitan Zone of the City of Mexico = DF + MCEM)

Organizations

CENAM : Centro Nacional de Metrología (National Metrology Center)

CFE : Comision Federal de Electricidad (Federal Commission for Electricity)

CONAE : Comision Nacional para Ahorro de Energia (National Commission for Energy Saving)

DDF : Departamento del Distrito Federal (Department of Federal District)

GEM : Gobierno del Estado de Mexico (Government of the State of Mexico)

IIE : Instituto de Investigaciones Electricas (Institute of Electrical Investigation)

IMP : Instituto Mexicano del Petroleo (Mexican Institute of Petroleum)

INE : Instituto Nacional de Ecologia (National Institute of Ecology)

JICA : Japan International Cooperation Agency

METROCOM : Comision Metropolitana para la Prevencion y Control de la Contaminacion Ambiental en el Valle de Mexico (Metropolitan Commission for Prevention and Control of Environmental Pollution in the Mexico Valley)

NIST : National Institute of Standards and Technology (USA)

PEMEX : Petroleos Mexicanos (Mexican Petroleum)

PROFECO : Procuraduría Federal de Consumidor (National Prosecutors' Office of Consumer)

PROFEPA : Procuraduria Federal de Proteccion al Ambiente (Federal Prosecutors Office of Environmental Protection)

SE : Secretaría de Energía (Ministry of Energy)

SECOFI : Secretaría de Comercio y Fomento Industrial (Ministry of Commerce and Industrial Development)

SECT : Secretaría de Comunicaciones y Transportes (Ministry of Communication and Transport)

SEDESOL : Secretaría de Desarrollo Social (Ministry of Social Development)

SEG : Secretaría de Gobernacion (Ministry of Home Affairs)

SEMARNAP : Secretaría de Medio Ambiente, Recursos Naturales y Pesca (Ministry of Environment, Natural Resources and Fishery)

SEMIP : Secretaría de Energia, Minas e Industria Paraestatal (Ministry of Energy, Mines and Public Industry)

SEP : Secretaría de Educacion Publica (Ministry of Public Education)

SES : Secretaría de Salud (Ministry of Health)

SHCP : Secretaría de Hacienda y Credito Publico (Ministry of Finance and Public Credit)

SINALP : Sistema Nacional de Acreditación de Laboratorios Pruebas (National System of Testing Laboratories Accreditation)

SPP : Secretaría de Programacion y Presupuesto (Ministry of Planning and Budget)

STPS : Secretaría de Trabajo y Prevision Social (Ministry of Labor and Social Security)

Technical Terms

EGR : Exhaust gas recirculation

FBC : Fluidized bed combustion

NO_2	: Nitrogen dioxide
NOM	: Norma Oficial Mexicana (Mexican Official Standard)
NOx	: Nitrogen oxides
PM	: Particulate matter
PM10	: Suspended particulate matter of diameters less than 10 μm
SO_2	: Sulfur dioxide
SOx	: Sulfur oxides
TSP	: Total suspended particulates
PICCA	: Programa Integral Contra la Contaminacion Atmosferica en la Zona Metropolitana de la Ciudad de Mexico (Integrated Program Against Atmospheric Pollution in the Metropolitan Zone of City of Mexico, METROCOM, October 1990)
IMECA	: Indice Metropolitano de la Calidad del Aire (Metropolitan Index of Air Quality)

The Study on the Combustion Technologies for the Air Pollution Control of Stationary Sources in the Metropolitan Area of the City of Mexico

Final Report

Main Report

Table of Contents

List of Tables

List of Figures

CHAPTER 1 INTRODUCTION

Chapter 1 Introduction

1.1 Background of the Study

The Metropolitan Zone of the City of Mexico (ZMCM) consists of all 16 wards (deligaciones) of the Federal District (DF) and 17 cities (municipios) of the State of Mexico (EM), the latter being generally called MCEM. ZMCM is one of the largest megalopolises in the world with the population of about 15 million and the area of about 3,600 km^2.

The problem of air pollution emerged in ZMCM in parallel with rapid motorization and industrialization, and became very serious by the middle of the 1970s. Besides the large amounts of air pollutant emissions, particular conditions of ZMCM in regard to geography, topography, and meteorology also have been having negative effects on air quality.

In the early 1980s, the Mexican Government began to intensify their efforts for abatement of environmental pollution, and enacted the Environmental Protection Law in 1982. In January 1986, an automatic air quality monitoring network comprising 25 stations was put into operation in ZMCM. In February of the same year, the Government promulgated a Presidential Decree of "21 Concrete Measures for Air Pollution Control," and initiated a wide range of action to reduce air pollution. These actions were reinforced through the enactment of the General Law for Ecological Balance and Environmental Protection in March 1988 and the formulation of "Integral Program Against Atmospheric Pollution in the Metropolitan Zone of City of Mexico (PICCA)" in October 1990.

In connection with these efforts, the Government of Japan has been providing assistance for mitigation of the air pollution problem, by available methods including technical cooperation by the Japan International Cooperation Agency (JICA). JICA conducted "The Study on Air Pollution Control Plan in the Federal District" in 1987/1988, and then "The Study on the Air Pollution Control Plan of Stationary Sources in the Metropolitan Area of the City of Mexico" in 1990/91.

Meanwhile, air pollution by sulfur dioxide (SO_2) has been considerably reduced as a result of measures taken by the Mexican Government such as the closure of an old oil refinery and replacement of high-sulfur fuels with natural gas and other better quality liquid fuels. However, the problem of photochemical smog is still unsolved, and therefore, control of emissions of nitrogen oxides (NOx) remains as a subject of vital importance.

The present Study (hereinafter called "the Study") was undertaken by JICA in such a context, and it aims to propose appropriate combustion technology for stationary sources in ZMCM with a particular emphasis placed on control of NOx emissions. The Scope of Work (S/W) for the Study was agreed upon between JICA and the Mexican agencies concerned in March

1993, and the Study actually began in June 1993 with the first visit of the JICA Study Team to Mexico.

1.2 Objectives of the Study

The objectives of the Study are as follows:

(1) To propose appropriate combustion control technology and methods to reduce emissions of NOx and smoke dust from stationary sources in ZMCM
(2) To transfer such technologies from the Study Team to the Mexican counterparts through the conduct of combustion tests in a test plant

1.3 Study Area

The Study Area is ZMCM as shown in Figure 1.1. However, combustion tests were conducted in the laboratory of IPM in Pachuka where the combustion test plant was installed for the Study.

1.4 Scope of the Study

The Study covered the following items as provided in the S/W.

(1) Background Study

1) Social and economic condition
2) National development plan
3) National environmental policies and regulations for emissions
4) Energy sector policy
5) Present condition of air pollution in ZMCM
6) Demand and supply of fuels
7) Environmental management
8) Training system in the field of combustion control

(2) Review of Present Conditions of Controlling NOx and Smoke Dust Emissions from Stationary Sources in ZMCM

1) Combustion facilities in factories
2) Emissions from factories
3) Investment plan of factories for environmental pollution control facilities
4) Combustion control

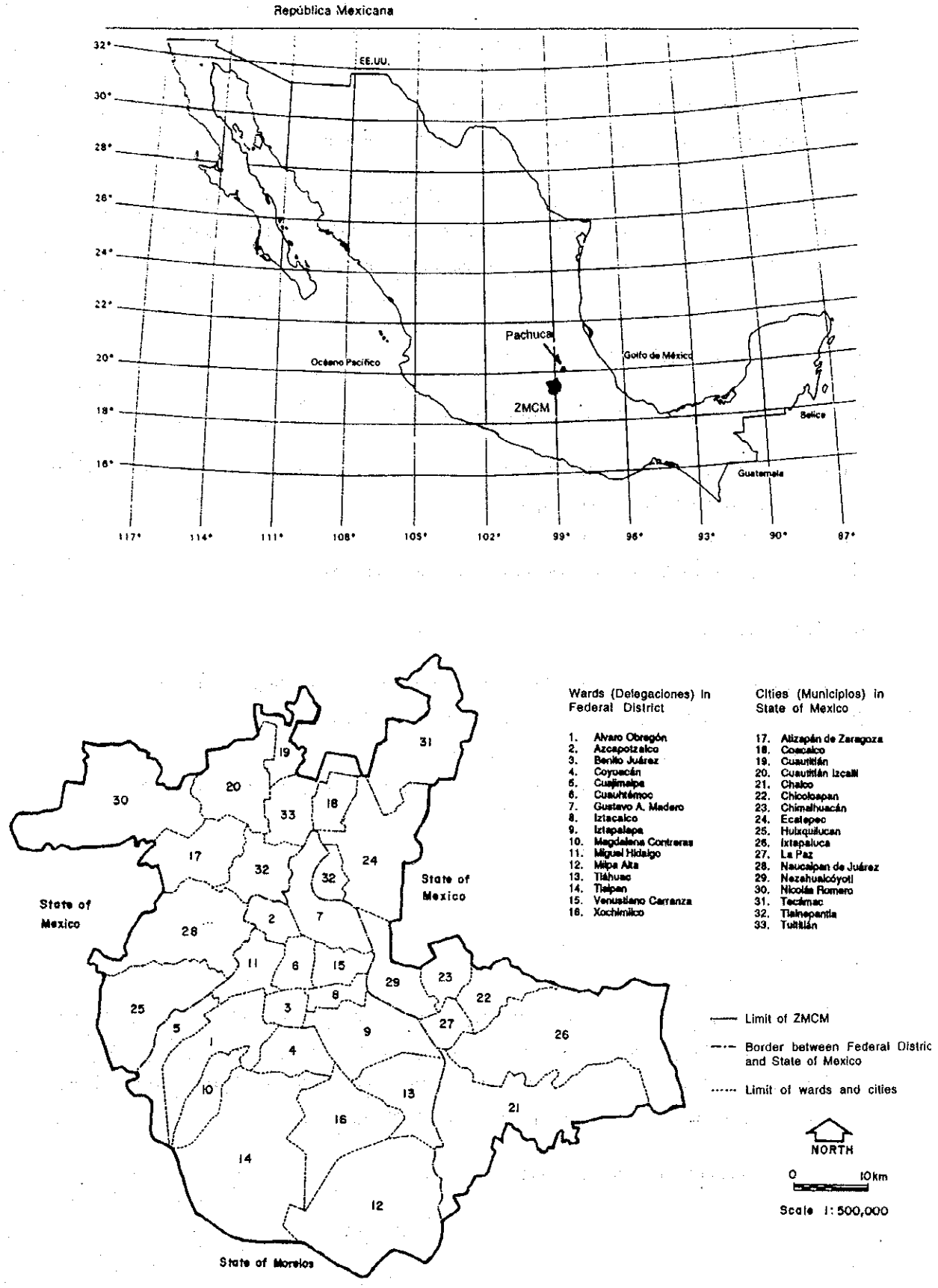


Figure 1.1 Study Area (ZMCM)

(3) Combustion Tests at the Pilot-scale Test Plant

1) Combustion tests of different types of fuels
2) Combustion tests by combustion methods and conditions
3) Transfer of technologies for combustion methods
   a) Demonstration of combustion operation practices in the combustion tests
   b) Dissemination of information on the combustion tests
   c) Preparation of operation manuals for the combustion test plant
4) Analysis of results of the combustion test

(4) Evaluation of Low-NOx Combustion Technologies

1) Cost effectiveness, comparative advantage, and appropriateness of several low-NOx combustion methods and techniques
2) Effectiveness for energy saving
3) Reduction of smoke dust by adequate combustion control

(5) Recommendations

1) Alternative measures for control of NOx emissions from combustion facilities
2) Institutional and legal arrangements for control of NOx emissions
3) Training program for combustion engineers
4) Operation principles for control of NOx emissions in typical combustion facilities

1.5 Execution of the Study

1.5.1 Study Organization

(1) Japanese Organization

The executing agency of Japan is the Japan International Cooperation Agency (JICA), which formulated and supervised the Study in consultation with the Ministry of International Trade and Industry (MITI) and the Ministry of Foreign Affairs (MOFA). JICA selected the Study Team for the execution of the Study.

The members of the Study Team are as follows:

Name	Field in Charge	Company
Dr. Akira Uchida	Team leader	PCI
Mr. Kihachiro Urushibata	Deputy leader / Environmental administration / Capacity development	PCI
Mr. Masao Kanekiyo	Leader of combustion test / Stationary source diagnosis / Energy saving	JEAC
Mr. Masahiko Odake	Combustion test / Combustion control	FES
Mr. Yasumoto Shimada	Combustion test / Combustion control	FES
Mr. Kazuhiro Ito	Combustion test / Combustion equipment	TIW
Mr. Motoji Katsuta	Combustion test / Flue gas measurement	JEAC
Mr. Minoru Hirao	Combustion test / Flue gas measurement	JEAC
Mr. Yoji Hara	Combustion test / Fuel analysis	JEACI
Mr. Kazuma Mizutani	Stationary source diagnosis / Energy saving	PCI
Mr. Takuro Nagai	Stationary source diagnosis / Energy saving	PCI

Note: PCI : Pacific Consultants International Co., Ltd.
JEAC : Japan Environment Assessment Center Co., Ltd.
FES : Furnace E. S. Co., Ltd.
TIW : Takao Iron Works Co., Ltd.
JEACI : Japan Environment Assessment Center International Co., Ltd.

(2) Mexican Organization

The Mexican side organized the Steering Committee and the Technical Committee, and assigned the Counterpart to the JICA Study Team.

1) Steering Committee

The members of the Steering Committee are as follows:

Role	Name	Position
Chairman	Fis. Sergio Reyes Lujan M.C. Julia Carabias Lillo Dr. Gabriel Quadri de la Torre	President, INE
Vice-chairman	Arq. Rene Alamirano Perez Dr. Gabriel Quadri de la Torre	Director General of Environmental Standardization, INE
	Dr. Adrian Fernandez Bremauntz	Director General of Environmental Management and Information, INE
Member	Lic. Fernando Menendez Garza	General Coordinator for Prevention and Control of Pollution, DDF
Member	Lic. Martin R. Gonzalez Hernandez	Director General of Standardization, Reorganization, and Environmental Impact, Secretariat of Ecology, GEM
	Ing. Rogelio Gonzalez Garcia	Director General of Ecological Planning, Secretariat of Ecology, GEM
Member	Dr. Rodolfo Rojas Rubi	Advisor of Sub-secretariat of Energy, SEMIP
Member	Lic. Julio Camelo Martinez	Auditor of Industrial Safety, Environmental Protection, and Energy Saving, PEMEX
Member	Ing. Victor Alcerreca Sanchez	Director General, IMP

Note: When two or more names are indicated with the same role, it means the succession(s) of the member of the committee in that order. The position is that at the time of being the committee member.

2) Technical Committee

The members of the Technical Committee are as follows:

Name	Position
Arq. Rene Altamirano Perez	Director General of Environmental Standardization, INE
Dr. Gabriel Quadri de la Torre	Director General of Environmental Standardization, INE
Dr. Adrian Fernandez Bremauntz	Director General of Environmental Management and Information, INE
Ing. Rodolfo Lacy Tamayo	Director General of Environmental Project, DDF
Ing. Luis Barojas Weber	Advisor of Sub-secretariat of Energy, SEMIP
Ing. Guillermo Andrade Gelabert	Director of Environmental Protection and Energy Saving, PEMEX
Dr. Alberto Jaime Paredes	Director of Environmental Protection, CFE
Ing. Jose Manuel Olivares	Director of Environmental Protection, IPM Director of Environmental Protection and Safety, PEMEX

Note: When two or more names are indicated in one name cell, it means the succession(s) of the member of the committee in that order. The position is that at the time of being the committee member.

3) Counterpart

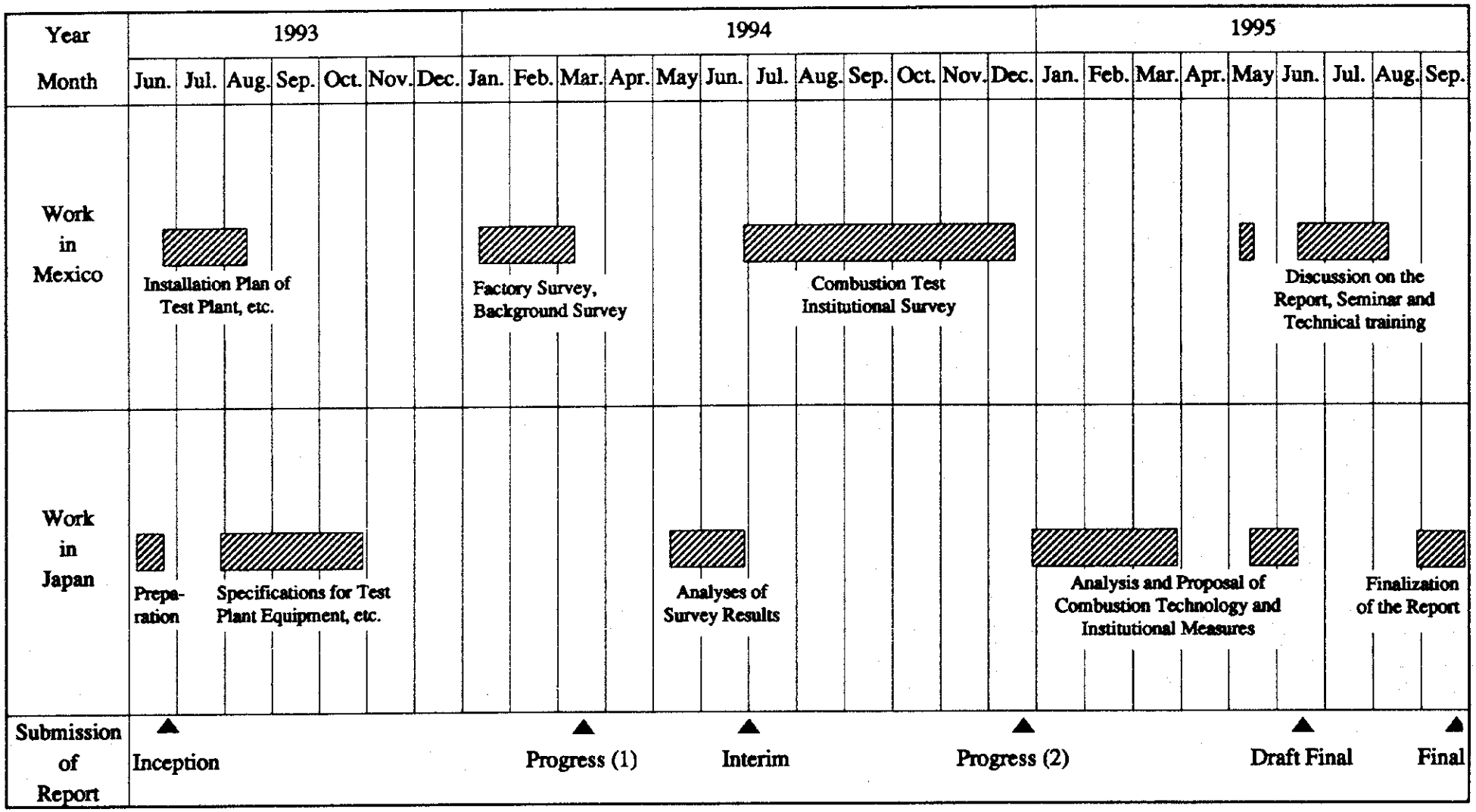
The counterpart members are as follows:

Field in Charge	Name	Agency
Leader	Victor Hugo Paramo Figueroa	INE
	Enrique Campuzano Balbuena	INE
Deputy Leaders	Enrique Campuzano Balbuena	INE
	Sergio Sanchez Martinez	DDF
	Rodolfo Casas Barba	IMP
Stationary Source Survey, Energy Saving, Combustion Equipment and Control	Mariano Montes Gonzalez	INE
	Julia Perez Ramirez	INE
	Martin Salas Martinez	DDF
	Enrique Llamas Torres	DDF
Combustion Test	Fernando Mosqueda	DDF
	Daniel Mejia Bañuelos	GEM
	Tomas Rangel Magos	IMP
	Guillermo Reyes Cepeda	IMP
	Francisco Robles Lopez	IMP
Flue Gas Measurement	Tomas Rangel Magos	IMP
	Guillermo Reyes Cepeda	IMP
	Francisco Robles Lopez	IMP
	Claudia Rivera Villa	IMP
Advisor (JICA Expert)	Yoshihiro Shigeta Ohashi	DDF

1.5.2 Time Schedule for the Study

General time schedule for the Study is shown in Table 1.1.

Table 1.1 General Time Schedule for the Study



CHAPTER 2 OUTLINES AND BACKGROUND OF AIR POLLUTION IN THE METROPOLITAN ZONE OF THE CITY OF MEXICO

Chapter 2 Outlines and Background of Air Pollution in the Metropolitan Zone of the City of Mexico

2.1 Social and Economic Conditions

2.1.1 Population

The population of ZMCM in 1990 was about 15 million, of which about 8.2 million are in DF and about 6.8 million are in MCEM. Of the total population of about 81 million in the United Mexican States, the population of ZMCM accounts for 18.5%. The composition of the population of ZMCM in 1990 by wards (delegaciones) in DF and cities (municipios) in MCEM is shown in Table 2.1.1. During the 10-year period from 1980, the population of ZMCM increased by 20%. While the increase in DF in the same period was only 2.6%, the increase in MCEM was remarkable at 52%.

2.1.2 Economy and Industry

The Gross Domestic Product (GDP) in Mexico at 1980 constant prices increased from 4,825 million new pesos in 1987 to 5,645 million new pesos in 1993. However, the GDP growth rate in the one-year period of 1992 - 1993 was only 0.4%. The trend of the national GDP in the recent years in each economic area is shown in Table 2.1.2 and Figure 2.1.1.

The ZMCM's share in the national GDP in 1980 was as follows (Source: Ref. A10): Agriculture: 0.4%; Manufacturing: 30.8%; Transport: 34.4%, and Service: 50.5%, for the Total: 38.2%.

The above share of the manufacturing sector is said to have decreased to 27% by 1988. In terms of income of the manufacturing sector, the ZMCM's share in the national income in 1998 was 29.3% of which 20% for DF and 9.3% for MCEM. The percentage for ZMCM decreased by 7.2% during the period of 1985 - 1988 (Ref. A2).

In terms of production value, the percentage distribution by types of manufacturing industry in ZMCM in 1988 was as follows: Foods and drinks: 32%; Machinery: 21%; Textile and apparel: 15%; Pulp and paper: 11%; Timber: 7%; Chemicals and petrochemicals: 7%; Cement and ceramics: 3%; Metals: 1%, and Others: 2%.

Table 2.1.1 Population of ZMCM in 1990

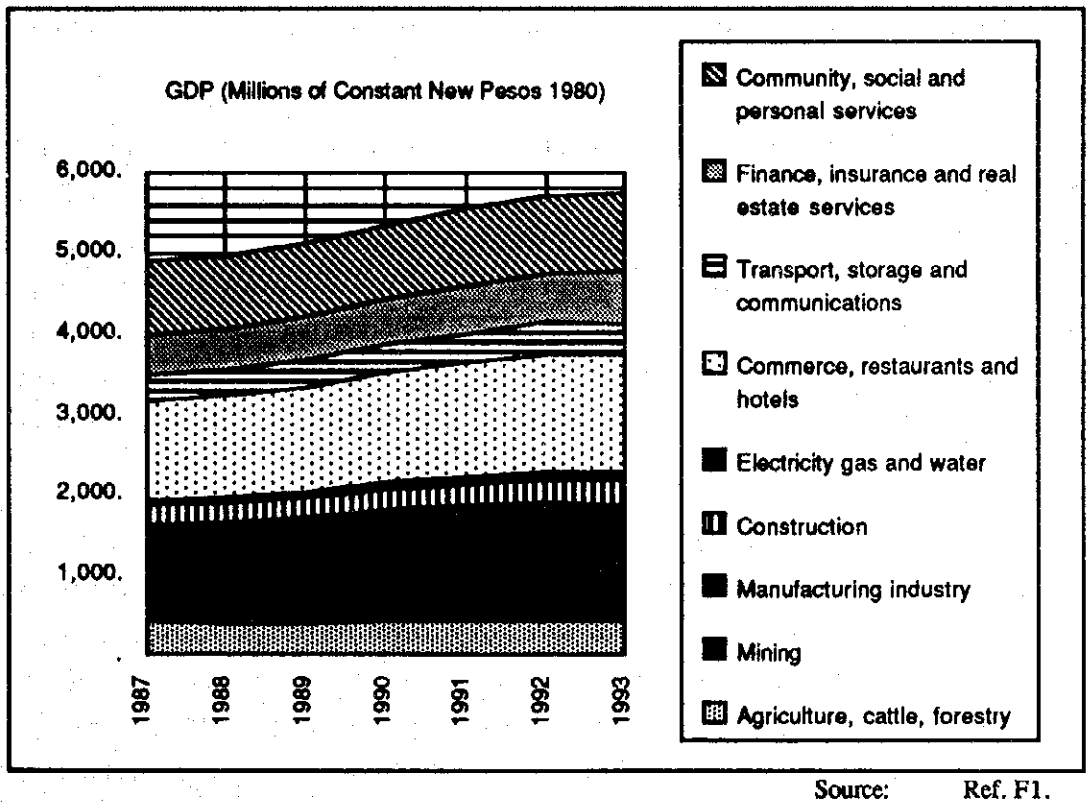
	Wards and Cities	Area	Population	Population density
		(ha)	(inhabitants)	(inhab./km2)
DF	1 ALVARO OBREGON	8,586	643,542	7,495
	2 AZAPOTZALCO	3,451	474,905	13,761
	3 BENITO JUAREZ	2,750	407,731	14,827
	4 COYOACAN	5,540	640,006	11,552
	5 CUAJIMALPA	7,700	119,720	1,555
	6 CUAUHTEMOC	3,309	595,972	18,011
	7 GUSTAVO A. MADERO	8,700	1,268,123	14,576
	8 IZTACALCO	2,306	448,357	19,443
	9 IZTAPALAPA	11,940	1,409,981	12,487
	10 MAGDALENA CONTRERAS	7,004	195,000	2,784
	11 MIGUEL HIDALGO	4,764	406,693	8,537
	12 MILPA ALTA	27,820	63,573	229
	13 TLAHUAC	9,300	206,688	2,222
	14 TLALPAN	31,200	485,043	1,555
	15 VENUSTIANO CARRANZA	3,442	519,606	15,096
	16 XOCHIMILCO	12,740	271,020	2,127
	DF Total	150,552	8,236,960	5,471
MCEM	17 ATIZAPAN DE ZARAGOZA	9,030	353,544	3,915
	18 COACALCO	3,480	170,902	4,911
	19 CUAUTITLAN	15,028	54,811	365
	21 CHALCO	28,820	317,298	1,101
	22 CHICOLOAPAN	6,006	63,849	1,063
	23 CHIMALHUACAN	3,795	270,754	7,134
	24 ECATEPEC	15,482	1,366,634	8,827
	25 HUIXQUILUCAN	14,258	148,008	1,038
	26 IXTAPALUCA	28,834	154,131	535
	27 LA PAZ	3,692	149,553	4,051
	28 NAUCALPAN DE JUAREZ	19,661	881,036	4,481
	29 NEZAHUALCOYOTL	6,240	1,411,812	22,625
	30 NICOLAS REMERO	25,967	206,625	796
	31 TECAMAC	15,541	138,185	889
	32 TLALNEPANTLA	8,505	788,169	9,267
	33 TULTITLAN	6,618	274,781	4,152
	MCEM total	210,957	6,750,091	3,200
ZMCM	ZMCM Total	361,509	14,987,051	4,146

Source: Ref. F4.
Note: The figures for CUAUTITLAN in MECM are the totals of CUAUTITLAN and CUAUTITLAN IZCALLI.

Table 2.1.2 GDP in Mexico (Millions of Constant New Pesos, 1980)

Year	Agri-culture, cattle, forestry, and fishery	Mining	Manufac-turing Industry	Const-ruction	Elect-ricity, gas and water	Comme-rce, resta-urants and hotels	Transport, Storage and Communi cations	Finance, insurance and real estate services	Community, social and personal services	Total
1987	412.2	183.4	1,026.1	246.2	67.0	1,233.9	305.1	523.4	893.8	4,825.4
1988	399.1	184.1	1,059.0	245.2	71.0	1,254.8	312.1	532.0	898.1	4,887.8
1989	387.8	182.9	1,135.1	250.4	76.5	1,302.1	325.1	547.5	911.0	5,049.0
1990	414.0	188.0	1,203.9	267.8	78.7	1,355.1	346.7	568.6	927.8	5,276.7
1991	418.6	189.5	1,252.3	274.3	80.8	1,413.6	367.0	590.4	962.0	5,468.6
1992	412.5	192.9	1,280.7	295.7	83.2	1,464.3	394.9	612.4	968.2	5,619.8
1993	419.9	195.1	1,261.7	304.7	86.5	1,447.0	404.2	642.5	978.6	5,644.7

Source : Ref. F1.



Source: Ref. F1.

Figure 2.1.1 GDP in Mexico (Millions of Constant New Pesos, 1980)

2.2 Energy Situation

2.2.1 Basic National Energy Policy

The energy policy of Mexico can be summarized as described below based on the information provided by SEMIP (Ref. D4):

Mexico is the sixth largest oil producing country, which produces 4.5% of the world's oil. The Mexican Government has been promoting efficient use of energy as one of the first priority policies. The targets of this policy were established considering globalization of the economy and are as follows:

- To satisfy the demand of energy products and related services at the lowest cost
- To upgrade technical and economical efficiencies in the energy sector
- To guarantee optimal stability, quality and safety in supply of energy products and related services
- To secure participation of private persons in generation of energy by means of the new legal provisions.

On this basis, the necessary coordination of tasks is successfully being accomplished by a group formed by principal agencies directly related to the energy sector, as well as the agencies responsible for the regulation of energy and environment and the public enterprises producing fossil fuels and electricity. The main duty of this group is to propose a long term integrated fuel policy of Mexico. The group has identified the policies and investments necessary for satisfying the fuel demand for industries, power generation, and transportation at the lowest cost in consideration of the future requirements of the environmental standards and the criteria of energy utilization efficiency.

The proposal implies a change of the national fuel policy that will bring about a reduction of heavy oil consumption and a significant increase of natural gas consumption instead. Most thermal power plants will produce electric energy by use of natural gas, because of the high efficiency achieved through the combined cycle technology, and the economical advantage of the use of natural gas for compliance with environmental standards. 70% of the existing thermal power plants of CFE located in the "Critical Zones" *1) are encouraged through economical incentive measures to change their fuels to gas. Private companies which intend to install a power plant in the said zone will be also encouraged to use gas through the mechanism of institutional development that facilitates their adoption of advanced, high-efficiency power generation technologies.

*1) Critical Zones:

The following are designated as the critical zones, in the emission standards NOM-CCAT-019-ECOL/1993 (NE), where high concentrations of air pollutants are prevailing:

Metropolitan zones : the Cities of Mexico, Monterrey and Guadalajara.

Population centers : Coatzacoalcos-Minatitlan in Veracruz State, Irapuato-Celaya-Salamanca in Guanajuato State, Tula-Vito Apasco in Hidalgo and Mexico States.

Industrial corridors : Tampico-Madero-Altamira in Tamaulipas State and the north border zone.

The present capacity of electric energy generation is 29 gigawatts (Gw): two-thirds is generated by fossil fuels and remaining one-third is generated by hydraulic, geothermal and nuclear energy. In addition to the present capacity, 27 Gw of electric energy is forecasted to be necessary in 2005; 17 Gw will be provided by thermal power plant with fossil fuels, 4 Gw provided by hydraulic, geothermal or nuclear power plants, and the rest (5 Gw) will be made available by energy saving by means of efficient and optimal use of fuels, reduction of transmission losses, and restraints on demand in the twelve years prior to 2005.

From the legislative point of view, two basic programs have been enacted in order to support the integrated policy on fuel: one is environmental regulations and the other is related to energy efficiency. As a part of the programs, the following standards were put into force in 1994: 1) emission standards were adopted for stationary sources using fossil fuels, and 2) fuel quality standards were established for industry and transportation. Also, efficiency standards for motors, refrigerators, air conditioners, household electric equipment and lighting systems were issued in 1994.

In Yucatan Peninsula, gas is used for both power generation and industrial operations, in conformity with the integrated fuel policy which reflects consideration for the environmental preservation of this specific district that is blessed with abundant tropical nature and historical properties. A series of projects are being planned to realize the policy. These include the construction by PEMEX of a gas pipeline 700 km long, to carry 400 million cubic feet per day, and infrastructure works for changing fuel from heavy oil to gas in eleven power generation units owned by CFE in this region. To complement this series of projects, construction of a thermal power plant with a capacity of 440 megawatts (Mw) consisting of two units of combined cycle power generator is scheduled. This project, named Merida 3, is the first power generation project to be carried out under the framework provided by the newly promulgated Law of Public Service and Electric Energy, which enables the participation of the private sector.

2.2.2 Energy Policy for Environmental Protection

(1) Present Administrative Measures

The Mexican Government has executed various measures in order to protect the atmospheric environment of ZMCM, derived from the basic policy of the Integrated Program Against Atmospheric Pollution (PICCA: Programa Integral Contra la Contaminación Atmosférica, Oct. 1990, Ref. A1).

First of all, heavy oil supply to ZMCM was stopped in December 1991 due to its high content of sulfur. Heavy oil was replaced by natural gas in plants of large-scale energy consumption, and by gasoil or diesel in facilities of small-scale energy consumption, with only one exception, i.e,. a cement manufacturing plant where heavy oil is still used. This measure has reduced emissions of sulfur oxides by almost 100% from the large industries and by 33% from small industries and service establishments.

The sulfur content of diesel oil has also been reduced to less than 0.05% by adoption of a direct desulfurization method. In addition, improvements of gasoline by reduction of lead content and use of oxygen supplying additives have contributed to reduce the lead concentration in the atmosphere enough to satisfy the national air quality standard.

In the public transportation sector, the trucks made during 1980 to 1990 are recommended to be converted to use gas, and this measure has already implemented for more than 18,000 vehicles. This measure aims to cut ozone generated by photochemical reactions through the fact that the activity of exhaust gas from gas-fueled engines is lower than that from oil-fueled engines.

Energy saving, another important subject of energy policy, is mainly promoted by a federal commission called CONAE (Comisión Nacional para el Ahorro de Energía). This commission was originally composed of representatives from the following federal authorities and supporting divisions:

Ministry of Energy, Mines and State Industries (SEMIP)
Ministry of Commerce and Industrial promotion (SECOFI)
Ministry of Treasury and Public Credit (SHCP)
Ministry of Communication and Transport (SECT)
Ministry of Public Education (SEP)
National Institute of Ecology (INE)
Department of Federal District (DDF)
Mexican Petroleum (PEMEX)
Federal Commission of Electricity (CFE)

Among the authorities listed above, SEMIP had held the leading position. After SEMIP was reorganized as the Secretaría de Energía (SE) in December 1994, SE has assumed the same role. Each representative has a responsibility of promoting energy saving in its respective field of concern. CONAE also offers a series of training programs for boiler operators and firemen.

(2) Expected Administrative Measures

In December 1993, the Mexican Government renewed the energy supply plan for the ZMCM in accordance with the progress of the heavy oil desulfurization project financed by the Overseas Economic Cooperation Fund of Japan (OECF), in which a process called "H-oil process" licensed by HRI, Inc. and Texaco Development Corporation is employed (hereinafter referred to as "the H-oil Project"). The new plan proposes to supply hydro-desulfurized heavy oil (H-oil) from 1998 in place of the gasoil used at the present.

The H-oil Project will provide a target output of 36,000 BPD of H-oil which suffices for the total demand of gasoil and heavy oil in ZMCM, that is estimated at about 20,000 BPD at present, while the input to the process is 50,000 BPD of residual oil. According to a letter from PEMEX, the sulfur content of H-oil is decreased to 0.8% or less from 4.7% of the input oil, and the nitrogen content is reduced from about 0.7% to 0.37% (see Table 2.2.1).

Table 2.2.1 Planned Characteristics of H-oil

	Input oil	H-oil
Sulfur content	4.71%	0.8% max.
Nitrogen content	6,969 ppm	3,660 ppm
Metal content	707 ppm	180 ppm
Viscosity at 50 °C	-	500 SFS
Specific weight	-	0.973

Source: PEMEX's letter to the Study Team dated February 4, 1994 and its attachment

Some characteristics of fuel oils used in stationary sources in ZMCM at the present and in the past are shown in Table 2.2.2.

Supply of H-oil in place of the presently used gasoil is expected to contribute to the reduction of sulfur oxides emissions. However, there is a fear that the emission of nitrogen oxides will be increased far above the level of the present because the nitrogen content of H-oil is expected to be higher than that of the gasoil by about 5 times as shown in Tables 2.2.1 and 2.2.2.

Table 2.2.2 Characteristics of Fuel Oils Used at the Present and in the Past in ZMCM

	Heavy oil (heavy)	Heavy oil (special light)	Gasoil
Sulfur content	4%	3%	2%
Nitrogen content	4,000 ppm	2,000 ppm	670 - 840 ppm
Vanadium content	340 ppm	290 ppm	0.6 - 0.9 ppm
Viscosity at 50 °C	550 SFS	55 SFS	-
Specific weight	0.997	0.951	0.89 - 0.90

Reference data for yield and product of the H-oil process are shown in Data Book.

2.2.3 Energy Production, Supply and Consumption

(1) National Energy Balance

Table 2.2.3 summarizes production and supply of primary energy in Mexico in 1992 based on "National Balance of Energy 1992" (Ref. D1).

The total production of primary energy was about 2,120 peta-calorie (10^{15} calorie) or 1.4×10^9 barrel of crude oil equivalent (BOE). Export of energy, that consists mostly of crude oil, was 756 peta-cal (0.5×10^9 BOE) which is about 36% of the total production.

Table 2.2.3 Production and Supply of Primary Energy in Mexico in 1992

Primary Energy	Production (10^{15}cal)	Export (10^{15}cal)	Loss (10^{15}cal)	Domestic Supply (10^{15}cal)	Share in Domestic Supply (%)
Coal	**35**	**0**	**0**	**35**	**2.6**
Hydrocarbon	**1,908**	**756**	**43**	**1,109**	**83.7**
Crude oil	1,470	756	0	714	53.9
Condensed gas	67	0	31	36	2.7
Natural gas	371	0	12	359	27.1
Electricity	**91**	**0**	**0**	**91**	**6.8**
Nuclear	10	0	0	10	0.7
Geothermal	15	0	0	15	1.1
Hydraulic	66	0	0	66	5.0
Biomass	**92**	**0**	**1**	**91**	**6.9**
Waste pulp of cane	20	0	1	19	1.5
Firewood	72	0	0	72	5.4
Total	**2,120**	**756**	**44**	**1,325**	**100**

Source: Ref. D1.

The gross domestic supply of the primary energy was 1,325 peta-cal (0.9×10^9 BOE), comprising 62% of the total production, and which was sent to refineries, gas plants, fractionating plants, coke plants and power plants. Among these energy transforming facilities, power plants received 110 peta-cal of primary energy (coal, nuclear, geothermal and hydraulic energy) and 197 peta-cal of secondary energy (natural gas and heavy oil) making a total of 307 peta-cal which corresponds to 23% of the total supply of primary energy.

Final consumption of energy and its equivalent in 1992 was 970 peta-cal (645 million BOE) as shown in Table 2.2.4. This amount corresponds to 73% of the gross domestic supply and 46% of the total production of the primary energy.

Table 2.2.4 Final Consumption of Energy by Type and Sector (1992)

Unit : Million BOE

Energy Type	Energy Consumption			Non-energy Consumption	Total	Share (%)
	Industry	Residential, Commercial, Public Utility	Transport and Agriculture			
Gasoline	0.0	0.0	152.7	10.2	**162.9**	25.3
Diesel	11.8	0.3	69.8	0.0	**81.9**	12.7
Kerosene	0.3	1.3	14.6	0.0	**16.2**	2.5
LPG	2.9	52.5	3.1	0.0	**58.5**	9.1
Heavy oil	42.9	5.4	0.4	0.0	**48.7**	7.5
Electricity	30.2	21.8	3.7	0.0	**55.7**	8.6
Coke	9.4	0.0	0.0	0.2	**9.6**	1.5
Waste pulp of cane	11.1	0.0	0.0	1.7	**12.8**	2.0
Materials for process	0.0	0.0	0.0	40.6	**40.6**	6.3
Natural gas	86.2	6.6	0.0	17.2	**110.0**	17.1
Firewood	0.0	47.6	0.0	0.0	**47.6**	7.4
Total	**194.8**	**135.5**	**244.3**	**69.9**	**644.6**	**100**
Share (%)	30.2	21.0	37.9	10.9	100	

Source: Ref. D1.

Stationary sources of air pollutant emission consist of industry and residences, and commercial and public utilities. They consume approximately a half of the total energy supplied for final consumption. Major energy sources for industry are natural gas, heavy oil and electricity, while that for residential, commercial and public utilities use are LPG, firewood and electricity.

(2) Fuel Consumption in ZMCM

The total consumption of fuels in ZMCM during the one-year period from April 1993 to March 1994 was 320.465 peta-calorie (320 x 10^{15} calorie). The daily average consumption of fuels in heat equivalent of gasoline in this period was 43.8 million liters. Consumption by sectors were as follows:

	1992/1993*1)	1993/1994*2)
Transportation	56.1%	56.2%
Industry and services	26.4%	24.6%
Domestic consumption	10.8%	10.4%
Thermal power plants	6.6%	8.8%
Daily average consumption (10^6 liter)*3)	42.7	43.8

Note: *1) From August 1992 to September 1993 (Ref. A8)
*2) From April 1993 to March 1994 (Ref. A7)
*3) Equivalent of gasoline Nova

Consumption by kinds of fuel in the same periods were as follows:

	1992/1993	1993/1994
Gasoline (Nova)	29.7%	27.7%
Gasoline (Magna Sin)	12.2%	14.0%
LPG	20.3%	19.5%
Diesel (Diesel Sin)	-	5.3%
Diesel (Normal)	12.4%	7.1%
Natural gas	22.0%	23.9%
Gasoil	3.4%	2.5%

As shown above, consumption in ZMCM gradually shifted to better quality fuels: the ratio of unleaded gasoline (Magna Sin) is increasing, supply of low-sulfur diesel (Diesel Sin, S = 0.05%) began in October 1993 resulting in the decrease of supply of normal diesel (S = 0.1%), and the ratio of natural gas is increasing.

As for industries, the daily average consumption of fuels was 11.29 million liters in gasoline equivalent during the period from August 1992 to September 1993. By kind of fuel, consumption was as follows (Ref. A8):

Natural gas	55.6%
LPG	26.9%
Gasoil	12.8%
Diesel	4.7%

2.3 Present State of Air Pollution in ZMCM

2.3.1 Ambient Air Quality Standards

The ambient air quality standards in Mexico are shown in Table 2.3.1.

Table 2.3.1 Ambient Air Quality Standards in Mexico

Pollutant	Averaging time (hr)	Concentration
Sulfur dioxide (SO_2)	24	0.13 ppm
Nitrogen dioxide (NO_2)	1	0.21 ppm
Total suspended particulates (TSP)	24	275 $\mu g/m^3$
Carbon monoxide (CO)	8	13 ppm
Ozone (O_3)	1	0.11 ppm

To help general citizens to understand the degree of air pollution, an index called IMECA (Indice Metropolitano de la Calidad del Aire: Metropolitan Index of Air Quality) is used in Mexico. Conversion of ambient concentration of each pollutant to IMECA is made as follows:

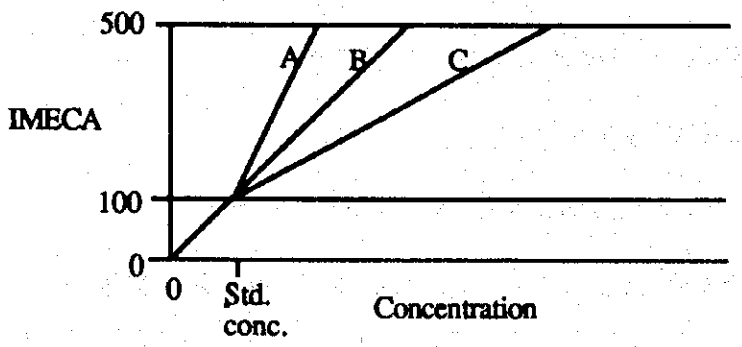
1) The ambient air quality standard value shown in Table 2.3.1 is set as IMECA 100, and concentration zero is IMECA zero.

2) The concentration limit beyond which there is a potential hazard to everyone is set as IMECA 500. This concentration is determined for each pollutant as follows:

   SO_2: 1.00 ppm NO_2: 2.00 ppm TSP: 1,000 $\mu g/m^3$
   CO: 50 ppm O_3: 0.6 ppm

3) Actual concentration values are converted to IMECA values by linear interpolation of the above three points.

The concentration - IMECA curve for each pollutant belongs to one of three types shown in the following figure. The curve for O_3 is of the type B in which the increase of IMECA value is almost proportional to the increase in concentration throughout the definition range of IMECA 0 - 500. The curves for TSP and CO are of the type A in which the rate of increase of IMECA value in the range 100 - 500 is higher than that of the concentration, and the curves for SO_2 and NO_2 are of the type C which is contrary to the type A.



The present ambient air quality standards shown in Table 2.3.1 are now being reviewed. A draft of new standards was proposed by the Ministry of Health (SES) and announced in the daily official gazette dated January 18, 1994 (Ref. C7). It is shown in Data Book. Major changes from the present standards are as follows:

1) Standards for PM10 (suspended particulate matter with diameters smaller than 10 μm) and lead are newly introduced. Limit values for the former are given as 24-hour and 1-year averages, and that for the latter is given as a 3-month average.

2) 1-year average value is specified for SO_2 and TSP in addition to the present 24-hour average value. A lower 24-hour average value is specified for TSP as compared to the present one.

2.3.2 Air Quality Monitoring Network in ZMCM

The ambient air monitoring network in ZMCM is composed of the automatic measuring stations and the manual measuring stations. These stations are operated by DDF, EDOMEX and INE, and the measurements are gathered and analyzed by INE everyday. Forecasts of IMECA values are publicly announced every day based on the analysis of the measured pollutant concentrations and meteorological conditions. The numbers of monitoring stations by measuring parameters are shown in Table 2.3.2.

Table 2.3.2 Number of Monitoring Stations in ZMCM

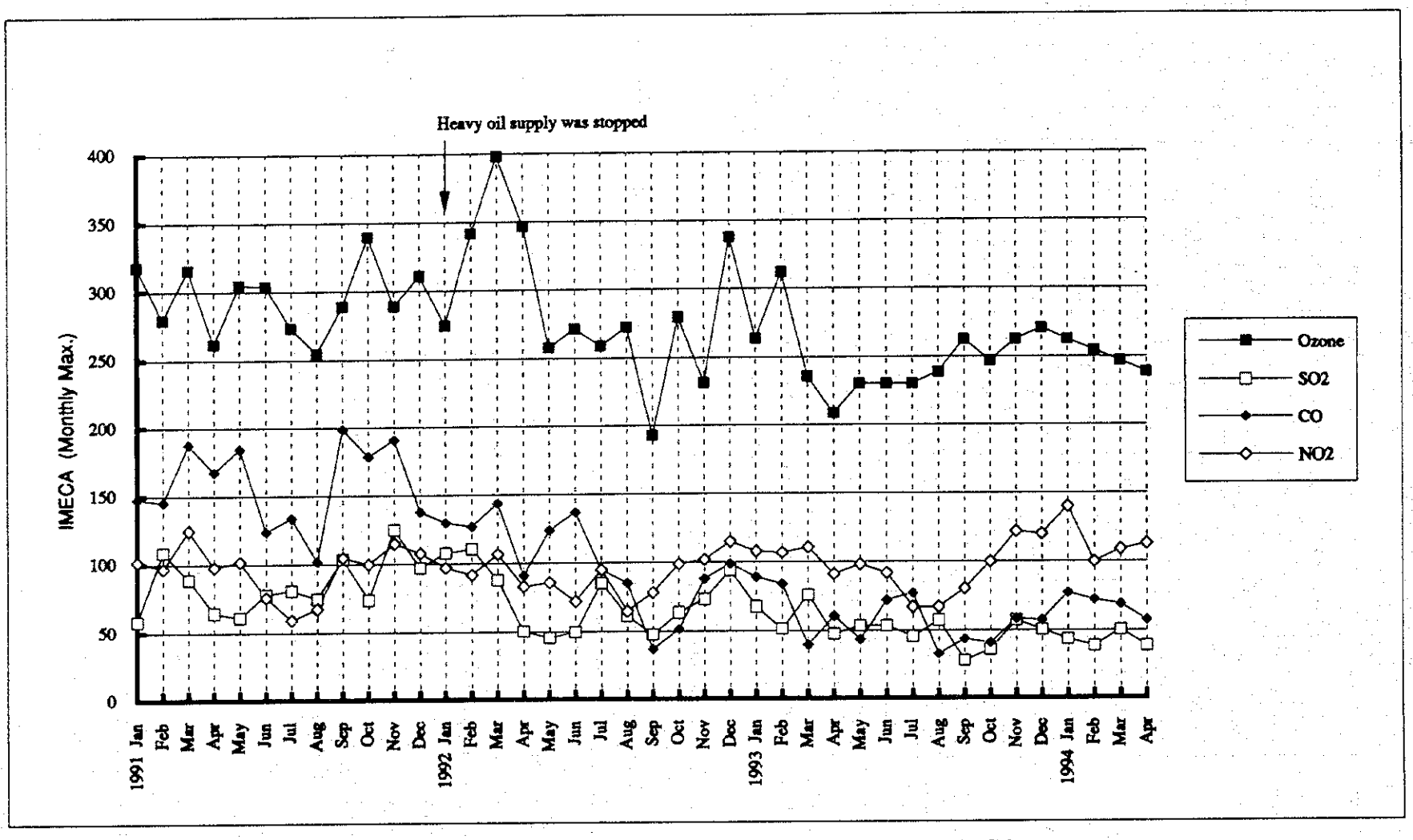
Type	District	Parameter									
		O3	CO	SO2	Met.	NO2	NOx	PM10	HC	TSP	Pb
Auto-matic	Northwest	4	7	7	3	5	5	2	1	0	0
	Northeast	3	4	8	2	3	3	3	0	0	0
	Central	4	5	2	2	3	3	1	1	0	0
	Southwest	4	2	2	2	1	1	1	1	0	0
	Southeast	4	3	2	1	1	1	2	0	0	0
	Total	19	21	21	10	13	13	9	3	0	0
Manual	Northwest	0	0	0	0	0	0	1	0	2	1
	Northeast	0	0	0	0	0	0	1	0	5	3
	Central	0	0	0	0	0	0	1	0	4	2
	Southwest	0	0	0	0	0	0	1	0	4	3
	Southeast	0	0	0	0	0	0	1	0	4	1
	Total	0	0	0	0	0	0	5	0	19	10

Source: Ref. C2.
Note: Met.: wind speed, wind direction, temperature and relative humidity
PM10: Suspended particulate matter of diameters less than 10 μm.

2.3.3 Trend of Ambient Air Quality in ZMCM

Monthly maximum concentrations of O_3, SO_2, CO and NO_2 in ZMCM since 1991 expressed in IMECA are shown in Figure 2.3.1.

In 1992, heavy oil supply to factories (except the cement plant) in ZMCM was terminated and replaced by natural gas and gasoil, and compulsory installation of a catalytic converter in each new model vehicles was started. Implementation of these measures seems to have had positive effects. Monthly maximum IMECA values of CO and SO_2 apparently decreased: they were, for example, roughly around the level of 50 in 1993. However, there is no significant improvement with ozone; its level still fluctuating around 250 since 1993. NO_2 also has not been improved; the IMECA level is fluctuating around 100.



Source: Refs. C2, C6.

Figure 2.3.1 Ambient Air Quality in ZMCM Expressed by IMECA (January 1991 - April 1994)

2.4 Institutional Framework for Air Pollution Control

2.4.1 Government Organization

The Mexican Government has placed a great emphasis on environmental protection, as national policy. While this policy is justified by the continuing problem of the air pollution in ZMCM, it has been adopted also in relation to the internationally-agreed concept of "sustainable development."

To solve the problems of air pollution in ZMCM, a special commission named the Metropolitan Commission for Prevention and Control of Environmental Pollution in the Mexico Valley (hereinafter called "the Commission" or "METROCOM") was organized. The Commission was originally composed of the representatives of the following governmental authorities:

SHCP	PEMEX
SEMIP (now SE)	SECOFI
SECT	SEP
SEDUE (now INE)	SEG
SES	IMP
DDF	CFE
GEM	

The Commission had been chaired by the General Coordinator for Prevention and Control of Pollution of DDF until April 1994 when the Sub-secretary of GEM succeeded to the position.

In October 1990, the Commission formulated and published a comprehensive air pollution control program for ZMCM called PICCA as mentioned in Section 2.2.2. PICCA, consisting of permanent, temporary and seasonal measures, has been implemented by various organizations of the federal, the state, and the municipal governments. PICCA was formulated through the minute studies on the environmental situation in ZMCM in consultation with Mexican scientists and engineers, and foreign specialists having sufficient experience in solution of urban pollution problems dispatched from such countries as Japan, the USA, Germany, France and the UK.

INE is the primary responsible organization with respect to environmental protection at the national level. Responsibilities of INE had been assumed by the Ministry of Urban Development and Ecology (SEDUE) until SEDUE was reorganized into SEDESOL and its affiliated organizations, i.e., INE and PROFEPA. Later on, INE and PROFEPA were transferred to a newly established Ministry of Environment, Natural Resources and Fishery (SEMARNAP) through the reorganization of the central government in late 1994. The duty