1990 TDRI Year-End Conference on
Industrializing Thailand and Its Impact on the Environment

Energy and Environment: Choosing the Right Mix

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INDUSTRIALIZING THAILAND AND ITS IMPACT ON THE ENVIRONMENT

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Research Report No. 7

Energy and Environment: Choosing the Right Mix

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Policy research is a team effort. The names of researchers mobilized to undertake the various studies in preparation for the 1990 TDRI Year-End Conference and their respective topics of responsibility are listed below:

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Contents

Abbreviations

CaCO3	Calcium Carbonate
CFC	Chlorofluorocarbon
CH4	Methane
CNG	Compressed Natural Gas
CO	Carbon Monoxide
CO2	Carbon Dioxide
EDB	Ethylene Dibromide
EDC	Ethylene Dichloride
H2O	Water
H2S	Hydrogen Sulfide
H2SO4	Sulfuric Acid
HC	Hydrocarbon
HNO3	Nitric Acid
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
N2O	Nitrous Oxides
NMHC	Non-methane Hydrocarbon
NO2	Nitrogen Dioxide
NOx	Nitrogen Oxide
O2	Oxygen
Pb	Lead
pH	Degree of Acidity or Alkalinity
SO2	Sulfur Dioxide
SO3	Sulfur Trioxide
SOx	Sulfur Oxides
SPM	Suspended Particulate Matter
TEL	Tetraethyl Lead

Weights and Measures

BDOE	barrel per day of crude oil equivalent
Btu	British thermal unit
cal	calories
cu.m.	cubic meter
g.	gram
GJ	giga joules
hr	hour
km	kilometer
kmh	kilometer per hour
KTOE	kilo ton of crude oil equivalent
kwh	kilowatt-hour
l	liter
lbs	pounds
m2	square meter
m3	cubic meter
mg	milligram
mmBtu	million British thermal unit

MMTOE	million ton of crude oil equivalent
MW	megawatt
ppm	part per million
TOE	ton of crude oil equivalent

Acronyms and Other Abbreviations

ADB	Asian Development Bank
AFBC	Atmospheric Fluidized Bed Combustion
AIT	Asian Institute of Technology
API	American Petroleum Institute
BMA	Bangkok Metropolitan Area
BMR	Bangkok Metropolitan Region
CBD	Central Business District
CEC	Cation Exchange Capacity
DLT	Department of Land Transport
ECC	European Economic Community
EGAT	Electricity Generating Authority of Thailand
EPRI	Electrical Power Research Institute
ESP	Electrostatic Precipitation
FGD	Flue Gas Desulfurization
GDP	Gross Domestic Product
GNP	Gross National Product
IAPCS	Integrated Air Pollution Control System
IEA	International Energy Agency
IGCC	Integrated Gasification Combined Cycle
IPCC	Integovernment Panel on Climate Change
IPSEP	International Project for Sustainable Energy Paths
JICA	Japan International Cooperation Agency
NAPAP	National Acid Precipitation Assessment Program
NEA	National Energy Administration
(O)NEB	(Office of the) National Environmental Board
(O)NEPO	(Office of the) National Energy Policy Office
(O)NESDB	(Office of the) National Economic and Social Development Board
OECD	Organization for Economic Cooperation and Development
PAH	Poly Aromatic Hydrocarbon
PDP	EGAT'S Power Development Plan
PFBC	Pressurized Fluidized Bed Combustion
PIC	Particles of Incomplete Combustion
PL	Police Department
PM	Particulate Matter
PRI	A Process Emissions Multiplier
PTT	Petroleum Authority of Thailand
REN	Reference Energy Network
SAE	Society of Automotive Engineers
SCR	Selective Catalytic Reduction
SPURT	Seventh Plan Urban and Regional Transport
TDRI	Thailand Development Research Institute
UNEP	United Nation of Environmental Program
U.S.EPA	United States Environmental Protection Agency
VOC	Volatile Organic Compound
WARA	The Workshop on Acid-Rain in Asia
WHO	World Health Organization

Acknowledgements

By most accounts, energy is regarded as a versatile product that fuels our vehicles so we can go about our business. It lights our houses and drives machinaries that produce goods. Energy is thus a necessity, without which economic prosperity is unattainable. However, the use of energy without appropriate control measures will produce toxic emissions like lead that pollute the air, and acid aerosols like sulfur dioxide that damage our environment.

While the impact of energy consumption on the environment has been extensively researched in most industrialized countries, the studies in this area in Thailand have just recently begun. We hope that our study will make useful contributions towards our understanding of this important subject.

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Part I

Introduction

Chapter 1

Introduction

ENERGY/ENVIRONMENT PROBLEMS

Environmental problems associated with energy use span a growing spectrum of pollutants, hazards and accidents, and degradation of environmental quality and natural ecosystems. Over the past few decades, the continuously increasing use of energy has expanded our concerns from what were once primarily local or regional issues, to a growing awareness of the international and global nature of major energy-related environmental problems. Particularly in developing or newly industrialized countries, where energy growth rates are typically extremely high and where environmental management has not yet been fully incorporated into the infrastructure, emerging environmental problems are becoming apparent. In some cases these are worsening chronic problems, but in many cases they represent acute or severe situations.

Thailand is no exception to the above trend, in fact it is somewhat of an extreme case because of its very high rate of economic development and associated rates of energy production and consumption. In a simplified conceptual sense, we might visualize environmental impacts of energy as being proportional to energy consumption, i.e., increasing linearly in relation to energy use. However, compounding this are several other complexities of the energy/environment interface which can lead to greater aggregate impact.

First, population in Thailand continues to grow and urbanize rapidly, with a steady concentration in the Bangkok Metropolitan Region (BMR). This results in higher densities of energy consumption in Bangkok and other specific regions, leading to a spatial concentration of the factors causing environmental degradation.

Secondly, as industrialization and energy use reach higher levels, there are increasing chances for exceeding the damage threshold, above which natural ecosystems and/or human health show lasting, potentially irreversible negative effects.

A third important factor is the increasing interrelationship of one country's environment, natural resources, and energy/industrial systems with those of its regional neighbors and with those of the world as a whole.

On a regional basis, it is becoming apparent in Asia that there is potential for energy-related acid deposition to cause significant damage. This results primarily from the very large increases in public and private fossil fuel power generation (mainly coal/lignite) planned in the region, combined with the current absence of strong policy measures for mitigating the impacts of fossil fuel combustion. The long-term implications of acidification touch not only the natural environment but also important economic activities such as forestry, agriculture, and tourism.

On a global basis, rapidly emerging recognition of the global warming problem associated with the emission of greenhouse gases is perhaps the ultimate example of a complex energy/environment interface. Only with improved worldwide scientific information gathering and analytic capability has the problem been identified and characterized. Although Thailand may well be only a minor contributor to the total global emission of greenhouse gases, there is a potential for it to be strongly impacted by both the environmental effects and by whatever international agreements or management policies are developed in the coming decade.

Because of the accelerating pace of these problems and their recognition by the public as well as the scientific world, Thai policy makers will be more frequently faced with the challenge of anticipating future environmental degradation. They will not only be required to intervene to mitigate existing environmental impacts, but also to take actions to avoid future impacts through preventive rather than curative measures. This will require policy foresight incorporating considerable scientific uncertainty and involving potentially significant public/private cost. An investment to avoid much of that degradation, however, will show long-term returns.

SPECIFIC ISSUES IN THAILAND

One of the main purposes of this paper is to describe and discuss the environmental consequences of alternative energy strategies for Thailand, and to address some of the policy implications associated with them. Toward that end, given the extent and diversity of the potential impacts, it is necessary to select a priority group of issues for treatment in this paper. The criteria for doing so relate to our quite subjective judgement of the evidence concerning the seriousness of the impact, the potential amenability of the problem to solution through intervention, the direct relevance to policy development for the National Plan, and our perception of the urgency to address the issue.

On this basis we have chosen to address the following environmental management issues in depth, while also summarizing or commenting more briefly on several other issues which we have judged less urgent or beyond the scope of our present work.

The three issues which will be discussed at length are:

1. Air pollution impacts and management policies for Thailand's urban energy/environment systems. (Part III)
2. The acid rain problem in Thailand and its relationship to the Asian Region. (Part IV)
3. Global climate change due to greenhouse gas emissions and its implications for Thailand's future energy systems. (Part V)

Each of these themes is quite comprehensive in nature and a portion of each analysis involves a broad-based examination of both the demand and supply components of Thailand's energy systems. To conduct this analysis, it is necessary to develop a description of Thailand's current and future energy systems (Part II), and from that picture, to examine and evaluate future impacts and the options/policies to mitigate them if appropriate. Conclusions and policy recommendations are provided in Part VI.

Chapter 2

Energy Consumption in Thailand

Primary commercial energy demand in 1990 was 29,750 Kilotons of Crude Oil Equivalent (KTOE), of which 12,517 KTOE was supplied from indigenous sources. The main source of domestic energy supply was natural gas (NG) followed by lignite, crude oil, hydroelectricity, and condensate. Together they supplied 40 percent of the 1990 demand. The remaining 60 percent of demand was satisfied by imports and stock draw downs (see table 2-1).

Of the 18,545 KTOE of energy imported in 1990, 98 percent was in the form of petroleum consisting of 10,127 KTOE of crude oil and 8,168 KTOE of oil products. The remainder consisted of coal and a small amount of electricity from Laos and Malaysia.

Although the share of imports in the total primary commercial energy demand decreased significantly from 88 percent in 1981 to 60 percent in 1990, the amount of imported energy remains substantial. Furthermore, as petroleum continues to dominate energy imports, the Thai economy will continue to be vulnerable to any future world oil price shocks.

As a result of the urbanization and industrialization of the Thai economy, particularly during the 1980s, the demand for modern forms of energy has been growing at a rate exceeding that of the Gross Domestic Product (GDP). Thus, the average real GDP elasticity of demand for primary commercial energy was 1.23 during the first half of the 1980s. The value of elasticity has continued to be greater than one since 1985 and is expected to remain so for the near future. Correspondingly, the value of primary commercial energy intensity also rose from 39 TOE per million baht of GDP in 1982 to 45 TOE per million baht at present.

The increased energy intensity resulted from the expansion of the power and manufacturing sectors. In 1980, oil was the main source of energy that fueled power plants and factories in Thailand. However, the discovery of significant natural gas and lignite reserves coupled with the world oil price shocks led the government to launch a policy of imported oil substitution that induced natural gas and lignite consumption to grow from 769 KTOE in 1981 to 8,697 KTOE in 1990. New power plants were fired by natural gas or lignite and major energy consuming industries, such as cement, adjusted their heating equipment to use natural gas or lignite. The resulting growth of natural gas and lignite utilization led to an increase of natural gas and solid fuels energy intensity from 1.0 and 1.5 TOE per million baht of GDP in 1981 to 9.5 and 6 TOE per million baht in 1989 respectively. At the same time, oil intensity gradually decreased from 34 TOE per million baht in 1981 to 26 TOE per million baht in 1985, but rose again 34 TOE per million baht in 1989.

FUTURE ENERGY CONSUMPTION

Despite a looming crisis in the Middle East and world economic slowdown, Thailand's economy is expected to grow at a moderate to strong average rate of 7 percent to 8 percent per year during the Seventh Plan (according to recent National Economic and Social Development Board (NESDB) projections). However, we cannot rule out the possibility that the Gulf crisis may be resolved peacefully in the near future, and that the country's economy may be back on the high growth path that had been forecast before the crisis began.

Under either of the above scenarios, it is expected that energy consumption in Thailand will continue to grow at a relatively strong rate during the Seventh Plan. The results of our projections show that the average growth rate of primary commercial energy consumption during 1991-1996 is expected to be 7.7 percent per year. The expected rate will be somewhat lower than the 14.5 percent average rate experienced during the Sixth Plan. In the longer term, the average growth rate of energy demand will fall to 6.3 percent during the Eighth Plan until 2011 (see table 2-2).

Due to domestic supply limitations, both natural gas and hydroelectricity consumption growth will be stagnant. However, consumption of lignite and coal is expected to grow strongly during the period. Most of the demand for solid fuels will come from the Electricity Generating Authority of Thailand (EGAT), where most future power generation will be lignite/coal fired. Lignite/coal demand will grow from 4,093 KTOE in 1991 to 13,021 KTOE by the end of the century and to 44,591 KTOE by 2011.

The share of lignite/coal in total primary energy demand will increase from 13 percent in 1991 to 28 percent by 2011.

As for petroleum, its share in primary energy demand will slightly decrease from 66.7 percent in 1991 to 63 percent by 2001. However, despite the accelerated demand for lignite/coal after 2000, the share of petroleum in total primary energy will fall further to 54 percent by 2011. The average petroleum demand growth is expected to be 7.8 percent during the Seventh Plan and will gradually fall to a 5 percent average during the Eighth Plan.

It is evident that the country will become increasingly dependent on high-carbon and high-sulfur fuels such as lignite and petroleum. Consequently, `clear' fuels like natural gas will have declining shares (see figure 2-1). This structure of energy consumption could pose a serious air pollution problem in Thailand in the coming years, since the use of such high-sulfur, high-carbon fuels lead to increased sulfur dioxide (SO_2), carbon dioxide (CO_2), carbon monoxide (CO), and other emissions.

As for total final energy demand, petroleum will continue to dominate final consumption well into the future. The current share of petroleum is 59 percent, which will increase to 66 percent by 2011. Electricity demand also shows strong growth during the period. Its share in final demand will grow from 10 percent to 19.5 percent by the year 2011. On the other hand, the use of lignite, coal, and natural gas is relatively small. Their combined share in 1988 was 3.7 percent, expected to grow slightly to 8 percent in 2011 (see table 2-3). The share of natural gas is 1.2 percent in 1991 whereas the share of lignite and coal is 5 percent. The future shares of natural gas and lignite/coal will continue to be small.

The use of renewable energy (fuelwood, charcoal,etc.) will be declining in absolute terms. It is expected that fuelwood and charcoal will become increasingly scarce due to the depletion of forest areas. Furthermore, there will be a continued penetration of commercial fuels, like Liquefied Petroleum Gas (LPG) and electricity, into rural areas which will replace the use of renewable energy.

The analyses of final commercial fuel consumption by sector reveal that Thailand has a relatively high share of transportation energy demand (table 2-4), compared to most other countries in the region. The 1989 share of the transportation sector in total final energy demand was 56 percent, having been 46 percent in 1973. According to

Asian Development Bank (ADB) statistics, Thailand's transportation share was the highest among the 13 Asian nations including Korea (15 percent), Taiwan (16 percent), Malaysia (36 percent), and Indonesia (30 percent).

Our analysis of Thailand's transportation sector shows that energy has been heavily used in "personal" passenger transport. The share of fuel use in private passenger cars, motorcycles taxies, and pick-ups is 49 percent of the total final energy demand, whereas fuel consumption in mass transit, such as buses, accounts for only 14 percent of the total. The freight sector is dominated by trucks, which account for 20 percent of final energy demand, while the mass transport modes, i.e., rail and cargo ships, demand only 2 percent and 6 percent, respectively. Heavy use of "personal" transport modes results in high energy demand for transportation since energy is used inefficiently.

On the other hand, the share of industry in final energy demand is only 24 percent at present. Our study indicates, however, that demand in the industrial sector will be growing at a relatively rapid rate. This is due to the high investment in industrial plants around Bangkok and the Eastern Seaboard during the past few years which will soon begin production. It is also expected that high investment in the industrial sector will continue in the future, resulting in an even higher growth of energy demand. The share of industry in final energy demand is expected to reach 30 percent by 2011, whereas the share of the transportation sector will gradually decline to 50 percent during the period.

Table 2-1 Primary Commercial Energy Demand and Supply

(Unit: KTOE)

	KTOE		Growth Rate (%aai)	
	1981	1990	1981-1990	1988-89
Demand				
Petroleum	10985	19603	6.65	24.83
Natural Gas	265	5381	39.76	0.16
Lignite	504	3316	23.28	21.82
Imported Coal	40	196	19.35	-6.67
Hydroelectricity	724	1254	6.30	48.98
Total Demand	12517	29750	10.10	19.26
Supply				
Domestic Production				
Crude Oil	15	1176	62.39	4.92
Condensate (Incl. export)	60	847	34.22	2.94
Natural Gas	265	5381	39.76	0.16
Lignite	459	3445	25.10	28.29
Hydroelectricity	659	1200	6.89	48.91
Import				
Crude Oil	8205	10127	2.37	31.47
Oil Products	2705	8168	13.07	18.96
Coal	40	196	19.35	-6.67
Electricity	65	54	-2.04	50.68
Export				
Condensate	0	-695	-	7.03
Total Net Supply	12472	29898	10.20	19.88

Source: National Energy Policy Office (NEPO)
National Energy Administration (NEA)

Table 2-2 Primary Energy Demand

(Unit : KTOE)

	1991	1996	2001	2006	2011
1. Petroleum	21647	31614	40610	48319	63456
2. Natural Gas	6289	9339	9722	9733	9733
EGAT	4762	6662	6142	6141	6141
Feedstock	1184	1821	2457	2457	2457
Industries	343	855	1123	1135	1135
3. Lignite & Coal	4093	5546	13021	27358	44591
Lignite	3835	5177	10384	12128	13610
EGAT	2580	3407	8028	8808	8808
Mae Moh #1-13	2516	3407	4110	3778	3778
Lampang	0	0	2882	3227	3227
Krabi+Other	64	0	1036	1803	1803
Industries	1255	1770	2356	3320	4802
Coal	258	369	2637	15230	30981
EGAT	0	0	2141	14530	29967
Industries	258	369	496	700	1014
4. Hydro & Electricity	416	566	658	664	664
5. Total	32445	47064	64011	86073	118444
6. Average Annual Increase (%)		7.72%	6.34%	6.10%	6.59%

Source: Thailand Development Research Institute (1990)

Table 2-3 Total Final Energy Demand by Energy Sources

(Unit : KTOE)

	1986	1988	1991	1996	2001	2006	2011
Lignite	323	568	1255	1770	2356	3320	4802
Coal	140	239	258	369	496	700	1014
Natural Gas	87	60	343	855	1123	1135	1135
Petroleum Product	10020	12747	16943	24174	32209	42873	58010
Electricity	1877	2406	3693	5906	8501	11937	17057
Total	12446	16021	22493	33074	44685	59965	82018

Source: National Energy Administration
National Energy Policy Office
Thailand Development Research Institute (1990)

Table 2-4 Final Energy Demand by Sector

(Unit : KTOE)

	1986	1988	1991	1996	2001	2006	2011
Industry	3033	3903	6022	9088	12700	18076	26278
Transport	7014	9222	11832	17258	23003	30166	40260
Agri.& Res. Comm.	2399	2896	4638	6728	8982	11723	15480
Total	12446	16021	22493	33074	44685	59965	82018

Source: National Energy Administration
National Energy Policy Office
Thailand Development Research Institute Estimates

Table 2-3 Total Final Energy Demand by Energy Sources

(Unit : KTOE)

	1986	1988	1991	1996	2001	2006	2011
Lignite	323	568	1255	1770	2356	3320	4802
Coal	140	239	258	369	496	700	1014
Natural Gas	87	60	343	855	1123	1135	1135
Petroleum Product	10020	12747	16943	24174	32209	42873	58010
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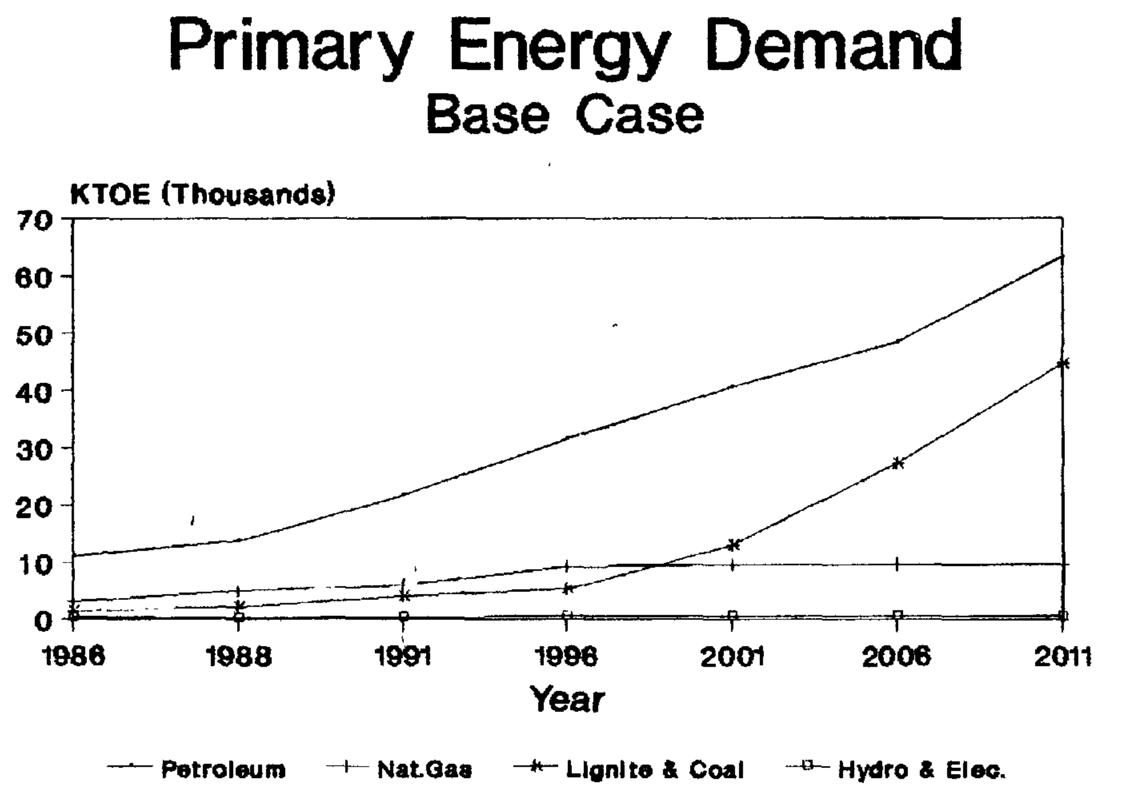

Primary Energy Demand
Base Case
KTOE (Thousands)
70
60
50
40
30
20
10
0
1986
1988
1991
1996
2001
2006
2011
Year
Petroleum
Nat.Gas
Lignite & Coal
Hydro & Elec.

Figure 2-1

Part II

Major Energy/Environment Issues in Thailand

Chapter 3

Analytic Approach

SCOPE OF ENVIRONMENTAL ANALYSIS—AN AIR QUALITY FOCUS

In this paper we attempt to describe the environmental consequences of alternative energy strategies for Thailand, and to address some of the policy implications associated with them. Toward that end, given the extent and diversity of potential impacts, it is necessary to select a priority group for analysis. As discussed in the Introduction the group chose to address the following environmental management issues in depth.

The three broad issues analyzed and presented include:

1. Air pollution impacts and management policies for Thailand's urban energy/environment systems.
2. The acid rain problem in Thailand and its relationship to the Asian region.
3. Global climate change due to greenhouse gas emissions and its implications for Thailand's future energy systems.

Each of these issues will be addressed separately in a comprehensive manner in this paper. However, since these issues are not completely independent, there is a need to develop an integrated analytic framework that can provide a comprehensive view of the issues.

MODELING METHODOLOGY

A substantial amount of analytical effort was focused on the development of a description of the environmental consequences of alternative energy scenarios for Thailand through the end of the Tenth Plan (2011). In depth analyses of particular elements within this framework were performed as dictated by the analytic needs of the three priority areas.

There existed an inherent advantage to incorporating these three areas of policy analysis within a comprehensive analytical framework. Such a framework provides a flexible and powerful basis for future analyses which can be broader in terms of pollution/environmental impact characterization, and more in-depth on specific sectoral, regional, or individual pollutant analyses. The framework used will contribute to the long-term Thailand Development Research Institute (TDRI) objective of tools and database development for energy/environment policy analysis.

Through the process of scenario building within a base model, TDRI has examined and will be able to continue exploring environmental consequences of a range of alternative assumptions and energy strategies, including:

- o Different fuel mixes by industrial subsector, transportation subsector, or electricity generation type.
- o Selected regional growth patterns.
- o Selected energy conservation and efficiency patterns.
- o Selected pollution management strategies, including pollution control technologies, emission standards, and travel demand management structures.

For the purposes of this study, attention was devoted largely to the industrial, transportation, and energy supply sectors, with little detailed discussion of the residential and commercial/services sectors. On the supply side, emphasis was given to the electricity sector, with particular attention given to lignite, coal, fuel oil, and natural gas-fired generation.

The overall procedure for building the scenarios upon which the environmental analysis was to be based, is illustrated schematically in Figure 3-1.

The main focus of our analysis consisted of building and integrating the environmental component. The base descriptions of the other analytic components such as economic activity, and the energy supply systems, came primarily from other sources, e.g., the TDRI long-term economic regional and national forecasts, the EGAT power plan, and the National Energy Policy Office's (NEPO) oil refinery and gas separation plant.

The alternative scenarios developed in this analysis were derived from parameter and base assumption variations used to examine the environmental implications of broad policy changes, i.e., altering fuel mixes and applying different control technology and emissions standards to the power generation, industrial, and transportation sectors.

A Reference Energy Network (REN) Model Structure for Characterizing Energy/Environment Impacts

The coordination of an entire energy system is needed to provide end-use energy, therefore a system-wide perspective should underlie the impact analysis. The energy systems for which the environmental impacts are calculated, encompass as much of the complete fuel chain as possible for each type of energy consumed. The fuel chain consists of such steps as resource extraction, transportation, refining, conversion, and consumption at the point of the reference energy network as shown in Figure 3-2.

Ideally, the REN is defined and described in considerable detail for each supply category, in order to account for each step in the energy chain and each environmental impact area. For the purposes of our necessarily abbreviated study, the model was simplified to focus on air emissions quantification, with an initial emphasis placed on tracing energy flows through the two major components of the system-sectoral end-use demand and main supply/conversion facilities.

An important goal of this network structuring was to provide a basis for analyzing a broader spectrum of environmental impacts in the future. An REN may be thought of as a set of modeling structures that aggregate the many intermediate steps between extraction and end-use consumption as shown in Figure 3-2.

Figure 3-3 shows the final structure established here for the general analysis of air pollutant impacts. Five key dimensions over which important variables were calculated include:

1. Energy by fuel type
2. Energy by sector (economic, supply system)
3. Pollutant type
4. Time (year)
5. National region (spacial resolution)

The core of the model is the energy system module which corresponds closely to the energy balance developed annually in National Energy Administration's (NEA) compilation of Thailand's energy statistics in spreadsheet form. The perimeter boxes boldly outlined in the model represent exogenous policy impacts to the analysis, e.g., pricing or environmental policies.

The Model's General Equations

The equations were specified at time intervals of five years. The base year for the analysis is 1986, the beginning of the Sixth Plan. As shown schematically in Figure 3-3, policy assumptions enter the energy system analysis through modification of:

1. Sectoral energy intensities
2. Sectoral fuel mixes

Both of these are explicit variables in the energy demand equations. In a like manner, policies or assumptions about technology can be introduced into the energy system equations, e.g., changes in efficiency or fuel mix for electricity generating plants. The following energy-based policy assumptions were included in some of the discrete analyses:

o Changes in demand side energy efficiency (EE)

o Changes in the fuel mix, i.e., in the fraction of major fuels for a primary sector (FF)

o Limits to capacity of key supply types (CL) i.e. natural gas

As shown schematically in Figure 3-3, emissions-based policy assumptions, regarding emissions controls or pollutant concentrations within fuels, entered the environmental analysis through modifications in the emission rate per unit fuel for each pollutant.

Tests of policies designed to limit total pollutant emission loads and emissions density followed the energy analysis. These can be viewed as loading capacity limits per pollutant per unit area under study. The emissions-based policy assumptions used for the analysis included the following:

o An emissions control level multiplier (i.e., percent reduction) based on technology or other control measures (%c).

o A fraction of pollutant per unit fuel mass (%f).

These were explicit variables in the emissions portion of the equations. The policy changes were determined exogenously and introduced as multipliers or limits in the base model equations.

The following elements drove equations that provided the model information layers and output:

- o Gross domestic product
- o Energy intensity
- o Fuel use
- o Sector emissions
- o Total emissions
- o Emissions density

Accounting for Non-combustion Emissions from the Energy System

Some energy demand and supply sectors have large process emissions for pollutants that do not relate to the use of combustion or transport fuels. These would relate directly to GDP but typically do not account for significant pollutant loading on a regional basis, except for evaporative hydrocarbon pollutants and particulates. To further address this concern, a Process Emissions Multiplier (PRI) per unit GDP could be added to the sectoral emissions based on fuel use for those particular pollutant models. Or, emissions factors based on fuel use could be increased to account for the process emissions generated in those sectors. At this stage, process emissions are assumed exogenous to the model, but further study would be warranted due to rapid industrial expansion in sectors that use significant quantities of reactive and sometimes toxic organic solvents.

Demand Projection/Supply Projection Linkage

Because of the need to link projections of end-use emissions with intermediate fuel processing/supply emissions, the model required a mechanism to project supply levels according to widely varied fuel demand scenarios. A more comprehensive model structure might allow end-use fuel demand to directly drive consumption of primary energy types in the "supply" sectors. Allocation to generation type or import/domestic product would then most simply be structured through a generation/production fraction. For this limited analysis, the principle energy analyst determined these figures exogenously by referencing supply capacity plans and recent refining capacity projections.

Based on this simplified model structure, it was necessary to establish limiting levels of supply or conversion capacity and make assumptions of maximum capacity factors and conversion efficiencies for particular policy tests. Capacity ceilings are exogenous to the model for the projection year, and reflect clearly binding constraints in the other system planning groups. This limited the scope of potential "blue sky" analyses, focusing on projections of those scenarios legitimately seen as feasible within the time horizons modeled.

Spreadsheet Structures

The general model was modified to address policy questions by incorporating a broad information base, and by allowing for coefficient/multiplier variations on intermediate spreadsheets. For the Bangkok transportation analysis, a separate model was constructed based on a more extensive urban infrastructure planning database and different algorithms, it is discussed separately in Chapter 5. The results of the two models show reasonable agreement, based on moderate calibration using regional energy data. Without an existing comprehensive emissions inventory for Thailand, further comparison is outside the scope of this model.

The environmental impact/emissions dimension of the model was necessarily limited in the current analysis, but could be significantly expanded for future analyses. For this reason, the parameters were assigned dimensions which would be the simplest to expand given the existing two dimensional energy balance template. In this fashion, future analyses of other environmental system impacts, such as solid waste disposal and water requirements, can be explored.

Regional Aggregation and Disaggregation

Regional analyses assumed the same energy intensity and unit emissions coefficients as the national analyses. Unless better information becomes available, this assumption will remain appropriate for all but the region-specific fuels, i.e., natural gas and lignite. Demand disaggregation, based on projected GDP and policy tests, drives emissions. The simplest method of calculation is to run separate regional models based on the same spreadsheet structure with some default assumptions. In the future, an additional calibration could involve summing regional models, updated with more detailed data, into a national total. Cross comparison with the initial national model would aid the fine tuning of models for regions with less information available.

SCENARIO BUILDING FOR ENERGY/ENVIRONMENT STRATEGIES

Views about the future scenarios, forecasts, predictions constitute the language of much development policy debate, and provide a frame of reference for decision and policy analysis. They clarify assumptions about what is, or is not, inevitable. Scenario building examines possible futures and the consequences of alternate assumptions and actions.

The future scenarios developed here may provide a better view of what could be avoided regarding energy system expansion, should systematic environmental safeguards be implemented. The analysis will serve to highlight important policy options, and indicate whether they are beneficial, imperative, or infeasible.

The following scenarios and sensitivity studies were chosen to address broad policy questions related to both short-term and long-term energy/environment policy decisions. We have attempted to choose a small set of energy scenarios which are in general consistent with those already under discussion in Thailand. The reference energy structure incorporates base energy use projections, built on the best available socioeconomic projections, into a description of the future consequences of environmental pollution. It also allows for the testing of policy options to identify the system-wide effects of possible pollution mitigation and alternate energy development strategies.

SCENARIOS

The study group built a framework which would address the breadth of major policy options, and allow for a consistent structure in which to compare their environmental outcomes. These general model scenarios examine two basic futures one with and one without increasing system efficiency for energy consumption.

The primary policy tests look at the impact of three additional environmental responses:

1. Implementation of appropriate pollutant control equipment on both energy conversion facilities and on end-use equipment.

2. A basic shifting of fuel dependency to those more environmentally benign.
3. An extended treatment of urban transportation to reduce critical area emissions concentrations.

Table 3-1 lists the general model scenarios and the major policy questions addressed by each. Individual issue discussions have provided extended sensitivity analyses over one or more of these general policy guidelines, but reference the noted policy as the primary question. Table 3-2 describes the broad assumptions of each scenario as applied to the transportation, industrial, and power generation sectors. Details of how each scenario effects the critical environmental impact issues, and the primary modeling assumptions involved, follow in appropriate chapters.

S1: Base Case

The base case represents a direct projection of current economic growth and energy utilization plans through the year 2011—the end of the Tenth Plan. It assumes a stabilization of modern energy intensity in all economic sectors and a decline in noncommercial intensity over the period. The scenario includes no pollution control requirements for the pollutants of primary concern, because existing standards are based on ambient air quality modeling rather than on an emissions rate or minimum technology basis. This provides a worst-case perspective given emerging control policy trends. The scenario does include the projected intermediate reductions of lead and sulfur in the transportation fuels required by current government policy, e.g., 0.15 grams per liter lead and 0.5 percent sulfur in diesel fuel.

The projections show that new power generation will shift to a dependence on domestic lignite, and then build on imported lower-sulfur coal. Natural gas maintains a strong share in generation, while levels of hydropower and fuel oil generation remain static—substantially decreasing their proportional shares over time. Industrial energy use continues to depend on an increasing electric and petroleum share, due to limited natural gas and lignite availability in that sector.

By 2011, the scenario exhibits a high-sulfur, high-carbon pollutant load. This will be the result of dependence on fuel oil, imported coal, and lignite, in that order, for industrial and electrical energy, and a very high diesel share in the transport fuels.

S2: Emphasized Fuel and Technology-Based Pollution Control

This scenario, and its related sensitivity analyses, highlight the pollution limiting potential of substantial investment in emission controls for refineries, power plants, large industries, and motor vehicles. The general scenario assumes strong sulfur dioxide, nitrogen oxide, and particulate controls on new power plants and industrial facilities. In addition, for the Bangkok urban analysis, it details the potential impact of broad-based emission control equipment standards for both gasoline and diesel-powered motor vehicles.

The vehicle standards depend on the installation of extensive desulfurization equipment during the planned refinery upgrades of the next five years. In addition, the level of controls modeled in this scenario requires the complete removal of lead from gasoline for new motor vehicles. This would require additional refining to boost final blend octane—older refineries will have this capability only after their upgrades. The scenario envisages the complete elimination of leaded gasoline during the 1990s.

The net results during the study period are a major reduction in projected levels of total sulfur emissions; negligible growth of the multiple urban air pollutants; the elimination of nearly all lead emissions from the urban environment, and a limit to the growth rate of nitrogen oxide and particulate emissions.

S3: Sectoral Fuel Shifts

This analysis highlights the potential implications for energy use and resultant emissions of a major transition to alternate fuels for power generation, industrial boiler use, and motor vehicle fuels in the Bangkok region. Sensitivity analyses initially examine lighter-carbon blends, including a greater dependence on imported natural gas and liquefied petroleum gas. Less extended analyses compare the various implications and costs of transition to nuclear and solar-based energy economies.

S4: Enhanced Energy Efficiency

This scenario looks at the environmental implications of enforcing energy conservation and equipment efficiency requirements. Policy mechanisms explored include fuel pricing/tax measures, vehicle and other energy equipment efficiency standards, and broad industrial/commercial/residential conservation incentives.

An analysis of this scenario looks at across-the-board efficiency improvements of 20-25 percent through the 15 year peiiod 1996-2011. It also examines the implementation of both optimum pollution control requirements and efficiency investments. This scenario varies slightly across the three sectors analyzed to reflect the varying efficiency potential of these different sectors.

S5: Comprehensive Environmental Response

This scenario highlights the pollution limiting potential of a comprehensive policy response to rapid energy expansion in the Thai economy. It includes basic elements of the pollution control and fuel standards scenario, assumes a broad-based energy efficiency response in all sectors, and combines a modest fuel shift in most sectors, as would currently seem most realistic.

We also established two levels of reduction measures for each of the above scenarios. For example, S2-A designates "moderate" fuel control while S2-B designates "maximum" fuel control. Chapters 6, 9, and 13 make use of the two levels of reduction measures in the analysis.

Table 3-1 Primary Policy Scenarios
TDRI - Energy/Environment Analysis
General Model

Basic Scenario:	Issue Area for Analysis:
No Efficiency Change in Energy Utilization Trend	
S1 Base Case	- All
S2 Fuel & Technology Controls	- Acid Rain, Urban Transportation & Industry
S3 Sectoral Fuel Shifts & Fuel/Tech Control	- Acid Rain, Urban T&I, Global Warming
(S*) (Urban/Transportation Sensitivity Tests)	- Urban Transportation Only
a+b : Various Demand Management (W/Transportation Controls)	
Long-Term Improvement in Energy Utilization	
S4 Improved End-Use Efficiency (System-wide 25% 2011)	- Acid Rain, Urban T&I, Global Warming
S5 Comprehensive Environmental	- Acid Rain, Urban T&I, Global Warming
(Efficiency + Fuel/Tech Controls + Fuel Shifts +Urban Transportation Management)	

Table 3-2 Sectoral Assumptions of The Scenarios

Scenarios	Sectors			
	Elec Power	Industry	Transport	Fuels
S1: Base Case	No Technology-Based Control Regulation	No Technology-Based Control Regulation	Existing Tech-2 Control Level (Minimum Tech)	Lead 0.15 gpl-'93 Gasoline 0.2%S Diesel 0.5%S-'93
S2: Fuels & Technology Controls	50%/90% SO2 25%/40% NOx 99.8% SPM (New Lignite Facilities)	Same As Power for Lignite/ Coal- Lower Controls for Fuel Oil (only on 50% of New Energy Use)	Tech 4 Control Standards (Cat. Converters/ Evaporative Controls/Diesel Particulate Controls)	Lead 0% New Cars Diesel 0.2,0.1%S Fuel Oil 2.0,1.0%s
S3: Fuel Shifts	S2 Plus Imported Nat Gas Expansion (Also Nuclear vs Solar/ Hydrogen)	S2 Plus Modest Nat Gas Expension	S2 Plus Bangkok Area Gasoline - Diesel to LPG Shift, Buses Use CNG	Imported LPG International Nat Gas Pipeline (or Nuclear or Solar Infrastructure Development)
S4: Enhanced Energy Efficiency	S2 Only	S2 Plus 15%,25% Energy Intensity Reduction for Each Fuel	S2 Plus 25% Gasoline Vehicle Efficiency Gain via New Car Standards	S2 Only
S5: Comprehensive Environmental Protection	S2, S3 & S4	S2, S3 & S4	S2, S3 & S4, S*(a)	S2, S3 & S4
S6: Demamd Control (Transport Only)			a) Controlled Access to CBD b) Limit Vehicle Usage	

Figure 3-1. The Basic Energy/Environment Model

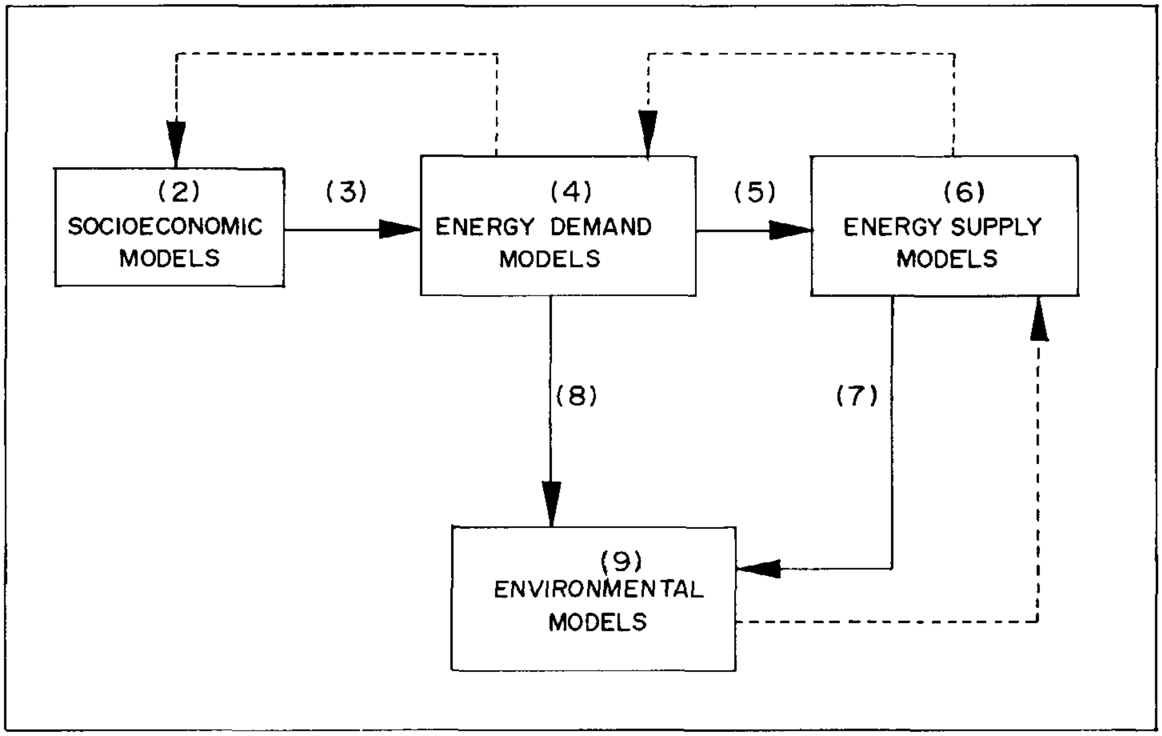
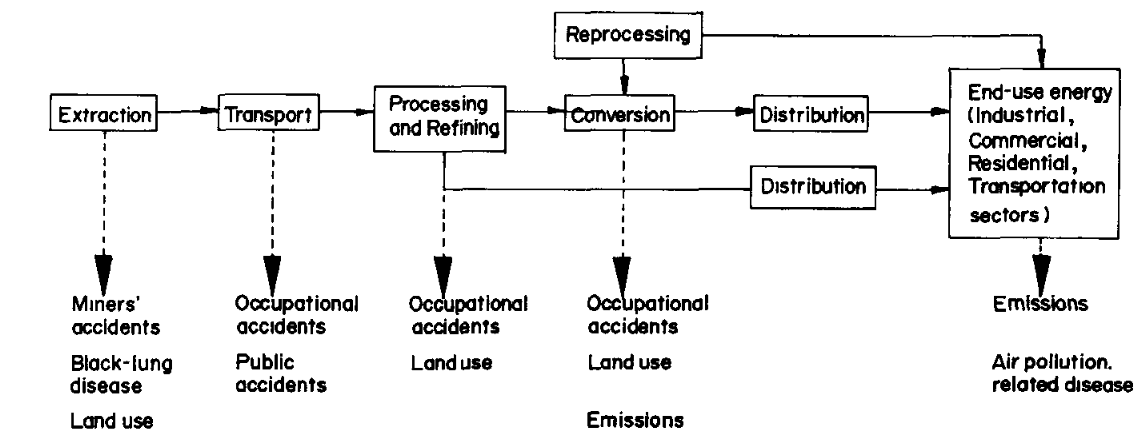


Figure 3-2 Reference Energy Networks- Fuel Chains



Typical environmental impacts associated with each point in the fuel chain.

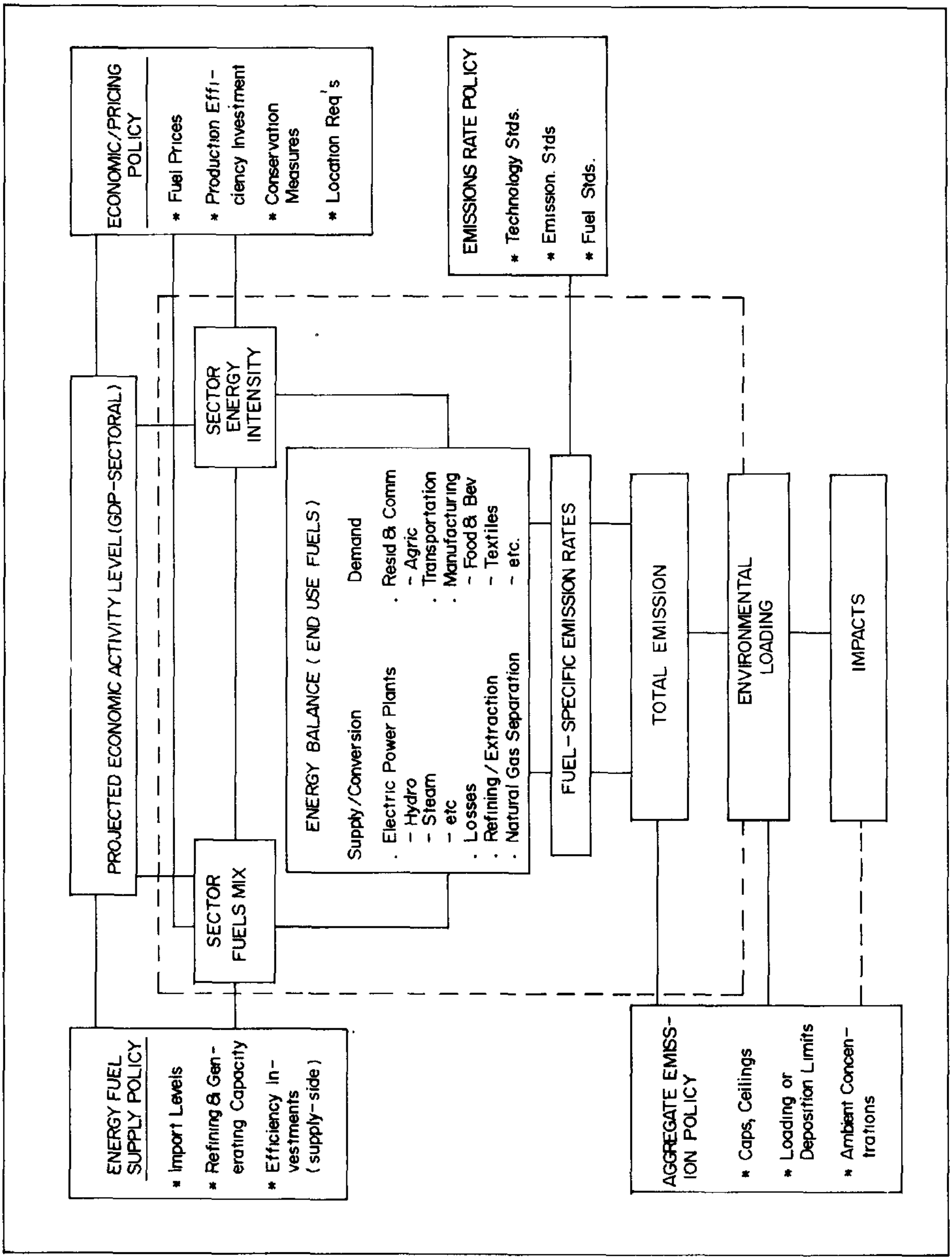


FIGURE 3-3 A GENERAL THAILAND ENERGY / ENVIRONMENT MODEL

Chapter 4

Information and Data Sources

DATA BASE AND INFORMATION

Economic Projection

GDP projections were made based on preliminary TDRI forecasts (1990-2011) using 1989 as a base year. Information for a total of 34 disaggregated sectors are available from the projections. The sectors can be grouped into four main categories; agriculture, services and commercial, transportation, and industry. The industrial sector can be further divided into 10 subsectors; mining, construction, food, textiles, wood, paper, chemicals, nonmetals, basic metals, and others'. Appendix D-1 shows preliminary GDP projections by sector.

A regional breakdown of GDP was performed using the NESDB'S provincial estimates as a basis. The five regions identified are the BMR (including the Bangkok Metropolitan Area (BMA), Nonthaburi, Samut Prakan, Samut Sakhon and Nakhon Prathom), the Northern, the Northeastern, the Central, and the Southern regions. Appendix D-2 lists the provinces included in each region, and Appendix D-3 shows the regional GDP projections used for the study.

Final energy demand and air pollution loading were then derived based on the GDP projections and regional distribution.

Energy Structure

Final energy demand in the four main sectors was compiled by fuel type using NEA statistical reports from 1982 to 1989. Future sectoral energy demands were then projected using these statistics. Since there are no specific data available for regional energy demand by sector and fuel type, some assumptions were necessary to derive these figures. It was assumed that sectoral energy intensity and fuel mix were indentical for most regions. To the extent that data were available, adjustments were made for specific fuels such as natural gas, lignite, and coal to reflect dependencies on location and supply facilities.

In this study, end-use energy demands by sector and by energy type were calculated based on two parameters, GDP and the energy/GDP intensity - a specific energy requirement to produce a given unit of output or activity. Sectoral projections of energy/GDP intensity were made using past statistical data and appropriate assumptions. Appendix D-4 shows energy/GDP intensity by sectors from 1982 to 1989.

Fuel mix patterns for future energy demand were assumed identical to those in 1988, except in the industrial sector where an adjustment was made to allow for the increased use of natural gas and lignite in some specific subsectors (appendix D-5).

Three main energy systems were included in the study; electricity generation, petroleum refinery, and gas separation. Base estimates of future electricity generation and related fuel requirements were obtained from EGAT's Power Development Plan (PDP-90-02) up to the year 2006, and extrapolated to the year 2011. An increasing trend of lignite and imported coal generation is expected due to future domestic gas supply constraints, and the lack of any major hydropower development projects. The electricity generation mix and fuel requirements for the base plan are shown in Appendix D-6.

Local refinery production through 1995 was obtained from NEPO (appendix D-7), and includes a new grassroots refinery expected to operate by 1994. Production up to 2011 is assumed at the same level that it is estimated to be in 1995. A regional breakdown of these systems was based on the location of their facilities. Approximately 4 percent of crude throughput is estimated as energy consumed in the refining processes, with equivalent amounts of fuel oil and fuel gas as energy sources.

The expected production of gas separation plants was obtained from the Petroleum Authority of Thailand (PTT) reports (appendix D-8). Both electricity and natural gas are used in these plants. A constraint on domestic gas supply compels the gas distributors -PTT- to regularly set up allocation plans for relevant gas users. Appendix D-9 indicates the recent plan, specified by supply sources and demand categories. Priority users are feedstocks for gas separation plants, petrochemical processes, and industrial fuel. Gas demand for feedstock and industrial uses are first specified and then demand/supply matching is obtained by using the gas available to EGAT for power generation as a buffer. Industrial and EGAT gas demand so identified is thus set as the upper gas limit available to that sector, reflecting the base case energy structure.

Fuel quality standards by type were obtained from various sources (appendixes D-10 and D-13). Sulfur content, ash content, lead content, and heating value are the major fuel qualities considered in this study.

For environmental reasons, the government has recently revised the quality standards for gasoline and diesel. The current gasoline lead content of 0.4 grams per liter, will be reduced to as low as 0.15 grams per liter. For diesel oil, a 0.5 percent sulfur content will replace the existing 1.0 percent standard. The revisions will take effect October 1, 1993. While there is currency discussion on similar reductions for fuel oil sulfur content, no conclusions have yet been reached.

Environmental Standards and Monitoring Standards

An ambient air quality standard was established by the National Environmental Board (NEB) in December 1981, regulating concentrations of carbon monoxide, sulfur dioxide, suspended solids, lead, and ozone (appendix D-14). The Thai Standard is based on the United States Environmental Protection Agency (U.S.EPA) guidelines, and modified to account for local conditions.

Industrial emissions standards were issued by the Ministry of Industry in 1971 to control smoke intensity at the mouth of the stack. Motor vehicle emissions standards were issued by three agencies; the NEB, the Police Department (PL), and the Department of Land Transport (DLT). Black smoke and carbon monoxide are two pollutants limited under these standards. Boat/ship/vessel emissions standards were issued by the Harbour Department in 1985 to control black smoke emissions.Appendix D-15 describes in more detail these emissions standards.

Monitoring

Ambient air quality data for Bangkok were obtained for the years 1985, 1987, and 1989. The data are specifically for carbon monoxide, suspended particulate matter, and lead. The 1985 and 1989 data were taken from NEB, while the 1987 data are from the Ekkamai-Ram Inthra Expressway Final Report. The 1987 and 1989 data are more site specific than that for 1985. These monitoring data are used to help specify air pollution problems related to transport energy consumption in the Bangkok area (appendixes D-16 to D-18).

Recent acid rain results monitored monthly at the NEB station in Bangkok are available for June 1987 to October 1989. The pH value and acidity (mg/l as $CaCO3$) of rainfall are measured against pH value of the soil. Detailed data are shown in Appendix D-19.

In this study, calculations of air pollutant loading are based on energy use and specific pollutants emitted per unit fuel. The latter elements, termed here "emission factors" are specified for seven substances; SO2, NOx, SPM, CO, HC, CO2, and Pb. Appendix D-20 shows these emission factors which are compiled from various international sources such as the U.S.EPA, API 42 & NAPAP inventory, WHO, TDRI, U.S.DOE, and OECD.[1] The factors are adjusted according to the domestic fuel qualities as mentioned earlier.

Additional Data

National provincial area data were obtained from the Department of Local Administration (Ministry of Interior 1987). The regional data were obtained by adding up all corresponding provinces within the region, and were used to identify air pollution density by region (appendix D-21).

Energy conversion factors used in this study were taken from the NEA statistical report (appendix D-22). Conversion from physical units to kilotons of oil equivalent (KTOE) was undertaken using these factors.

FUTURE INFORMATION REQUIREMENTS

Emissions Data

Lack of monitoring data on emission sources, both vehicular and stationary, make the quantitative linkage with air quality impossible. There is a need to construct a data base estimating emissions of all sources based on sample tests.

Air Monitoring Data

An air quality montoring network and data base should be established. These data would help not only in assessing air quality problems, but they could also be used as NEB guidelines in the formulation of appropriate emissions standards.

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[1] API 42= American Petroleum Institute 42.
NAPAP = National Acid Precipitation Assessment Program.
WHO = World Health Organization
DOE = Department of Energy
OECD = Organization for Economic Cooperation and Development

Part III

Air Pollution Impacts and Management Policies for Thailand's Urban Energy/Environment System

Chapter 5

Transportation Emissions

Preserving an acceptable level of environmental quality will require the adoption of major policies to address transportation pollutant emissions. This chapter outlines the urban development pattern, transportation system structure, and vehicle emissions characteristics that have contributed to the rapid degradation of Bangkok's environment. It discusses the air pollutants of immediate concern and their health and environmental impacts. The analysis develops a series of policy options, consistent with the options in the generalized energy/environment model, to help address the growing problem. Final policy recommendations to address urban air quality degradation are presented in Chapter 7.

OVERVIEW OF URBAN DEVELOPMENT PATTERNS AND THEIR IMPLICATIONS FOR TRANSPORTATION, ENERGY, EMISSIONS, AND AIR POLLUTION

Urban Development Patterns

The growth of global population has been the source of much attention and anxiety among those concerned with the future of the global environment. More recently, attention has focused on the massive urbanization that has come as a product of population growth, the increase in economic opportunity in urban areas as development occurs, and the limited ability of a fixed land base to support people in rural agriculture.

The growth in demand for motorized travel is well understood. As urban areas expand, available land is generally at the edges of the urban area and in areas previously considered unsuitable for development. As the distance of residential locations from the city center or other subcenters increases, there is an increasing need for motorized travel. Motorized travel, often in private vehicles, supplants traditional modes of travel such as walking, various bicycle forms, water travel, and even mass transit. The need is necessitated by the decrease in population densities with distance from urban centers.

The evolution of the form of urban areas is influenced by the growth of income and accompanying increases in the acquisitions of private motor vehicles and changes in travel habits. It is also influenced by public policy towards land use, housing, and transportation infrastructure. While the proportion of middle- and upper-income households in developing and newly industrialized countries able to afford automobiles and motorcycles is lower than in industrialized nations, the number of private vehicles still becomes very large as the middle- and upper-income groups grow. The number of vehicles and levels of congestion are comparable to or exceed that of major cities in industrialized countries. With the increase in motorized travel and congestion come increases in energy use, emissions, and air pollution.

The development of Bangkok described in major recent studies such as the "Medium to Long Term Road Improvement Plan: Main Report" by Japan International Cooperation Agency (JICA 1990) and the "Seventh Plan Urban and Regional Transport" by the Office of NESDB (SPURT 1990) follows the general development path described above. In particular, the studies indicate that unless some policy measures are taken to alleviate the situation, the number of person trips, the amount of energy use, the amount of emissions, and the level of air pollution will double or triple between 1989 and the year 2006. In addition, unless traffic demand is controlled or a large investment is made in transportation infrastructure, the extreme levels of congestion will *increase*.

Why this is the case can be explained in the following simplified description of urban development. Urban development can be represented by concentric rings, with growth in an outward direction from the center as depicted in Figure 5-1. Geographers have noted that the pattern of net residential density follows a pattern similar to that in Figure 5-2.

The advent of motorized transportation at the turn of the century, and later the automobile (and in the case of Bangkok, the motorcycle), have led to expanded roadway systems resulting in cities having increasing spatial area (Figures 5-1 and 5-2). For cities whose development has come after the advent of the widespread use of private motor vehicles, overall densities are lower. In the case of Bangkok, a density depression or crater at the center is emerging.

Transportation Infrastructure Considerations

Overlayed on and intimately associated with this development pattern is the transportation infrastructure. The level of infrastructure provision relative to population density, income, and transportation pricing, as well as other related policies, determine the level of congestion. In the case of Bangkok, high population density, rapidly increasing income levels, low fuel prices, moderate vehicle prices (except for passenger car prices which are fairly high), and a relatively limited transportation infrastructure have resulted in severe congestion. The rapid growth in population and economic activity is pushing both the population and various urban subcenters outward, in a combination of a linear and a polynucleated or multinucleated pattern. Vehicle flow and congestion are also expanding outwards.

Within this context, further growth in travel in the central urban areas will not be possible without the provision of added infrastructure. This is strikingly shown in recent data (JICA 1990) which suggest that traffic volume is decreasing in central areas while it is growing dramatically further out (figure 5-3).

If infrastructure is added in the central areas of Bangkok, the SPURT and JICA studies agree that traffic volumes will increase so as to maintain congestion at essentially the same level, except over more lane-kilometers. The implication for air pollution is that it will increase approximately proportionally to the roadway lane-kilometers provided and vehicle-kilometers traveled. In order to provide, with the proposed new infrastructure, a higher level of service and prevent air pollution concentrations and energy use from doubling or more by the year 2006, demand management and other pollution control policy measures are required.

The Urban Transportation Air Pollution Concern

Bangkok exhibits the vehicle-based air pollution problems typical of all large industrial cities. Concentrations of various pollutants are high enough along major travel arteries to pose a significant concern for human health. Air pollution in the future, without some corrective measures, will encompass a much broader geographic area.

As noted in previous TDRI and NEB documents - lead, CO, ambient acid aerosols (from SO2 and NOx emissions), SPM, and products of incomplete combustion from diesel and 2-stroke motorcycle engines - represent the primary pollutants of concern from transportation energy use. However, directly related fuel combustion residuals and fuel evaporation constituents are of almost equal concern at much lower concentrations. These include, among others, 1,3 butadiene, ethylene dibromide and dichlorides, and gasoline's various aromatic hydrocarbon elements including benzene, xylenes, and toluene. The following paragraphs discuss these pollutant groups in terms of potential health and welfare impacts.

The photochemical oxidants (e.g., ozone) that result from extended reactions between ambient NOx and HC have not yet proven to be pollutants of concern in the BMA. Apparently, during the critical hot and dry months, the dominant winds flow steadily from the gulf most days. Also, the significant vertical instability typical of tropical cities at sea level is sufficient to disperse the reactants to prevent heightened ambient concentrations. Finally, the very low speed traffic conditions and high levels of hydrocarbon emissions suggest a NOx-limited chemical environment which would tend to slowdown ozone reaction cycles. These factors combined lead to ozone formation occurring downwind and in an elevated air mass relative to metropolitan Bangkok.

Tetraethyl Lead and Engine Lead Detergents

Tetraethyl lead (TEL) was introduced as a gasoline octane enhancer during the 1920s. Since that time its use became almost universal within the gasoline industry as a cheap mechanism to reduce the level of refining necessary to meet a given level of gasoline octane. It also served indirectly as a means to extend cast iron engine valve seat life.

In the last twenty years, the reintroduction of unleaded gasoline in several countries and the use of aluminum and iron-alloy block engines with hardened, pressed-in valve seat inserts has eliminated the need for lead in gasoline. In vehicle systems with catalytic converter emission controls, the use of leaded gasoline must be prevented to avoid catalyst contamination.

Lead is a multiple pathway toxin which causes retarded child development and general system poisoning. It causes elevated blood pressure at low concentrations and directly affects the circulatory, reproductive, nervous, and kidney systems. Lead's primary path for entering the human body is direct oral ingestion. The primary source is TEL, the octane additive for gasoline, which is deposited in close proximity to all major roadways where the additive is still in use. A major threat from lead is its accumulation over time in body tissues. Where leaded gasoline remains the dominant automotive fuel type, lead and lead scavenger exposure overshadow all other acute toxins for total population health risk.

The primary indicator for human health is blood concentration of lead. In fact, blood levels of lead in exposed populations have proven to provide a better picture of ambient lead concentrations than ambient air quality monitoring because of the predominance of the ingestion pathway in total body exposure. Over time, in urban areas such as the United States, cities where lead has been almost completely removed from the gasoline inventory, blood levels have shown a linear correlation of decline with the decrease in the total lead inventory for gasoline. Ambient air concentrations of lead have not approached the Thai standard in most locations, but, as noted, this is not a good indication of total body burden in a locally exposed population.

Secondary pollutants that result from the use of tetraethyl lead in gasoline are 1,3 butadiene, ethylene dibromide (EDB), and ethylene dichloride (EDC). All three substances are considered carcinogenic to humans at low concentrations and may be acute toxins at higher concentrations. 1,3 butadiene is a gasoline combustion residual that occurs much more frequently in combustion exhaust tests using leaded gasoline than in tests using unleaded gasoline.

Though lead produces a significant octane boost, and extends valve life in some older engines by coating the valve seat surface to lessen pitting (the "lubrication" benefit), the use of even small quantities of lead without detergent scavengers significantly shortens engine life. The use of lead in gasoline generally causes the need for much more frequent engine tune-up and maintenance. Several international studies suggest the fuel cost savings associated with the use of TEL as an octane enhancer is overshadowed by the lifetime increased maintenance cost for automotive engines.

Carbon Monoxide

Like exposure to lead, exposure to the combustion product carbon monoxide is a localized concern. CO tends to disperse rapidly and though fairly unreactive does alter in form upon exposure to photochemical oxidants (ozone) and to various hydrocarbons. CO results when insufficient oxidation occurs to produce the primary combustion products of carbon - CO2 and water (H2O). This can occur as the result of either insufficient oxygen (O2), incomplete fuel/air mixing, or too low a combustion temperature.

High CO emission levels tend to indicate poor engine maintenance or maladjustment. The Thai standard for emissions as a percent of the idle exhaust stream (6 percent) for all motor vehicles should be met by any existing engine if all cylinders are properly firing, and even by many improperly maintained engines. New engine designs, *without catalytic exhaust treatment*, should be able to meet a 1 percent to 2 percent standard. Emissions from catalytically-equipped vehicles should meet a standard well below 1 percent. Generally, diesel engines and engines fired on gaseous fuels instead of gasoline should emit low CO levels due to more complete and higher temperature combustion.

Elevated levels of ambient carbon monoxide cause an extended loss of the capability of the blood to fully transmit oxygen to critical body tissues. The CO attaches itself to the hemoglobin and blocks the attachment of oxygen. The effects are cumulative over short periods such that chronic exposure to lower levels will produce a worsening condition of general body functioning. At higher concentrations, CO can rapidly poison the system and cause death by asphyxiation. Chronic exposure levels usually cause headaches, dizziness and productivity losses associated with impaired perception, slowed thinking, and dulled reflexes. Most effects at these levels are reversible except for populations at higher risk due to existing respiratory and circulation problems.

Emissions of CO from vehicle engines are heightened under conditions of extended idling and other operation far from the engine design optimum i.e., at low speeds with frequent stops and starts. These are the conditions typical of the Bangkok urban environment. These conditions also reflect areas of heightened general exposure to direct CO sources. This includes drivers, passengers, street pedestrians, vendors, and shopkeepers. In congested situations, dispersion associated with rapid vehicle passage and good ground level ventilation does not occur. Therefore both local emissions and local exposure are maximized. If the current planning for expanded two-tier highways continues for primary travel routes, a significant localized CO concentration problem may result. These designs will have to account for adequate ventilation under and around the elevated sections.

Monitoring at higher elevations such as protected areas on building tops and on surfaces set back from the roadway do not capture these high CO concentrations except under unusual meteorologic conditions. Existing ambient concentration data should therefore not be the sole basis for establishing CO controls policies. While individual exposure in the Bangkok environment is much lower away from the primary vehicle routes, most of the population spends many hours per week in transit on these routes and a substantial population lives and works within a few meters of the roadway surface.

The existing Thai standard for ambient carbon monoxide concentration over an 8 hour period (20 mg/cu.m.) is established at the level where direct effects of CO inhalation start to be observable in patients with chronic cardiovascular (lung/heart/circulation) problems. While this nearly matches the recommended WHO guideline (20 parts per million or ppm), it is double the United States standard aimed at preventing direct health impairment (9 ppm).

Particulate Matter

Particulate matter from motor vehicles comes from three sources; engine exhaust, mechanical wear, and throwing of roadway dust (reentrainment). Diesel exhaust particulates tend to be the smallest in size (90 percent are 2.5 microns or smaller) and include fully combusted carbon and various products of incomplete combustion (PIC or PM-2.5). Mechanical wear products include lubricant aerosols and brake pad scrapings of a much larger average size, greater than 10 microns. Reentrained particles may be all sizes but tend overall to be the largest and account for a significant fraction of the total mass of suspended matter (SPM or PM-10). Reentrainment particles are those most sensible to the public as immediate irritants in high traffic conditions.

Health effects from particulate matter are inversely proportional to sensible impact potential. PM-2.5 (less than 2.5 microns) exhibits the highest health risk due to its deep inhalation in the lungs and extended duration in the deep lung pouches. Significant lung residence time leads to extended chemical interaction in this environment. Many otherwise benign carbon particles in exhaust streams contain absorbed organic compounds highly toxic, carcinogenic, and mutagenic to the human body.

Particles 10 microns and larger cause significant visibility degradation (smoke is emitted between 1.0 and 50 micron sizes) because of carbon's effective light blockage potential. However, larger particles tend not to penetrate to the deepest lung areas and are more easily removed from the eyes and upper respiratory tracts. While the smoke from diesel engines is probably the most obvious urban pollutant, it may be unseen particles in conjunction with the smoky exhaust that, like lead, cause the highest health hazard.

Lead is the dominant particulate emitted from leaded gasoline. Other compounds include very small particles of incomplete combustion such as polyaromatic hydrocarbons (PAH), other organic aerosols, and various unburned lubrication and detergent elements. Additionally nitrates and sulfates come from fuel residues of these elements.

Diesel exhaust emissions tend to be predominantly elemental carbon and various PICs including the PAHs. The notable exception is for diesel engines working outside of their optimum torque such as occurs with frequent starting and stopping. Here inefficient combustion conditions lead to significant increases in the lubrication and larger carbon ring compound emissions most toxic to the human body. It is theorized that these conditions also promote the absorbance of volatized hydrocarbons on the surface of the carbon particles that then are carried deep into the lungs.

Like diesel engines, small two-stroke motorcycle engines result in significant particulate emissions when operated under anything other than optimum conditions. Unlike well-tuned diesel engines, the highly visible emissions are dominantly unburned hydrocarbons rather than elemental carbon. Though it is impossible to adequately characterize the relative health impact of this complicated exhaust stream, it is appropriate to note that two-stroke engines emit four to eight times the hydrocarbons and many times the particulates of equivalently sized four-stroke automobile engines. Engine design and exhaust treatment modifications are available to reduce the typical high emission rates for new equipment. The particulate emissions from this rapidly growing engine population may be the most chronically threatening pollutant besides the lead compounds for the general Bangkok population.

Volatile Organic Compounds (Non-Methane Hydrocarbons)

In many urban areas, concerns with high volatile organic compounds (VOC) emissions relate most directly to the negative health impacts from photochemical oxidants (ozone or smog). Given the low measured ozone levels and the observable dispersion patterns, hydrocarbons of concern are those toxins that pose direct or chronic health impacts. These would tend to include the more complex hydrocarbon compounds, such as the aromatics discussed in regard to particulates.

A typical hydrocarbon constituent of gasoline that exemplifies these concerns is benzene, a six carbon compound. Extended epidemiologic studies of benzene show a strong linkage to increased leukemia incidence, a common and usually fatal blood/bone marrow cancer. Benzene use as an industrial solvent has been strongly curtailed in most parts of the world due to its carcinogenic nature, but as a natural crude oil refining constituent of gasoline, exposure by most populations is significant. European gasolines contain higher benzene levels, typically 2 percent to 5 percent, while United States gasolines tend to contain 1 percent to 2.5 percent by volume due to differing refining patterns. Current Thai gasoline is mostly a straight-run refinery blend with little catalytic alteration to optimize gasoline constituents. With the typically heavier crudes utilized, this would show a higher than average aromatic fraction. Proposed existing refinery investment and the development of high technology new refinery capacity should improve this picture.

Hydrocarbon emissions come from three inventory areas; gasoline evaporation, industrial and commercial solvents evaporation, and directly exhausted combustion and process emissions including vehicle exhaust. Gasoline evaporation and vehicle exhaust probably account for half the total hydrocarbons, but a much larger fraction of the heavier aromatic hydrocarbons. The exhaust from gasoline combustion tends to concentrate the higher carbon fraction of HC emissions such that untreated exhaust contains about twice the proportion of complex carbon compounds as the fuel. Lighter carbon compounds burn more rapidly and completely. Without exhaust treatment such as occurs with catalytic converters, exhaust emissions of benzene overshadow most other sources.

Acid Aerosols (NOx and SO2)

Given the favorable local climatology of the Bangkok region, acid emissions, such as NOx and SO2, from motor vehicles, would not initially be expected to cause substantial health problems. Instead, most concerns are directed at the use of high-sulfur fuel oil and solid fuels in industrial and power plant sources. Indeed, limited monitoring data from the 1970s and 1980s suggest low ambient concentrations. However, the uncontrolled vehicle fleet, with its rapid expansion and transition to diesel fuels, heightens the prospect of an increasing problem. In addition, the lone sulfur dioxide monitor in the metropolitan area has been removed, precluding the tracking of ambient concentration trends.

In the urban environment, NOx and SO2 would be expected to contribute to three environmental problems:

1. Direct health impairment for sensitive populations (i.e., the elderly and those with existing respiratory problems and bronchial illness)
2. Visibility limitation
3. Local vegetation and material damage

Significant projected emission increases, particularly of NOx, may cause the development of more widespread problems. Indeed, increasing NOx and SO2 emissions resulting from the expanding areawide vehicle travel by an uncontrolled fleet combined with rapid industrial development still dependent on fuel oil boilers could pose a long-term health and environment problem for the city.

DEVELOPMENT OF A TRAVEL AND EMISSIONS INFORMATION BASE FOR POLICY ANALYSIS

In order to understand the growth of travel, energy use, and emissions, as well as to identify and evaluate various policy measures, a Bangkok transportation model was developed. The modeling of the Bangkok transportation system complements and serves to calibrate the general energy/environment model.

Considerable effort by Thai researchers and foreign consultants has been devoted to transportation modeling and analysis for Bangkok. Much of this effort has focused on traditional transportation planning which emphasizes infrastructure planning, i.e., what investments should be made in added roadway and mass transit, which in the case of Bangkok would include the sky train and an elevated rail system. The underlying economic rationale for these investments is both the provision of economic benefits from added travel opportunities, as well as the time savings that will occur if the new infrastructure is not overwhelmed by demand. The SPURT and JICA reports conclude that at least in the central parts of Bangkok, travel increases are expected to be so great, that travel time reductions will *not* occur in the long run. The advantage of the rail proposals is that they are on separated grades, which means that travel time savings can be provided for those portions of the city that are served by the systems.

The extensive transportation studies which have been undertaken to evaluate infrastructure options neither can nor should be duplicated in this evaluation of energy use and air pollution. Rather, the existing models are used as a basis for this analysis. The information for evaluating energy and air pollution consists of:

- JICA model and travel projections.
- Data base and forecasting model for energy demand in the transport sector (NESDB/NEPO 1987).
- Various emissions models including MOBILE 4 (U.S.EPA 1989).
- In-house model for using output from the above sources and calculating aggregate energy use, emissions, and price effects.

The relationship of these information components is shown in Figure 5-4.

Travel Data Base

The travel data base and projections used in this analysis are drawn from the JICA (1990) report. As that report is available to Thai analysts, only a few observations are made on the suitability of the JICA projections as a basis for analysis.

An important observation is that the JICA projections of vehicle ownership growth and the number of person and vehicle trips, appear to be very conservative for the economic and demographic assumptions used. The number of private vehicles roughly doubled between 1989 and 2006. This outcome is a result of the logistic functions used for anticipating future ownership patterns for automobiles and motorcyles. The ownership assumptions may have been made because of the untenable levels of traffic that would result without saturation functions on ownership built into the models. For a different view on the private vehicle ownership question, SPURT (NESDB 1990) estimates that the vehicle fleet will grow by a factor of 3 to 4 during that same period.

While the limits on vehicle ownership growth surpresses the number of passenger trips in the JICA study, the large increase projected in average trip length may exaggerate the number of vehicle-kilometers projected for the year 2006. If trip lengths were to remain constant, as has been the case in large urban areas in the United States (Gordon et al. 1987), then the potential underestimate of trip numbers and overestimate in trip lengths may compensate each other in projecting future travel levels. No estimates of error are provided in the JICA study.

The other main observation in using the JICA work is that only the case with the new infrastructure is considered in our analysis. Without at least a significant portion of the incremental roadway capacity brought into place, the capacity would not exist to support the growth in vehicle travel projected by JICA for the year 2006. In other words, the non-provision of new infrastructure would serve as an effective constraint on the growth of vehicle-kilometers in Bangkok.

Within these limitations, we believe the JICA report is a reasonable basis for the analysis of energy and emission levels and policies. Because JICA excludes some trips and treats trips with more than one mode as a single trip, we increased the number of single mode trips to calibrate the in-house model to estimates of vehicle-kilometers and energy use in the portion of the Bangkok region treated in this analysis.

Emissions Data Base

Emissions are calculated for each of the personal transportation modes and fuel types used in Bangkok, with the exception of river and rail travel which are of little consequence for aggregate emissions. The emissions model used for hydrocarbon, carbon monoxide, and nitrogen oxide emissions for gasoline and diesel powered vehicles was the U.S.EPA model MOBILE 4 (1989). Additional information for sulfur and particulate matter emissions and for efficiency changes at low speeds are taken from the California ENFAC7 and the United States NAPAP Emissions Inventory literature. Alternate fueled vehicles information comes from the emerging literature on alternative fueled vehicles (e.g., OECD 1986, SAE compilations, and Sperling 1990). These sources were used to estimate emissions for vehicles with and without specified levels of emission controls.

Model Framework for Evaluating Transportation Policy Options

In order to provide a flexible model for incorporating input from JICA, the emissions models, and potential demand management strategies, a flexible model for estimating energy use and emissions was developed in-house. The model was developed on LOTUS spreadsheet at TDRI under the supervision of Dr. Mark Hanson and Mr. Robert Lopez. The overall structure of the model is shown in Figure 5-4. The geographic basis of the model is the 19 zones identified in the JICA study and shown in Figure 5-5. Energy use and emissions are estimated for each of these 19 zones individually as well as in aggregate. The calculation procedure follows a conventional approach of trip generation, modal split, trip distribution, and vehicle loading. This series of calculations results in an estimate of vehicle-kilometers by mode eminating from or occurring in each of the 19 zones. Energy use and emissions by mode for each of the zones are projected using the estimates of vehicle-kilometers, vehicle speed, and coefficients of energy use and emissions per kilometer.

The coefficients of energy use are taken from an extensive survey and study in 1987 by NESDB/NEPO. The average fuel economy levels by mode are adjusted to approximate mean speed in each of the 19 zones by setting speed to 8, 16, or 24 kilometers per hour based on JICA projections and our judgment. Fuel consumption rates vary significantly with speed as discussed in the next section.

The emissions coefficients are based on Type 2 vehicle controls (i.e., very modest engine improvement and limited controls, but without catalytic converters and other add-on devices) used in the U.S.EPA MODEL 4. This emissions model is based on extensive in-use vehicle tests. As described in the next section one policy option considered is introducing type 4 vehicle controls, catalytic converters with NOx controls and evaporative emissions canisters.

Structure for Policy Scenarios

The transportation policy options considered using the model are a mix of air pollution and energy measures. These measures, which are matched to the overall energy/environment analysis are outlined in Table 5-1.

Policy S1 is in some respects a "do nothing" policy. It does, however, assume that the extensive improvements anticipated in the JICA and SPURT reports are instituted so as to be able to prevent the current congested situation from deteriorating further. Because nothing is done to constrain energy use and emissions, both grow dramatically between the base year 1989 and the policy impact projection year of 2006.

Policy S2 is an emission control policy for all new vehicles which requires, in the case of cars, motorcycles, and pickup trucks, the use of catalytic converters common in Japan and the United States, and the removal of lead from fuels. The policy also assumes the elimination of most of the sulfur from transportation fuels.

Policy S3 (fuel shift) reflects an aggressive policy to reduce emissions and improve air quality in Bangkok without any explicit energy efficiency requirements, or attempts to control the amount of travel by private vehicles.

Policies S4-a and S4-b are energy efficiency policies which are adopted simultaneously with the emission control policy S2. The policies are intended to result in a Bangkok automobile fleet that is slightly more efficient than the United States new car standards, with an equivalent level of emissions.

Policies S^*a and S^*b probe the use of demand management to improve environmental conditions and conserve energy. Policy S^*a focuses on an area control initiative similiar to the one described in JICA and which is implemented in Singapore. An important feature of this policy is the shift of infrastructure investment in this area into rail or skytrain technologies, pedestrian paths, and bicycle paths. Policy S^*b is based on a program now in use in Mexico City which has almost equal congestion and even worse air pollution than Bangkok.

Policy S5 is as comprehensive a policy as might be imagined at the present time, it combines both fuel shift and technology- based air pollution control strategies (S2 and S3) with a firm energy efficiency policy (S4-a). It also includes the quiet zone policy of S^*a.

Table 5-1 Transportation Policy Options Structure

S1	Base Case:	New infrastrucuture as indicated in SPURT and JICA reports; no energy or emissions policies.
S2	Controls:	Lead and sulfur removed from transportation fuels; Type 4 emission controls adopted.
S3	Fuel Shift:	Urban automobile and pickup fleet shifted to LPG, samlors use LPG, buses use Compressed Natural Gas (CNG), and all vehicles including two- and four-stroke motor cycles have Type 4 emission controls.
S4-a	Standards:	Emission controls required and fuel economy standards adopted for automobiles and light trucks; from 11 to 8 liter/100 km @24 km.
S4-b	Pricing:	Emission controls required and fuel price is doubled due to external events or taxation policy; price elasticity assumed to be -.46 and response in terms of purchase of more efficient automobiles and light truck resulting in 8 liter/100 km @24 kmh.
S5	Comprehensive Policy:	Combination of fuel shift (S3), emission controls(S2), fuel economy standards (S4-a), and area control (S^*a); the scenario is a major commitment to energy conservation and air pollution prevention.[1]

[1] There are specific policy options for transportation only.

S^*a Area Control: Emission controls required and automobile, pickup truck, motorcycle, and samlor traffic is limited in the central business district by means of a toll/ permit system; infrastructure for rail, walking, and bicycles developed including reintroductionof pedicabs.

S^*b Use restrictions: Emission controls required and auto-mobiles, pickup trucks, and motorcycles are prohibited from use for two days per week.

EMISSION CALCULATIONS MODEL

Each of the policy options considered affects fleetwide emissions somewhat differently. They necessitate the capability to model expected in-use emissions for different vehicle and fuel types at different speeds and with differing pollution control equipment.

No single existing model is comprehensive enough to treat all the vehicles and conditions. The model used for estimating emissions for automobiles, pickup trucks, motorcycles, and light and heavy duty diesel vehicles is MOBILE 4 (U.S. EPA 1989). The model was applied using a 1976 United States emissions rate reference fleet (pre-catalytic control technology or Tech-2) and a 1990 United States emissions reference fleet to reflect the effect of catalytic converter controls technologies (Tech-4). These are used to represent fleet emissions characteristics before and after controls requirements.

An important determinant of emissions rates is vehicle speed. Thus, emissions rates were calculated at idle, 8 km/hr, 16 km/hr, 24 km/hr, and 32 km/hr average speeds using the model both with and without catalytic converters for specific vehicle modes. Estimated emisssions rates under these conditions are shown in Tables 5-2 to 5-4 for CO, HC, and NOx. The differences in emission levels between the Tech-2 and Tech-4 technologies are shown in these tables by comparing the left and right side of the tables. The tables are organized by vehicle type on the left and mean speed across the top of each section. The top half of the table is in terms of grams per mile while the lower half is shown in terms of grams per kilometer.

Table 5-5 provides the base emissions rates for SPM, SO2, lead, and benzene, and Table 5-6 shows the fuel consumption multipliers related to speed that are used in adjusting the base emission levels in Table 5-5. As previously noted, these factors along with those for alternate fuels came from a variety of sources and are applied with the authors' judgment to best match MOBILE 4 assumptions regarding in-use average emissions rates. Table 5-5 is organized in a similar fashion to Tables 5-2 to 5-4 except that no speed range is provided. Emission levels, however, can be adjusted for speed using the adjustment factors shown in Table 5-6.

Daily trip generation (adjusted) and total annual trips in all of the policies with the exception of $S^{*}a$ and S5 are shown in Table 5-7. These trip numbers are modified JICA values and show the 69 percent increase in travel anticipated by JICA. Although this is already a substantial increase in travel, the SPURT team anticipates travel to increase by more than 200 percent, i.e., by more than a factor of 3 (see appendix B2).

TRANSPORTATION POLICY MEASURE EVALUATION

Energy conservation and air pollution reduction offer large potential benefits to Thailand. There are important and necessary benefits provided by the transportation system. The challenge to policy makers is determining the optimal mix of transportation services, energy conservation, and environmental protection. Failure to provide necessary transportation infrastructure can choke the economy. Equally, failure to protect the environment, particularly in a country that has a large tourism sector, can choke the economy as well.

A recent innovation in planning has been the emergence of integrated resource planning or what has also been called, particularly in electric utility planning, least-cost planning (Hanson et al. 1990). The fundamental objective of least-cost planning applied to transportation is the provision of transportation services at the least possible cost. What differentiates least-cost planning from traditional transportation planning are two key concepts. The first is that transportation needs (accessibility) can be met with both supply-side *and* demand-side measures. In other words, to move a person from one point to another in a highly congested situation, capacity can be added or demand controlled so as to make capacity available. The second key concept is that environmental and other costs must be considered on equal footing with traditional transportation costs. The key to policy is then the selection of the best combintation of options, considering all costs.

In this section, the policies outlined in Table 5-1 are considered in terms of:

1. The cost of implementation.
2. The effect on energy use and costs, emissions and air pollution, and travel time.
3. The effect on emissions and general air pollution.
4. Other important considerations in implementing the policy.

The comparisons are based on results of the model described in this chapter. The point of comparison is the Base Case or policy S1 as described in Table 5-1. *In using these results for policy evaluation, we stress that the results for 1989 have a range of uncertainty on the order of 15 percent. The results for the year 2006 are obviously subject to great uncertainty. The policy analyses, however, are internally consistent and provide a valid basis for comparing policy options.*

Policy S1: Base Projection

The results of policy S1 in terms of energy use and overall emissions in 1989 and 2006 are shown in Table 5-8. Energy use increases by a factor of 3 during the period. Contributing to the increase in energy use is the continuing shift to private motor vehicles due to rapid growth in the Thai economy. As noted earlier congestion levels and therefore travel times per kilometer do not improve, the provision of added infrastructure is just able to hold congestion levels constant at the city center while the area of this high congestion level expands outward from the city center.

Emission levels increase by over a factor of 3 for CO, HC, and SPM, and by over a factor of 2 for NOx. Due to the lead reduction currently planned, lead emissions will grow by only 14 percent. Emissions grow at greater levels than travel due to the greater areal extent of congestion and the greater reliance on private motor vehicles, which as indicated are much more energy intensive than public transit.

Because Bangkok already exceeds WHO guidelines for air pollution, certainly in regards to CO and SPM, and most likely in terms of lead, it may be concluded from these results that air pollution by the year 2006 will more regularly exceed acceptable levels. Higher peak concentrations will occur over a broader geographic area for a much larger exposed population. Only the adoption of pollution limiting policies will prevent this from happening.

Policy S2: Emission Controls

An important policy option for reducing transportation pollution emissions is to adopt vehicle emission controls. This policy has been vigorously adopted in Canada, Japan, and the United States, and is being adopted in much of Europe and other parts of the world at the present time. This policy necessitates the refinery level modification of gasoline and diesel fuel to directly reduce acid gas and lead emissions from the motor vehicle fleet. In turn, removal of these exhaust stream contaminants allows for the use of advanced pollution control technologies on motor vehicles to reduce volatile and reactive hydrocarbon (including benzene and other toxins), carbon monoxide, particulate, and nitrogen oxide emissions.

The group of policies contained in this strategy represent a technology-based reduction in air emissions. The strategy can be viewed as either a stand-alone option or one to utilize in conjunction with various demand management or fuel switching policies.

Critical Policy Elements

- Introduction of lead-free gasoline at all service stations.
- Rapid phase-out of 0.15 grams per liter lead gasoline in the urban market.
- Desulfurization of high speed diesel fuels to a level below 0.5 percent sulfur content (modeled at either 0.25 percent or 0.1 percent sulfur content depending on the analysis).
- Establishment of automobile and light truck emissions standards for new vehicles at the Technology 4 level (that level necessitates either emerging engine designs or catalytic converters with existing engines, and is equivalent to current Japanese, United States, and European Economic Community (EEC) new design practices).
- Establishment of diesel emissions standards for new vehicles at the current diesel engine design standard (for NOx, SPM, and benzene/toxin reduction).
- Establishment of a certification structure to determine compliance for various vehicle classes.

The production of lead-free gasoline requires significant modification of refinery processes and the use of an octane enhancer (alcohol-based blend like ethanol/methanol or ether-based blend like MTBE) to substitute for tetraethyl lead (see Appendix B1 for details).

Policy Cost

This strategy encompasses three basic costs:

- Investment in refinery structure (some investment isalready scheduled to occur) and octane enhancer additives.
- Individual vehicle buyer investment in improved vehicleengine and/or emission control design.
- Fiscal support for a requisite testing and certification effort to determine manufacturer compliance.

Total refinery cost is presented in terms of a cost per unit of energy. This cost includes enhancing base fuel octane with extended fuel refinement, substitution of alcohol based blends (ethanol, methanol) or ether-based blends (MTBE, etc.) for tetraethyl lead as an octane enhancer, and installation and utilization of expanded desulfurization capacity.

Unit fuel costs are assumed incremental to the cost needed to produce the maximum 0.15 grams per liter regular and premium gasoline projected for 1993.

International experience in lead removal indicates the maximum refinery cost for lead removal to be 0.5 baht per liter, some of which will be incurred earlier to meet the 0.15 grams per liter lead standard. Additional refinery cost for desulfurization should average 0.2 baht per liter. This includes the desulfurization cost required to reach the projected 0.5 percent regulation for diesel starting in 1993.

New vehicle emissions standards result in modest on-engine control equipment combined with catalytic converter investment. This control level costs about 20,000 baht per typical new gasoline automobile assuming that no taxes are placed on pollution control equipment and ignoring potential efficiency gains from redesign that would reduce the cost of fuel over the lifetime of the vehicle.

The fiscal implications for compliance certification can be minimized if existing international standards are adopted or if specific engine class and control equipment combinations used in other countries are required. Otherwise fiscal cost estimates must include the development of an emissions testing facility for certification purposes. Such an effort is proposed as part of the 1991/92 transportation emissions monitoring initiative.

Policy Impact

This policy affects local and regional air pollutant emissions, concentrations, and deposition. The emissions modeling for 19 urban zones shows a significant air quality improvement for the regional acid gases and reactive hydrocarbons (non-methane), along with more localized CO, Pb, SPM, and benzene/toxins air quality improvement.

From an acid rain control perspective, the average cost per ton removal for SO2 is pojected at 16,000-25,000 baht per ton. From an urban air quality perspective, lead has been shown to be the most critical of all urban air toxics in terms of direct negative health impact on the broadest population base in almost any major urban area still dependent on the use of leaded fuel.

The results of Policy S2 are summarized in terms of aggregate emissions in Table 5-9. SOx and lead emissions fall drastically despite the growth of travel and energy use. Hydrocarbons also show a modest reduction from the 1989 levels. CO shows a large reduction from uncontrolled 2006 levels due to the controls but still is twice the 1989 level. NOx and SPM also have significantly reduced emission levels compared to the 2006 levels without controls, but nevertheless show a major increase relative to 1989.

The conclusion to be drawn from this scenario is that a *new vehicle standards control policy is very effective in reducing emissions.* However, even considering this effectiveness once established, *CO and SPM will continue to present a serious and growing problem for air quality in Bangkok.*

A more stringent strategy to reduce emissions in Bangkok is to combine vehicle emission controls with a fuel shift where (1) 25 percent and (2) all new automobiles, pickups, and taxis sold for use in the Bangkok region are manufactured to use LPG, and the bus fleet is shifted to CNG.

Critical Policy Elements

- The Thai refined products mix is altered to maximize LPGproduction and internal refinery energy consumption istuned to the use of heavier fuels (with controls)
- A substantial increase in LPG imports would be required
- Implementation of other features of Policy S2
- A significant portion of the domestically assembled light vehicle fleet is manufactured for LPG—large buses would be assembled for CNG use

Policy Cost

This policy could reduce the cost of vehicle manufacture as those vehicles which are manufactured for LPG would be slightly less costly in mass production than gasoline and diesel vehicles equipped with full Tech-4 technologies (assuming diesel engine exhaust treatment). This results from the lower typical cost of oxidation controls compared to oxidation/reduction controls (using a lean burn technology). The scenario assumes a lesser NOx reduction potential for the LPG substitute vehicles compared to the base controlled gasoline vehicles (on a par with diesel vehicles). For details see Appendix B1-1.

There would also be a modest energy efficiency advantage for vehicles optimized to run on the gaseous fuels. Costs would be incurred at the refinery in terms of altering the mix of output. Importing LPG would most probably be somewhat more costly than importing and refining gasoline, but this depends on the regional value of the lighter refinement/gas separation products.

Policy Impact

The most important consequence of the fuel shift strategy is that it further addresses the problem of CO, bringing the aggregate emission level in 2006 down to 1.4 million tons, which is only 30 percent above the level in 1989. It specifically addresses the emissions concentrations associated with the high traffic congestion zones.

The policy also results in reduced levels of NOx. Other benefits of the fuel shift policy are a reduction in energy use of 10 percent due to the efficiency advantage of gaseous-fueled vehicles. HC emissions increase slightly overall but are made up of a much less toxic mix of carbon compounds than in the Controls Scenario S2.

Policies S4-a and S4-b: Standards and Pricing

Strategies S4-a and S4-b are discussed together as they are designed to accomplish the same objective of reducing energy use in the Bangkok urban transportation system. The policies are geared towards the most energy intensive aspect of the systems, the automobiles, pickup trucks, and taxis as shown in columns 3 and 4 of Table 5-8. Policy S4-a accomplishes a 20 percent to 30 percent reduction in energy use in these vehicles, and an 18 percent reduction in all passenger transport by imposing a fuel economy standard of 8 liters per 100 kilometers on all new vehicles. For comparison, automobiles using premium gasoline in 1984 achieved 11.0 liter per 100 kilometers (NESDB 1987).

The United States is the only country to have adopted fuel economy standards and there is agreement, for the most part, that the policy has been extremely successful. The current United States standard is nominally 8.55 liters per 100 kilometers. Because of the adjustment necessary from the dynamometer to actual road conditions, the true level is about 9.8 liters per 100 kilometers. Even before the Iraqi invasion of Kuwait, the notion of increasing the standard in the United States was discussed as a strategy to help reduce United States oil imports. A standard in the range of 6.7 to 5.9 has been mentioned, although the actual efficiency would not be as great if the current testing method is kept.

An alternative means of achieving equal savings of energy is through a fuel pricing policy. If Thai drivers responded to fuel price increases in the long run by adjusting the efficiency of the vehicles they purchase (this would certainly be part of any response), then some price exists which would result in an 8 liter per 100 kilometers efficiency. A study by Ashakul (1985) found that the price elasticity of gasoline was -.65. If that is the case, if the elasticity is accurate for large changes in price, and if gasoline prices in Thailand were doubled from 8.45 baht per liter to 16.90 baht per liters (the same real price as in 1982), the resulting efficiency would be about 7 liter per 100 kilometers. Noting that European efficiencies are in the range of 9 to 10 liters per 100 kilometers despite prices in the vicinity of 17 baht, it would appear that an elasticity of -.65 is not plausible. An elasticity of -.46 results in an 8 liters per 100 kilometers efficiency and is assumed here. It must be noted, however, that *fuel economy standards are a surer way to achieve this large energy efficiency improvement* as even the assumed elasticity of -.46 is, in our judgment, probably too large.

Critical Policy Elements

Either efficiency improvenment strategy may prove to be politically difficult to adopt. If the current difficulty in the Middle East results in a more than short-term loss of oil production, external events could result in a large price increase. Otherwise, government imposed price increases would be necessary.

The difficulty with the standards is that the government would have to set up a testing center for certifying vehicles and would have to find an agreement with the domestic vehicle assembly industry. A substantial penalty for noncompliance would have to be set and enforced. As with the emissions standards for new vehicles, efficiency standards modeled on an external set of standards would probably be the easiest to establish and enforce.

Policy Cost

The cost of a more efficient vehicle fleet is difficult to ascertain. While innovation and lighter materials such as aluminum and plastic can be more expensive, a number of the smaller and less costly vehicles currently available in Thailand come rather close to meeting the standard at a mean speed of 32 or even 24 kilometers per hour. The difficulty is for the drivers who demand larger vehicles as a matter of personal preference.

Policy Impact

As noted above, the impact of a fuel economy standard, and a doubling in the price of fuel if the elasticities are accurate, would result in an 18 percent reduction in energy use in the year 2006 compared to the case without controls (S1). Either policy would have minor direct costs to the government or to individuals and in the case of a pricing policy where the underlying cost of oil is not the source of the doubling, the policy could net the government a large amount of revenue. Vehicle owners, on the other hand, would incur increased fuel cost for any elasticity less than 1.0 in absolute terms.

Policies S*a and S*b: Area Controls and Use Restrictions

These policies are a direct response to a major dilemma. The dilemma is that it is highly desirable to reduce congestion on Bangkok's roads, but enough roadway cannot be provided to reduce congestion levels. Congestion relief would result in shorter travel times for a fixed set of trips, higher fuel economies, and lower emissions rates. Demand management policies, however, could be imposed which could reduce congestion.

Policy S*a borrows a policy pioneered in Singapore and now adopted in a number of cities such as Athens and Oslo, which is to charge a fee, using tolls or a sticker system, to enter the central portion of the city. The objective is to reduce the vehicle-kilometers by motorized vehicles by some combination of car pooling, shifting from private vehicles to mass transit, and shifting from private vehicles and mass transit to walking and bicycles. Policy S*a sets a schedule of fees for various types of vehicles so as to result in a 40 percent decline in vehicle-kilometers, and an increase in average speed to 24 kilometers per hour in an area bounded by Sri Ayutthaya Road, Wittayu Road, Sathon Road, and the Chao Phraya River (roughly corresponding to zones 1 and 4). This area was identified in the JICA study.

In order to reduce the vehicle-kilometers and provide for access, investment would be required to increase mass transit, with light rail and/or a sky train being very appropriate. In addition, investment would be required for pedestrian paths to provide for unserved walking demand.Some improvements in the sois, including bridges at selected locations, is required to provide for access to mass transit by means of bicycles and pedicabs, which would be reintroduced into this area of Bangkok. Motor vehicles would be banned on many of the sois for most hours. Finally, borrowing on the extremely successful experience of many cities in Europe over the last two decades, certain important central shopping and cultural areas would be designated as pedestrian only zones. The overall purpose of the policy is to provide for what might be termed a quiet zone with a high level of access under pleasant conditions.

Policy S*b is a more drastic policy, one adopted and pioneered in Mexico City. The policy is to ban the use of all private vehicles used in Bangkok for two days each week, based on a sticker system which would allocate the reduction of traffic over seven days. The objective is to reduce the number of automobiles, pickup trucks, and motorcycles by 29 percent on any given day and increase average vehicle speed in all zones.

Critical Policy Elements

The quiet area policy would require considerable will and vision. Necessary elements include moving ahead with the sky train, light rail, and/or improved bus service. In addition, investment in pedestrian and bikeways is required.

The vehicle ban is primarily a matter of political will and the willingness to enforce, including severe penalties for violators.

Policy Cost

A determination of costs for the quiet zone requires a detailed design of the area. It would appear, however, that a net increase in investment is not required if the new mass transit systems are assumed to move forward in any case. Because of the reduction in congestion, large travel time savings would occur within the area.

The cost of the vehicle sticker systems is primarily the cost of administration, including enforcement. Fees paid for violation could be set to pay for the cost of administration. Because of the reduction in congestion, some travel time savings would occur throughout Bangkok.

Policy Impact

The results of the quiet area policy are a decline in energy use and CO emissions in Bangkok of 9 percent and 12 percent, respectively, compared to Case S2. Energy use and emissions in the restricted area, Bangkok's most congested, fall precipitously by more than 50 percent.

The impact of the vehicle use restriction policy is a reduction of 43 percent in energy use and 59 percent in CO emissions. These dramatic results assume strict adoption and enforcement of the policy. They point out the large impact of congestion on energy use and emissions. To the degree that the vehicle speed effects are overestimated (the assumption is an 8 kilometers per hour improvement in each zone), these reductions will be overstated.

Policy S5: Comprehensive Policy

The comprehensive policy is a combination of some of the previously discussed policies which are chosen to significantly improve the environment in Bangkok and reduce energy use. Specifically, this policy includes the adoption of emission controls (S2), fuel shift (S3), fuel economy standards (S4-a), and area control (quiet zone $S^{*}a$).

The impact of this combination of policies results in a net overall improvement of air quality in Bangkok despite greater travel. However, even with this directed effort, projected CO emissions are still 14 percent worse than in 1989. SPM is also greater than in 1989, although the mix of particulate matter is less harmful. HC, NOx, SOx, and lead are below their estimated 1989 levels as shown in Table 5-9. Overall personal transportation energy use is reduced by 33 percent from the Base Case projection (S1) for 2006.

Table 5-2 Emission Factors by Fuel/Vehicle Pair

Adjusted for Average Speed of Zone in Urban Environment

(Grams/Mile)

Carbon Monoxide (CO)		Average Speed in Km/Hr:	Uncontrolled Emissions - ie, Tech II Vehicles 0-1	8	16	24	32	Controlled Emissions - ie, Tech IV Vehicles 0-1	8	16	24	32
Gasoline:	LD Cars and Trucks	-	980	310	150	100	80	297	108	55	37	29
	4 Stroke Motorcycle	-	280	130	70	50	40	165	113	54	35	26
	2 Stroke Motorcycle	-	238	111	60	43	34	140	96	46	30	22
LPG:	Small 3 & 4 Wheel	-	21.0	13.0	10.5	7.5	6.0	10.5	6.5	5.3	3.8	3.0
	Taxis	-	49.0	23.3	15.0	10.0	8.0	24.5	11.6	7.5	5.0	4.0
Diesel:	LD Cars, Trucks, Vans	-	19.0	6.0	4.0	3.0	2.0	22.3	4.8	3.3	2.3	2.0
	HD Trucks & Buses	-	53.0	41.0	28.0	20.0	15.0	49.5	32.0	22.0	16.0	12.0
Nat Gas:	LD	-	Base Case assumes no use of CNG.					24.5	11.6	7.5	5.0	4.0
(Compressed- CNG)	HD	-	Base Case assumes no use of CNG.					36.8	29.1	26.3	22.5	18.0

(Grams/Kilometer)

Carbon Monoxide (CO)		Average Speed in Km/Hr:	Uncontrolled Emissions - ie, Tech II Vehicles 0-1	8	16	24	32	Controlled Emissions - ie, Tech IV Vehicles 0-1	8	16	24	32
Gasoline:	LD Cars and Trucks	-	609	193	93	62	50	184	67	34	23	18
	4 Stroke Motorcycle	-	174	81	43	31	25	102	70	34	22	16
	2 Stroke Motorcycle	-	148	69	37	26	21	87	60	29	18	14
LPG:	Small 3 & 4 Wheel	-	13.0	8.1	6.5	4.7	3.7	6.5	4.0	3.3	2.3	1.9
	Taxis	-	30.4	14.4	9.3	6.2	5.0	15.2	7.2	4.7	3.1	2.5
Diesel:	LD Cars, Trucks, Vans	-	11.8	3.7	2.5	1.9	1.2	13.9	3.0	2.0	1.4	1.2
	HD Trucks & Buses	-	32.9	25.5	17.4	12.4	9.3	30.7	19.9	13.7	9.9	7.5
Nat Gas:	LD	-	Base Case assumes no use of CNG.					15.2	7.2	4.7	3.1	2.5
(Compressed- CNG)	HD	-	Base Case assumes no use of CNG.					22.8	18.1	16.3	14	11.2

Table 5-3 Emission Factors by Fuel/Vehicle Pair

Adjusted for Average Speed of Zone in Urban Environment

(Grams/Mile)

Hydrocarbon (Non-Methane)		Average Speed in Km/Hr:	Uncontrolled Emissions - ie, Tech II Vehicles 0-1	8	16	24	32	Controlled Emissions - ie, Tech IV Vehicles 0-1	8	16	24	32
Gasoline:	LD Cars and Trucks	-	72	26.5	16.7	13.4	11.9	26.3	10.2	6.1	4.8	4.1
								(most 3-way catalytic converters - some old)				
	4 Stroke Motorcycle	-	150	32.6	18.1	13.2	11.0	64.3	10.8	7.2	5.9	5.4
			(Mobile4)					(Mobile4)				
	2 Stroke Motorcycle	-	125	60	40	30	25	64.3	10.8	7.2	5.9	5.4
			(Lower Idle Slope-32gpm ratioed to 4 Stroke inc) evap / lit suggests controls to same level									
LPG:	Small 3 & 4 Wheel	-	83	17.9	10	7.3	6.1	41.3	9	5	3.6	3
			(Ratioed to Gasoline 4 stroke MC equiv.)									
	Taxis	-	40	14.6	9.2	7.4	6.5	19.8	7.3	4.6	3.7	3.3
			(Ratioed to Gasoline equiv. -55%)					(50% reduction to existing)				
Diesel:	LD Cars, Trucks, Vans	-	7.0	1.9	1.5	1.2	1.0	7.0	1.5	1.1	0.9	0.8
								(newer LD designs)				
	HD Trucks & Buses	-	22.0	9.4	7.4	5.9	4.8	17.6	4.8	3.8	3.0	2.5
			(Mobile4)									
Nat Gas: (Compressed- CNG)	LD	-	Base Case assumes no use of CNG.					6.6	2.6	1.5	1.2	1.0
								(75% reduction from Tech 4 Fleet)				
	HD	-	Base Case assumes no use of CNG.					26.3	10.2	6.1	4.8	4.1
								(Size ratioed to LD equiv)				

(Grams/Kilometer)

Hydrocarbon (Non-Methane)		Average Speed in Km/Hr:	Uncontrolled Emissions - ie, Tech II Vehicles 0-1	8	16	24	32	Controlled Emissions - ie, Tech IV Vehicles 0-1	8	16	24	32
Gasoline:	LD Cars and Trucks	-	45.0	16.5	10.4	8.3	7.4	16.3	6.3	3.8	3.0	2.5
	4 Stroke Motorcycle	-	93.0	20.2	11.2	8.2	6.8	39.9	6.7	4.5	3.7	3.4
	2 Stroke Motorcycle	-	78.0	37.3	24.8	18.6	15.5	39.9	6.7	4.5	3.7	3.4
LPG:	Small 3 & 4 Wheel	-	51.0	11.1	6.2	4.5	3.8	25.6	5.6	3.1	2.3	1.9
	Taxis	-	25.0	9.1	5.7	4.6	4.1	12.3	4.5	2.9	2.3	2.0
Diesel:	LD Cars, Trucks, Vans	-	4.0	1.2	0.9	0.7	0.6	4.3	0.9	0.7	0.6	0.5
	HD Trucks & Buses	-	13.0	5.8	4.6	3.7	3.0	10.9	3.0	2.4	1.9	1.6
Nat Gas: (Compressed- CNG)	LD	-	Base Case assumes no use of CNG.					4.1	1.6	0.9	0.7	0.6
	HD	-	Base Case assumes no use of CNG.					16.3	6.3	3.8	3.0	2.5

Table 5-4 Emission Factors by Fuel/Vehicle Pair

Adjusted for Average Speed of Zone in Urban Environment

(Grams/Mile)

Nitrogen Oxids (Nox)		Average Speed in Km/Hr:	Uncontrolled Emissions - ie, Tech II Vehicles 0-1	8	16	24	32	Controlled Emissions - ie, Tech IV Vehicles 0-1	8	16	24	32
Gasoline:	LD Cars and Trucks	-	8.3	3.5	3.2	3.2	3.4	3.8	1.9	1.7	1.6	1.6
	4 Stroke Motorcycle	-	0.6	0.4	0.3	0.3	0.3	2.4	0.8	0.7	0.7	0.8
	2 Stroke Motorcycle	-	0.6	0.4	0.3	0.3	0.3	0.6	0.4	0.3	0.3	0.3
							(4 Stroke Up : Size & CO/HC Control - 2 Stroke No Chang)					
LPG:	Small 3 & 4 Wheel	-	5.0	2.1	1.9	1.9	2.0	2.3	1.1	1.0	1.0	1.0
	Taxis	-	8.3	3.5	3.2	3.2	3.4	3.8	1.9	1.7	1.6	1.6
							(Moderate Control Level - Not Total 3-Way/EGR)					
Diesel:	LD Cars, Trucks, Vans	-	20.1	3.1	2.6	2.2	2.0	18.1	2.5	2.0	1.8	1.6
	HD Trucks & Buses	-	55.2	45.2	37.5	32.2	28.7	25.0	28.9	24.0	20.6	18.4
							(HD Potential Lower - LD Incl Some Traps, 1990)					
Nat Gas:	LD	-	Base Case assumes no use of CNG.					3.8	1.9	1.7	1.6	1.6
(Compressed- CNG)												
	HD	-	Base Case assumes no use of CNG.					9.5	7.6	6.8	6.4	6.4
							(LD Assumes LPG Equiv / Hd Only Mid Level Control)					

(Grams/Kilometer)

Nitrogen Oxids (Nox)		Average Speed in Km/Hr:	Uncontrolled Emissions - ie, Tech II Vehicles 0-1	8	16	24	32	Controlled Emissions - ie, Tech IV Vehicles 0-1	8	16	24	32
Gasoline:	LD Cars and Trucks	-	5.2	2.0	2.0	2.0	2.1	2.4	1.2	1.1	1.0	1.0
	4 Stroke Motorcycle	-	0.4	0.2	0.2	0.2	0.2	1.5	0.5	0.4	0.4	0.5
	2 Stroke Motorcycle	-	0.4	0.2	0.2	0.2	0.2	0.4	0.2	0.2	0.2	0.2
LPG:	Small 3 & 4 Wheel	-	3.1	1.3	1.2	1.2	1.3	1.4	0.7	0.6	0.6	0.6
	Taxis	-	5.2	2.2	2.0	2.0	2.1	2.4	1.2	1.1	1.0	1.0
Diesel:	LD Cars, Trucks, Vans	-	12.5	1.9	1.6	1.4	1.2	11.2	1.6	1.2	1.1	1.0
	HD Trucks & Buses	-	34.3	28.1	23.3	20.0	17.8	15.5	18.0	14.9	12.8	11.4
Nat Gas:	LD	-	Base Case assumes no use of CNG.					2.4	1.2	1.1	1.0	1.0
(Compressed- CNG)												
	HD	-	Base Case assumes no use of CNG.					5.9	4.7	4.2	4.0	4.0

Table 5-5 Adjusted for Average Speed of Zone in Urban Environment

Fuel -Based Emission Factors		Average	1989 Tech II Vehicles SPM (GPM)	SO2 (GPM)	Lead (GPM)	Benzene (GPM)	2006 Fuel Controls SO2 (GPM)	Lead (GPM)	Tech IV Vehicles SPM (GPM)	Benzene (GPM)
			Average Emissions @ 24 Kph (Vary by Fuel Index)							
Gasoline:	LD Cars and Trucks	-	4.5	0.80	0.062	0.30	0.20	0.002	3.4	0.075
:assumes 95% S & 75% Pb emis rates and base .2% S & .45gpl Pb							(Pb=unleaded new & 0.15 GPL old)			
	4 Stroke Motorcycle	-	1.5	0.40	0.031	0.45	0.10	0.001	1.1	0.113
	2 Stroke Motorcycle	-	9.0	0.31	0.024	2.40	0.08	0.0008	6.8	0.600
(SPM value includes reentrained particulate per NAPAP area source							(S=0.05% or 75% less)		(SPM=25% Control)	
						(BENZENE =4% exh HC)			(B=75% Control)	
LPG:	Small 3 & 4 Wheel	-	3.0	0.80	na	0.09	0.12	na	2.3	0.023
	Taxis	-	4.0	1.20	na	0.13	0.18	na	3.0	0.033
	(assumes 0.3% sulfur in ave LPG)					(2% exh HC)	(S=0.05% or 85% less)		(SPM=25%,B=90%)	
Diesel:	LD Cars, Trucks, Vans	-	5.0	2.50	na	0.10	0.25	na	2.5	0.050
	HD Trucks & Buses	-	10.0	6.00	na	0.48	0.60	na	5.0	0.240
	(assumes 1.0% sulfur in light diesel - base year)						(S=0.1% or 90% less)		(SPM=50% Control)	
						(10% exh HC)			(B=75% Control)	
Nat Gas:	LD	-	Base Case assumes no use of CNG.				0.20	na	2.3	na
(Compressed- CNG)										
	HD	-	Base Case assumes no use of CNG.				0.10	na	3.8	na
							(S=0.05% - no additional control)			

Fuel -Based Emission Factors		Average	1989 Tech II Vehicles SPM (GPM/Km)	SO2 (GPM/Km)	Lead (GPM/Km)	Benzene (GPM/Km)	2006 Fuel Controls SO2 (GPM/Km)	Lead (GPM/Km)	Tech IV Vehicles SPM (GPM/Km)	Benzene (GPM/Km)
Gasoline:	LD Cars and Trucks	-	2.80	0.50	0.039	0.19	0.12	0.0013	2.1	0.047
	4 Stroke Motorcycle	-	0.93	0.25	0.019	0.28	0.06	0.0006	0.7	0.070
	2 Stroke Motorcycle	-	5.59	0.19	0.015	1.49	0.05	0.0005	4.2	0.373
LPG:	Small 3 & 4 Wheel	-	1.86	0.50	na	0.06	0.07	na	1.4	0.014
	Taxis	-	2.48	0.75	na	0.08	0.11	na	1.9	0.020
Diesel:	LD Cars, Trucks, Vans	-	3.11	1.55	na	0.06	0.16	na	1.6	0.031
	HD Trucks & Buses	-	6.21	3.73	na	0.30	0.37	na	3.1	0.149
Nat Gas:	LD	-	Base Case assumes no use of CNG.				0.12	na	1.4	0.000
(Compressed- CNG)										
	HD	-	Base Case assumes no use of CNG.				0.06	na	2.3	0.000

Table 5-6 Emission Factors by Fuel/Vehicle Pair

Absolute Fleet Efficiency		Average Speed in Km/Hr:	Adjusted for Average Speed of Zone in Urban Environment (Mile/Gallon) — Efficiency Comparisons - ie, Tech II Vehicles: 0-1	8	16	24	32	Efficiency Comparisons - ie, Tech IV Vehicles: 0-1	8	16	24	32
			(idle)	(5 mph)	(10 mph)	(15 mph)	(20 mph)					
Gasoline:	LD Cars and Trucks	-	na	9.2	15.0	19.0	21.7	na	10.5	17.2	21.8	24.9
	4 Stroke Motorcycle	-	na	18.1	29.2	37.7	44.2	na	18.1	29.2	37.7	44.2
	2 Stroke Motorcycle	-	na	23.5	38.0	49.0	57.5	na	23.5	38.0	49.0	57.5
				(2 stroke assumes higher efficiency of base design and smaller typical size)								
LPG:	Small 3 & 4 Wheel	-	na	13.7	22.1	28.4	33.0	na	13.7	22.1	28.4	33.0
				(assumes efficiency between 4-stroke and car based on weight)								
	Taxis	-	na	9.2	15.0	19.0	21.7	na	9.2	15.0	19.0	21.7
		(assumed gasoline equivalent btu)										
Diesel:	LD Cars, Trucks, Vans	-	na	7.9	12.8	16.3	18.6	na	7.9	12.8	16.3	18.6
				(assumes efficiency savings of light cars and light trucks)								
	HD Trucks & Buses	-	na	3.75	4.5	5.0	5.5	na	3.8	4.5	5.0	5.5
Nat Gas: (Compressed- CNG)	LD	-	Base Case assumes no use of CNG.					na	7.9	12.8	16.3	18.6
	HD	-	Base Case assumes no use of CNG.					na	3.8	4.5	5.0	5.5

Multipliers for Efficiency/Linked Pollutants (Particulates, CO_2, Benzene & Lead) — Indexed to 1.00 @ 24 kph or 15 mph

Relative Fleet Efficiency		Average Speed in Km/Hr:	Uncontrolled Emissions - ie, Tech II Vehicles: 0-1	8	16	24	32	Controlled Emissions - ie, Tech IV Vehicles: 0-1	8	16	24	32
Gasoline:	LD Cars and Trucks	-	na	2.07	1.27	1.00	0.88	na	2.06	1.27	1.00	0.87
	4 Stroke Motorcycle	-	na	2.08	1.29	1.00	0.85	na	2.08	1.29	1.00	0.85
	2 Stroke Motorcycle	-	na	2.08	1.29	1.00	0.85	na	2.08	1.29	1.00	0.85
LPG:	Small 3 & 4 Wheel	-	na	2.08	1.28	1.00	0.86	na	2.08	1.28	1.00	0.86
	Taxis	-	na	2.07	1.27	1.00	0.88	na	2.07	1.27	1.00	0.88
		(assumed gasoline equivalent btu)										
Diesel:	LD Cars, Trucks, Vans	-	na	2.06	1.27	1.00	0.88	na	2.06	1.27	1.00	0.88
	HD Trucks & Buses	-	na	1.33	1.11	1.00	0.91	na	1.33	1.11	1.00	0.91
Nat Gas: (Compressed- CNG)	LD	-	Base Case assumes no use of CNG.					na	2.06	1.27	1.00	0.88
	HD	-	Base Case assumes no use of CNG.					na	1.33	1.11	1.00	0.91

Table 5-7 Annual Trips in BMR by Zone

Zone	Trip Generation (Trips/day)				Annual Trips (Million Trips/Year)	
			Adjusted Trips			
	1989	2006	1989	2006	1989	2006
1	1,023,695	1,152,064	2,047,390	2,304,128	747	841
2	855,316	1,238,900	1,710,632	2,477,800	624	904
3	936,972	1,301,782	1,873,944	2,603,564	684	950
4	1,101,716	1,255,758	2,203,432	2,511,516	804	917
5	626,436	698,250	1,252,872	1,396,500	457	510
6	870,818	1,490,916	1,741,636	2,981,832	636	1,088
7	497,111	826,636	994,222	1,653,272	363	603
8	634,453	1,304,982	1,268,906	2,609,964	463	953
9	865,871	1,348,638	1,731,742	2,697,276	632	985
10	616,509	969,787	1,233,018	1,939,574	450	708
11	713,355	1,534,619	1,426,710	3,069,238	521	1,120
12	1,135,549	1,799,130	2,271,098	3,598,260	829	1,313
13	592,629	1,513,693	1,185,258	3,027,386	433	1,105
14	366,194	1,138,093	732,388	2,276,186	267	831
15	307,180	802,272	614,360	1,604,544	224	586
16	537,664	963,862	1,075,328	1,927,724	392	704
17	219,312	456,319	438,624	912,638	160	333
18	466,727	934,793	933,454	1,869,586	341	682
19	379,113	783,775	758,226	1,567,550	277	572
Total	12,746,620	21,514,269	25,493,240	43,028,538	9,305	15,705

Note: Adjustment Factor for Trips = 2.00

Source: Japan International Cooperation Agency Report (March 1990)

Table 5-8 Energy Use of Transport in BMR

	Total Energy Use (1000 TOE)		Energy Use/MM P-Km (TOE/MM P-Km)	
	1989	2006	1989	2006
- by Fuel Types	2,180.58	6,519.66	41.64	52.63
Premium Gasoline	620.34	2,175.24	11.85	17.56
Regular Gasoline	370.38	1,240.84	7.07	10.02
Diesel	1,015.43	2,817.46	19.39	22.74
LPG	174.43	286.13	3.33	2.31
- by Mode	2,180.58	6,519.66	41.64	52.63
Private Cars	591.53	2,082.28	61.05	69.67
Pickups-Trucks	667.54	2,349.84	64.88	74.04
MC	330.22	1,162.42	34.65	39.54
MC-Taxi	28.38	46.56	41.58	47.44
Bus-Minibus	378.40	575.92	18.99	20.10
Taxi	152.88	250.78	105.45	120.33
Samlor	15.39	25.25	40.02	45.67
Silor	16.23	26.63	39.27	44.81

Source: Thailand Development Research Institute (1990)

Table 5-9 Aggregate Emissions for the Year 2001 in BMR

(Unit : 1,000 Tons/Year)

	BASE CASE		S2	S3-A	S3-B	S4	S5-B	* S-A	* S-B
	1989	2006							
CO	1,075	3,830	2,081	1,362	1,206	2,081	1,060	1,835	850
HC *	295	976	250	245	154	250	140	227	136
NOx	46	104	71	40	9	71	8	66	58
SPM	116	376	261	236	159	261	144	236	198
SO2	23	11	11	7	3	11	2	10	8
LEAD	0.501	0.057	0.057	0.023	0.023	0.057	0.020	0.052	0.042

Note: * Non-methane

Source: Thailand Development Research Institute Estimates (1990)

Figure 5-1 : General Urban Growth Pattern

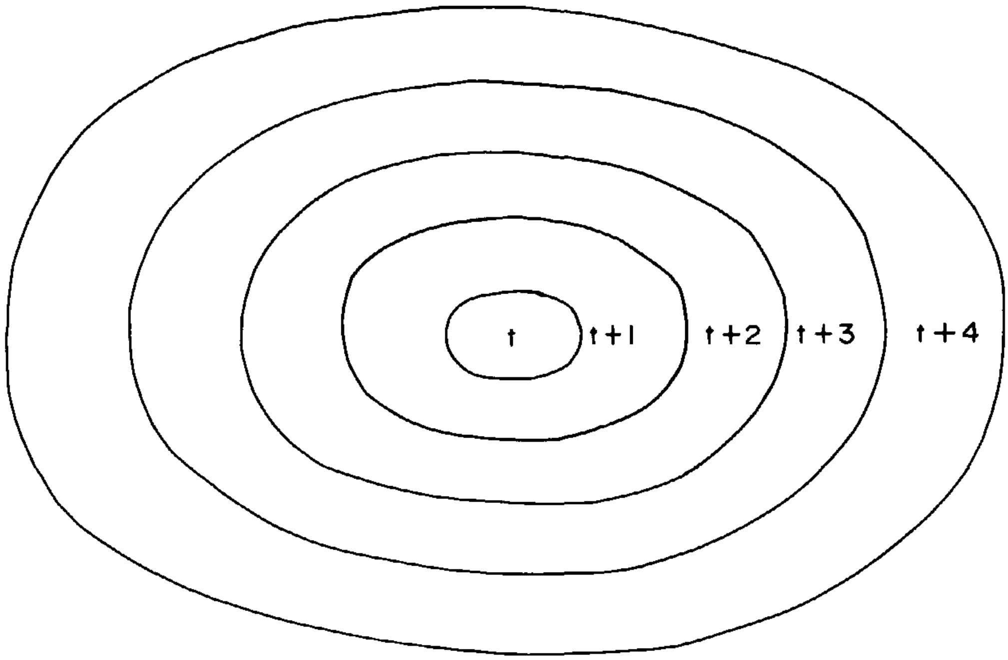


Figure 5-2 : Residential Density Patterns

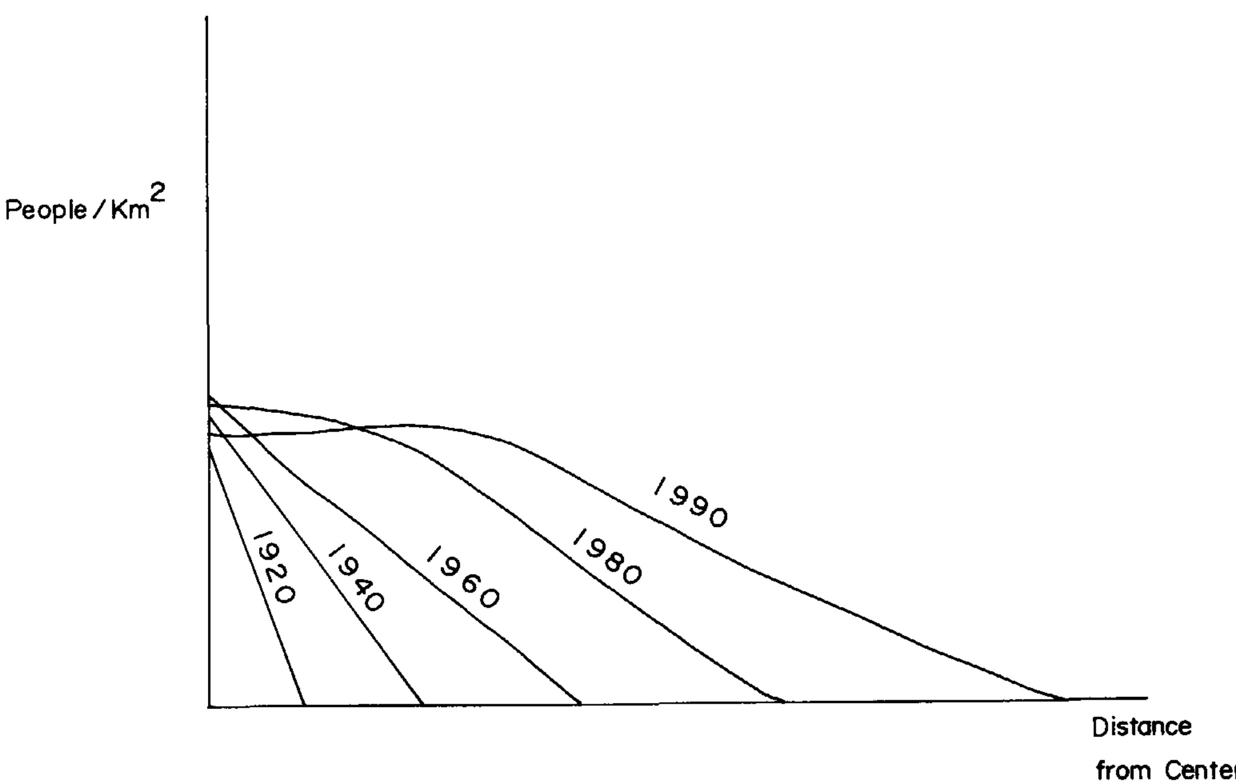
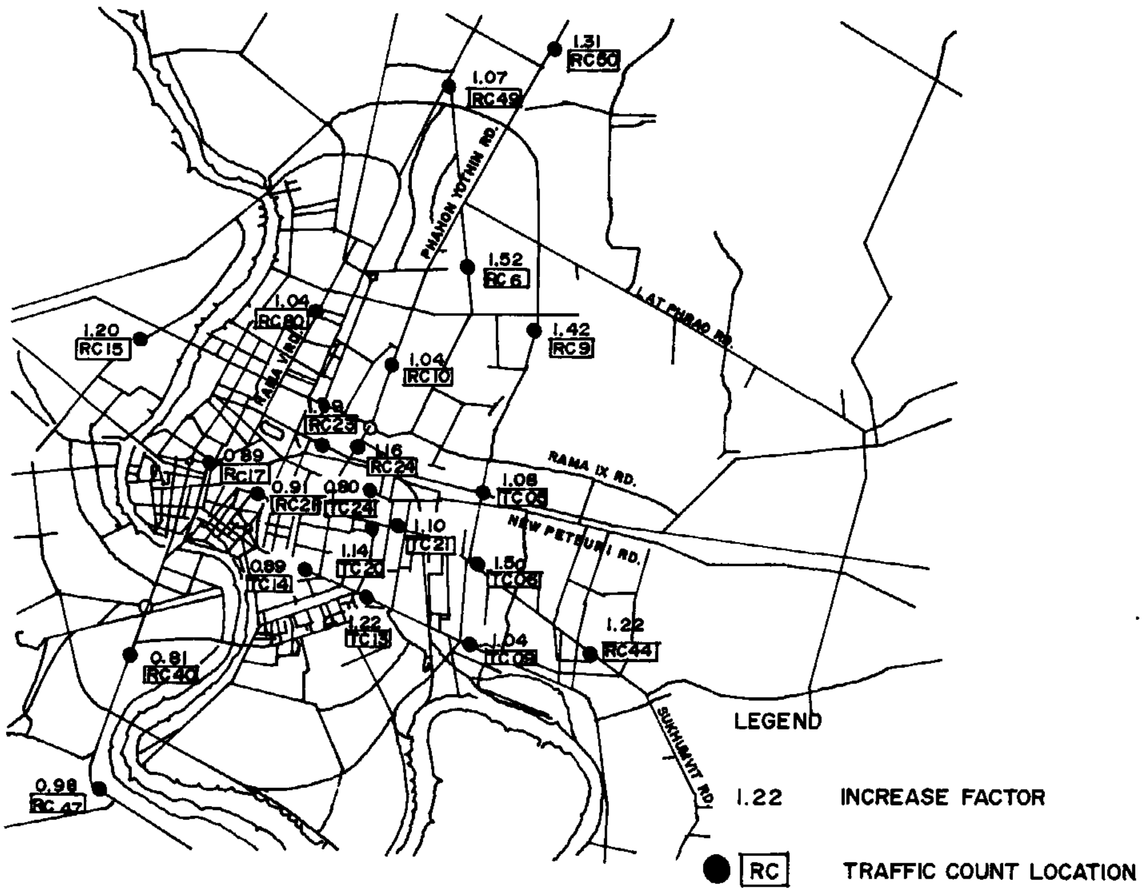


Figure 5-3. 12-Hour Traffic Volume Growth Factor

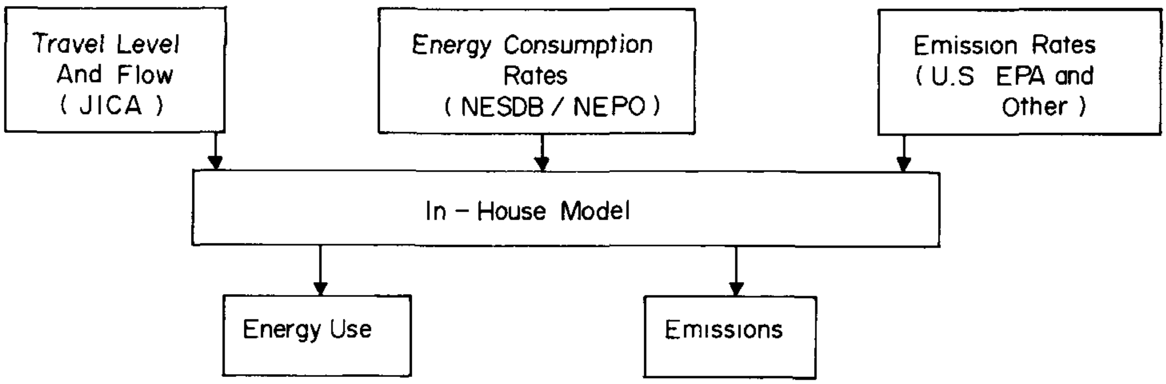


Source: JICA 1990, p.91

NOTE: GROWTH RATE 1989/1985

SOURCE: SIMR 1989

Figure 5-4 : Transportation Information Base



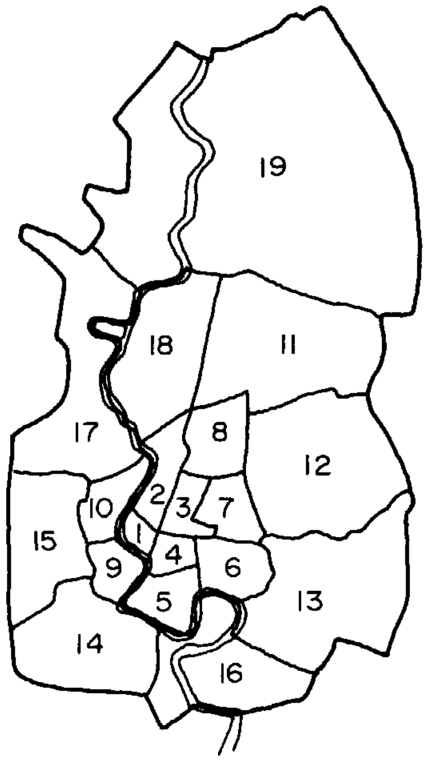


Figure 5-5 : Zone Division Inside the Study Area

Chapter 6

Industrial Energy Use and Its Implications for Effects on Air Quality in the Bangkok Metropolitan Region

INDUSTRIAL ENERGY DEMAND

Energy Consumption in the Industrial Sector

Energy is a major component of any economy, both as a necessary commodity and as an input in most other economic activities such as agriculture, industry, and transport. The industrial sector in Thailand accounted for an average share of 27 percent to 30 percent of total energy demand from 1979 to 1988. The future projection of energy demand in the industrial sector indicates a 31.6 percent to 34.5 percent share of total energy consumption from 1990 to 2011 (table 6-1). The distribution of total energy consumption from 1986 to 2011 has also shown that 57 percent to 62 percent of energy consumption by the industrial sector is in the BMR, as shown in Table 6-2.

Industrial Energy Demand by Fuel Type in the BMR

The industrial energy demand by fuel type consists of lignite, imported coal, natural gas, petroleum products, electricity, and renewable energy. Petroleum products and renewable energy are the major fuels used by the industrial sector in the BMR. Lignite and imported coal have small shares of fuel use when compared with petroleum products, but their annual growth rates of consumption are very high. From 1986 to 1988 the growth rates of lignite and imported coal increased by 55 percent, whereas petroleum products increased by 13 percent. The growth rates of imported coal and lignite consumption by the industrial sector will have significant implications for pollution in the BMR during the next 10 to 20 years.

In 1988 the industrial sector, which includes manufacturing, mining, and construction, accounted for 59.2 percent of total energy consumption in the BMR. In that year, oil made up 20.9 percent of the fuel use in the industrial sector, followed by renewable energy, electricity, coal and lignite, and natural gas with 21.5 percent, 12.4 percent, 39 percent, and 0.48 percent, respectively (table 6-3). Within industry, most of the fuel was consumed in the production of non-metals, basic metals, and textiles. Industry also makes extensive use of traditional fuels; both fuelwood and charcoal are used in producing non-metals, and bagasse is used as a boiler fuel in the sugar mills, roughly 1.37 million TOE were utilized in 1988.

The growth rates of industrial sector fuel use are consistent with the number of industrial boilers. There are 4,057 boilers in Thailand (KMIT 1989), 35 percent of these are in the BMR. Nearly 90 percent of these boilers are in the food and beverage, textiles, wood products, paper, and chemicals manufacturing industries. Next to industrial boilers, the cement industry will be the largest user of domestic lignite by 1991. Energy demand in the industrial sector by energy sources from 1986 to 2011 is shown in Table 6-3. It is notable that energy consumption in the industrial sector between 1991 and 1996 is high at 58 percent, with a slight increase to 60 percent in the year 2001 toward 2011. This is due to the expected economic growth rate of 6.98 percent during that period.

Within the manufacturing sector, food-processing is the major energy consumer, with 50 percent of industrial sector energy use, followed by textiles and non-metals (table 6-4). In the past, renewable energy has played a vital role as an energy input for industry, but the demand for modern energy has increased almost twice as fast as the demand for renewable energy since 1988. In the future, industry will be increasingly dependent on modern energy as its major energy input (table 6-3). The dependency on modern energy will have environmental implications in terms of air quality, because energy types in this group, i.e., fossil fuels, emit more gaseous pollutants than renewable energy.

TRENDS IN GASEOUS EMISSIONS FROM INDUSTRY IN THE URBAN AREA

Trends in Traditional Air Pollution Emissions

Traditional gaseous pollution is defined as gases from the combustion of fossil fuels and renewable energy, which consist of SO2, NOx, SPM, HC or VOC, CO2 and CO. High economic growth rates in recent years, and an industrial growth rate around 10 percent per year, have a significant impact on energy consumption due to the concentration of manufacturing in the BMR. There are four gaseous emissions from industry that are significant in term of emissions volume, and that should be given priority consideration in the BMR. They are SO2, SPM, CO2, and NOx.

Past and future projections of these gaseous emissions from the industrial sector are compared with emissions from other sectors in figures 6-1 to 6-4. In the past, from 1986 to 1988, the emission of SO2 was primarily from the energy sector. From 1991 to 2011, due to the growth of manufacturing in the BMR, industry will steadily increase its share of SO2 emissions from 35 percent and 41 percent in 1986 and 1988, respectively, to a very high share of 59 percent in the year 2011. The growth rate between 1991-2011 is expected to be 7.7 percent per year. For NOx, in terms of percentage share, contributions from manufacturing will be only 10 percent from 1991 to 2011, in terms of volume NOx is increased at a rate of 6.4 percent per year. Then CO2 gaseous emission contribution of the industrial sector from 1979 to 1988 was 23 percent on the average, second to that of the residential and commercial sector. The trend of CO2 emissions will rise from 1991 to 2011, with growth rates of 18 percent per year. Similar to other gaseous emissions from the manufacturing sector, SPM is increasing at a rate of 5.2 percent per year, and from 1991 to 2011 SPM from the manufacturing sector will be the major contributor with 49 percent to 56 percent of total SPM emissions.

Within the manufacturing sector, the gaseous emissions of SO2, NOx, CO2, and SPM vary in terms of manufacturing output, and also by the type of fuel used. For SO2, food-processing was the major emitter in 1986, but the trend is shifting. After 1991 textiles, non-metals, and other manufacturing will be the major sources of SO2. The trends in NOx and CO2 emissions remain the same, with food and textiles as the major contributors of these pollutants. For SPM, food-processing, non-metals and the paper industries are the major emitters (figures 6-5 to 6-8).

Table 6-5 shows the fuel costs and the fuel types used in the industrial sector and their related pollutants (SO2, NOx, CO2, and SPM) in tons of emission per one unit fuel. The cost of fuel is base on ton of oil equivalent, baht per KTOE. Among the eight types of fuel used in the industrial sector, lignite is considered to have the lowest cost in baht per KTOE, but in terms of gaseous emissions it emits NOx and SPM than other fuel types. The energy demand in the industrial sector by energy sources from 1991 to 2011 (table 6-3), shows that growth in lignite consumption will average 10 percent per year. The attractive low price of lignite is driving industries to convert their boilers to use lignite as their main energy source. The consequence of this conversion will be the emission of pollutants into the atmosphere without any emission controls under the present regulation of air emissions standards. Lignite fuel pricing should be one of the alternative measures considered in order to control the emission of air pollutants in urban areas, in addition to air emissions standards and control technology standards.

Control Scenarios of Industrial Air Pollution

This section will directly address the emissions reduction potential of the various modeled control scenarios for fuel use in the BMR. The scenarios' structures are built to address the major policy options and to allow for comparisons of gaseous emissions. There are six scenarios addressed in this analysis, they are:

S1	:	Base Case
S2-A	:	Moderate emission controls with implementation of pollutant control equipment
S2-B	:	Maximum emission controls with implementation of pollutant control equipment
S3-B	:	S2-B plus shifting of fuel dependency from solid fossil fuel to natural gas
S4-B	:	S2-B plus enhanced energy efficiency such as increased systems efficiency for energy consumption
S5-B	:	Combination of S2-B, S3-B, and S4-B

Table 6-6 shows the results of control scenarios by year and by type of emission for all gaseous emissions from the industrial sector. SO2, NOx and SPM are considered to be the most important in terms of environmental implications and their volumes of emission. The implementation of S2-A alone will reduce 45,000 tons and 150,000 tons of SO2 of emissions in the years 1996 and 2011, or 30 percent and 31 percent, respectively. S2-B will reduce 86,000 tons and 285,000 tons of SO2, or 58 percent and 60 percent, respectively. Reductions in SO2 emissions of as much as 75 percent and 83 percent can be achieved in the years 1996 and 2011, respectively. For NOx, the situation is rather different, the level of possible NOx reduction is much less than that of SO2. The maximum level of NOx reduction which can be achieved is seen in the control Scenario S5-B, with reductions of 36 percent and 58 percent in 1996 and 2011. Controls of SPM emissions were no incorporated into S2-A and S2-B but have been implemented in by S3-B, S4-B, and S5-B. The S3-B scenario is relatively efficient, reducing SPM emissions by 27 percent, compared to a 6 percent reduction in Scenario S4-B. In order to achieve the maximum possible reduction of SPM, however, it is necessary to implement scenario S5-B which would reduce SPM by 30 percent and 63 percent in 1996 and 2011.

Related Toxic Air Pollution from Industrial Emissions

Along with the criteria air pollutants associated with energy supply, toxic air pollutants have been noted as a serious problem for local populations since the earliest industrial development. Some of these pollutants are the result of fuel combustion and some are used in various manufacturing and commercial processes.

As the use of new and unknown chemical compounds becomes ever more widespread, the total exposure and resulting health impacts also expand. These impacts can be acute at high concentrations and more chronic at low concentrations. The term chronic, when applied to toxic air contaminant impacts, usually indicates a compound found to cause cancer or other biologic and/or genetic responses, or shown through screening analyses to have a high potential to cause these impacts on humans. Many compounds show both an acute or direct poisoning effect at higher concentrations, and a chronic impact over time at much lower concentrations.

Management of the use, direct and indirect air release, and disposal of these compounds proves to be problematic due to their very dispersed use in all economic sectors including the home. While large accidental releases from industrial sources, such as occurred at Bhopal, India, catch the public eye, their frequency and aggregate impact is usually far lower for a metropolitan population, over time, than the chronic impact of steady releases from combustion and manufacturing processes over a number of years. Because of the immediate concern for worker safety and frequent regulation of many on-site practices and facilities, accidental releases can be more easily managed. However, steady emission of compounds through process stacks, workplace venting, and inappropriate disposal, often shifts the immediate worker exposure problem to the surrounding neighborhood.

These toxic or hazardous air pollutants come from a variety of sources including motor vehicles, the motor vehicle fuels system, other smaller or area sources, and larger industrial or commercial point sources. This section addresses the regulation of the industrial point sources and larger area sources. The significant impact of toxic pollution directly caused by motor vehicles is treated in Chapter 5. Air pollutants of the following types account for most of these emissions:

- Acids
- Cyanides
- Industrial gases
- Chemical intermediates
- Industrial process contaminants
- Plasticizers
- Elemental metals and metal compounds
- Monomers
- Fumigants
- Solvents
- Pharmaceuticals
- Polycyclic organic matter
- General use chemicals including catalysts and reagents.

Ambient Air Quality in Industrial Concentration Areas: Samut Prakan

Samut Prakan Province, one of the five provinces of the BMR, is located in the south of the BMR. There are about 3,000 small and large factories located in the province. In addition to the existing factories there are two industrial parks; Bang Poo and Bang Plee. In 1988-89, JICA carried out the Study on the Air Quality Management Planning for Samut Prakan. There were 2,465 factories which had smoke stacks in the Samut Prakan area. The amount of SO2 emitted from the area was 21,606 tons per year, of which 18,330 tons per year (84.8 percent) were attributed to factories. The amount of NOx emitted was 18,729 tons per year, and 8,820 tons per year (47.1 percent) were from factories.

Measurements of ambient air quality were also made for SO2, NOx, and particulates. The two gases were found to comply with the NEB ambient air quality standard at all monitoring stations. For SPM there is no standard stipulated in Thailand. When compared with ambient air quality standards in other industrialized countries, SO2 is found to have exceeded standards at most of the stations. Similarly, for NOx and SPM, measurements exceed the United States yearly average standard. The predicted annual average ambient concentration of SO2 and NOx will exceed the ambient air quality standard in 1992. The mitigation measures concerning ambient air quality in Samut Prakan proposed by JICA, were to raise the stack heights of all plants in the area. It is estimated that the implementation of measures concerning stack height, energy saving, desulfurization of fuel oil, fuel conversion to natural gas, and desulfurization of flue gas for 49 facilities would cost 115 million baht, 160 million baht, 880 million baht, 83 million Baht, and 540 million Baht, respectively.

Implications for Human Health

Estimating the effects of pollutants on human health is extremely complicated. A persons' exposure to a pollutant occurs in a variety of ways, for example, through the skin, the digestive system, and the respiratory system. Depending on the pathway and the chemical nature of the pollutant, a number of systems within the body may be affected before expulsion or execution occurs. The effects of air pollution on human health can be defined in terms of acute mortality, progressive deterioration of the human system, and temporary discomfort. Acute mortality effects generally occur in individuals who are already in poor physical condition. Progressive deterioration occurs with such diseases as bronchitis and cancer, and eventually leads to death. Eye irritation is an example of a temporary health effect. In addition to the problems associated with air quality data and health records availability, there are other difficulties in establishing correlations between air pollution and its effects on human health.

The health effects of air pollution in humans manifest themselves largely in the respiratory system, and mostly in those persons already weakened by respiratory or cardiovascular disease. Relationships among the many stressors of the human system make it difficult to determine the effect of any one variable on death and the incidence of disease. Environmental and behavioral factors modulate the physical, chemical, and biological responses of the human system to air pollution. These modulators may increase or decrease the person's adverse response.

RECOMMENDATIONS

Regulatory Strategies to Control Emissions

Several management strategies exist to facilitate control of traditional and toxic pollutant air emissions. Four primary examples include:

1. Flue or stack emission standards
2. Control technology standards
3. Ambient air concentration limits
4. Risk-based standards

These are listed in a general ranking of complexity to implement, and to range from control of acute emissions, i.e., prevention of hazardous episodes, to control of chronic ambient emissions.

Some of these strategies can be combined with each other. All can and should be implemented with a tracking system that accounts for the full life-cycle of a chemical compound, essentially accounting for its passage from cradle (purchase) to grave (disposal). This practice discourages cross-media dumping, and encourages the most efficient use as well as disposal of noxious industrial products.

Emissions Standards

These process and boiler-based standards impact the design of industrial facilities to control both intentional and unintentional releases. They can be based on either a flue gas concentration or on a mass limit over time. Generally, stack-based emissions meet a concentration standard while fugitive process emissions are regulated with mass-based limits. Thailand maintains guideline emissions standards for approximately thirty compounds ranging from heavy metals to hazardous organic and acid species. However, these have not been codified to date, suggesting an inconsistent application at the licensing stage.

Because emissions standards primarily impact process and boiler design (for new installations) they require less frequent facility inspection. Basically these checks determine the adequacy of maintenance and continued connection of control equipment to the process stream. However, emission standards do not directly address total areawide emissions, ambient air concentration past the flue exit, or chronic population exposure/risk.

Technology Standards

These standards assume that beyond a minimum facility and/or process line size, a given control technology or processing technology will be required in equipment design. They differ from emissions standards by not requiring an extended process modeling exercise or critical engineering review to determine compliance. Instead, equipment manufacturers guarantee a certain level of control.

These controls can be applied more easily to a wider range of facilities than emissions standards because of the lesser review requirement. In addition, area emissions modeling can determine the most appropriate industries and minimum size facility/process to regulate. In this way they more adequately address the total areawide exposure for critical toxic pollutants that show potential for chronic impact.

Ambient Air Concentration and Pollutant Loading Standards

These ambient (public) air quality and affected resource standards specifically address areawide rather than single facility pollution problems. The health and environmental standards in place for the criteria pollutants are designed to limit exposure to specific pollutants to levels shown not to harm health (primary ambient standards) or the resources of concern (loading or deposition standards and secondary ambient standards).

Ambient and loading standards can and have been expanded to application for some acute toxins, but probably are not applicable to carcinogens because of the lack of a lower threshold value for observable effects. It is widely held by public health officials that cancer causing substances can impact individuals at any concentration level and therefore a standard that allows emissions to a given areawide concentration is inappropriate. As a result these standards are probably less appropriate for chronic air pollutants. In addition, ambient air quality monitoring and modeling is slow and expensive and would be institutionally difficult to apply to too broad a range of pollutants.

Risk-Based Standards

While any air quality standard indirectly incorporates some analysis of risk in setting minimum facility size, minimum technology, or maximum air pollutant concentration, risk-based standards regulate exclusively on those criteria. Such standards determine the relative likelihood of the potential negative impacts from a particular compound upon a particular target population.

In theory, risk standards limit emissions from all sources that emit a specific pollutant in the target region to ensure that the maximum population risk level is not exceeded. However, they do no tend to address additive risks from multiple pollutants that impact the same health pathway, nor do they usually address the most exposed population. The premise is somewhat akin to a market approach that suggests a given risk level for a general population can be achieved in a single most efficient path, and that the market, or areawide emission level can float at that level. In some ways, the

Prevention of Significant Deterioration program in the United States has functioned in this manner.

While the market concept may be appropriate to describe the desired ambient air/population exposure outcome, the regulatory structures and necessary mechanisms to achieve this result are neither efficient nor particularly politically viable. By its nature this structure would provide significantly different treatment for facilities with different emission levels and provides little long-term control investment stability. As industrial expansion occurs, tighter and tighter general control levels are required for a particular pollutant, with little certainty as to whether the reduction requirement would fall on new or existing industry.

Regulatory Trend

The Federal Clean Air Act revisions under debate in the United States and existing individual state regulations provide the best current models for the regulation of non-acute industrial air toxic emissions. The most recent trend has been to adopt technology-based standards that deal with a majority of the aggregate community risks. These have been developed to complement existing new source and permit-based emissions standards for acute toxins on specified process types, and include both acute toxins and carcinogens. These requirements tend to impact sources above a cut-off emission level established on either an hourly or annual emission rate, depending on whether the compound is acute or chronically problematic. Some state regulations only affect existing sources, however, the federal proposal and some existing states' standards apply to all facilities. In most cases, the only major exemption applies to emissions of specific heavy metals from coal-based power plants.

To support the implementation of new technology and expanded emissions standards the United States government is proposing a significant expansion of mandatory state-level permitting/licensing bureaucracies with federal review power to ensure consistency. Permits will be expanded to facilities emitting a broader range of pollutants, and will be required for the operation of existing large facilities as well as new facilities. This structure is already in place in most states for criteria pollutants.

Financial support for all permitting/licensing procedures come from the regulated industries through state fees adjusted to reflect actual review and inspection costs. This existing fee generation procedure is being expanded in the proposed Clean Air Act revisions with an added annual emissions fee tied to development of large source emissions inventories at the state level. As at the Department of Industrial Works in Thailand, many states have pursued a one-stop license application structure to speed the permitting process.

Supporting an Air Emission Inventory and Permitting Structure for Industrial Sources

All of the control strategies discussed require the implementation of a source level air emissions inventory for facilities above a minimum projected emission level. These structures provide a benefit equivalent to permits required for industrial wastewater treatment and hazardous waste disposal.

With the advent of computerization at all levels of bureaucracy and industry, these tracking mechanisms no longer need be cumbersome to industry and, in fact, provide for the expeditious review of industrial design and efficient pollution control investment. Industry can be certain to receive equivalent treatment for equivalent facilities.

Bureaucracies need this type of data base and review structure to determine community exposure and minimize local population risk. Inventories help direct scarce inspection resources and allow agencies to manage air quality rather than continually respond to entrenched problems. Finally, an inventory/permit structure provides for a better return on the community investment allocated to support industrial infrastructure expansion by ensuring a minimized environmental impact with maximized controls efficiency.

Table 6-1 Projection of Energy Demand by Sector (As % of Total)

(Unit: Percent)

Sector	1979	1981	1986	1988	1991	1996	2001	2006	2011
Industry	29.9%	28.9%	27.8%	27.1%	31.6%	32.6%	32.5%	33.4%	34.5%
Transport	26.8%	27.4%	36.0%	40.2%	41.5%	44.2%	45.7%	46.1%	46.0%
Agriculture & Res. Comm.	43.3%	43.7%	36.2%	32.7%	26.8%	23.2%	21.8%	20.5%	19.4%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Source: 1979-1988 are actual data from National Energy Administration
1991-2011 Thailand Development Research Institute Estimates

Table 6-2 Distribution of Total Energy Consumption by Industrial Sector

(Unit: Percent)

			Estimated Value				
	1986	1988	1991	1996	2001	2006	2011
Whole Region	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
BKK	57.96%	59.21%	57.48%	58.16%	59.80%	60.73%	61.58%
Central	19.34%	20.20%	23.20%	24.18%	23.53%	22.85%	22.08%
North	7.82%	7.37%	7.92%	8.22%	8.55%	9.31%	10.17%
Northeast	7.49%	6.69%	5.92%	5.10%	4.47%	3.99%	3.52%
South	7.39%	6.54%	5.48%	4.34%	3.66%	3.12%	2.65%
Total Region	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

Source: Thailand Development Research Institute (1990)

Table 6-3 Final Energy Demand in Industrial Sector by Energy Sources in BMR

(Unit: KTOE)

	1986	(%)	1988	(%)	1991	(%)	1996	(%)	2001	(%)	2006	(%)	2011	(%)
Lignite	76	2.4%	180	4.9%	453	8.7%	555	7.5%	751	7.7%	1186	8.9%	1676	9.0%
Coal	26	0.8%	64	1.7%	71	1.4%	79	1.1%	135	1.4%	181	1.4%	271	1.5%
Natural Gas	47	1.5%	30	0.8%	195	3.8%	519	7.0%	679	6.9%	689	5.2%	692	3.7%
Petroleum Product	1011	32.2%	1296	35.3%	1440	27.8%	2084	28.2%	2993	30.5%	4430	33.3%	6773	36.4%
Fossil Energy	1160	36.9%	1569	42.7%	2159	41.7%	3238	43.7%	4558	46.5%	6486	48.8%	9412	50.6%
Electricity	610	19.4%	772	21.0%	1256	24.3%	1977	26.7%	2992	30.5%	4440	33.4%	6703	36.1%
Modern Energy	1770	56.3%	2341	63.7%	3415	65.9%	5215	70.4%	7550	77.0%	10926	82.3%	16115	86.7%
Renewable	1371	43.7%	1334	36.3%	1763	34.1%	2189	29.6%	2256	23.0%	2358	17.7%	2477	13.3%
Total BMR	3141	100.0%	3675	100.0%	5178	100.0%	7403	100.0%	9807	100.0%	13284	100.0%	18592	100.0%
As % of Whole Country	58.0%		59.2%		57.5%		58.2%		59.8%		60.7%		61.6%	
Total Country	5419		6206		9010		12730		16398		21876		30191	

Source: Thailand Development Research Institute (1990)

Table 6-4 Forecast of Final Energy Demand in Industrial Sector in BMR

(Unit: KTOE)

	1991	(%)	1996	(%)	2001	(%)	2006	(%)	2011	(%)
Mining	4	0.07%	5	0.07%	7	0.07%	10	0.07%	14	0.07%
Manufacturing	5107	98.61%	7300	98.60%	9710	99.02%	13181	99.22%	18510	99.56%
Food	2147	41.46%	2760	37.28%	3021	30.81%	3379	25.44%	3891	20.93%
Textile	971	18.76%	1599	21.59%	2495	25.44%	3812	28.69%	5911	31.79%
Wood	75	1.44%	114	1.53%	157	1.60%	218	1.64%	312	1.68%
Paper	247	4.78%	363	4.91%	485	4.94%	636	4.79%	850	4.57%
Chemical	368	7.11%	526	7.11%	788	8.03%	1173	8.83%	1790	9.63%
Nonmetal	644	12.43%	888	12.00%	1190	12.13%	1677	12.62%	2406	12.94%
Basic Metal	223	4.31%	306	4.13%	437	4.45%	604	4.54%	838	4.51%
Others Mac.	431	8.33%	745	10.06%	1138	11.61%	1682	12.66%	2513	13.52%
Construction	68	1.31%	98	1.33%	89	0.90%	94	0.71%	68	0.36%
Total Industry	5179	100.00%	7404	100.00%	9806	100.00%	13284	100.00%	18591	100.00%

Source: Thailand Development Research Institute (1990)

Table 6-5 Comparison of Gaseous Emission VS. Fuel Cost in Manufacturing Sector (Fuel Cost 1988)

Fuel Type	Cost/Unit		Baht Per KTOE (x 1000)	Tons of Emission/KTOE			
				SO2	NOx	CO2	SPM
Coal	1785	B/Ton	2859.71	15.26	16.06	3702.2	89.92
Lignite	550	B/Ton	1261.64	68.47	27.95	3692.3	167.69
LPG	9.9	B/Kg	8483.15	0.01	1.98	2980.3	0.05
Dist.(HSD)	6.2798	B/Litre	7285.32	19.73	4.41	2978.9	0.58
Fuel Oil	2.9899	B/Litre	3176.55	60.59	7.02	2979.0	3.21
NG	70	B/MMBT	2834.71	0.00	3.31	2129.8	0.06
Fuelwood	0.70	B/Kg	1849.50	1.32	3.18	4045.6	10.58
Bagasse	0.27	B/Kg	1513.96	1.69	3.37	4044.6	44.94

Source: Thailand Development Research Institute (1990)

Table 6-6 Total Emissions by Year by Scenarios in BMR for Industrial Sector

(Unit : Ton/Year)

	BASE CASE			S2-A		S2-B		S3-B		S4-B		S5-B	
	1986	1996	2011	1996	2011	1996	2011	1996	2011	1996	2011	1996	2011
HC or VOC	6957	11486	13562	11486	13562	11486	13562	11423	13265	11389	13160	11331	12937
NOx	14872	41406	107418	38119	97600	35670	90341	28291	57370	32832	69817	26190	45090
SO2	58255	146622	475638	101679	327539	60525	190202	39121	104581	54825	143650	35561	79434
CO	27803	49439	68137	49439	68137	49439	68137	47122	56941	48597	62775	46512	54378
CO2 (1000 Ton)	9035	18508	38851	18508	38851	18508	38851	17585	35098	17543	31643	16712	28828
SPM	68798	188316	417799	188316	417799	188316	417799	136950	171973	177689	336694	131460	152325

Source: Thailand Development Research Institute (1990)

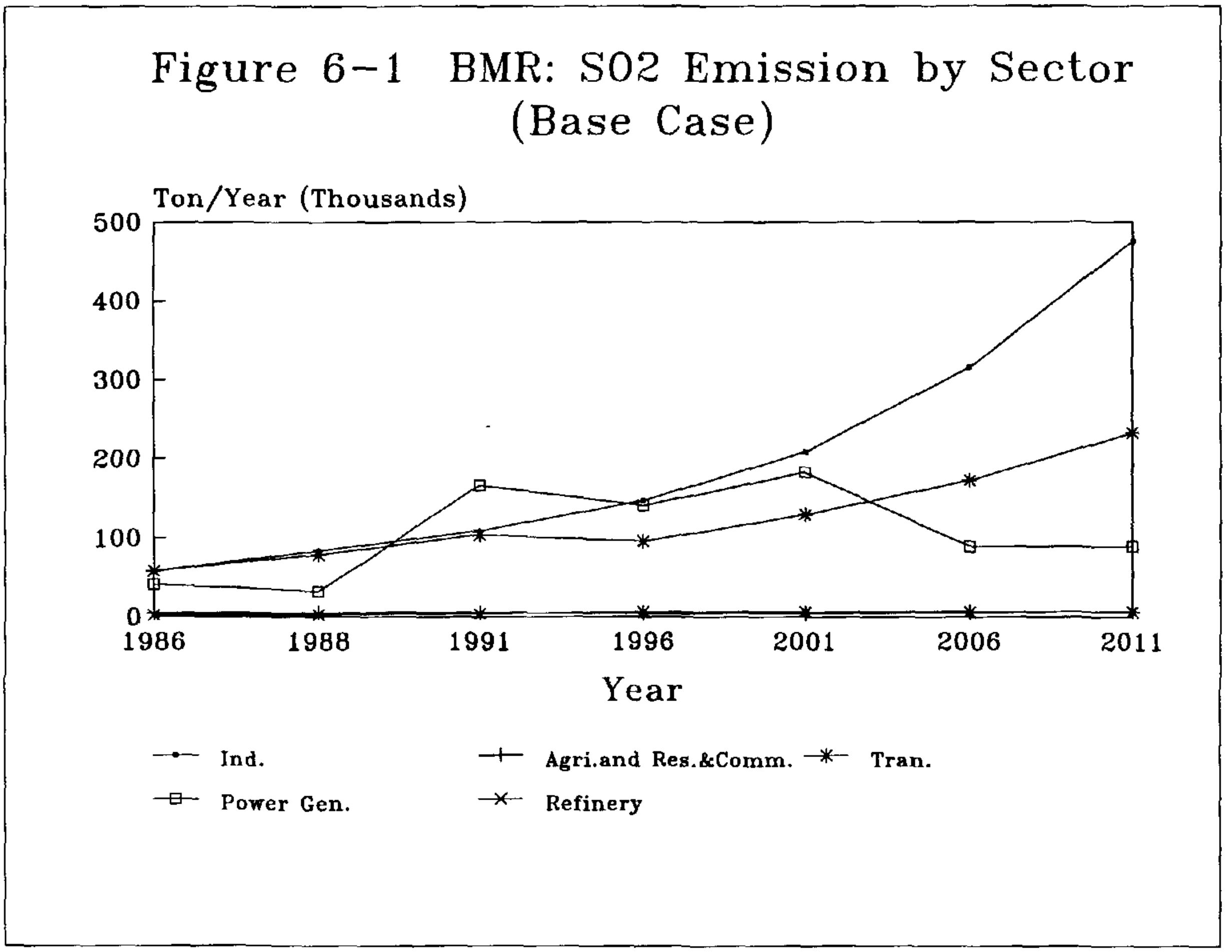
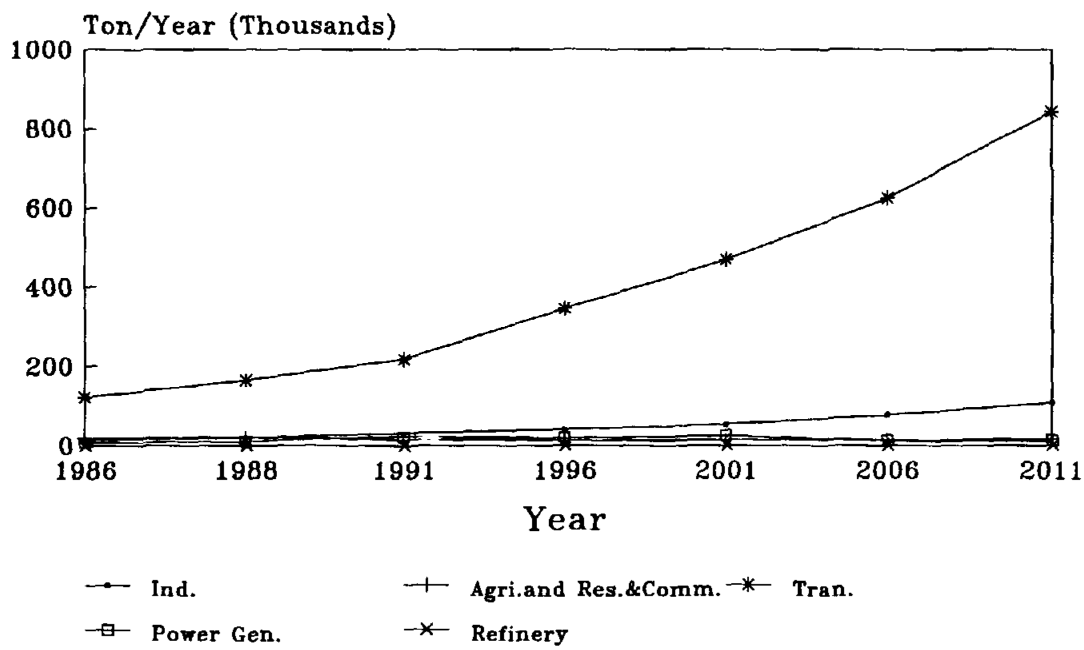


Figure 6-1 BMR: SO2 Emission by Sector
(Base Case)
Ton/Year (Thousands)
500
400
300
200
100
0
1986
1988
1991
1996
2001
2006
2011
Year
Ind.
Agri.and Res.&Comm.
Tran.
Power Gen.
Refinery

Figure 6-2 BMR: NOx Emission by Sector (Base Case)



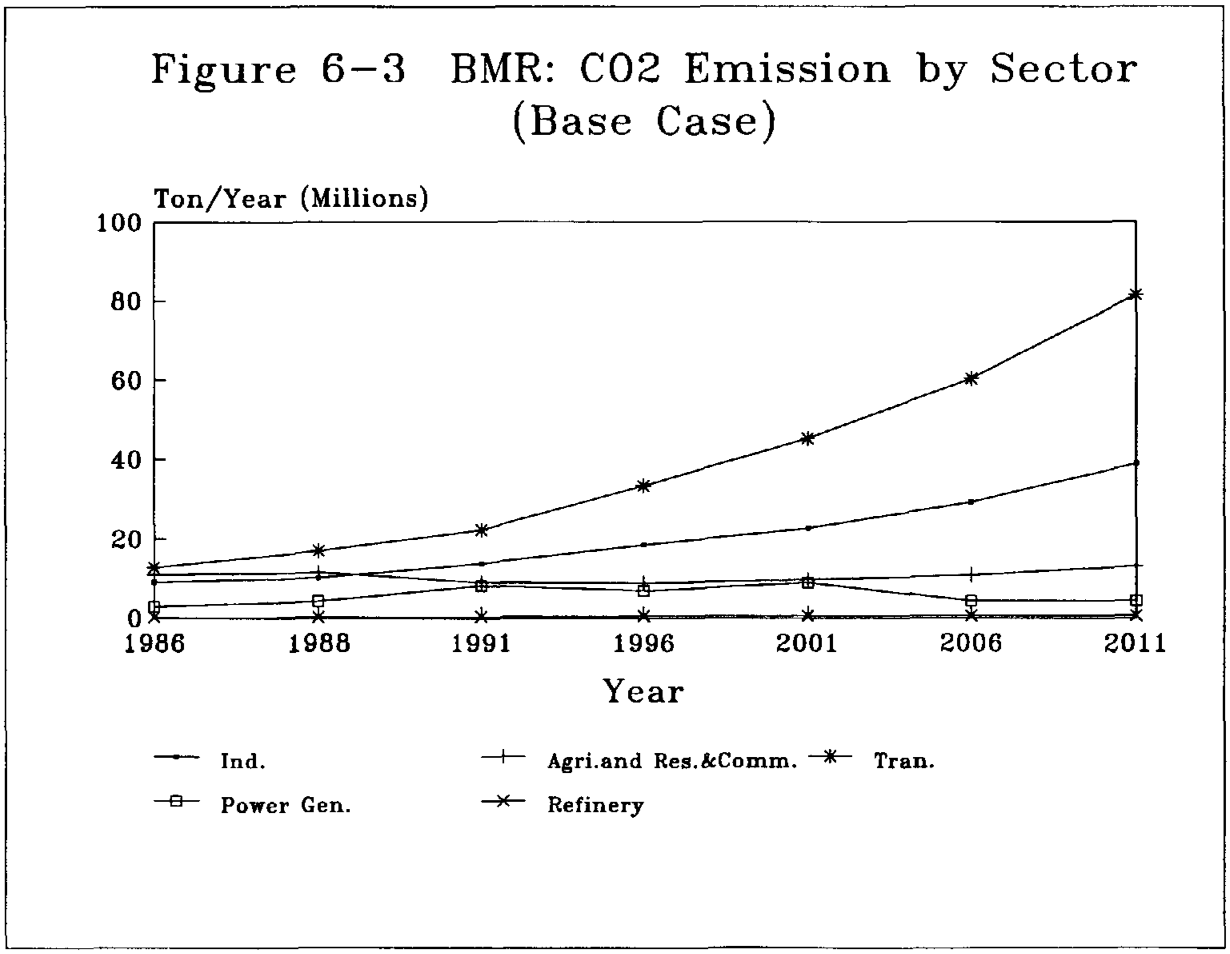
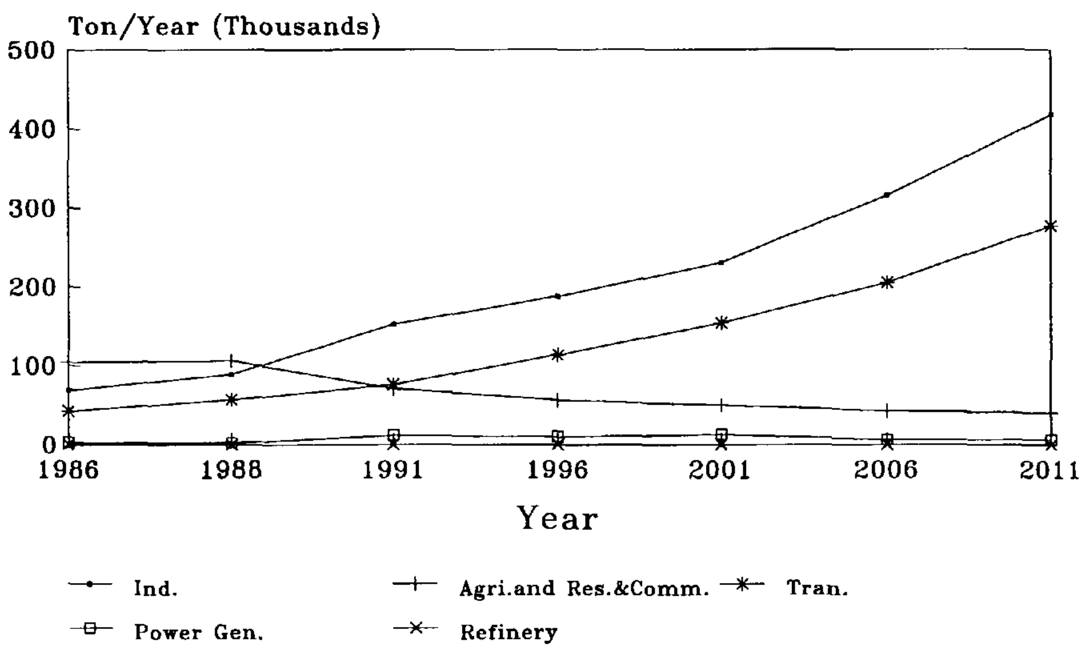


Figure 6–3 BMR: CO2 Emission by Sector
(Base Case)
Ton/Year (Millions)
100
80
60
40
20
0
1986
1988
1991
1996
2001
2006
2011
Year
Ind.
Agri.and Res.&Comm.
Tran.
Power Gen.
Refinery

Figure 6–4 BMR: SPM Emission by Sector (Base Case)



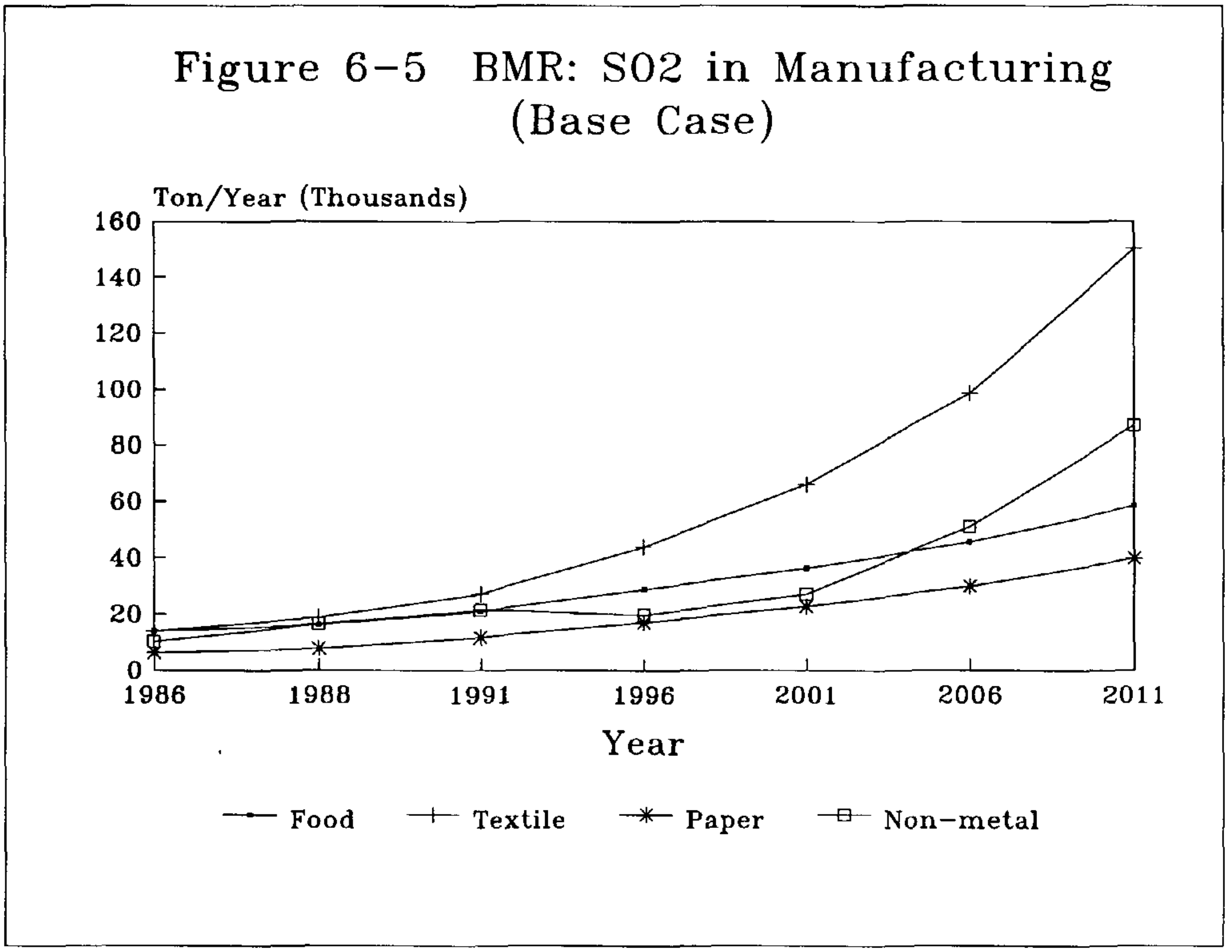


Figure 6-5 BMR: S02 in Manufacturing
(Base Case)
Ton/Year (Thousands)
160
140
120
100
80
60
40
20
0
1986
1988
1991
1996
2001
2006
2011
Year
Food
Textile
Paper
Non-metal

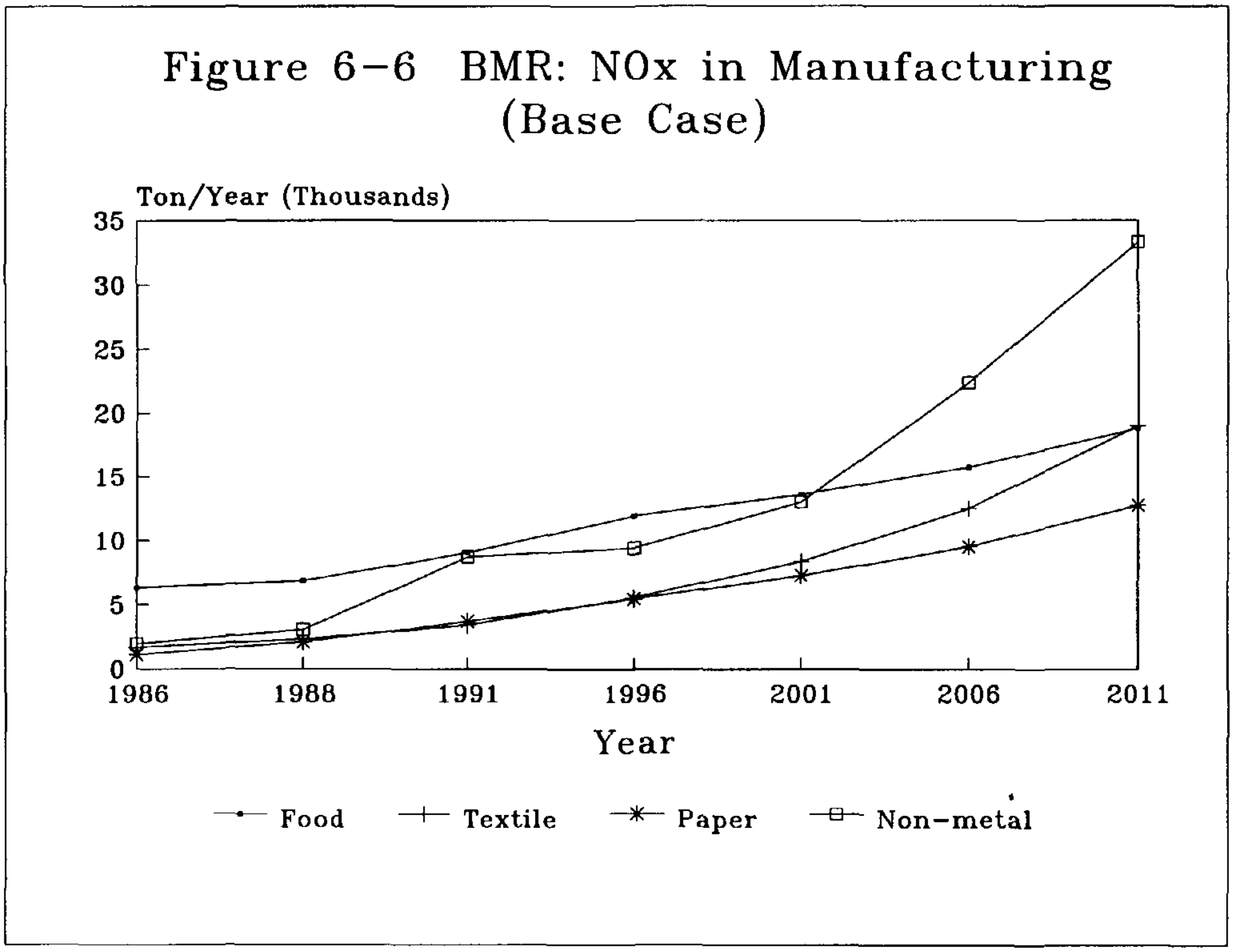


Figure 6-6 BMR: NOx in Manufacturing
(Base Case)
Ton/Year (Thousands)
35
30
25
20
15
10
5
0
1986
1988
1991
1996
2001
2006
2011
Year
Food
Textile
Paper
Non-metal

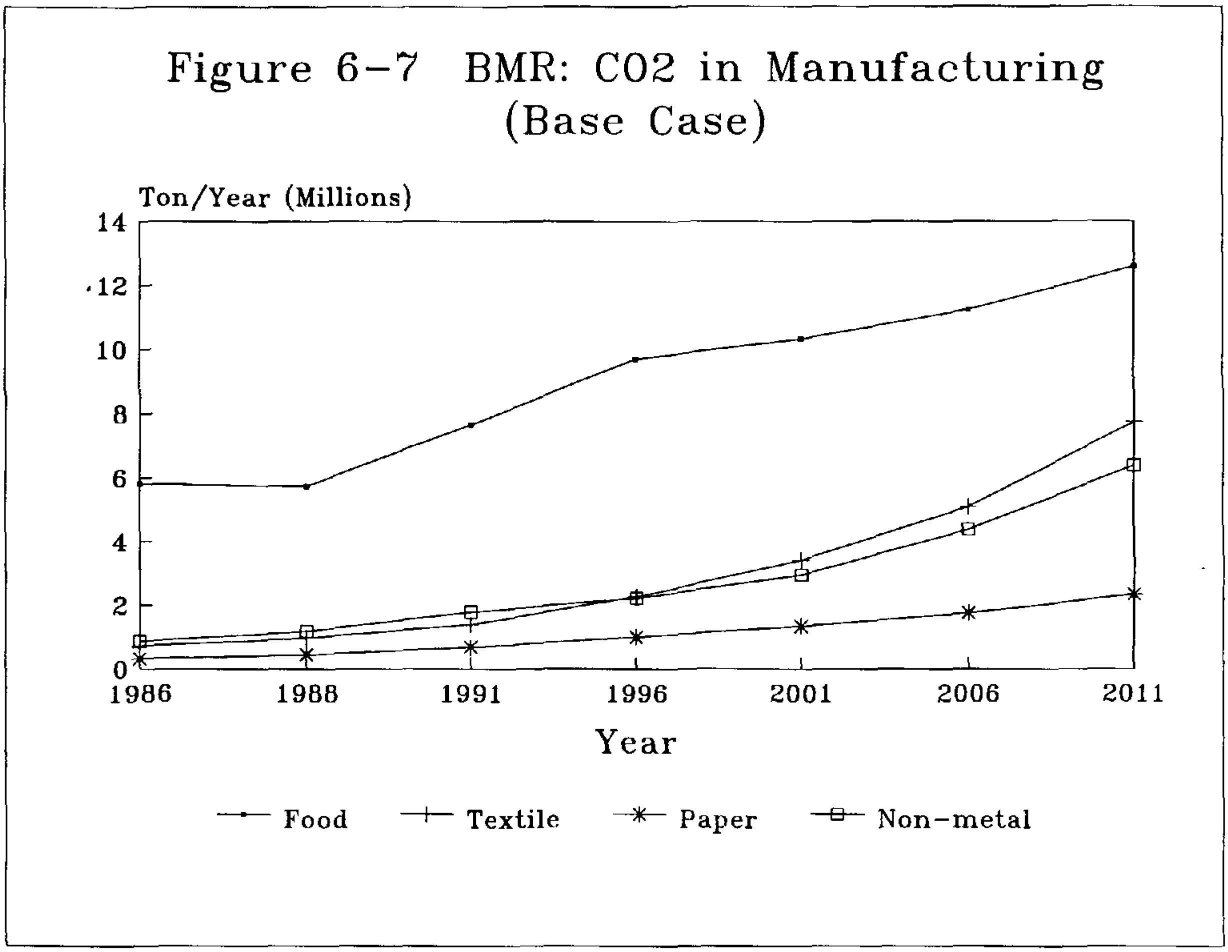


Figure 6-7 BMR: CO2 in Manufacturing
(Base Case)
Ton/Year (Millions)
14
12
10
8
6
4
2
0
1986
1988
1991
1996
2001
2006
2011
Year
Food
Textile
Paper
Non-metal

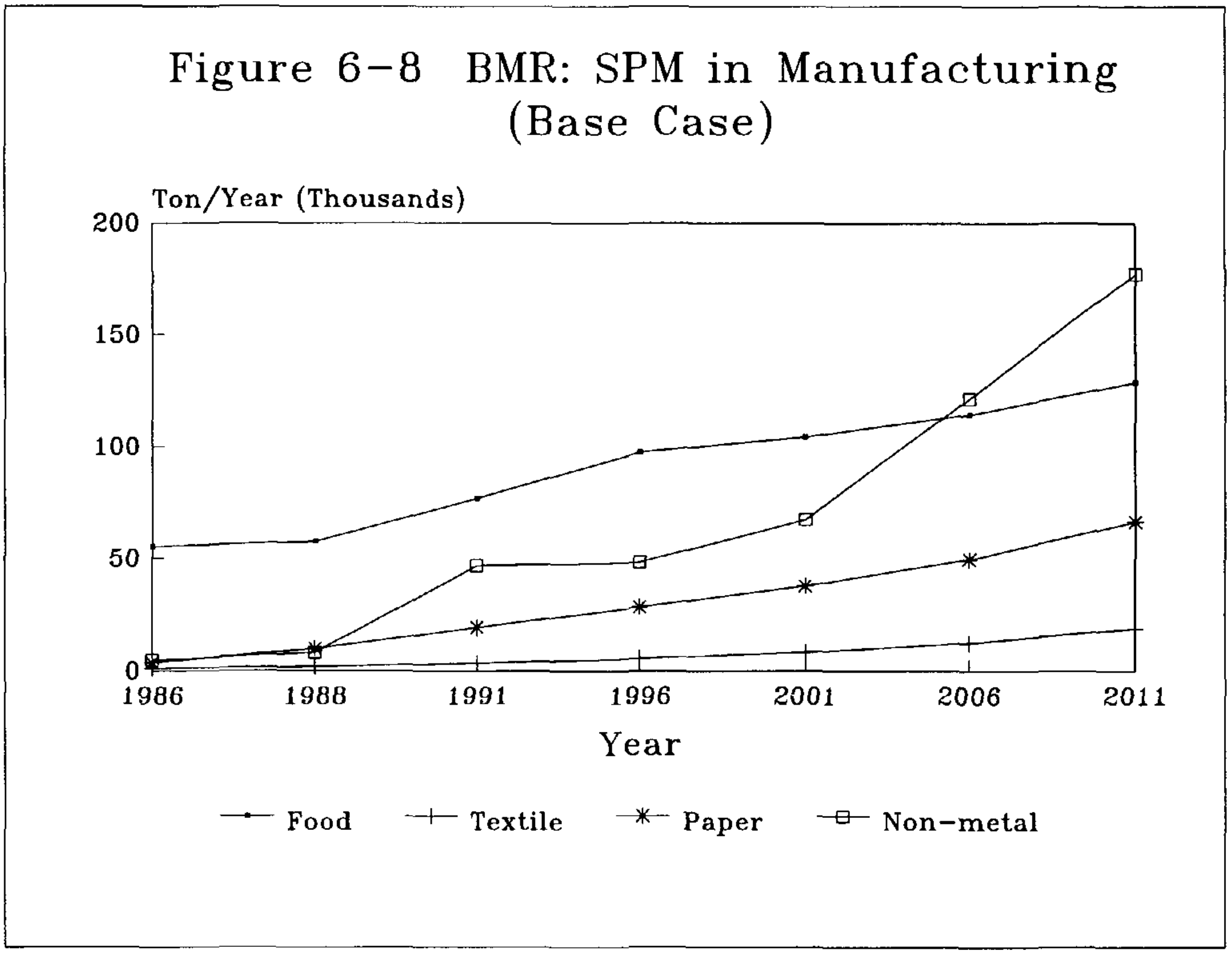


Figure 6-8 BMR: SPM in Manufacturing
(Base Case)
Ton/Year (Thousands)
200
150
100
50
0
1986
1988
1991
1996
2001
2006
2011
Year
Food
Textile
Paper
Non-metal

Chapter 7

Urban Energy/Environment Policy Recommendations

The analysis of transportation and industrial energy use and resultant emissions in Chapters 5 and 6 reveals disturbing trends for environmental conditions and the quality of life in Bangkok. The analysis also points to serious air pollution questions in all of Thailand, particularly with respect to acid rain as presented in Chapters 8 to 11. Current air quality conditions in Bangkok are near or have failed to meet national and international standards for health, despite favorable local meteorology that helps disperse air pollutants.

While air quality may be worse in some other major cities around the globe, e.g., Mexico City, Los Angeles, and Cairo, the prospects for further rapid growth in Bangkok pose an extremely serious challenge. Beyond basic environmental and health issues, there are the related issues of Bangkok's future as a tourist destination and a financial center. If recreational and investment prospects are not already dimmed by existing conditions, they are likely to be challenged by future conditions if a comprehensive mitigation strategy to address the deteriorating environmental condition is not implemented.

The general scenarios developed in Chapter 5 (table 5-1) and Chapter 6 provide a basis for weighing some of the foremost air pollution management policies available to Thailand. Based on the results of these scenarios, additional sensitivity studies, and using a least-cost planning approach, a set of policy recommendations have been developed.

As introduced in Chapter 5, a least-cost approach identifies, evaluates, and recommends emissions reduction and energy conservation policies which minimize traditional economic costs as well as environmental costs. Least-cost policies in the context of transportation include both policies which add infrastructure, such as mass transit and expressways, as well as demand management policies, such as vehicle emission controls, restricted areas, and vehicle use limitations. Policies which provide the greatest improvement in air quality and reduction of energy use can be adopted and modified as the results of the early policies are determined and evaluated. *While a least-cost philosophy is used in making policy recommendations, data, methodological, and time limitations precluded full least-cost evaluation.*

The set of recommended transportation and industrial policies are summarized in the following recommendations. The policies are divided into the following categories:

- Petroleum fuel standards
- Stack emissions and emission control technology requirements
- Travel demand management and infrastructure investments
- Efficiency standards and energy pricing policies
- Sectoral fuel shifting
- Institutional policies

As shown below, we note two levels of recommendations. The high priority recommendations (that could be initiated in a short time frame) are denoted by "●", and other recommendations (that could be initiated in a medium time frame) by "▸". The "other" recommendations require longer lead times and/or should be further evaluated as the higher priority items are implemented.

RECOMMENDATIONS FOR EMISSIONS CONTROL: TRANSPORTATION, INDUSTRY, AND INSTITUTIONAL POLICIES

Petroleum Fuel Standards

Gasoline -

● 1. Require the retail sale of unleaded gasoline starting in 1993.

▸ 2. Set the octane standard for unleaded regular between 92 RON to optimize efficiency/power/emission control.

● 3. Establish a schedule to phase out the sale of leaded gasoline in the 1990s.

High Speed Diesel -

● 1. Reduce the maximum sulfur content from 1.0 percent to 0.25 percent.

▸ 2. Establish a schedule for further reducing the sulfur content to 0.05 - 0.1 percent when enhanced diesel particulate control equipment (i.e., catalytic converters) is required on new motor vehicles.

Fuel Oil -

- 1. Establish a maximum sulfur content at 2.0 percent in 1994.
- 2. Establish a schedule for further reduction to 1.0 percent.

Emissions Standards and Emission Control Technology Requirements

Motor Vehicles (National) -

- 1. Mandate the manufacture and sale of engines requiring unleaded gasoline after 1992.
- 2. Establish exhaust and evaporative emissions standards for HC, NOx, and CO in gasoline-powered automobiles and other light vehicles at the Tech 4 level (current United States, Japan, or EEC design standard).
- 3. Establish HC, CO, and particulate control technology or emissions standards to include all two and three wheel motorcycle types to address the rapidly growing emissions from 2-stroke engines.
- 4. Require all diesel engines manufactured after 1993 to utilize particulate control technology (traps and/or catalytic converters), match timing with refinery desulfurization schedule.

Industrial Boiler and Electric Power Facilities (BMR) -

- 1. Set equipment performance standards for new and replacement industrial boiler equipment located in the BMR - these include low emission rate levels for NOx and particulates from all gaseous, liquid, and solid fuels. At a minimum, if coal, lignite, or fuel oil is utilized as boiler fuel in new facilities, require sulfur to meet a SO2 emission rate less than the uncontrolled rate for 1.0 percent sulfur in fuel oil, 0.5 percent sulfur in coal, or to meet other codified emissions rates already set as design targets.
- 2. Set a standard control level for solvents and other volatile organic emissions from new process or fugitive emission sources by general facility or process type by 1994. The level of control should reflect international standards, (such as United States reasonably available control technology levels). Establish a four to six year schedule for the retrofit of pollution prevention equipment to existing facilities to an economically equivalent level using a permit renewal process.

Travel Demand Management and Infrastructure Investments

Infrastructure Capacity Additions -

- 1. Set a clear priority for rail and other mass transit investment for the Seventh Plan.
- 2. Model proposed expressway and primary arterials deck additions to assure the avoidance of carbon monoxide violations at peak use periods.
- 3. Set standards for pedestrian paths, and repair and build paths in existing built-up areas. For newly developed areas, paths are to be provided by developers. Construct a set of bicycle paths, using sois in the restricted area zone.

Congestion Reduction Mechanisms -

- 1. Establish a quiet (motor vehicle exclusion) zone in the central area defined in Chapter 5. A toll or purchased vehicle sticker is required for entry.

Efficiency Standards and Energy Pricing Policies

Motor Vehicle Efficiency Standards -

- 1. Set fleet average fuel efficiency standards for automobiles, light vans, and light trucks.

Fuels Pricing -

- 1. Establish a price disincentive to purchases of leaded premium and regular fuels. The requirement would call for a leaded fuel tax or a codified price differential between blends. To encourage continued use and further adoption of LPG, the price differential between LPG and gasoline is maintained relative to unleaded gasoline. To support fuel economy standards, consideration should be given to increasing all fuel prices.
- 2. Establish a price reform on domestic lignite the price of which is far more distorted than other energy sources in order to slowdown the growth of lignite consumption. The measure would be a sulfur tax on lignite to reflect the external costs such as those of air pollution.

Energy Equipment (Appliance) Efficiency Standards -

- 1. Set minimum efficiency targets for all packaged boiler, refrigeration, air conditioning, and industrial motor equipment.
- 2. Establish residential LPG and electrical major appliance efficiency standards.

Sectoral Fuel Shifting

- 1. Set a quota on the sale of, or high road use tax for gasoline and diesel-powered vehicles in the BMR. LPG vehicles are excluded from the quota and should pay lower road use tax.
- 2. Provide incentives for further transport LPG and industrial NG infrastructure development in the region.

Institutional Needs for Urban Environmental Management

- 1. The permit review process required for approval to start industrial facility construction should entail a modeling effort to ensure that existing air quality standards will be met at the facility property boundary. Permit fees should be established to fund the full cost of operating an effective permit review.
- 2. Initiate a biannual industrial and large commercial source emissions inventory for individual existing facilities that emit more than 50 tons of volatile organic compounds (non-methane), carbon monoxide, nitrogen oxides, sulfur oxides, or particulates. A second inventory should track the use or emissions of acute and carcinogenic toxins that exceed 10 tons annually. The list of toxins included should reflect those for which emissions standards and other disposal constraints have been established.
- 3. Set a pollution fee for facilities listed in the emissions inventory to provide an emissions disincentive, and to pay the full fiscal cost of operating a more comprehensive monitoring and pollution control program for the BMR. Fees for particular pollutants should be based on the relative importance of emission controls within the inventory region and relative toxicity to exposed populations.
- 4. Provide for the development and operation of a testing and certification laboratory to address both fuel efficiency and emissions standards for motor vehicles and industrial equipment. The laboratory would include research staff to

test the impact on emissions of alternate fuels and engine systems. This institution could be public, private, or university operated.

DISCUSSION OF POLICY RECOMMENDATIONS

Petroleum Fuel Standards and Emission Controls

The large and certain reduction in projected emissions for the year 2006, brought about by emission controls combined with the recommended refinery modifications (Scenario S2), makes this policy the highest priority for consideration. This strategy would reduce lead and sulfur emissions in Bangkok and Thailand as a whole compared to 1989 levels. Though carbon monoxide emissions drop significantly from projected levels, the frequency of ambient concentrations in Bangkok above international health standards would still increase significantly relative to 1989 levels because of the enormous energy demand increase. The fact that CO emissions and ambient levels increase despite the effectiveness of controls, is indicative of how large the air pollution problem is becoming. Recommended controls would affect new motor vehicles, new and existing power plants, and new industrial facilities above a critical size.

Emission controls such as lead and sulfur removal at the refineries, sulfur, NOx, and particulate removal at power plants, and new industrial source controls, are costly. If structured correctly, particularly in the case of automobile controls, most of the burden falls on fuel users who are generally more able to pay. The added cost to a Toyota Corolla is about 3 percent if pollution controls are not taxed. Fuel cost increases are projected at *less than* 0.5 baht per liter, or 6 percent of 1990 prices when all structural changes are considered.

In calculating these costs, there is no adjustment for efficiency improvements or fuel penalties. Improved motor vehicle design based on engines and equipment not being exposed to the lead and sulfur contaminants, should exceed the energy penalty associated with NOx controls. A small fuel penalty on the order of 1.0 percent to 3.0 percent is anticipated in both refining and power production for implementation of fuel pollution controls including particulates, SO2, and NOx.

Both the Thai government and the private fuel refiners have committed to a substantial investment in the refining sector for the Seventh Plan. That effort will upgrade existing facilities, add substantial new capacity, and include most of the capital necessary for processing unleaded gasoline and desulfurizing diesel and fuel oils. A timely decision is necessary to assure that these investments provide the appropriate fuels for comprehensive pollution controls in the transport and industrial sectors.

A pricing disincentive to the purchase of leaded gasoline, relative to unleaded, would facilitate a steady but manageable shift from regular and premium leaded grades, to mid-range octane unleaded grade. This policy would prevent the substantial vehicle catalyst poisoning that occurs when new technology cars are fueled with leaded gasoline. Such a policy would be simple to implement in Thailand's vertically integrated fuel market. In the United States, failure to implement this policy delayed the full effectiveness of the unleaded gasoline control strategy for several years. In conclusion, it is our recommendation that the emission controls defined in Scenario S2, be adopted in the early 1990s. Without them, air quality in vast areas of Bangkok will deteriorate to levels considerably below World Health Organization standards. This policy will hold the line on regional acid rain precursors from the transportation, energy, and industrial sectors, while preventing Bangkok from slipping into the worst category of international cities for chronic air pollution, with consequent health, environmental, and economic implications.

CONGESTION REDUCTION

Rail Transit, Pedestrian/Bicycle Paths, and Quiet Zones

In addition to the policies discussed above, Bangkok has four main options for improving environmental quality and energy efficiency:

1. Congestion reduction.
2. Infrastructure capacity additions.
3. Technical energy efficiency improvements.
4. Fuel switching.

Any policy which results in a significant reduction in congestion brings about large improvements in emissions and energy efficiency, as was shown by the striking results of Scenarios S^*a and S^*b in Chapter 5. The difficulty is identifying proposals that policy makers are willing to implement. While speed improvements and associated emissions and energy improvements are certain to occur if traffic volumes are reduced by say 30 percent, the precise level of improvement is beyond the scope of this study. Any demand management policies adopted require ongoing management and adjustment.

Given the level of suppressed demand, any private vehicle trips eliminated on a given day may be replaced in part by other trips that are now suppressed.

With or without demand management policies, investment in an electrically powered mass transit system on a separate grade, would be one of the two most beneficial infrastructure investments that could be made. These transit systems add capacity to the overall transportation system, with energy-related emissions occurring at power plants. Not only can these emissions be better controlled, but the plants are located away from the dense population centers. Studies elsewhere have indicated that Bangkok's situation is ideal for introducing a properly routed rail mass transit because the levels of congestion and presumed suppressed demand guarantee high levels of utilization. If enough capacity is added to the transportation system in a coordinated manner, some reduction in congestion can be brought about which will result in a decline in both energy use and emissions.

The other public infrastructure investment that holds considerable promise is the systematic development of pedestrian paths, bridges, and bicycle ways. The advantage of these investments is that they provide for considerable mobility without the accompanying energy use and emissions. This option is treated in the SPURT study (SPURT 1990). Investments in rail transit and pedestrian paths were explicitly considered in Scenario S*a in combination with an area control or quiet zone to reduce the number of vehicles in the center of Bangkok. The use of an exclusion zone may be necessary to return many of the sois to bicycle and pedicab use, and to improve the immediate environment so as to make walking and bicycling attractive options.

A larger policy to reduce congestion throughout the study area is considered in Scenario S*b. While the estimated energy savings and emissions reductions of this "Mexico City" type policy are very large, it may be politically impossible to ban private vehicles two days per week.

The design and cost of extensive and systematic pedestrian and possibly bicycle ways remain to be determined. Given their relatively small area and the weights for which they need to be constructed, we anticipate that their cost would be a very small fraction of new roadway costs which in the JICA report are estimated at baht 110 billion between 1990 and 2006 (JICA 1990).

Increased Efficiency

Fuel efficiency improvements, at any specified level of congestion, can be made in Thailand's vehicle fleet over the long run. Because of their relative energy intensiveness, the automobile and pickup truck fleets used primarily for passenger movement are the main targets for fuel efficiency improvements. The advantage of such improvements is that they reduce energy use and associated lead, sulfur, and overall carbon emissions. They may not, however, linearly reduce emissions of HC, CO, and NOx, because these rates are established by emissions standards and may therefore be relatively independent of the fuel economy levels.

The cost of the efficiency standards, based on vehicle fleet averages for each manufacturer, involves no insurmountable barrier to most vehicle manufacturers because of their established capability to meet these cost targets. Some development cost may be involved for manufacturers of larger luxury vehicles who would have to alter their vehicle mixes to meet fuel economy standards.

As discussed in Chapter 5, substantial fuel taxes such as those in Japan, Korea, and most of Europe, could also be imposed to achieve a result similar to an efficiency standard on new vehicles. As noted in that discussion, there is uncertainty in setting the necessary price to achieve desired fuel efficiency targets.

Structural Fuel Shifts

A fuel shift policy in combination with emission controls, has the advantage of reducing both transportation emissions, primarily CO, as well as energy demand in Bangkok. A further advantage of this policy is a reduction in power plant emissions, with resulting implications for acid rain and global climate change. The BMR transport sector shift from higher carbon gasoline and diesel oils to lower carbon LPG (and very modest CNG penetration for large buses), would exploit local knowledge of both fuels and technologies. It is a shift that could therefore occur rapidly, but would impact planned refinery investment and expand energy imports.

A transport fuels shift designed to optimize pollution prevention across the range of pollutants, rather than just CO and HC, may require consideration of less familiar fuels such as the alcohols - including neat methanol and neat ethanol. A less rigorous shift, and one partially incorporated in the transition to unleaded gasoline, is the use of "reformulated" gasoline. This fuel demands a more severe refining effort and the use of fuel oxygenates of a low vapor pressure, ethers rather than ethanol, but does decrease HC and CO emissions, especially in older technology vehicles.

Any long-term structural fuel shift analysis must address full system impacts. Development of an unprecedented solar electric hydrogen-based transport system would entail research, development, and infrastructure support over several years. International examples do not yet exist to assist current decision making, yet this technology is the most environmentally benign devised to date. While the solar photovoltaic and hydrogen end-use technologies are already well-established and undergoing rapid improvements, slow development in efficient hydrogen storage is delaying full system tests.

Current market considerations and the lack of directly comparable in-use emissions testing results for any of the alternate fuels, prevent more extended analysis or recommendations here. If a decision is made to pursue this policy, we recommend a comparative fuels analysis designed to examine the full structural impacts on both the economy and the environment, including concerns other than air pollution.

Institutional Needs

The institutional elements recommended address two basic needs. The first involves development of an environmental quality management capability within both government and industry to ensure the priority of pollution prevention during the rapid projected growth of Thailand's industrial sector. The second involves basic mechanisms to track and enforce established environmental policies. To those ends, government and industry need to share the information gathering and enforcement burden, and to establish efficient means for equipment and emissions testing and comprehensive review. The structures recommended incorporate those aspects of environmental management systems found most effective on an international basis, and least burdensome to those portions of the economy that propagate little or no environmental degradation.

Part IV

The Acid Rain Problem in Thailand and Its Relationship to the Asia Region

Chapter 8

The Acid Rain Problem in Thailand and Its Relationship to the Asia Region

THAILAND'S ACID DEPOSITION PROBLEM

Introduction

Acid rain has been an issue of widespread concern in North America and Europe for more than 15 years. As a result of the industrialized countries' heavy and increasing use of fossil fuels during this century, the acidity of rain has increased markedly in many areas, as has the cumulative loading of acid deposition. Damage to lakes, forests, and materials in many countries has been attributed to this fact. In response to these problems, the countries have carried out major programs of monitoring, damage assessment, modeling, and analysis of various technical and economic strategies for mitigating the effects of acid deposition.

Although policy makers in Europe and North America are still grappling with thorny issues related to precise choice and implementation of these strategies, there is clearly progress toward targets of decreased acid deposition. This progress is based upon a number of steps, including existing or anticipated laws and agreements, deployment of emission control technologies, energy conservation and efficiency improvements, and in some countries, shifts away from fossil fuels emitting large quantities of acid precursors.

The trend of acid deposition in Asia appears much worse over the long run. Fossil fuels are already used in large quantities, such that local air pollution (based on ambient air quality concentrations) is becoming a serious problem, and increasing pollutant deposition levels are being measured.

Emission regulations in most countries, with the notable exception of Japan, are not very stringent. Energy plans in many countries, particularly China, India, Thailand,

and South Korea, call for very large increases in coal combustion in the future. In most countries there do not appear to be strong scientific, bureaucratic, or public constituencies to address the potential effects of acid deposition in either the short or long run. Together these factors imply potentially serious problems in the future for long-range transport and deposition of sulfur and nitrogen species, and consequent damage to ecosystems, health, and materials within these countries.

The political ramifications of addressing trans-boundary environmental pollution in Asia are serious because of historic regional conflict patterns, a void of previous experience in multi-government environmental decision making, and significantly different industrial development trends.

What is Acid Rain?

Acid rain is the term commonly used to describe those pollutants included under the broader, technical term "acid deposition". In a strict definition, acid rain refers to the wet precipitation of pollutants SO2/SO3 and NO2/nitric acid (HNO3), which have dissolved in cloud and rain droplets to form sulfuric acid and nitric acids. But dry deposition also occurs, when acid precipitation falls from the atmosphere as gases or attached to particles of soot and dust. The acidity of a liquid is determined by its concentration of hydrogen ions, the higher the concentration the more acidic, the lower the hydrogen ion concentration the more basic. Acidity is best described by a pH scale (figure 8-1). The pH scale is a negative logarithmic scale in base 10. Normal precipitation has a pH of 5.6, which is slightly acidic because carbon dioxide that occurs naturally in the air mixes with water to form a mild solution of carbonic acid. Traditionally, rain with a pH of less than 5.6 has been considered acidic. However, a number of studies show evidence of unpolluted rainfall having a pH in the range of 4.5 to 7.4.

What are the Principle Sources of Acid Rain?

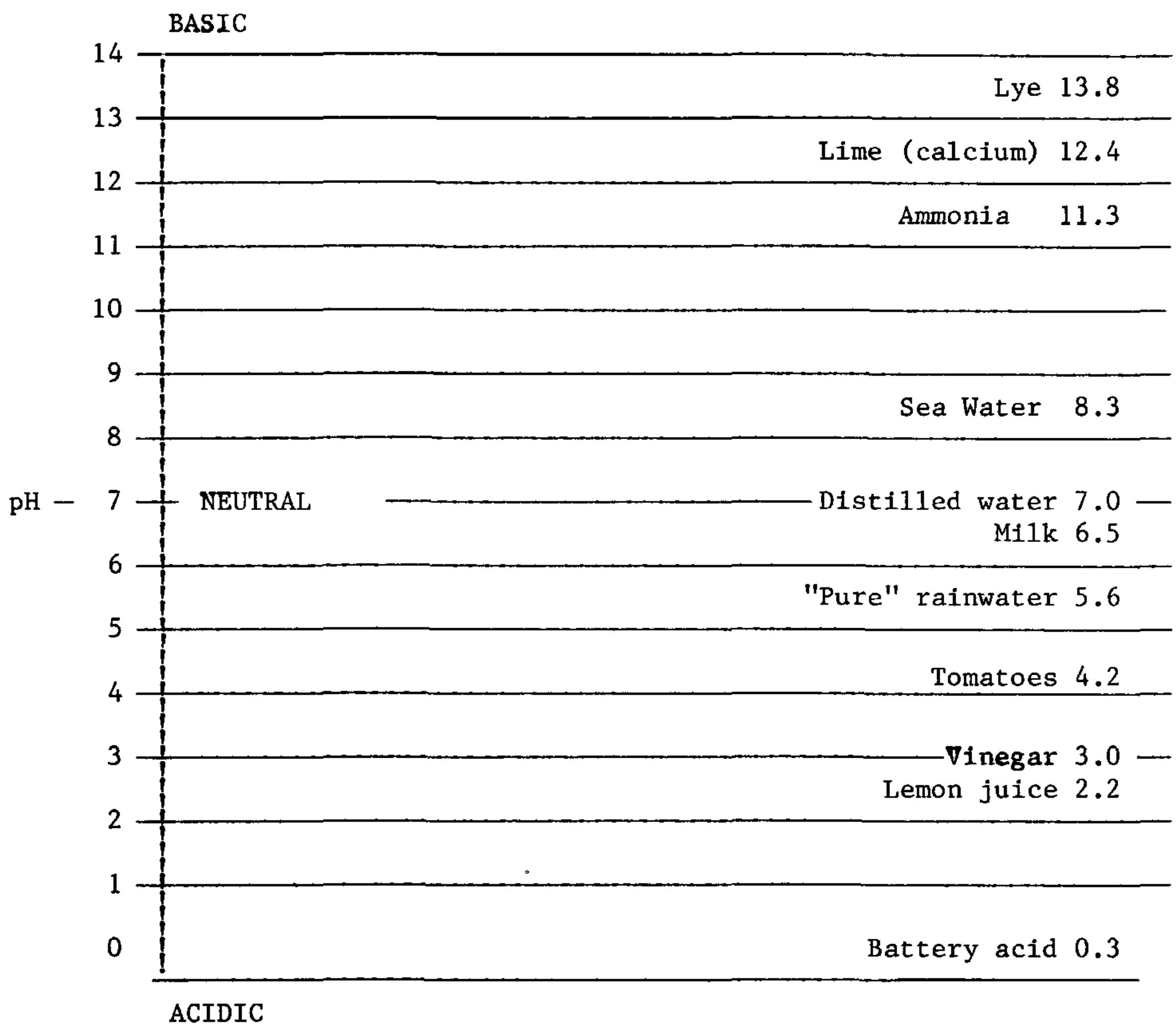
Acid rain forms when SOx and NOx in the atmosphere combine with water to make sulfuric acid (H2SO4) and HNO3. The sources of SOx and NOx in the atmosphere are both natural and human-made. The natural sources are gasthermal activities, sea spray, and bacteria. The major human-made source is the burning of fossil fuels. The energy and industrial sectors are the main contributors when coal and oil are burned. The formation of NOx is also prevalent in large gas-fired power plants. Another major sources of NOx is transportation, exhaust emissions from vehicles, air planes, etc. A comparison of the lignite SO2 and NOx emission factors shows that in the case of Thailand's lignite power plants, SO2 is the predominant acid rain precursor.

Table 8-1 Sulfur Dioxide and Nitrogen Oxides Emission Factors

Fuel	SO2 Emission ($kgSO2/10^9cal$)	NOx Emission ($kgNOx/10^9cal$)
Lignite (Mae Moh)	15	0.9 to 1.8
Fuel Oil (No. 6)	4	0.5 to 1.3
Natural Gas	0	0.2 to 0.5

Source: World Bank (1989)

Figure 8.1 pH Scale



Acid pollutants go through one of three-stage routes before interacting with the environment:

Route 1: Emission ➡ dispersion ➡ dry deposition

Route 2: Emission ➡ chemical transformation/dispersion ➡ dry deposition

Route 3: Emission ➡ chemical transformation/dispersion ➡ wet deposition (acid rain)

This process and the principal chemical substances involved are illustrated in Figure 8-2.

Why the Concern About Acid Rain?

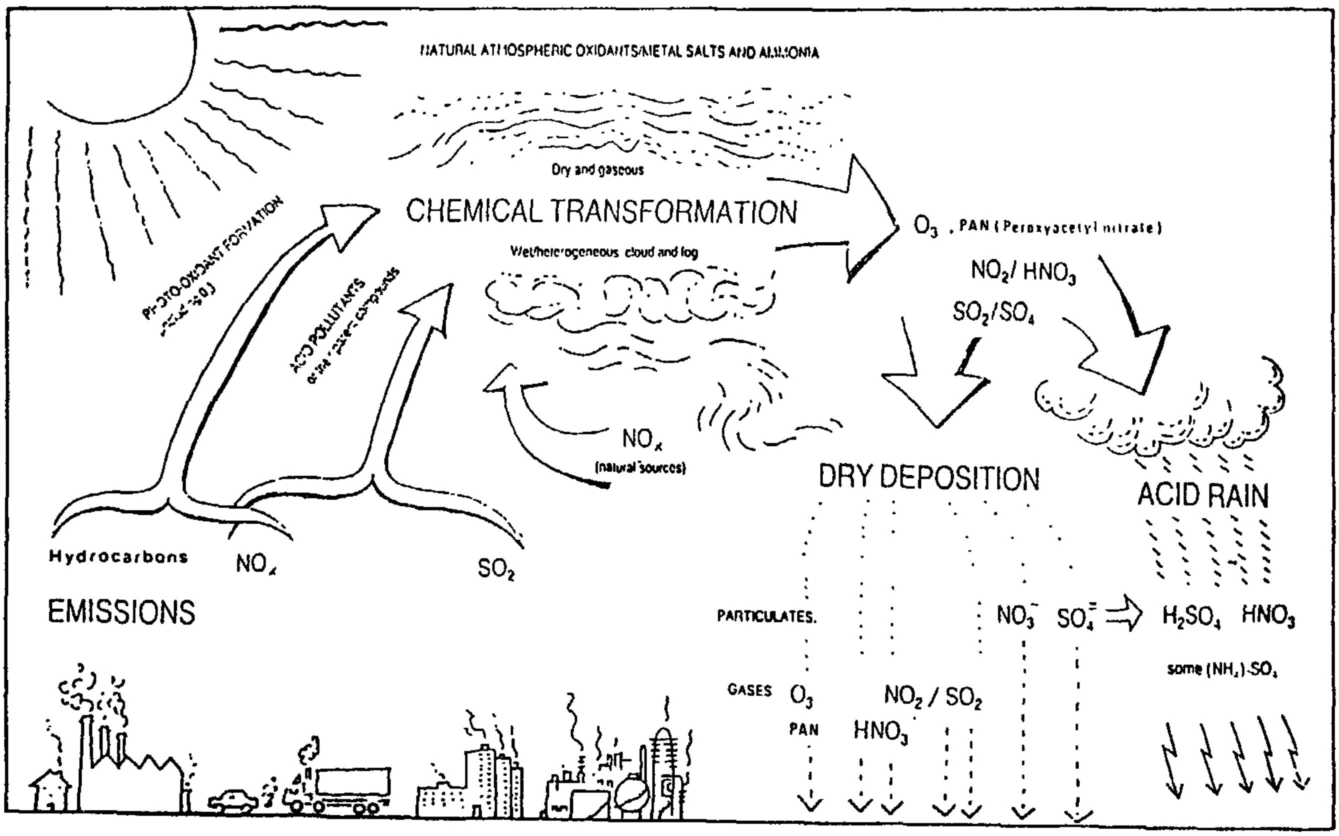
There is an increasing recognition of a potentially serious acid rain problem in Thailand. Very large increases in both SO2 and NOx emissions are projected over the next 20 years. These increases would come primarily from expansion of a lignite-based power sector supporting the rapidly expanding industrial base. Repowering and cogeneration in some sectors, especially cement, may also be based on the high-sulfur lignite resource due to its significantly lower fuel cost.

Concern about the acid rain problem in Thailand is heavily influenced by consideration of the country's growing economy and associated systems of energy consumption and production. These are powerful driving forces behind the rapidly increasing use of fossil fuels whose combustion is ultimately responsible for the emissions leading to acid deposition. A recent coal utilization and development study by the World Bank estimated that total domestic demand for all types of coal in Thailand would increase from 7.6 million tons in 1988, to 38 million tons in the year 2000, with its dominant use being power generation. This corresponds to an annual increase of 17 percent.

A longer-term study on the environmental impact of coal-fired power plants in Thailand was carried out by Wanchai Asvapoositkul and W.K. Foell at the Asian Institute of Technology (AIT) (Asvapoositkul, 1988). This study, showing results similar to those of the World Bank analysis, developed a scenario yielding a power sector coal utilization of almost 60 million tons in the year 2011, and sulfur dioxide emissions of approximately one million tons, based on the assumption of uncontrolled emissions. This represents a dramatic increase from the estimated 1987 emissions of approximately 160,000 tons.

In the past EGAT has mitigated the local effects of increased emissions by using taller stacks to increase dispersion distances. This strategy provides a mean to meet ambient air quality standards, but at possible cost of greatly exacerbating problems of long-range pollutant transport and resultant acid deposition.

Figure 8.2 Processes and Chemicals in Pollutant Emissions and Acid Precipitation

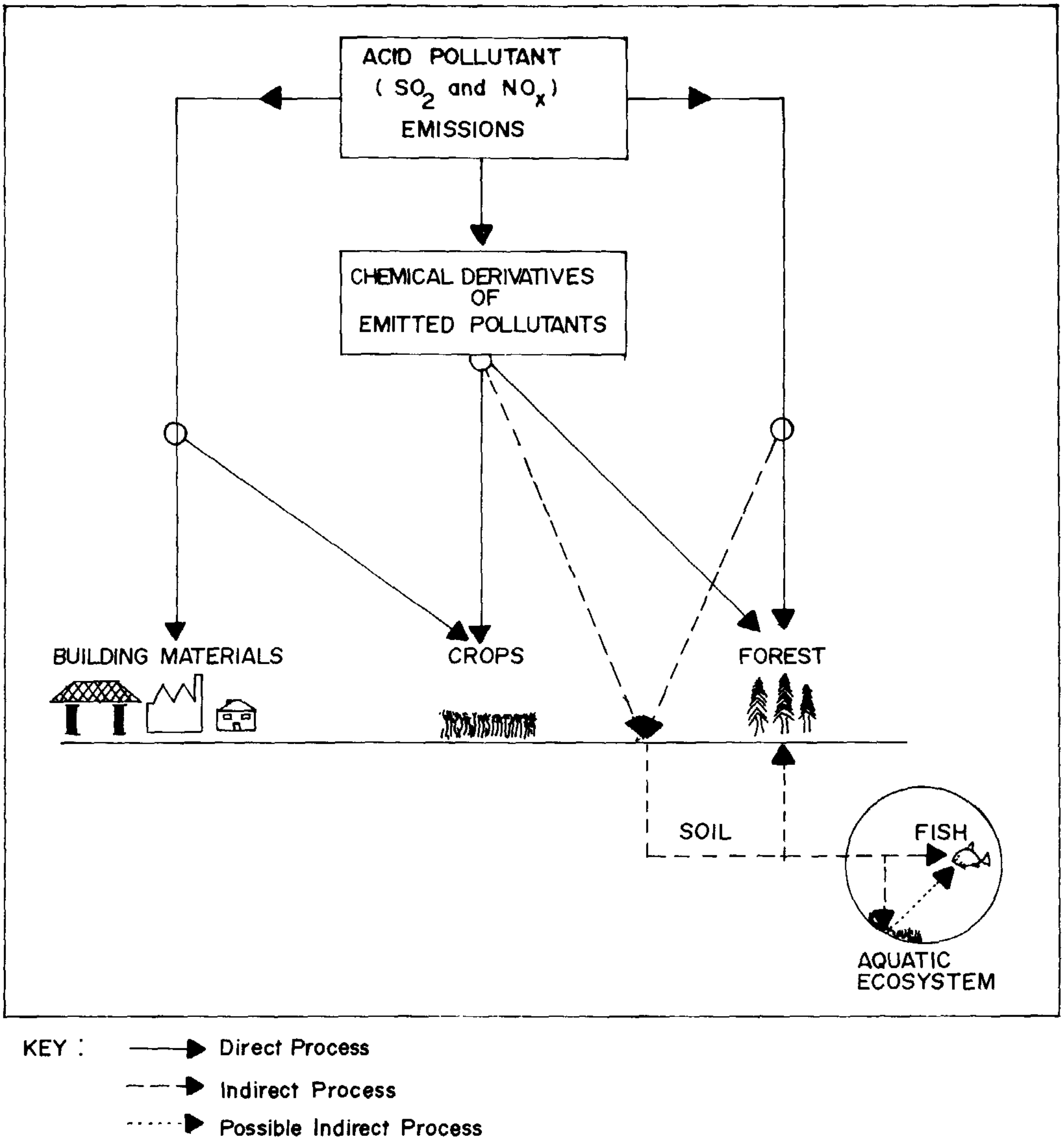


Source : Environmental Resource United , 1983

The possibility that acid deposition could occur in Thailand has only recently begun to be addressed. Among the few attempts to measure deposition acidity has been a recent limited study of rainfall acidity, supported by the United Nations Environment Program (UNEP) and coordinated by the Environmental Engineering Department of Chiang Mai University. It is well-known that acid deposition can damage fresh water ecosystems, terrestrial systems including crops and forests, man-made structures, and human health. Ultimately it is the impact of acid deposition on the natural and man-made environment of Thailand that will be of greatest concern. The impact of acid pollutants is illustrated in Figure 8-3. The effects of acid rain in Europe and North America have spurred much scientific research and many policies to mitigate against further damage. However in Asia, and in Thailand specifically, there is little information available on the possible consequences of acid deposition. Determining the potential impact on Thailand therefore requires an analysis and assessment of the vulnerability of the natural and anthropogenic environment to acid deposition.

Despite the need to develop a better understanding of the extent and impact of acid rain in Thailand, it is not too early to begin examining a broad set of options and strategies for attacking it. These strategies need to be identified at an early stage so that their eventual application can be analyzed and tested thoroughly before implementation. This early assessment is particularly important because of the extremely high energy growth rates currently being experienced in Thailand. Implementation of appropriate strategies at an early date could preclude very expensive retrofitting or costly policy reversals at a later time.

Figure 8-3 Acid Pollutant Impacts-Direct or Indirect Process



Source: Environmental Resources United, 1983.

Chapter 9

Current and Future Sources of Acid Rain Precursors in Thailand and Asia

EMISSIONS OF ACID PRECURSORS IN THAILAND: PAST AND PRESENT

Basis and Evolution of Emissions of Acid Rain Precursors in Thailand

This section presents an overview of the evolution of the sources and emissions of acid rain precursors in Thailand. As mentioned earlier, photochemical reactants such as ammonia, volatile organic compounds (VOC), and alkaline dust, are also important in the chemistry of acid rain. However the main focus in this section will be on the direct acid rain precursors, namely, SO2 and NOx.

Based on the methods described in Chapter 3, annual values of SO2 and NOx emissions were estimated in Thailand for the years 1979, 1981, 1986, and 1988 for each of the main economic sectors. These sectors were then aggregated into the four categories: power generation and refineries; industrial; transportation; and residential/agricultural/commercial (RCA).

Figures 9-1 and 9-2 present the estimated national-level historical trends for the two pollutants, respectively.

Over the ten year period, the annual growth of SO2 emissions was 3.0 percent and 3.6 percent in the electricity and industrial sectors, 12.3 percent in the transportation sector, and essentially zero in the RCA sector. Emissions growth in the power sector reflects the increased use of high-sulfur lignite in EGAT's Mae Moh power complex, increasing from an annual value of 178,000 tons in 1979 to 245,000 tons in 1988. In the transport sector, the SO2 growth is from high diesel consumption. The share of diesel in the total fuel use of the transportation sector increased from 42 percent in 1979 to 54 percent in 2011. At the present time it is estimated that electric power plants are responsible for approximately 45 percent of the sulfur dioxide emissions in Thailand, with industry and transport responsible for approximately 26 percent and 23 percent, respectively.

The picture for NOx is quite different. In the late 1970s, before the extremely rapid growth of the automobile fleet in Thailand, the transportation, industrial, and RCA sectors shared much of the responsibility for NOx emissions. However, through the decade of the 1980s, the transportation emissions grew at a dramatic rate, while the other sectors remained virtually constant.

In the past, there was in general a concentration of energy-related pollutant emissions in only a few areas of the country. The SO2 emissions from the power sector originated mainly in the Northern Region, whereas the industrial emissions were most heavily concentrated in the Bangkok area. NOx emissions were initially quite dispersed among a variety of combustion sources, but as transportation assumed more importance they became concentrated in urban areas on the one hand, and, to a slightly lesser degree, in the power plant complexes. In 1986, it was estimated that more than 50 percent of the transport sector NOx emissions originated in the BMR.

There are additional important trends taking place which have important implications for the potential problem of acid rain in Thailand. The first of these is related to the increasing size of electricity generating complexes and industrial facilities, both leading to increasing concentrations of energy production or consumption at a given site. Because of the increased concentration of emissions and potentially of pollutant depositions at these sites, pollutant dispersion through high stacks is becoming increasingly common. EGAT's most recent facilities at Mae Moh have 150 meter stacks. Some stacks at plants in the Eastern Seaboard are expected to be over 120 meters. These high stacks greatly change the nature of the dispersal and chemical transformation of the acid precursors, as is discussed in more detail later. With the longer anticipated transport distance, there is now potential for pollutant interactions and transfers between more distant regions of the country.

A second potentially exacerbating factor is the concurrent increase of acid precursor emissions in other Asian countries, with the resultant transport and deposition of acid substances in Thailand. This will be discussed further below.

SCENARIOS OF FUTURE EMISSIONS OF ACID RAIN PRECURSORS

Because Thailand is now seriously considering setting air pollution emissions standards and the installation of emission control technologies at power generation and other industrial facilities, there is an urgent need to examine the effects of various pollution control measures and their relationship to the standards and technologies under consideration, as well as other potential standards. This section presents the results of the energy/environment scenarios which were developed to analyze the impact of these alternative energy strategies and pollution control measures.

Basis of Scenarios For Acid Rain Policy Analysis

The overall framework for development of energy scenarios was described in Chapter 3.

The scenarios can be summarized as:

S1: Base case energy scenario with no emission controls

S2: Base case energy scenario with SO2 and NOx reduction measures (table 9-1)

S2-A: Moderate reduction measures

SO2: Emissions from new lignite-fueled power plants built after 1991 are reduced 50 percent in aggregate. Reductions of 50 percent are instituted on 50 percent of industrial facilities. Diesel sulfur content is reduced to 0.5 percent in 1993, as now specified in Government regulations.

NOx: Emissions from lignite-fueled power plants are reduced 25 percent on all new facilities after 1991. Reductions of 25 percent are instituted on 50 percent of all new lignite/coal industrial facilities after 1991. Moderate controls on gas-fueled power plants and industrial facilities.

S2-B: Stronger reduction measures

SO2: Lignite- and coal-fueled power plants and industrial facilities treated as in S2-A but reduced 90 percent instead of 50 percent. Sulfur in fuel oil is reduced by an additional 50 percent beginning in 1993.

NOx: Lignite- and coal-fueled power plants and industrial facilities treated as in S2-A except reduced 40 percent rather than 25 percent. Controls installed on gas-fueled power and industrial plants which would reduce their NOx emissions by 20 percent.

S3: Fuel shift

A major shift is made to low-sulfur and low-carbon fuels for power generation, industrial boiler use, and motor vehicle fuels in addition to the emissions control measures in S2-B. Alternate fuels considered are natural gas - for power generation and industrial use - and LPG - for the transportation sector. Gas supply limitations in the Base Case could be relaxed through imports either in liquefied form (LNG) or pipeline gas.

Natural gas is assumed to replace fuel oil and new coal generation in power generation after the year 2000. For the industrial sector, 50 percent to 80 percent of solid fuel and fuel oil in the BMR will be shifted to natural gas. Additional areas for consideration are other industrial groups located in the BMR in which natural gas penetration could occur for 50 percent of their solid fuel and some fuel oil use. The use of diesel and gasoline gradually shifts to use of LPG, from 8 percent in 1991 up to 25 percent to 30 percent by 2011.

S4: Enhanced energy efficiency

In addition to S2-B, directed energy conservation in all sectors is included in this scenario. Improvement of modern energy efficiencies up to 20 percent to 25 percent is assumed by 2011 with an equivalent percentage savings of electricity and fossil fuels consumption in the industrial sector. For the transportation sector, setting standards will provide vehicle efficiency improvements up to 16 percent to 25 percent for all vehicle types except motorcycles. A 25 percent improvement by 2011 is assumed for LPG and diesel, while 16 percent is assumed for gasoline. The lower percentage improvement in gasoline efficiency arises from the fact that roughly one-third of the gasoline users are motorcycles, which are relatively inefficient. An efficiency improvement in the power generation sector has already been incorporated into the generation plan. The savings potential thus stresses a lowering in generation requirements from lesser electricity consumption by end-use sectors.

S5: Comprehensive Environmental Response

This scenario includes basic elements of the pollution control and fuel standards Scenario S2 assumes a broad-based energy efficiency response in all sectors (S4), and incorporates a modest fuel shift (S3) in most sectors. It highlights the pollution limiting potential of a comprehensive policy response to rapid energy expansion in the economy.

Results for the Base Case Scenario

The estimated emissions of SO2 and NOx are shown for the Base Case (S1) in Figures 9-3 and 9-4, respectively, disaggregated according to the individual contributions of the electricity/refinery, industrial, transportation, and RCA sectors. The overall growth of SO2 is very dramatic, with the total emissions growing from 440,000 tons in 1986, to more than 2 million tons in 2001, and to more than 3 million tons by the year 2011. As expected the largest contributor is the electric power industry. However after the year 2000, as additional power generation capacity will be based primarily on low-sulfur imported coal, the relative contribution of the industrial sector will become increasingly important. By the year 2011, industrial sector emissions will reach 800,000 tons, approximately 44 percent of the emissions of the power sector. The transportation sector will contribute only 10 percent of the total SO2 emissions in 2011.

The total emissions of nitrogen oxides are approximately 1.1 million and 1.6 million tons in 2001 and 2011, respectively, growing steadily from a value of 300,000 tons in 1986. The transportation sector plays a dominant role throughout the entire period, contributing between 60 percent and 65 percent of the total.

The spatial distribution of SO2 and NOx is of significance in the acid rain analysis because of the possible influence of regional climatology on the atmospheric transport and transformation of the acid precursors. Experience in Europe and North America has shown that the fate of these acid precursors is subject to a complex set of atmospheric processes. In order to provide a basis for examining spatial distributions of the pollutant emissions, they have been calculated for each of the main geographical regions in Thailand, namely:

- Bangkok Metropolitan Region
- Central Region
- Northern Region

- Northeast Region
- Southern Region

The maps in Figures 9-5 and 9-6 show the total emissions of SO2 and NOx, respectively, for each of the above regions in 1986 and 2011. For SO2, it can be seen that there is a broad distribution of the emissions contributions from each of the geographical regions. With the exception of the Northeast Region, all regions contribute significantly to total emissions in the year 2011. Table 9-2 gives the percentage contribution of each region.

As shown in Figure 9-6 and Table 9-2, the BMR remains the dominant emitter of NOx, responsible for more than 45 percent of the emissions in both 1986 and 2011. Together, BMR and the Central Region contribute more than 60 percent of the NOx emissions in the year 2011.

Base Case Scenario Implications for Thailand

Chapter 8 presented some of the concerns about acid rain. These included effects on aquatic bodies, on forests and vegetation, on agricultural crops, on materials, cultural structures and artifacts, on visibility, and on human health. The Base Case Scenario presented (S1) provides a useful baseline with which to examine the implications of acid precursor emissions in Thailand. This section discusses these implications and lays the basis for (1) the acid rain control scenarios of the next section, and (2) conclusions and policy recommendations of Chapter 11. The framework of the discussion is organized according to a cause-effect chain which leads to the final environmental impact, namely:

- Socioeconomic activity based upon energy services
- Energy supply/utilization
- Emissions (and emissions density) of acid precursors.
- Acid precursor transport and transformation
- Acid deposition and dose to receptor
- Environmental quality and impacts to receptor

Growth of Socioeconomic Activity

Clearly, Thailand's very high rate of economic growth is one of the main driving forces behind the rapidly increasing environmental impacts of energy systems. Most industrialized countries are now experiencing only modest economic growth rates, and many of the energy-related environmental impacts resulting from this modest growth can be ameliorated, or even reduced, by technological fixes such as pollution abatement equipment. In contrast, Thailand's annual growth, on the order of 6 percent to 10 percent, is bringing about extremely rapid changes and disturbing levels of environmental loading, such as air emissions and depositions including acid precursors. Over the time period of these scenarios, 1986-2011, the GDP has grown by a factor of 6.5, from 413 billion to 2,706 billion, in terms of 1972 baht.

Energy Supply/Utilization

Coupled with strong economic growth rates is the major penetration or growth of fuels with great potential for emissions of acid precursors, namely, lignite with low specific energy and high-sulfur content, and petroleum-based fuels with significant sulfur content. Over this 25 year time period, annual lignite use will grow from 4.6 million to 49 million tons, a factor of 10, and petroleum use will grow from 11.2 million to 63.4 million tons of crude oil equivalent (MMTOE), a factor of 6.

Emissions of Acid Precursors

Because the emissions of the acid precursors SO2 and NOx are essentially uncontrolled in the Base Case, they are driven directly by the above energy increase. As shown in Figure 9-3, SO2 emissions increase from 444,000 tons in 1986, to 2.2 million tons in 2001, and to 3.1 million tons in 2011. The large absolute magnitude of this emission can be appreciated by comparing it to several other European countries for the year 1984. SO2 emissions were 2.3 and 0.3 million tons in France and Sweden, respectively. The level of emission in the United States was 4.8 million tons in 1989.

An additional relevant indicator is the density of the acid precursor emissions measured in tons per square kilometer per year. This indicator, when averaged over an airshed or a region of comparable size as the mean transport distance, gives some idea of the intensity of the source. Table 9-3 compares the SO2 annual emissions and emission densities for Thailand and some of its regions in 2001 and 2011, with those of several European countries as well as the Southeast Region of the United States, a region somewhat similar to Thailand.

It is notable that the total emissions and emission densities of Thailand are comparable in those years to several countries with significant sources, e.g., Germany, Hungary, Poland, and the Southeast Region of the United States. Although the resulting acid depositions are not necessarily directly proportional to emission density, there is a strong correlation as shown by extensive analysis in the United States and Europe (Rodhe, 1988). The actual relationships between emissions and deposition depend of course on the detailed meteorologic conditions of the region, as will be discussed further below.

In a similar fashion, the NOx emissions and emission densities show dramatic growth, increasing from 311,000 tons in 1986, to 1.1 million tons and 2.0 million tons in 2001 and 2011, respectively. As shown by the map in Figure 9-6, NOx emissions are more evenly divided between the Northern Region (from power plants) and the Bangkok/Central Region, where they originate from both the industrial and transportation sectors.

Acid Precursor Transport and Transformation

Because acid deposition is essentially a secondary pollutant, (it is not emitted in the same form as it is deposited), and its precursors can travel long distances before reaching the earths surface, an identification of the transformation and transport processes is critical to understanding acid deposition and its impact. As pointed out earlier in this paper, many of Thailand's air pollution problems have been considered to be confined to localized areas of high emissions, e.g., in the Bangkok area or near the Mae Moh lignite-fueled power plant complex in the north. However the projected very high emissions and the particular meteorological conditions of Southeast Asia are causing reconsideration of this perception for a number of reasons:

1. The increased use of very high smokestacks will result in increased residence time and greater potential for long-range transport of acid deposition precursors.
2. The higher temperature and sunlight intensity present in Southeast Asia, and Thailand specifically, increase the efficiency of atmospheric chemical reactions, particularly those transforming SO2 and NOx to acidic sulfates and nitrates (Chatfield and Crutzen, 1984).
3. Stable air masses in Southeast Asia during large portions of the year may increase the residence time of pollutants, thereby allowing greater opportunity for conversion to secondary pollutants. In addition, the strong vertical mixing of the lower portion of the atmosphere characteristic of much of the tropics and subtropics would transport pollutants to higher altitudes (thus mimicking tall smokestacks) where they would have longer residence times and be carried farther afield (Chatfield and Crutzen, 1984).
4. High rainfall rates (at least seasonally) would increase the proportion of SO2 and NOx that is converted into sulfates and nitrates by aqueous-phase

> reactions. These sulfates and nitrates can then be coupled to large-scale precipitation-producing weather systems and deposited farther from emission sources than the same acidic substances produced via gaseous-phase (dry) processes. Also, the greater amounts of rainfall in these regions would contribute to larger total hydrogen ion deposition than that predicted on the basis of precipitation pH alone (Mc Dowell 1988).

From the above, one might conclude that in the summer, when the moisture-laden monsoon winds dominate much of Thailand (except the far south), the acid precursors and reactants would be carried farther from their source than in the dry season. Due to the predominant south-southwest winds during this period, much of the acidic substance could be wet-deposited in areas north-northeast-northwest of emission sources. In the dry cooler season, the transport pattern would be completely different. Gaseous-phase reactions and deposition could dominate; because dry deposition processes occur closer to the source of emission than wet deposition, transport distance might be reduced.

Clearly the above factors are complex, and their unambiguous interpretation would require further analysis and substantiation. However, the potential for acid precursor transformation and transport to regions beyond the local areas of concern is clearly a strong possibility and warrants serious consideration of preventive measures.

Acid Deposition and Dose to Receptors

Due to the general paucity of empirical measurements of current deposition pH, and of long-term data on the chemical composition of precipitation in Thailand and the surrounding regions, it is difficult to determine which areas are experiencing acid deposition and if there are any trends toward an increased deposition acidity. An initial very limited measurement program in Thailand was sponsored by UNEP and conducted from April to November of 1987. The results of that study did not show a current significant level of acid rain in the geographic regions studied (Koottatep, 1988). However a number of low pH rain measurements were recorded in the Bangkok, Chiang Mai, and Songkhla areas. The study strongly recommended an expanded program, and the improvement of a methodology for acid rain monitoring and analysis.

Environmental Quality and Impacts to Receptor

Ultimately it is the impact that acid deposition has on the natural and man-made environment that are of greatest concern to society. From a public policy perspective, the most important issue is not whether or not acid deposition does or can occur, but whether the environment of the area is vulnerable to its potential effects. In Europe and North America there is now substantial accumulated evidence on the capacity of acid deposition to damage a number of components of the environment. Unfortunately in Thailand, as in most of Asia, there is an absence of both research and empirical evidence.

Soils, through their differing ability to process and neutralize acidic inputs. determine to a large extent how acid deposition will affect the terrestrial and aquatic ecosystems. Soil sensitivity to acidification is based on a number of factors, the most important of which are texture, base saturation and cation exchange capacity (CEC), organic matter content, anion mobility, thickness of vegetation cover, and rainfall rate. In general the more acid-sensitive soils are those which (1) are underlaid by hard granite or gneiss bedrock, which do not weather easily, and thus have low base saturation and CEC, (2) are located in areas of moderately high rainfall (500-1000 millimeters per year), (3) have high organic matter content and/or low sulfate adsorption capacity, or (4) are in areas of rapid deforestation and/or agricultural intensification. Various areas of Thailand would appear to satisfy one or more of these conditions.

The impact of acid deposition on the natural environment is dictated by the sensitivity of the flora and fauna of a region as well as the sensitivity of its soil. Any change in productivity of the flora or fauna of Thailand could have severe consequences because of the large human populations dependent on these resources. However very little research has been done on species extant in Thailand. Among the general concerns, two points have been raised which may be particularly relevant. It is possible that in the tropical and subtropical climates of Thailand, with the associated longer leaf life, the cumulative effects of acid deposition could be large enough to cause direct damage, although this has not been observed in temperate climates. Secondly, some of Thailand's forests are located in mountainous areas where exposure to acidic species is potentially higher than at lower levels, as experienced in Europe and North America.

Acid deposition corrodes man-made surfaces such as those of statues, monuments, buildings, and vehicles. Due to the prevalence in Thailand of a vast number of significant cultural, religious, and historical relics, often hundreds or thousands of years old. Deterioration due to acid deposition could be of great concern, both because of deep cultural values and because of potential long-term negative impacts on tourism.

As research into the acid deposition phenomenon has intensified, potential human health effects have become evident. These effects are caused not only by acid precipitation but also by acidic aerosols, particularly sulfates and nitrates. Such substances can affect human health both directly, through contact with the skin, eyes, and respiratory system, and indirectly. At ambient levels of acidity in North America and Europe, very little direct damage has been observed except through the inhalation of acidic aerosols, particularly sulfates.

Indirect effects of acid deposition on human health may be potentially more serious. These impacts include contamination of drinking water supplies, as well as mercury and toxic metal poisoning caused by ingestion of fish from acidic waters and crops grown in acidic soils. No such effects have yet been observed in North America and Europe. In Asia, however, where population density is extremely high and the health of a large segment of the population may be weakened by other stresses, the potential for human health damage from acid deposition may be greater.

Summary Comments on Impacts

Thailand's acid rain situation is becoming increasingly similar to that which many industrialized countries experienced one to two decades ago, when they first recognized the seriousness of the problem. At that time, those countries responded with varying degrees of preventive actions and further investigation. Their experiences should provide some valuable guidelines for Thailand. However the particular conditions in Thailand and the Asian Region may provide some significant differences.

Scenario Results for Acid Rain Control

As described in Chapter 3 and above, a set of scenarios was developed which explicitly examined the emissions consequences of SO2 and NOx emission control technologies. Table 9-1 contains the percentage reductions in emissions which were assumed to be associated with each of the control scenarios. Scenarios S2-A and S2-B were moderate and stronger control measures, respectively. Scenario S3 was based on maximum control measures including shifts from coal to natural gas in the electric power sector. Scenario S4 included the measures in S2 but also assumed efficiency improvements in energy consumption. Scenario S5 was based on the same fuel shifts (S3), but also included the assumption of increased efficiency of energy consumption.

SO2 Emissions

The estimated SO2 emissions for the Base Case and four of the alternative scenarios are shown in Figure 9-7. Table 9-4 shows emissions by sector for all of the scenarios. Most striking are the reductions, relative to the Base Case, brought about by the control measures in Scenarios S2-A and S2-B. Emissions in the year 1996 were decreased by 23.6 percent and 42.0 percent, respectively, and in the year 2011, 25.8 percent and 45.2 percent, respectively. As will be described in Chapter 10, the control technologies which are used to bring about these reductions are now widely used in Japan, Europe, and North America. It can be seen from Table 9-4 that the largest reduction of emissions results from control in the power sector, a reduction of 670,000 tons per year in the year 2011 for the stronger control scenario. The next largest reduction is seen in the industrial sector, with a reduction of 482,000 tons in 2011.

As shown in Figure 9-7, both the fuel shift and the efficiency scenarios also bring about large reductions of SO2 emissions relative to the Base Case, although not quite as large in absolute or percentage terms as the stronger control scenario. However, relative to the moderate control scenario, the fuel shift scenario reduced SO2 emissions by 700,000 tons in 2011. This amount slightly exceeds the reduction resulting from a shift from moderate to stronger control without a fuel shift.

The comprehensive cases (which includes controls in Scenarios S2, S3 and S4) results in an additional reduction of approximately 19,000 tons in 1996, and 122,000 tons in 2011, relative to the fuel shift case. Emissions in the year 2011 are estimated at 924,000 tons, approximately 71 percent lower than in the uncontrolled Base Case. Nevertheless it is notable that even with these measures and interventions, the 2011 SO2 emissions will have increased by more than twice that of 1986 base year.

NOx Emissions

The estimated NOx emissions for the Base Case and the six emission reduction scenarios are shown in Figure 9-8. Table 9-5 shows emissions by sector for all of the scenarios. The moderate and the stronger control technologies bring about reductions of 14 percent and 16 percent, respectively, in the year 2011. The small difference between the two scenarios results form the fact that both scenarios have the same control technology for the transport sector, which is the largest contributor of NOx emissions. For absolute reductions of NOx emissions for the scenarios, relative to the Base Case, it can be seen that by far the largest reduction of emissions results from controls in the transportation sector, 240,000 tons in the year 2011. This amounts to approximately 75 percent of the total reduction in that year.

As shown in Table 9-5, both the fuel shift and comprehensive environmental scenarios bring about even larger reductions of NOx emissions relative to the Base Case and control cases. In particular the fuel shift to natural gas results in a reduction of

190,000 tons in the year 1996, and 838,000 tons in the year 2011. This shift is largest in the transportation sector, followed in magnitude by the power sector. The comprehensive case results in an additional reduction of approximately 7,000 tons in the year 2011.

The comprehensive environmental case is relatively effective, resulting in a combined reduction in NOx emissions in 2011 of approximately 59 percent from the Base Case. Nevertheless, emissions in that year still increase by more than a factor of four from the 1986 base year value. As will be discussed in Chapters 10 and 11, there are additional control measures, becoming commonplace in Japan and Europe, which could be considered for use in the power sector.

The transportation and power generation sectors are the major emitters of NOx, together they account for 85 percent of all emissions. The regional distribution of NOx is skewed toward the BMR and the Central Region, where transportation is heavily concentrated.

From the results of the scenarios described above, it is evident that there do exist options for reducing emissions of acid precursors. The options chosen for study do show the possibility for reducing emissions by more than 50 percent from the Base Case over the next two decades. This reduction does not necessarily lead to a directly proportional reduction in acidic deposition. However there is good evidence from work in industrialized countries that the linearity assumption is a reasonable policy guide for the options under consideration here. Although even at the end of the study period (2011), the emissions of acid precursors are still increasing at a rapid rate, control measures bringing about these reductions do delay the time when emissions reach the levels and potential impacts discussed previously. Chapter 10 describes these technologies for the power and industrial sectors, including their performance, their status in other parts of the world, and the economic implications of their implementation in Thailand.

ASIAN REGION ACID RAIN OUTLOOK

Because of the potential regional influences and impacts of acid rain, Thailand cannot treat its own situation as isolated from other countries in Asia. There is clearly the potential for Thailand to both export and import acid rain precursors yet there remains uncertainty as to the extent of geographical coverage relevant to Thailand's situation. Therefore this section brings an Asia-wide perspective to our analysis in order to broaden the policy framework within which Thailand's policy can be analyzed.

The topic of acid rain has only very recently begun to be addressed on a truly region wide basis in Asia. Much of the material presented here has been derived from the discussions and analysis at the recent Workshop on Acid Rain in Asia held at the AIT in November, 1989. In the following sections this source is referred to as the Workshop on Acid Rain in Asia (WARA).

Current and Future Energy Use and Emissions in Asia

Concern about the acid rain problem in Asia is heavily influenced by consideration of Asia's population, its growing economy, and associated systems of energy consumption and production. Growth of both population and the economy are powerful driving forces behind the rapidly increasing use of the fossil fuels whose combustion is ultimately responsible for acid deposition. Both the size and the growth rate of Asia's population intensify this concern. Asia currently accounts for more than 55 percent of world population, and by the year 2010, according to United Nations scenarios, it could total close to 4 billion people. The economic growth rate of Asia is far higher than any other region of the world. If current trends continue through the end of the century, the Western Pacific countries would have an economy comparable in size to those of North America or Western Europe.

The current energy system which has evolved to fuel Asia's economic development is striking in many respects. First, it is almost completely dependent on fossil fuels, the source of more than 95 percent of Asia's commercial energy. Second, approximately 60 percent of the consumed fossil fuel is in the form of coal, with most of the remainder fuel oil. Both of these fuels contribute significantly to the emissions of acid rain precursors in Asia. The annual rates of these emissions have greatly exceeded those in western industrialized countries, which are now relatively stable at a few percent or less. If the western experience can be used as a guide, even with strong conservation measures we can expect continued very high growth in Asia for many years.

Of particular concern is the continued growth of coal use. Coal use in the region was approximately 1,360 million metric tons in 1987, the three largest users being China, India, and Japan. Preliminary data and estimates (see table 9-6) from WARA indicate that regional coal use in the year 2000 could be as high as 2,300 million metric tons, with very large growth increments in China and India, and significant growth in several other countries, including Indonesia, Thailand, and the Koreas.

To put Asia's energy-related acid precursor emissions in perspective with the industrialized countries, preliminary estimates of Asia's total sulfur dioxide emissions for a base year (1985) and for the year 2000 were developed by WARA. These are based on the coal scenarios shown in Table 9-6 and the assumption that petroleum use will increase at a 4 percent annual growth rate. As shown in Table 9-6, the total energy sector sulfur dioxide emissions in 1985 in Asia was approximately 22 million tons, roughly 85 percent of which resulted from coal and 15 percent from oil combustion. For comparison, the estimated sulfur dioxide emissions in the United States in 1985 were also 22 million tons. WARA's estimate for Asia in the year 2000 is a total energy sector SO2 emission of approximately 37 million tons. Thus the Asian emissions in 2000 would be approaching twice that of today's emissions in the United States, and would considerably exceed the combined emissions of Western and Eastern Europe.

WARA did not develop estimates of NOx emissions for Asia. With the rapid increase of automobile usage in addition to the coal growth described above, however, it is likely that NOx emissions will also exceed European and North American levels early in the next century.

Acid Deposition in Asia

Of the developing countries in Asia, China has understandably shown the most concern about acid rain. In its southwestern province of Guizhon, pH of precipitation has been measured as low as 3.4 in urban areas. In rural areas, mean precipitation pH is approximately 4.6. It is generally believed that acid rain in Guizhon occurs both as the result of local emission and, to a lesser degree, the long-range transport of substances from more distant areas. Because most of the emissions are currently released at or near ground level, much of the deposition is confined to areas close to their sources. However, many large coal-fired power plants and factories with tall stacks are now being built in China, as well as in other countries in Asia. Consequently the emissions released at greater heights will increase dramatically in the future, control measures may be limited or non-existent, and sulfur and nitrogen species may be transported hundreds or thousands of kilometers.

In addition to concerns about the level of total emissions early in the next century, WARA anticipated increasingly serious problems associated with the high density of emission sources in some areas. Such areas include eastern and central India, northeast and southwest China, the Korean peninsula, Japan, northern and possibly southern

Thailand, and western Java. The majority of these emissions would likely result from uncontrolled coal combustion and/or motor vehicle use.

An overview of key elements in the acid rain situation has been sketched in Figure 9-7. Relative sulfur dioxide emissions in 1985 by country or region are indicated by vertical bars. Emissions are already significant in China, India, Japan, and the Koreas, and are small but very rapidly growing in several countries of South and Southeast Asia. Deposition patterns are strongly determined by wind flow patterns, sketched in summary by arrows in the figure. In winter (January) the flow is generally from the land mass to the ocean, while in summer (July) the reverse is true. Typical monitored values of pH are shown in the circles. Low pH values, e.g, 4.5, occur in Japan and southern China where emissions are large, elsewhere the pH values are 6 to 7. However, due to lack of sufficient monitoring sites, one cannot discount the possibility of low pH at other unsuspected locations. As discussed above, three is little information available on the possible consequences of acid deposition in Asia.

Implications for Thailand

Thailand should have concerns both as a potential receptor, and as an export source of acid precursor in Asia. Unfortunately there does not yet exist an adequate regional emissions transport model for South and Southeast Asia which could give even approximate quantitative measures to the above concerns. Even the current status of acid deposition is not addressed adequately by monitoring systems in Thailand or anywhere in Asia. An initial goal for Thailand should therefore be to ensure that both monitoring and analysis capabilities are put into place as soon as possible in order to better understand the regional implications of acid rain developments.

In the absence of quantitative information, it is still possible to speculate based on meteorological information, semi-quantitative estimates of emissions, source locations, etc. Despite the potential very long-range transport of acid precursors, it would appear that the near-term transport into Thailand of large quantities of acid substances would most probably originate from China, India, and possibly Indonesia, or Malaysia. Whether winds coming out of the northeast from China in the winter would result in deposition in Thailand or not is unclear. Wind patterns could also result in most of the large emissions form northern India remaining in that country.

The actual or perceived export of acidic substances from Thailand could also be an issue which deserves serious attention, as suggested by the major international problems which have arisen from transnational pollution in North America and Europe. Acid rain deposition in Canada, much of it originating in the United States, has been the most serious political issue confronting those two countries in the past several years. In Europe, the satisfactory understanding and political resolution of the acid rain problem has been one of the key irritants in inter-country relations for more than a decade. Thailand's neighbors are unlikely to be any less sensitive to this problem, particularly since a great part of their livelihoods depends on crops, forests, and other terrestrial ecosystems which are potentially sensitive to acid deposition.

Table 9-1 Emission Control Assumptions-% Reduction Scenario 2: Acid Rain Analysis

	Moderate Control 2A			Stronger Control 2B		
	Elec.	Industry	Transport	Elec.	Industry	Transport
SO2						
Lignite	50% a)	50% a)	-	90% a)	90% a),b)	-
Low-Sulfur Coal	0%	0%	-	0%	0%	-
Natural Gas	0%	0%	-	0%	0%	-
Diesel	60% [0.2%S]	60%	60%	80% [0.1%S]	80%	80%
Fuel Oil	33% [2%S]	33%	33%	66% [1.0%S]	66%	66% 75%
Gasoline	-	-	75%	-	-	-
LPG	-	-	-	-	-	-
NOx						
Lignite	25% a)	25% a)	-	40% a)	40% b)	-
Low-Sulfur Coal	25%	25% b)	-	40%	40% b)	-
Natural Gas	15%	15% b)	-	30%	30% b)	-
Diesel	20%	20% b)	20%	20%	20% b)	20%
Fuel Oil	15%	15% b)	-	30%	30% b)	-
Gasoline	-	-	50%	-	-	50%
LPG	-	-	50%	-	-	50%

Assumption: a) Lignite controls only on new facilities
b) Industrial controls only on 50% of new facilities
(i.e.,cut % in half for new energy)

Table 9-2 Region Percentage of SO2 and NOx Emissions in 1986 & 2011

	SO2		NOx	
	1986	2011	1986	2011
BMR	37.8	25.5	53.3	47.3
Central	8.2	26.2	12.7	28.6
North	41.0	36.2	14.3	9.7
Northeast	5.1	1.9	8.7	4.7
South	8.9	10.2	11.0	9.7
Total	100.0	100.0	100.0	100.0

Table 9.3 Comparison of Thailand SO2 Emissions with Other Regions

Country or Region	Land Area (mil.sq.km.)	Year	Total Emission (Mil.Tons)	Emission Density (ton/km2)
Thailand (Entire)		2001		
-North	0.55		2.2	3.9
-Central	0.211		1.06	5
-South	0.069		0.38	5.2
-Central &	0.091		0.19	2.05
BMR	0.077		0.91	11.9
Thailand (Entire)		2011		
-North	0.55		3.1	5.7
-Central	0.211		1.14	5.41
-South	0.074		0.85	11.92
-Central &	0.091		0.32	3.5
BMR	0.077		1.6	21.6
France	0.55	1984	2.3	4.2
Hungary	0.092	1980	1.6	17.6
Italy	0.294	1980	3.8	12.8
Netherlands	0.031	1980	0.26	8.6
Poland	0.304	1980	3.5	11.4
Romania	0.23	1980	1.5	6.6
Sweden	0.412	1984	0.29	0.7
West Germany	0.245	1980	2.7	11.3
U.S. Southeast Region	0.993	1989	4.8	4.9

Table 9-4 SO2 Emission for the Base Case and Alternative Scenarios

(Unit : Thousand Tons)

SO2	Base Case			S-2A		S-2B		S-3B-G		S-5B-G	
	1986	1996	2011	1996	2011	1996	2011	1996	2011	1996	2011
Industry	107	280	854	199	601	127	372	93	232	85	175
Agri.	17	18	28	8	12	4	6	4	6	4	6
Res.& Com.	7	5	7	5	6	4	4	4	4	4	4
Transport	96	147	342	72	168	43	100	41	82	42	88
Power Gen.	207	816	1923	687	1558	564	1253	453	712	442	640
Refinery	11	31	31	21	21	11	11	11	11	11	11
Total	444	1297	3186	991	2365	752	1745	606	1046	587	924
SO2 reduction compared with the base case											
Industry	0.0%	0.0%	0.0%	29.0%	29.7%	54.5%	56.5%	66.6%	72.9%	69.7%	79.5%
Agri.	0.0%	0.0%	0.0%	58.8%	58.8%	78.6%	78.6%	78.6%	78.6%	78.6%	78.6%
Res.& Com.	0.0%	0.0%	0.0%	12.8%	23.8%	25.4%	47.2%	25.4%	47.2%	25.4%	47.2%
Transport	0.0%	0.0%	0.0%	50.8%	50.8%	70.9%	70.9%	72.2%	75.9%	71.5%	74.4%
Power Gen.	0.0%	0.0%	0.0%	15.8%	19.0%	30.9%	34.8%	44.4%	63.0%	45.8%	66.7%
Refinery	0.0%	0.0%	0.0%	33.3%	33.3%	66.0%	66.0%	66.0%	66.0%	66.0%	66.0%
Total	0.0%	0.0%	0.0%	23.6%	25.8%	42.0%	45.2%	53.3%	67.2%	54.7%	71.0%

Table 9-5 NOx Emission for the Base Case and Alternative Scenarios

(Unit : Thousand Tons)

NOx	Base Case			S-2A		S-2B		S-3B-G		S-5B-G	
	1986	1996	2011	1996	2011	1996	2011	1996	2011	1996	2011
Industry	33	98	242	89	218	83	201	69	142	64	110
Agri.	5	10	16	10	16	10	16	10	16	10	16
Res.& Com.	37	23	26	23	26	23	26	23	26	23	26
Transport	199	532	1241	430	1003	430	1003	407	789	418	840
Power Gen.	35	129	548	117	524	104	506	94	262	92	236
Refinery	2	5	5	4	4	4	4	4	4	4	4
Total	311	798	2077	674	1790	655	1755	608	1239	611	1232
NOx reduction compared with the base case											
Industry	0.0%	0.0%	0.0%	9.1%	10.0%	15.3%	16.9%	29.5%	41.1%	35.3%	54.5%
Agri.	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Res.& Com.	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Transport	0.0%	0.0%	0.0%	19.2%	19.2%	19.2%	19.2%	23.5%	36.4%	21.4%	32.3%
Power Gen.	0.0%	0.0%	0.0%	10.0%	4.4%	19.7%	7.7%	27.4%	52.1%	29.2%	56.9%
Refinery	0.0%	0.0%	0.0%	5.8%	5.8%	11.7%	11.7%	11.7%	11.7%	11.7%	11.7%
Total	0.0%	0.0%	0.0%	15.6%	13.8%	18.0%	15.5%	23.8%	40.3%	23.4%	40.7%

Table 9-6 Estimated Coal Use and Energy Sector SO2 Emissions for Major Emitting countries

	Coal Use (Million Tons)		Energy-Sector SO2 Emissions (Million Tons)	
	1987	2000	1985(est'd)	2000(est'd)
China	918	1500	15.8	25.5
India	186	417	2.8	6.1
Japan	106	-	1.3	1.3
N.Korea	52	72	-	-
S.Korea	43	74	1.1	1.6
Taiwan	15	37	-	-
Thailand	7	43	0.44	2.1
Indonesia	3	18	0.2	0.7
Region Total	1350	2300	22	37

Note: * Emission from coal and petroleum emissions controls assumed for Japan only

- = not available or not estimates

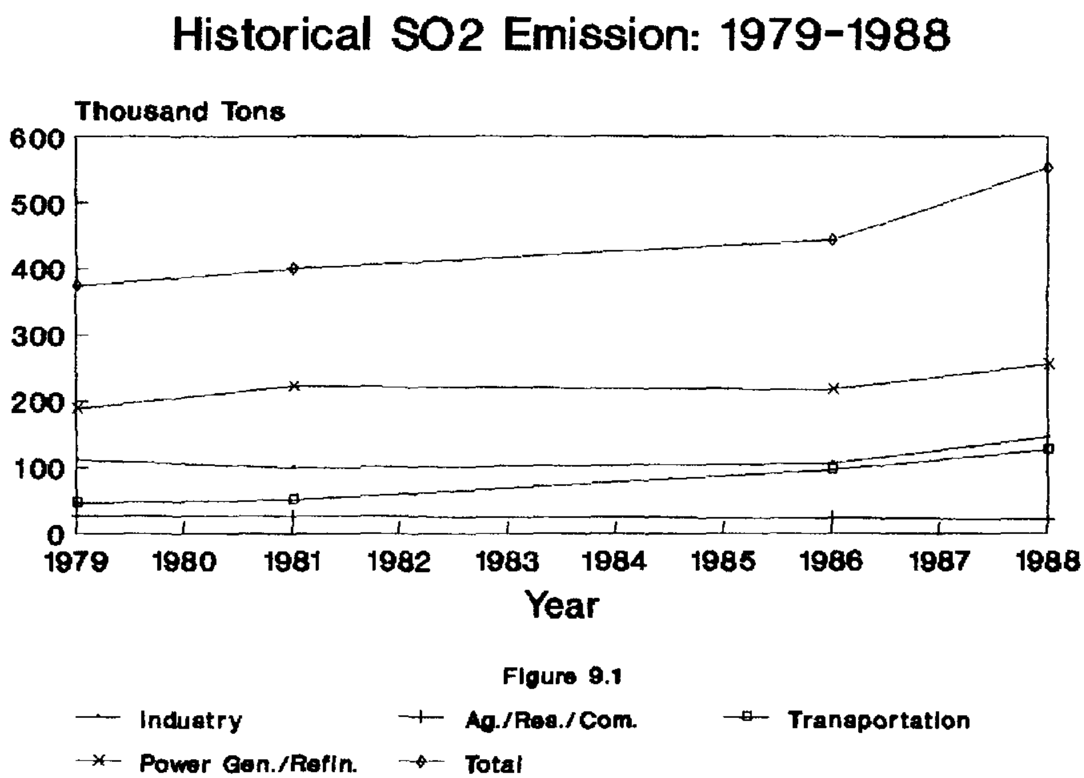

Historical SO2 Emission: 1979-1988
Thousand Tons
600
500
400
300
200
100
0
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
Year
Industry
Ag./Res./Com.
Transportation
Power Gen./Refin.
Total

Figure 9.1

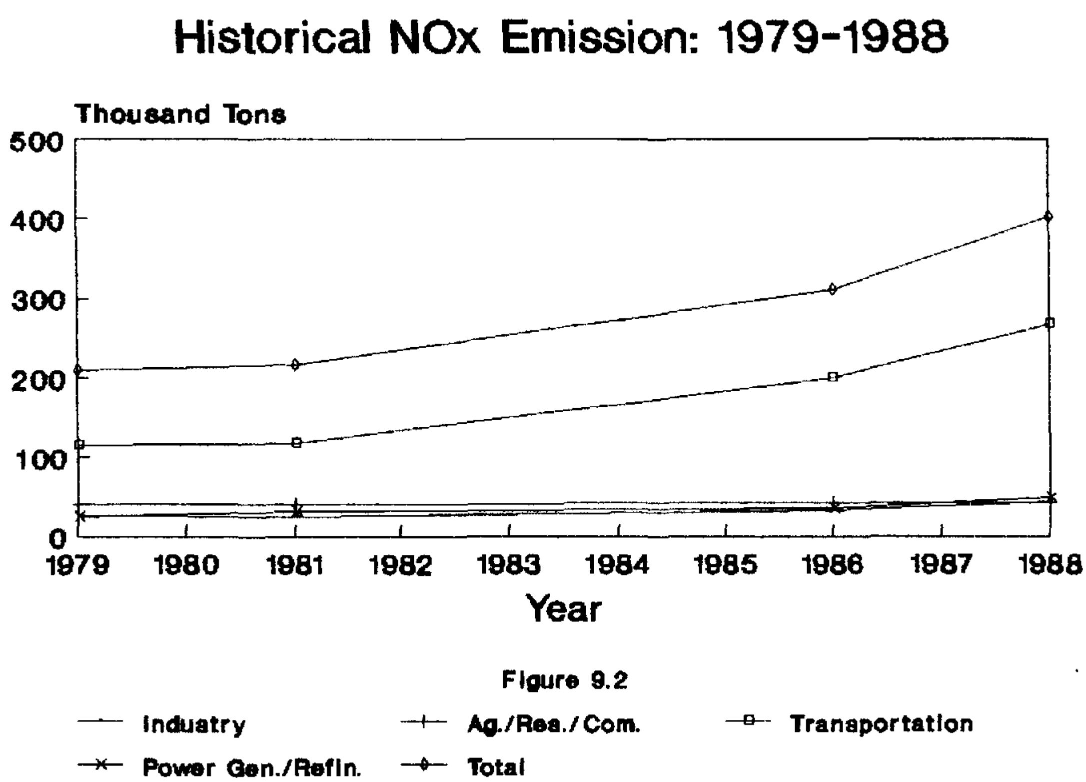

Historical NOx Emission: 1979-1988
Thousand Tons
500
400
300
200
100
0
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
Year
Industry
Ag./Res./Com.
Transportation
Power Gen./Refin.
Total

Figure 9.2

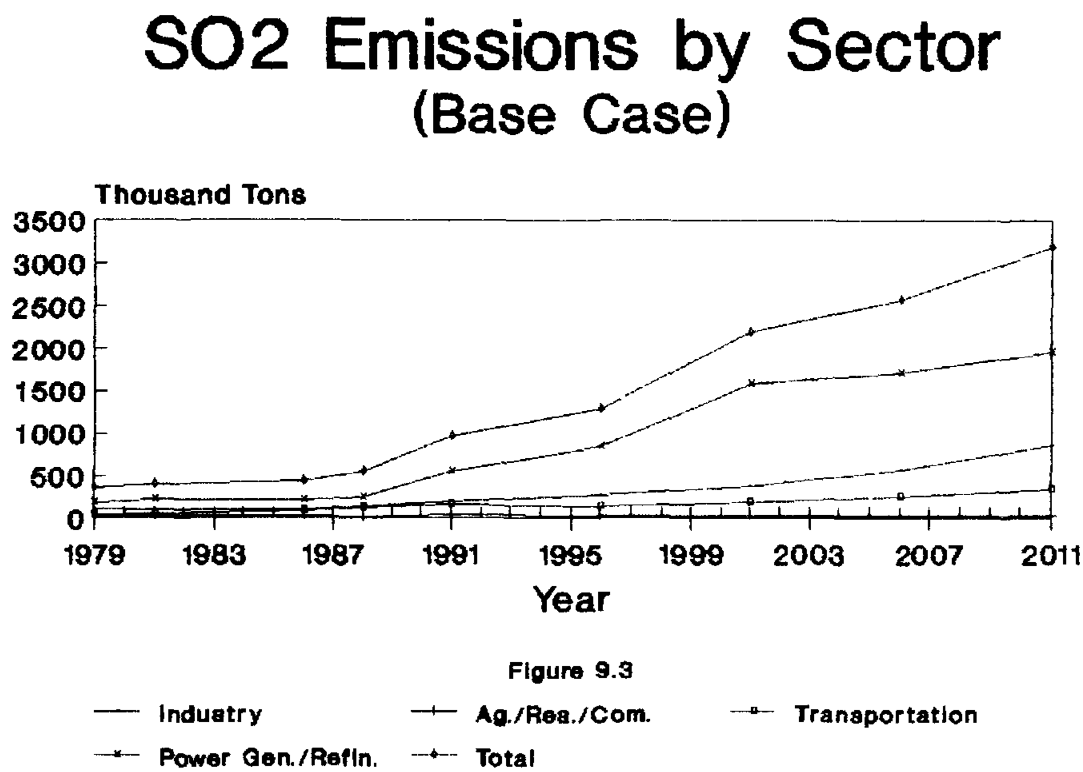

SO2 Emissions by Sector
(Base Case)
Thousand Tons
3500
3000
2500
2000
1500
1000
500
0
1979
1983
1987
1991
1995
1999
2003
2007
2011
Year
Industry
Ag./Res./Com.
Transportation
Power Gen./Refin.
Total

Figure 9.3

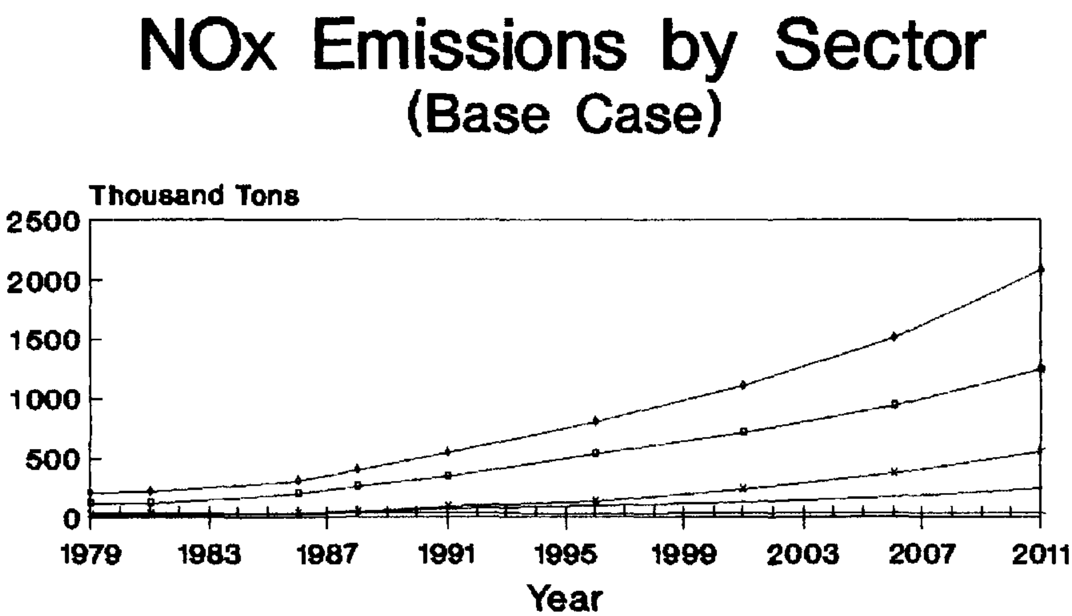


Figure 9.4

Industry
Ag./Res./Com.
Transportation
Power Gen./Refin.
Total

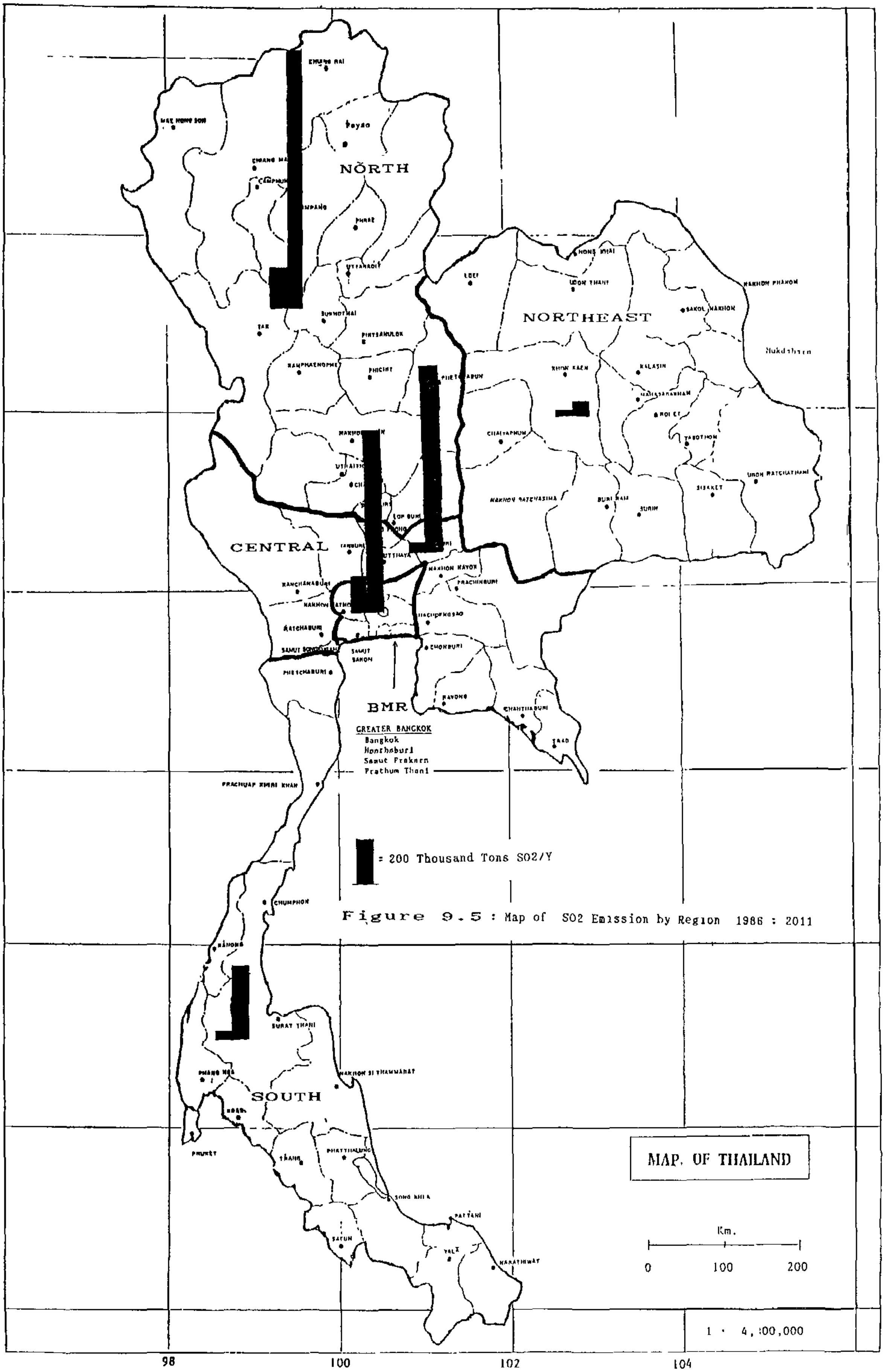


Figure 9.5 : Map of SO2 Emission by Region 1986 : 2011

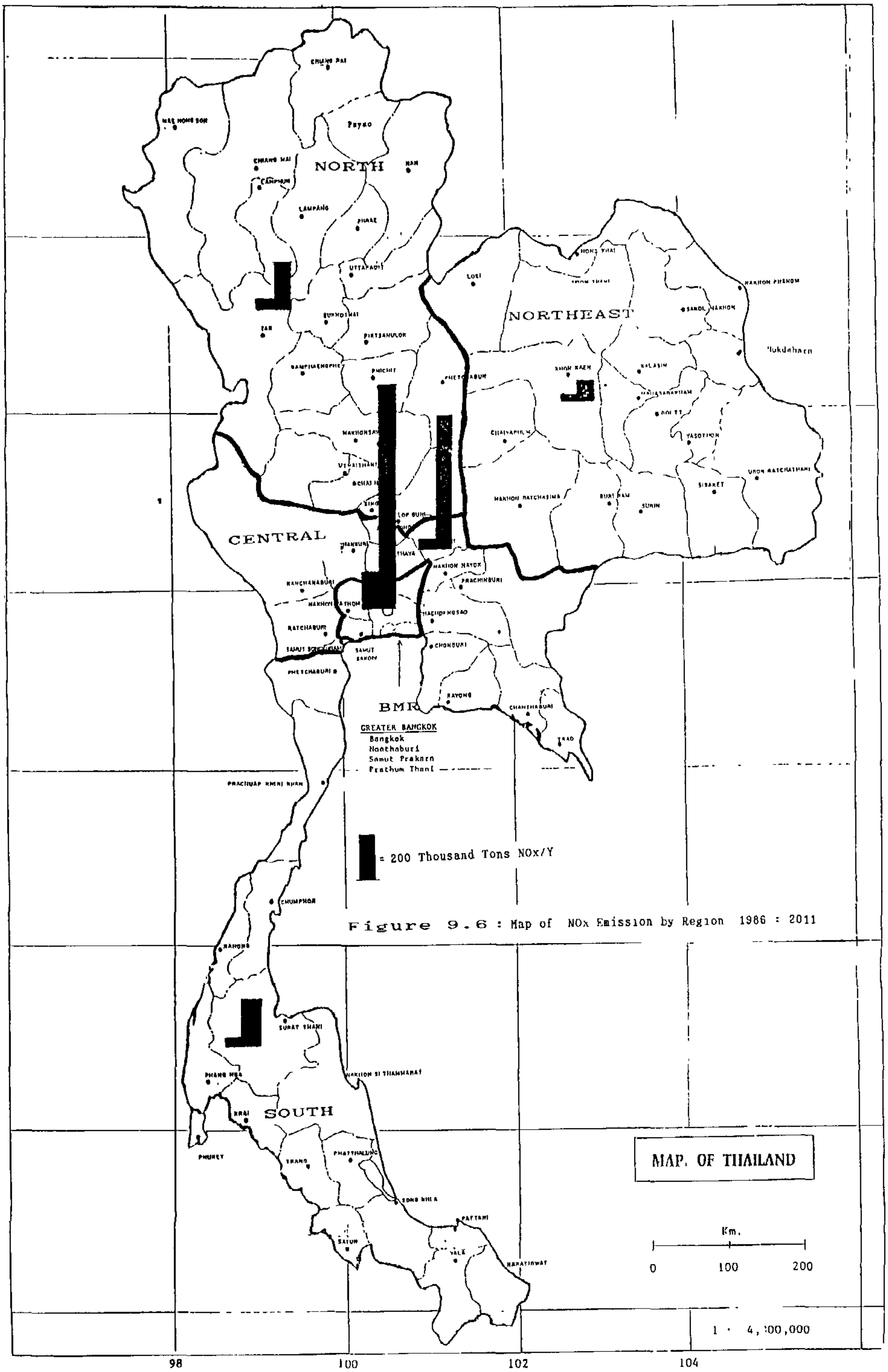


Figure 9.6 : Map of NOx Emission by Region 1986 : 2011

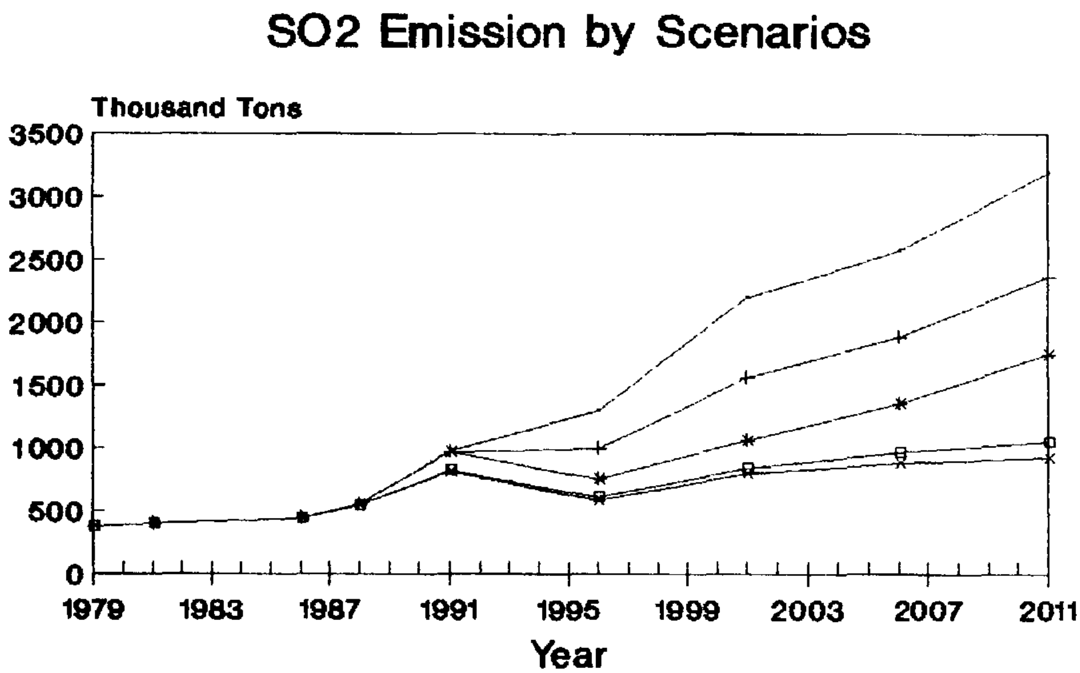

SO2 Emission by Scenarios
Thousand Tons
3500
3000
2500
2000
1500
1000
500
0
1979
1983
1987
1991
1995
1999
2003
2007
2011
Year

Figure 9.7

Base
S-2A
S-2B
S-3B-G
S-5B-G

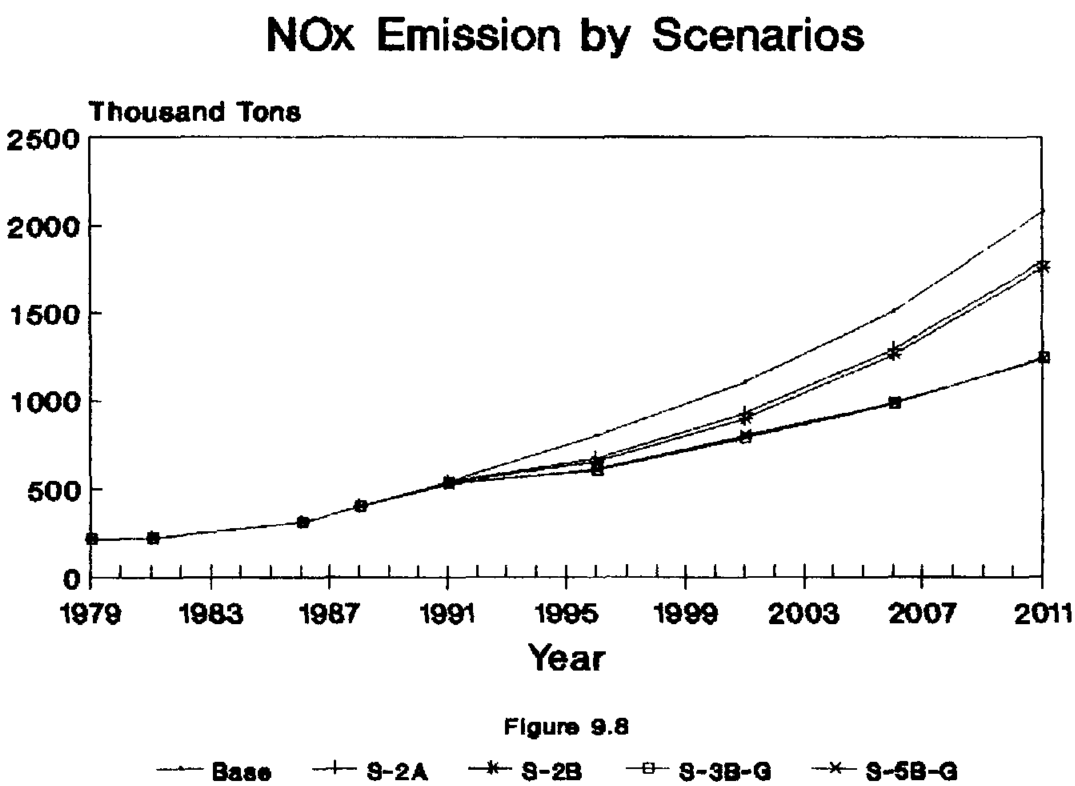
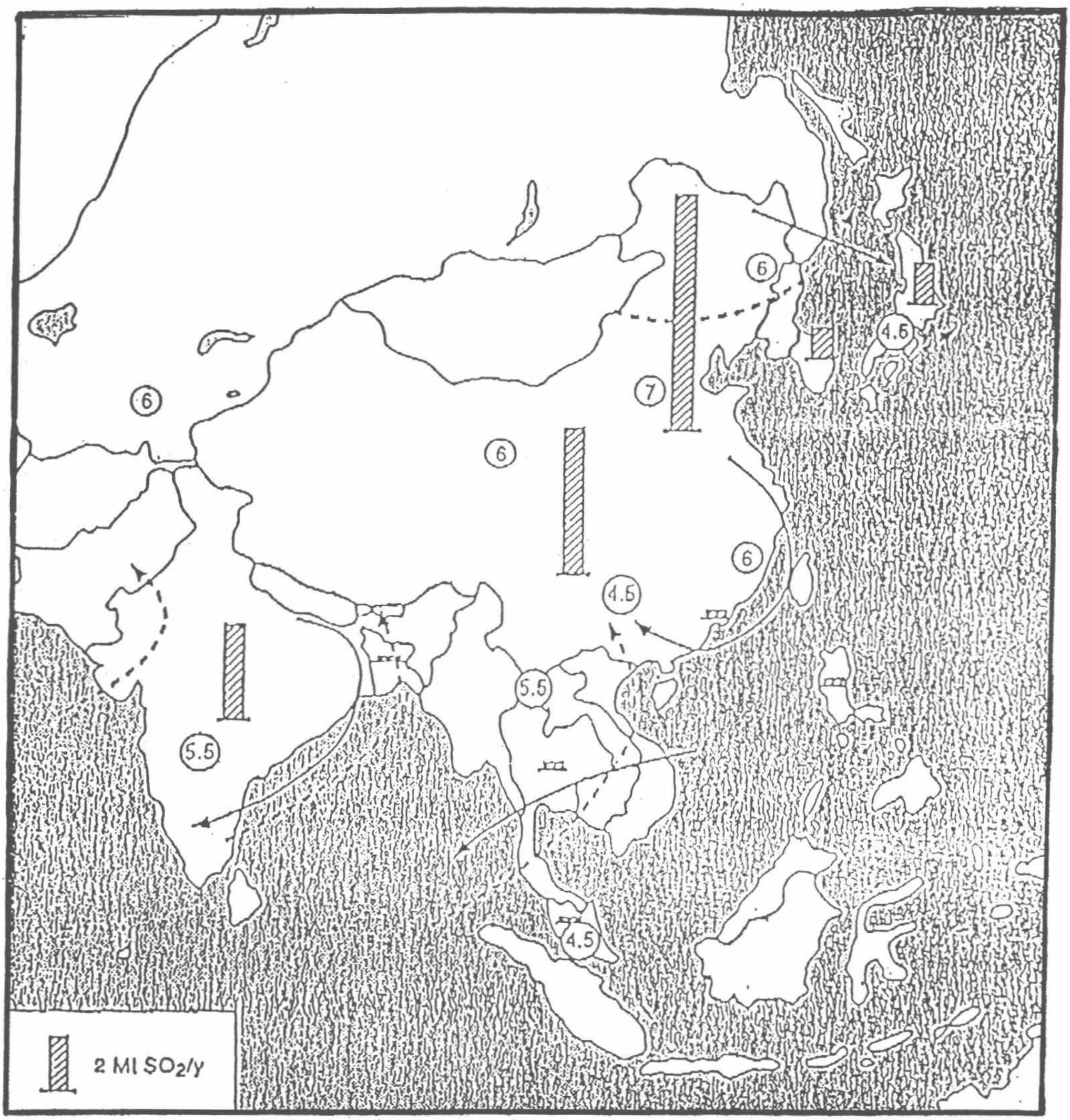

NOx Emission by Scenarios
Thousand Tons
2500
2000
1500
1000
500
0
1979
1983
1987
1991
1995
1999
2003
2007
2011
Year
Base
S-2A
S-2B
S-3B-G
S-5B-G

Figure 9.8



○ = pH Value

——→ = winter wind flow

- - - -→ = summer wind flow

▨ = Annual SO2 emission

Figure 9-9 Key Elements of the Acid Rain Situation in Asia

Chapter 10

Acid Rain Control Technology Options in Thailand

The previous chapter presented a description of potential sources of acid rain precursors in Thailand and some of their environmental implications. It also described the emissions reductions potential associated with a variety of emission control scenarios for various energy sectors and types of energy facilities. This chapter focuses specifically on the technological options for control of the acid rain precursors, SO2 and NOx, and to a lesser degree, the associated particulate matter emissions. The primary focus is on lignite fueled plants in the power sector, although some of the same technologies and issues are also relevant to the industrial sector.

This chapter begins with a summary discussion of the past experiences and current status of various control options, based primarily on experiences in the industrialized countries. It follows with a discussion of some of the economic consequences of èmission controls, based on work in Europe, Japan, and the United States. Initial results are then presented for cost and performance analyses of selected emission control options on a future lignite fueled generating plant at the Mae Moh plant.

TECHNICAL STATUS AND EXPERIENCE WITH ACID RAIN CONTROL OPTIONS

Thailand's past emphasis on power plant and industrial boilers air emission controls has focused on maintaining air quality levels necessary to prevent direct public health impacts in the vicinity of the plant. The primary approach in the past has been to model the plant stack emissions dispersion pattern for a particular plant, and to design the stack high enough to prevent violation of ambient air quality standards in the area directly affected by the plant. Particularly important was the area where the plume first reached the ground. However, with the incorporation of longer range transport of acid precursors as described in Chapter 9, serious consideration must now be given to emissions reduction technology instead of a strategy relying strictly on pollution dilution.

As described in Appendix D-14 the NEB established ambient air quality standards in 1981 for major air pollutants, including SO2 and NOx. These standards are intended to play a major role in protecting human health in the vicinity of the facilities. However, because of the possibility of meeting these standards through the dilution of emissions, e.g., with tall stacks, these ambient standards are not adequate to limit the total emissions in a way which satisfies the objectives of the acid precursor control strategies discussed in the previous chapter.

In general, the optimum process for controlling a given pollutant depends on the degree of control required. Processes that reduce emissions to an extreme degree are quite expensive and are often not cost effective unless the high control is essential. On the other hand, the less costly techniques are generally not capable of a high degree of control. Basic energy balances suggest that a portion of the thermal energy released by oxidation of acid species and external inputs must be utilized to chemically recapture them from the exhaust stream.

The two pollutants of primary concern are the sulfur oxides and the nitrogen oxides. The control system will also have to deal with the solid materials carried in the effluent gas stream referred to as particulates, such as ash from the fuel, unburned carbon, and other non-gaseous materials. Most of these pollutants come from the fuel itself, by the reaction of sulfur and nitrogen compounds with oxygen supplied by the combustion air, and by burning out the combustible compounds leaving the ash as small solid particles. This occurs more rapidly above specific threshold temperatures.

Sulfur dioxides and particulates are removed from the gas stream by a variety of methods. The general arrangement of equipment is shown in Figure 10-1. For nitrogen oxides the early practice had been to reduce emissions by altering the combustion condition in the boiler in such a way as to reduce NOx formation. Since this was only partially effective, there has been increased use, in Japan, Europe, and the United States of catalysts or reducing agents that split NOx into nitrogen and water to remove NOx from the gas.

In the control of SO2 emissions, several technical options are available, with many factors involved in choosing them. Considerations include; the degree of control required, whether to apply controls to new or retrofitted power systems, and byproduct recovery. The main options available are fuel desulfurization, coal gasification with solids recovery, desulfurization during coal combustion, and flue gas desulfurization.

The regulatory pressure to control the nitrogen oxides has generally been less intense in industrialized countries than for sulfur dioxides. However this has been changing quite rapidly, and strong concerns now exist in Europe, North America, and Japan. The technical alternatives for NOx reduction are; combustion modification to reduce NOx formation, and flue gas treatment to remove it from the gas stream. Combustion modification, by far the less expensive of the two, has been extensively used in the United States and Japan. However, flue gas treatment is growing rapidly in Japan and Europe.

The most common methods in the power industry for removing the very fine PM originating as ash from fuel, are electrostatic precipitation (ESP) and fabric filtration. The trend is increasing toward the use of fabric filters (bag houses) in the United States and Europe as a means of attaining the more stringent emission standards increasingly adopted for new boilers.

The removal levels in percentage terms, and a process ranking for SO2 and NOx are presented in Tables 10-1 and 10-2 for general comparison. The process categories and orderings are somewhat arbitrary and judgmental, and site-specific conditions could very well change them. Criteria used were based on subjective evaluation of factors including costs, commercial viability, absorption efficiency, and process reliability. However the tables do provide a useful overview of the available options. Lignite power plants that use a dedicated, high-sulfur and high-ash fuel with low energy content pose particular design constraints that must be addressed individually.

The control methods for particulates from coal firing have changed over the history of the power industry. Cyclonic collectors were used widely in the beginning, but low efficiency and high maintenance have practically eliminated them. Electrostatic precipitators became popular first in tandem with cyclones, and later as the sole collection device. The use of fabric filters, usually called bag houses in larger sizes, is an old technique for dust collection but it has been applied to utility boilers only during the last 10-15 years. Fabric filters are probably superior for low-sulfur and low-ash coals, and for some applications with higher-sulfur coal where dry control systems are involved. Generally, for moderate PM control, ESP has been considered more cost effective, but the cost gap has narrowed significantly as bag house designs improve.

In summary, pre-, post-, and in-combustion techniques of emission control are now quite well developed and commercially available, with the most effective methods (post-combustion flue gas treatment), reducing SO2 and NOx by approximately 90 percent. Cost motives and increasingly stringent emissions standards in industrialized countries are driving the technological developments, particularly for NOx control. The selection and use of emission control technologies by industry and the power plant sector depends on a variety of factors, including required emissions performance, cost, fuel type and characteristics, application (new or retrofit), and related regulatory requirements such as by product regulations. As more stringent regulations have come into place, the design thrust has moved toward joint SOx/NOx control techniques such as fluidized beds, to optimize performance and controlled combustion techniques to reduce total capital costs.

COST CONSEQUENCES OF EMISSION CONTROLS IN INDUSTRIALIZED COUNTRIES

Capital and operating costs of electricity production are directly affected by the control of air emissions from the combustion facilities. Both the type of control equipment and the control cost varies significantly among type and size of facility, fuel type, and fuel quality and emissions reduction requirements or targets. The discussion in this section draws on information from those countries with the most experience with control technology, Germany, Japan, and the United States. It is based primarily on a summary of costs reported for those countries, carried out by the International Energy Agency (IEA) and as developed to estimate the cost and reduction potential for the United States NAPAP Acid Rain Program.

The costs of emissions reduction technologies have been the subject of major debates in these countries. In recent years much additional actual operating experience has been gained, providing some improved information on the real costs of these technologies. However, at the same time the technologies have improved, the commercial options available have increased, widening the choice and creating a greater and more complex spectrum of performance and costs. Thus there still exist considerable variations in cost estimates and methods for annualizing those costs, both within and among the countries. Despite these variations IEA has arrived at some general conclusions, based on their surveys and analysis for the three countries, and a less detailed study for several other countries. The focus of the study is on coal and lignite fueled systems, and on flue gas desulfurization (FGD) for SO2 removal and selective catalytic reduction (SCR) for NOx removal.

Costs of FGD and SCR are particularly substantial. IEA estimates that capital costs of FGD and SCR would account for 15 percent and 9 percent, respectively, of capital costs for a new base load coal facility. Total generation costs for the two technologies rise by 9 percent in both cases for a total increase of about 18 percent. Although the capital and total costs vary considerably among the countries, they are shown to have decreased over time as experience is gained with each technology.

The levelized annual costs of FGD and SCR controls are quite sensitive to the plant capacity factor, the assumed discount rate (particularly for FGD), and the catalyst lifetime for SCR. Table 10-3 presents the cost of FGD in Germany, Japan, and the United States for a wet limestone system for use with coal of 1 percent to 2 percent sulfur content. Both "reported" and "adjusted" costs are presented. Although the reported levelized annual costs differ significantly among the countries, the differences are greatly reduced after corrections are made for technical differences and methods of economic analysis. Total levelized annual costs range from 3.4 mills/kwh in Germany, to around 6.3 for Japan and the United States.

A more representative cost estimate for power plant controls was developed by a thorough literature review of materials supporting the United States, NAPAP, and Electrical Power Research Institute (EPRI) research efforts. The estimates in Table 10-4 include the increased capital cost associated with firing and cleaning the emissions from high sulfur, low grade lignite fuels. Capital costs associated with high level SOx and NOx control again suggest an incremental new facility controls cost on the order of 20 percent to 25 percent, and an increased power cost of 25 percent to 35 percent. The international eperience suggests that high level air emissions, water, and solid waste disposal controls in aggregate can add up to 30 percent to 50 percent of any new power plant. At these higher control and cost levels, substantial fixed and variable cost savings can be obtained by constructing a new facility based on emission controls and efficiency-optimized designs. The newer modular combustion designs, including pressurized fluidized bed and conbustion integrated gasifier combined-cycle technoligies, hold a strong promise for use with Thailand's low-grade, high-sulfur lignites.

In most industrialized countries, retrofitting costs are also a major issue in acid rain policy discussions. IEA states that in comparison to capital costs for new facilities, flue gas treatment equipment can cost up to 40 percent more per KW when retrofit to an existing facility. The additional cost of retrofit controls depends upon a number of site specific factors, of which available space is one of the most important. In comparison to the retrofit of FGD, repowering existing facilities with advanced technologies, such as integrated gasification combined cycle (IGCC), pressurized fluidized bed combustion (PFBC), and atmospheric fluidized bed combustion (AFBC) can in some cases result in similar emissions reductions but at a lower cost per ton removed.

INITIAL CASE STUDY OF COSTS AND PERFORMANCE OF EMISSION CONTROLS ON A LIGNITE-FUELED PLANT IN THAILAND

To bring the above discussion into better perspective on the specific situation and needs of Thailand's power industry, we present here a limited case study, based on a future generating unit at EGAT's Mae Moh plant. Because cost and performance estimates require close scrutiny in actual engineering design, this study can be considered as only indicative in nature. Yet it is useful in identifying and illuminating some of the key issues. A model developed by the U.S.EPA was used in this study. However, it reflects capital and cost escalation assumptions from the early 1980s. Interim surveys suggest the model, as used, overstates capital cost by a significant fraction. An updated version is being released in the next few months.

The Integrated Air Pollution Control System (IAPCS) Design and Cost Estimating Model

Costs of installing and operating air emission control equipment to meet sulfur dioxide, nitrogen oxides, and particulate matter emission standards have grown significantly and now represent a large portion of the total power plant cost. The significance of these costs has led to emergence of the concept of integrated environmental control of utility power plant air emissions within the past decade. One logical means of addressing the design and operation of an air emission control system is to consider that system as an integral part of the power plant. By optimizing the interactions of control devices, the integrated concept can effect the necessary control level at a minimal cost.

The IAPCS is a computerized simulation model developed for the Air and Energy Engineering Research Laboratory of the United States EPA to estimate the costs and predict the performance of SO2, NOx, and PM emission control systems for coal-fired utility boilers. The model includes conventional and emerging technologies that effect, pre-, in situ, and post-combustion emission controls. The model can accept any combination of the technology modules built into the system. The control technologies (modules) included in the available version (1986) are:

- Physical coal cleaning (PCC)
- Low-NOx combustion (LNC)
- Limestone injection multistage burner (LIMB)
- Electrostatic precipitator (ESP)
- Fabric filter (FF)
- Spray humidification (SH)
- Dry sorbent injection (DSI)
- Lime spray drying (LSD)
- Flue gas desulfurization - wet (FGD)

A revised model is being released soon that also addresses the emerging combustion technologies. The PCC, LNC, and LIMB modules, pre-combustion and in situ technologies, are applicable to the boiler unit; the effects of these devices are accounted for in materials balance reflecting flue gas conditions at the air heater exit. An uncontrolled materials balance column is calculated, prior to the boiler control modules, so that the net effect of emission controls can be calculated on a system basis. Outputs from the model include; the reduction in SO2, NOx, and PM emissions, associated capital and annualized costs of such reductions, and associated cost-effectiveness values calculated as dollars per ton of pollutant removed across the entire emission control system. The system output also reports the utility's requirement for the system operation on an annual basis, e.g., process water, electricity, diesel fuel, and lime/limestone.

Application of IAPCS to the Mae Moh Power Plant

As discussed in Chapter 9, a continuing dominant source of SO2 emissions in Thailand over the next twenty years will be lignite- and coal-fired power plants. EGAT is currently planning the construction and operation of eight additional 300 MW units at Mae Moh (Units 12 through 19), all to be fired by lignite from a high-sulfur resource base. By the year 2011, without any additional control, the Mae Moh power plant would emit to the atmosphere approximately 1.6 million tons of SO2 and 230,000 tons of NOx, an amount significant as a potential precursor for acid rain, in addition to the already recognized local air quality effects.

In this section, technologies for controlling SO2 and NOx, as previously discussed, will be assessed for their potential as options for control of emissions. The reference power plant for this assessment is based on the design of EGAT's Mae Moh Unit 10, which started construction in 1990 and is scheduled to be completed in 1992. The input date for costs of operation, water, electricity, process material, etc., are based on EGAT and DMR data. The costs of control equipment are based on the parameter input set of the IAPCS model. Although the IAPCS costs originated from 1983 data, the model updates them to the year of actual operation. However, it is recognized that the greatly expanding use of control technologies in the past several years is changing the cost structure. Work is underway at EPA on an updated version which will be incorporated in future TDRI analysis.

The technologies selected for this case are limited to those options viable by 1985 and appropriate for Mae Moh's lignite characteristics. The PCC, FF, DSI, and SH technologies were screened out due to the following reasons:

1. The lignite at Mae Moh is too soft for physical cleaning
2. The high-sulfur lignite at Mae Moh is not suitable for use with fabric filtering unless the fabric surface is integral to the control mechanism
3. In the model, DSI accepts a maximum sulfur of not more than 1.5 percent
4. SH is less efficient when compared with ESP and uses large amounts of water

The technologies selected in this case study are LNC, LIMB, LSD, wet FGD, and ESP. The combination of technologies were arranged into three cases;

Case #1	=	LNC + LIMB + ESP
Case #2	=	LNC + LSD + ESP
Case #3	=	LNC + FGD + ESP

The reduction of NOx that can be achieved is at the maximum 25 percent allowed by the model and particulate matter at 99.8 percent are given in all cases. For SO2, the reduction rates were set at 30, 50, 80, and 90 percent for Case #1 and Case #3, whereas Case #2 was set at 30 and 50 percent which is the maximum performance of the system.

In general the initial results based on the IAPCS model yield capital costs and levelized annual costs which are significantly higher than those discussed in the previous section. For example the share of emission control costs in the total plant cost ranges from approximately 20 percent (Case #1) to 36 percent (case #3). In contrast the IEA quotes a figure of 15 percent for its analysis of FGD alone, for the case of high control as in Case #3; these estimates would appear to take into account the most recent European experiences. The IAPCS result is based on an integrated analysis of cost for control of all three pollutants, SO2, NOx, and PM; this is likely responsible for a significant part of the difference. A difference in sulfur content, 1 percent to 2 percent in IEA and 3.5 percent to 3.8 percent at Mae Moh, is also likely responsible for the large difference.

The magnitude of the levelized costs from the IAPCS analysis also differs from that shown in the IEA reference comparison (Table 10-3) of costs in Germany, Japan, and the United States. The IAPCS result ranges from approximately 17 mills/kwh (Germany), 6.3 (Japan), to 6.4 (United States). Again it should be noted that some of the conditions may differ significantly. The results may also differ in part due to a slightly different treatment of time streams in the legalizing process.

The other critical factor in selecting an appropriate control strategy is the availability of water supply in the Mae Moh area. In Case #3 the wet FGD requires a very high volume of water to reach a high level of reduction (up to 89 percent). However, in terms of water consumption per percentage of reduction, Case #2 is the least efficient. Case #1 consumes less water than the other two cases in all aspects.

In summary, we believe that the IEA costs and the costs calculated from the initial IAPCS analysis can be considered as an initial lower and upper limit, respectively, on estimates of emission control costs. The costs presented in Table 10-4 represent the best estimate available for this analysis and include the most recent international experience. The projected cost variation reflects a number of the difficulties in such comparisons and underscores the need for concerted attention to be devoted to this important problem, preferably by more than one team of analysts. It also highlights the need to look at a broad range of emission control options including joint SOx/NOx mechanisms and the newly emerging controlled combustion technologies.

Table 10-1 SOx Removal Efficiency and Process Ranking

Removal Efficiency Level (Percent)		Process Ranking
Higher than 90 Percent	1.	Double alkali
	2.	Limestone scrubbing with promoters
	3.	Coal gasification (combined cycle)1
	4.	Recovery processes (gypsum)
	5.	Pressurized fluidized bed combustion
90 percent	1.	Limestone scrubbing with promoters
	2.	Limestone scrubbing
	3.	Double alkali
	4.	Circulating fluidized bed combustion
50 percent to 90 percent (high-sulfur coal)	1.	Limestone scrubbing with physical coal cleaning
	2.	Atmospheric fluidized bed combustion[1]
	3.	Chemical coal cleaning[1]
	4.	Sorbent injection
50 percent to 90 percent (low-sulfur coal)	1.	Spray drier process
	2.	Limestone scrubbing
	3.	Sorbent injection
	4.	Low-sulfur coal substitution for high-sulfur coal
Below 50 percent	1.	Physical coal cleaning
	2.	Low-sulfur coal substitution for medium-sulfur coal

Note: [1] Already Developed

Source: Environment Canada (1982) and EPRI/EPA

Table 10-2 NOx Removal Efficiency and Process Remaking

Removal Efficiency Level (percent)		Process Ranking
70 percent to 80 percent	1.	Catalytic reduction with more than the normal amount of catalyst, preceded by combustion modification
50 percent to 80 percent	1.	As above, with a normal amount of catalyst
	2.	Combustion modification (all types) followed by non-catalytic reduction (ammonia or urea injection without catalyst)
	3.	Combustion modification alone (for low part of range so as to minimize boiler problems) or low NOx burners with maximum air staging
Below 50 percent	1.	Staged combustion[1] (overfire air)
	2.	Low-NOx burners1
	3.	Gas recirculation (except for coal)[1]

Note: [1] Used in combustion with others if necessary to achieve the required reduction level.

Source: Environment Canada (1982) Acurex

Table 10-3 Costs of FGD in Different Countries

(Unit: 1986 United States Dollars and National Currencies) 1/

	Germany		Japan		United States
	$	DM	$	Yen	$
Reported Capital Cost per kW	81	(251)	155	(38-750)	170
Reported Level Annual Costs per kWh	mills	DM 10^{-3}	mills	Yen 10^{-3}	mills
Variable O and M	0.8	(2.5)	2.2	(550)	7.6
Fixed O and M	1.1	(3.4)	1.2	(300)	4.4
Total O and M	1.9	(5.9)	3.4	(850)	12.0
Total Capital Cost	1.4	(4.3)	4.9	(1225)	4.6
Total Level Annual Costs	3.3	(10.2)	8.3	(2075)	16.6
Adjusted Level Annual Cost 2/ per kWh					
Variable O and M	0.8	(2.5)	2.2	(550)	2.0
Fixed O and M	1.0	(3.1)	1.2	(300)	1.8
Total O and M	1.8	(5.6)	3.4	(850)	4.7
Total Capital Cost	1.6	(5.0)	2.9	(725)	1.7
Total Level Annual Costs	3.4	(10.6)	6.3	(1575)	6.4

Note: 1/ All capital costs adjusted from 1984 United States dollars (as reported by OECD) using capital price index 1986/84 = 1.04. The price index for operating costs (producer prices) has remained relatively constant, therefore no adjustment was made. National currency figure are shown in parentheses, base on the following 1984 (end of year) exchange rates: 3.1 DM/$: 250 Yen/$)

2/ Adjustments made by the OECD to reflect common assumptions of economic method and plan scope. Capacity factor, 65 percent levelized fixed charge factor obtained from "Technical Assessment Guide" (ERI,1982) for nominal assumptions. Captital costs adjusted to uniform fixed-charge rate of 0.175. Corresponding to 10 percent real interest rate and 20 year amortization period.

Table 10-4 Reference Power Plant Options & Typical Environmental Controls Costs

(300 MW/35%S 5000 BTU Lignite)

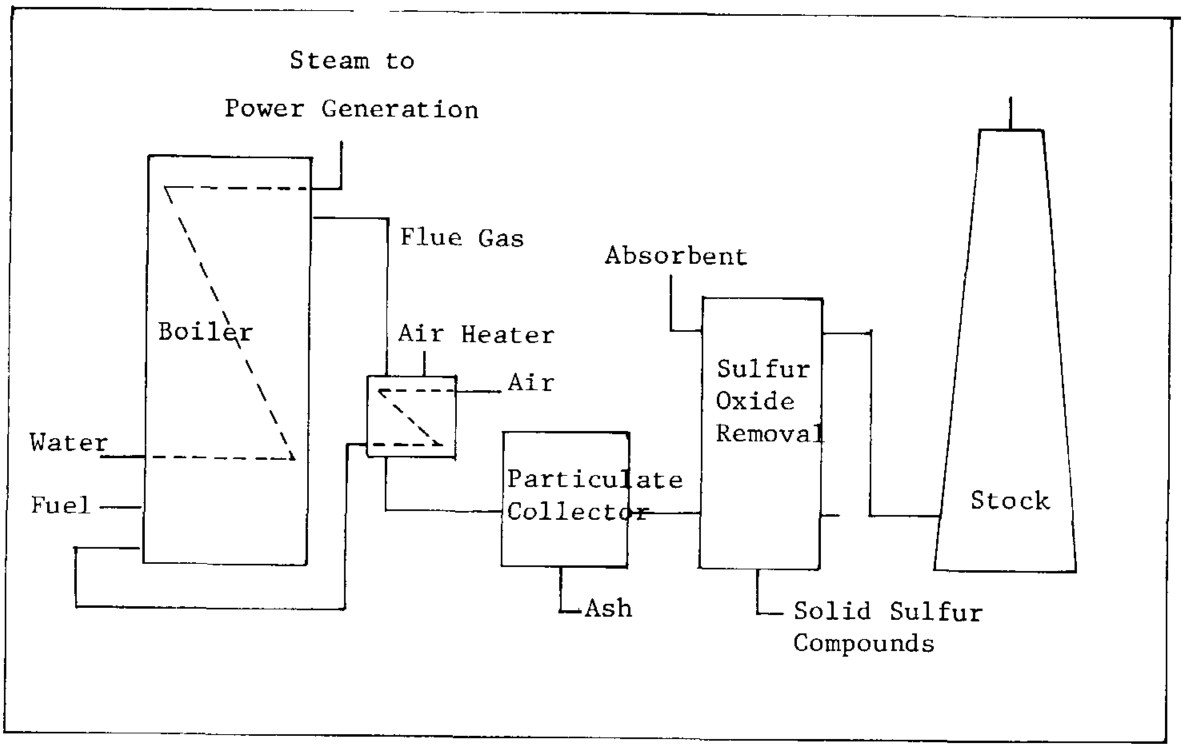
	Capital Costs				Annualized Constant Cost				Total Environment Control Cost
	Total Cap. Cost $/kw	Incr. Cap. Cost $/kw	Fixed O&M $/kw yr	Incr. Fixed O&M $/kw yr	Fixed O& + Cap. Cost mills/kwh	Variable O&M mills/kwh	Fuel Cost mills/kwh	Total Power [Busbar] mills/kwh	mills/kwh
Base Reference Plant: 9500 BTU/KWH [10,000 BTU,3.5%S BIT. Coal, W/ESP (98-99%)] [NAPAP & Japan] * (Imported Coal Higher) (Low Sulfur Coal Cheaper Capital Cost)	1475		20	-	32	3	* 20	55	3-5
Lignite Reference Plant: 9500 BTU/KWH (Thai Lignite @5000 BTU/LBS HIG 3.5-3.8%S, ESP @98-99%) Basic Controls=/+S-10% of Cap'l Cost &Xtra Scale Cost	1650		35	-	38	6	18	66	4-7 (5-10%)
LIG. Reference Plant Control Scenarios	Total Plant	Added Ctrls Portion							
a) 50% SO2/25% NOx Part.>99.8%	1875	225 (12%)	40	20	46.2	9	18.5	73-74	11-15 (15-20%)
b) 90% SO2/40% NOx Part.>99.9%	2000	350 (18%)	45	25	49.8	12	19.0	80-81	18-22 (23-27%)
c) 90% SO2/80% NOx Part.>99.9%	2085 (Incl.SCR)	435 (21%)	50	30	52.4	13	19.1	84-85	22-26 (26-31%)
Lignite Reference PFBC (Steam Cooled) - 95% SO2/80-90% NOx	2000-2050	-	52-58	-	44-46	14-16	16	74-78	
IGCC - 95-99% SO2/95% NOx	2100-2250	-	45-50	-	45-48	8-10	17-18	70-76	

Assumptions:

1) Constant 1988$, Base Plant FCR = .10, Envir. Controls FCR = 12.65% Cap Factor
2) 1st Yr O&M Cost, Disc. Approx. Equal to Escalation
3) Higher Capital Cost Based on: a) Lignite Scaling Factor, b) High Acid Gas Rate, c) High Ash Loading.
4) Reference Controls = Esp to 98-99%, Ash+Particulate Disposal, Water System Control

Sources: 1st NAPAP (SOS/T2S), IEA, OECD, EPA, EPRI

Figure 10-1 Typical Arrangement of Equipment for Flue Gas Cleaning



Source : U.S. EPA

Chapter 11

Conclusions and Policy Recommendations

INTRODUCTION

The three preceding chapters have laid out the basis of the rapidly evolving acid rain problem, its implications for Thailand, and some potential responses. This chapter incorporates those results into a policy analysis framework in order to discuss specific policy options and instruments for addressing the problems. This chapter contains a set of individual policy recommendations and a discussion of each of the recommendations.

RECOMMENDED POLICIES FOR ADDRESSING ACID RAIN

Because of the seriousness of the potential acid rain problem, it is recommended that the Government of Thailand initiate several specific strategies. These include implementation of specific technical measures, as well as more broadly based economic and institutional responses. The policy recommendations are divided into the following categories:

- o Power plant and industrial emission control requirements.
- o Petroleum fuel standards.
- o Fuel shift policies for the power and industrial sectors.
- o Implementation of pricing policies to ensure effectiveness of the polluter-pays-principle.
- o Establishment of an adequate national monitoring system for pollutants related to the acid rain problem.
- o Development of a regional program on acid rain in cooperation with other Asian countries and international or regional organizations.

Power Plant and Industrial Emissions Standards and Control Requirements

Establish Phase I new equipment performance standards for SO2 and NOx emissions from power plants and large industrial combustion facilities. For all facilities going into operation beginning in 1992, the weight of the respective pollutants emitted shall not exceed 520 g/GJ (1.2 pounds per mmbtu) for SO2, and 215 g/GJ (0.5 pounds per mmbtu) for NOx. These standards would affect new or significantly modified combustion facilities above 250 mmbtu input (75 MW thermal).

A Phase II set of standards shall be established for plants going into operation beginning in the year 2000 with SO2 and NOx values of 215 and 150, respectively (table 11-1).

Petroleum Fuel Standards

Establish a revised set of liquid petroleum fuel standards to lower sulfur limits in two phases. By 1993, reduce the standard for high- and low-speed diesel fuel sulfur to a 0.25 percent limit by weight, setting further limitations on high-speed diesel sulfur content to 0.05 percent by 1995, to coincide with the introduction of diesel vehicle particulate control standards. Establish a maximum fuel oil sulfur limit at 2 percent in 1993, scheduled for further reduction to 0.65 percent to 1.0 percent by 2000, to vary according to refinery size and configuration, and domestic versus imported products.

Fuel Shift Policies for the Power and Industrial Sectors

Examine thoroughly the economic, trade, and international dependence consequences of pronounced shifts from lignite and coal fueled power to non-sulfur bearing fuels, including natural gas and new and renewable energy sources such as solar and nuclear energy.

Implementation of Pricing Policies to Ensure Effectiveness of the Polluter-Pays-Principle

Implement energy pricing policies which will effectively internalize the external environmental and social costs of acid rain impacts and the control costs associated with their mitigation.

Establishment of a National Monitoring Systems for Pollutants Related to the Acid Rain Problem

Design and implement a national acid rain monitoring system to enable monitoring and analysis of emissions of relevant acid precursors and acid deposition in rural and non-rural environments throughout the country. Establish an associated program to monitor the impact on sensitivity receptors in both natural and man-made systems.

Development of a Regional Program on Acid Rain in Cooperation with Other Asian Countries and International or Regional Organizations

Work with other Asian countries to design and establish a comprehensive program for long-term regional monitoring, analysis, cooperation, and policy development to combat the potential acid rain problem.

DISCUSSION OF POLICY RECOMMENDATIONS

Power Plant and Industrial Emissions Control Requirements

Uncontrolled petroleum fueled industrial boilers and lignite and coal fueled power plants would produce by far the largest share of the rapidly increasing emissions of sulfur dioxide through the end of the Tenth Plan, amounting to 87 percent in the year 2011. During this period these plants would also account for a major portion of the country's total NOx emissions, more than 32 percent in 2001 and 38 percent in 2011. To avoid these dangerously high emissions which are likely to contribute significantly to Thailand's acid depositions, it is recommended that the following emissions standards be implemented on all new power plants and large industrial boilers brought into operation in 1992 or later. The following Phase II standards should be established for plants going into operation beginning in the year 2000 (table 11-1).

The Phase I standards are essentially equivalent to the new source performance standards implemented in the United States in 1971. They are considerably less stringent than those now being implemented in Europe and Japan, and currently proposed for North America. The required SO2 emission levels can be achieved with the conventional widely-adopted flue gas desulfurization (FGD) (wet-scrubber) system, leading to a reduction of approximately 90 percent of the sulfur dioxide. The NOx emission levels can be achieved with the use of low-NOx burners and overfire air combustion modification which has been the standard new boiler design for many years.

The Phase I standards would require that the above controls, or their equivalent, be installed on the planned units 12-19 Mae Moh. Although the controls would be costly, they would serve to slow the growth of vast emissions of acid precursors. As described in Chapter 10, controls of the above type could increase the capital costs of a 300 MW lignite fueled plant by approximately 25 percent. However, when taken over the entire generation system, the estimated increase in electricity generation cost in 2001 would be only 3 percent to 4 percent. In calculating these costs, adjustment has been made for the small energy penalty (approximately 2 percent to 4 percent) which results during refining and electric power production from the implementation of the controls on higher-sulfur fuels.

The Phase II standards, applied to plants going into operation after the year 2000, will require a further sulfur reduction equivalent to approximately 95 percent from the pre-1992 uncontrolled values. The Phase II standards would still be less stringent than those now in effect in Japan and most European countries, and those being implemented in the new United States acid rain legislation which is expected to be signed into law by President Bush this year. However, these standards should provide Thailand with a strong start in controlling, and eventually eliminating the potentially damaging emissions resulting from the extremely high growth in the coming decade.

The minimum size of facilities subject to new source standards should reflect permit, inventory, and equipment requirements and constraints. Lower limits can be based either on potential emissions, maximum emission rates, or boiler size. Smaller facilities may also require different standards than larger electricity generation facilities.

Small lignite power and thermal boilers, such as those used in the cement industry, may need somewhat higher emissions standards based on design type, particularly during Phase I. Above 50 MW TO 75 MW thermal, however, these facilities should be regulated in a similar fashion to power plants. Smaller facilities will be utilizing package designs that should be subject to technology-based requirements. Phase I NOx limits may be established as noted for the lignite power plants. Phase II limits should be based on fully emerged clean coal technologies. The versatile fluidized bed combustion technology was initially developed for use in the industrial sector, and can be adapted to a wide range of fuels providing for significant switching capability.

Petroleum Fuel Standards

For liquid petroleum fuels used in the transport and small industrial sectors, fuel content standards provide the most efficient mechanism to limit total sulfur emission. A 2.0 percent sulfur fuel oil standard results in uncontrolled emissions of approximately 1.1 lbs/Btu - very close to the Phase I solid fuel emission rate target. Combustion of 0.65 percent sulfur fuel oil results in emissions very close to the Phase II standard for solid fuels. Establishing a system of refinery credits for fuel oil sulfur content in the industrial sector would provide greater refining and utilization efficiency. Upper limits should not exceed 1.0 percent sulfur by weight, and the target level should be a system average 0.65 percent sulfur for domestic and imported fuel oils.

Changes in diesel fuel sulfur standards have already been proposed as part of the refinery refurbishment effort under the Seventh Plan. These levels should be restructured from the 0.5 percent level proposed, to a near-term target of 0.25 percent, an international transport fuel standard. A schedule for deeper reduction of all transport diesel fuel to 0.05 to 0.10 percent sulfur by weight, provides the opportunity to introduce catalyst and particulate trap control technologies on trucks and other diesel vehicles. This final increment of reduction, however, is far more important to urban air quality policy, than to acid rain policy.

Further standards have been proposed regarding lead content, these involve the gasoline blends and allow for the use of catalytic converters in other light gasoline vehicles. Fuel effectiveness could be ensured by lowering the gasoline sulfur limits by a significant margin. The current standard of 0.2 percent should be reduced by 75 percent to 80 percent to reach the average international standard for unleaded gasoline. Sulfur content at the current level produces noticeable quantities of hydrogen sulfides (H2S) in cool-state catalytic converters, and precludes the use of converters due to the fouling of the catalyst material.

Fuel Shift Policies for the Power and Industrial Sectors

A strong fuel shift policy for the power and industrial sectors, in combination with the proposed emission controls, would have a greater effect on SO2 and NOx emissions than strong controls alone. Yet a significant shift to alternative fuels, such as natural gas or nuclear power, entails other considerations generally more complex than those arising due to immediate technological fixes such as emission control systems. These considerations include import dependence, trade balance, supply infrastructure, and, in the case of nuclear technology, transfer considerations.

As a result of these additional considerations, the true cost of newly developing technologies will be more difficult to calculate. Therefore, no attempt has been made here to assess their cost in more than a semi-quantitative manner. However, because of these systems' greater potential for curbing acid rain, it is recommended that a vigorous program be established to assess the economic and sociopolitical impact of the fuel shift strategies. Such studies might include identification of domestic industrial market niches within the currently developing renewables technologies, such as photovoltaics and hydrogen storage systems.

In addition to its impact on acid rain, another important advantage of a fuel shift policy would be its positive impact on carbon dioxide reduction. This will be discussed further in Chapter 14.

Implementation of Pricing Policies to Ensure Effectiveness of the Polluter-Pays-Principle

The polluter-pays-principle, generally accepted among industrialized countries, requires that the polluting industries and their beneficiaries pay for the cost of their related anti-pollution measures. In Thailand, application of this principle would help to internalize environmental costs. In the case of acid rain control measures, it is essential that these costs be incorporated in a timely way into electricity prices, to provide appropriate pricing signals to consumers. As stated earlier, the necessary overall changes in generating costs will not increase prices drastically, nevertheless, even a modest increase will encourage greater long-term efficiency in consumption.

Establishment of a National Monitoring System for Pollutants Related to the Acid Rain Problem

The magnitude of predicted acid precursor emissions in Thailand and its neighboring countries, make it essential that a comprehensive monitoring network and associated analysis program be established as soon as possible. As described previously, in the next several years the density of emissions and subsequent acid depositions will be comparable to those in several industrialized countries already experiencing acid rain.

An initial effort in this direction has been made through the inter-university network effort. This could provide the basis for a much more comprehensive effort, coordinated with programs of the National Environmental Board, to facilitate a regional exchange of environmental information. Permanent monitoring networks should be established in selected rural and urban areas to determine the spatial and temporal gradients in precipitation chemistry, and the concentrations of airborne gases, fine aerosol particles, and particulate matter. Chemical constituents of interest should include the levels of pH and conductivity, major cations and anions, organic acids, sulfur dioxides, nitrogen oxides, ozone, ammonia, and nitric acid vapors. The network should be equipped with automatic sampling equipment and preserved, treated, and analyzed in accordance with international standards.

Beyond the measurement of acid deposition, it is imperative to monitor its impact on receptors in both natural and man-made systems. This can best be done through an interdisciplinary and inter-institutional program conducted by Thai government laboratories and universities. For example, permanent monitoring networks should be established to determine long-term changes in the chemistry of soils and aquatic bodies. Epistemological investigations should be conducted to see if damage has already occurred, and to test hypotheses concerning the influence of airborne chemicals both on public health and on the health and productivity of forest and agricultural crops.

Development of a Regional Program on Acid Rain in Cooperation with Other Asian Countries and International or Regional Organizations

It was shown in Chapter 9 that Thailand's concerns about acid rain cannot be divorced from those of the region, as Thailand is both a potential exporter of acid precursors to neighboring countries, and a potential receptor of acid deposition originating in other countries. The problem is clearly more complex when viewed from a regional perspective. The costs and benefits derived from any particular acid rain strategy will be unevenly spread across countries. However, based upon the European and North American experiences, the benefits of international cooperation in addressing this problem are significant. Cooperative efforts have in almost all cases resulted in less costly overall solutions than would have resulted from individual actions, necessarily addressing only partial solutions.

It is therefore recommended that Thailand take the initiative to work with the appropriate Asian countries to design and establish a comprehensive program for long-term regional monitoring, analysis, cooperation, and policy development to combat potential acid rain problems.

Table 11-1 Proposed Power Plant and Industrial Plant Emissions Standards

Phase 1 Standards (Year 1992-1999)

		g/GJ	lb/MM	kg/Gcal	mg/N.cu.m. ***	ppm(v)**
SO2						
	Solid	520	1.20	2.20	1230 *	460 *
	Liquid	475	1.10	2.00	1280	480
	Gaseous	130	0.30	0.54	430	160
NOx						
	Solid (wet bottom - lignite)	345	0.80	1.45	980 *	480 *
	All other coal & lignite	215	0.50	0.90	610	300
	Liquid	130	0.30	0.54	460	220
	Gaseous	106	0.25	0.45	400	190

Phase 2 Standards (Year 2000 and later)

		g/GJ	lb/MM	kg/Gcal	mg/N.cu.m.	ppm(v)
SO2						
	Solid	215	0.50	0.90	510	190
	Liquid	215	0.50	0.90	580	220
	Gaseous	85	0.20	0.36	290	110
NOx						
	Solid (All)	150	0.35	0.63	430	210
	Liquid	85	0.20	0.36	310	150
	Gaseous	65	0.15	0.27	240	120

Note: * Currently proposed standards from the Ministry of Industry are: SO2-400 ppm(v) for Bangkok Metropolitan Region (700 ppm elsewhere); NOx-1000 mg/N.cu.m.

** NOx conversion factors vary based on molar assumptions for NO vs NO2 and assumed normal condition. (N = normal)

*** Mass per unit energy conversions to mass per unit exhaust volume (mg/cu.m.) and exhaust volume fractions (ppmv) vary significantly depending on on standard conditions assumed.

Part V

Global Climate Change Due to Greenhouse Gas Emissions: Implications for Thailand's Future Energy Systems

Chapter 12

Global Climate Change Due to Greenhouse Gas Emissions

INTRODUCTION

Global climate change resulting from excessive concentrations of greenhouse gases is potentially one of the most important of the emerging environmental problems related to energy. Greenhouse gases include carbon dioxide, methane, water vapor, nitrous oxide, ozone, the chlorofluorocarbons (CFCs), and halons. The "greenhouse effect" is not scientific speculation, but rather a well-understood phenomenon caused by trace concentrations of these gases which are transparent to incoming short-wave radiation (light), but relatively opaque to outgoing reflected long-wave radiation (heat).

The phenomenon is responsible for the earth's long-term equilibrium temperature being considerably warmer than what it would be if such gases were not present. However, anthropogenic activities are now causing the atmospheric concentrations of these gases to increase above their pre-industrial levels, with the potential of leading to major changes in global and regional climates. The major scientific uncertainties and debates now existing are not whether these events would lead to climate changes, but rather over the exact nature and time scale for the changes to take place. There are some prominent scientists who believe that we are already experiencing the effects of these increased concentrations; other believe that it will be at least another decade before we can assert this with reasonable confidence.

Climate scientists state that these effects could include higher global temperatures, changing precipitation and seasonal patterns, and rises in sea level, all of which could have far-ranging impacts on human activities throughout the world. They also believe that long lag times, on the order of many years or decades, are associated with these processes, so that by the time the process is known for certain to exist, additional decades may be needed in order to counter or even retard the process of climate change.

BASIS OF THE GREENHOUSE EFFECT

Before discussing the practical details of addressing the greenhouse effect, this section presents a brief description of the physical basis of the effect, and the mechanisms through which it occurs.

The energetic source responsible for weather and climate is the sun. Of the incoming solar radiation which is intercepted by the earth, about one-third is reflected; the remainder is absorbed by the earth's atmosphere, land, ocean, ice, and biota. The temperature of the earth is determined by the composition of the earth's surface, and the amount of solar radiation it reflects back into space. This outgoing radiation is in the form of long-wave invisible infrared energy, so-called terrestrial radiation.

It is a well established and accepted fact that the warm temperatures on earth, which have made possible the current forms of life on earth, are a result of the trapping of a part of this terrestrial radiation by very small "natural" amounts of gases in the atmosphere (Amfield 1987). These gases are not the main constituents of the atmosphere, but are trace amounts of water vapor, CO2, methane (CH4), nitrous oxide (N2O), and ozone (Remanathan 1985). Small atmospheric particles called aerosols may also affect the climate through their reflection or absorption of radiation.

Finally, it must be emphasized that the earth's climate has a pronounced natural variability of its own, subject to statistical variations and natural phenomena such as sunspots and other influences not man-made in origin. This natural variability is one of the factors which greatly complicates the empirical verification of a man-made greenhouse effect.

Analyses of measurements based on ice cores, dating back more than 160,000 years, provide a correlation between the temperature of the earth and concentrations of carbon dioxide and methane in the atmosphere (Barnola et al. 1987). The details and exact mechanisms of the cause and effect of the relationship are not known, however: "Calculations do indicate that changes in these natural greenhouse gases were part but not all of the reason for the large (5-7 degrees celsius) global temperatures swings between ice ages and interglacial periods" (IPCC Working Group I 1990).

Humankind is now capable of enhancing this natural greenhouse effect by increasing the concentrations of the natural greenhouse gases, or by adding new greenhouse gases such as CFCs. Concentrations of the greenhouse gases have all increased significantly since pre-industrial times. The CO2 concentrations of 351 ppm in 1988, were more than 20 percent higher than at any time in the past 160,000 years. Within the past century the world has seen CO2 concentrations increase 70 ppm, half of which has occurred in the past three decades. Atmospheric methane levels have more than doubled from their pre-industrial levels; growth is about one percent per year. Table 12-1 summarizes the present and preindustrial concentrations, rates of change, and atmospheric lifetimes of the anthropogenic greenhouse gases. It can be seen that concentrations of other significant greenhouse gases, nitrous oxide, and CFCs are also increasing.

The magnitude of the contribution of fossil fuel combustion to CO2 increases is well known. However, the concurrent input due to deforestation, which reduces the carbon-sequestering capacity of the earth's biotic system, cannot yet be estimated accurately. In addition, although about half of the emitted carbon dioxide stays in the atmosphere, we have only a rough estimate of how much of the remainder is absorbed by oceans and biota. Methane and nitrous oxide sources are more difficult to quantify. Rice production, cattle rearing, biomass burning, and coal mining leading to ventilation of natural gas, are likely the main factors leading to a doubled methane concentration. Although nitrous oxide appears to have increased roughly 8 percent since pre-industrial times, it is difficult to specify the sources. Agricultural activity is a likely factor.

There is very little scientific disagreement about the above measurements and description of the increasing concentrations of greenhouse gases. More uncertainty is associated with the analysis of to what degree and when these increases will lead to global warming and the other associated climatic effects. However a strong, but not unanimous, consensus has been emerging in the past few years that these continued greenhouse gas emissions will indeed lead to global warming. Scientists have modeled the warming from known past emissions and from anticipated future emissions of each important gas. Although considerable uncertainty is still associated with their predictions of climate change, their results nevertheless are providing insight into the range of impacts expected.

One of the commonly-used parameters to describe their results is the temperature change resulting from a doubling of absorption of radiation. The generally accepted range of this parameter is 1.5 to 4.5 degrees celsius, i.e., a doubling of carbon dioxide concentration would lead to a 1.5 to 4.5 degree rise in average global temperature. Most scenarios indicate that CO2 concentrations would not double before 2050 at the earliest. However, the above type of modeling suggests that, if current trends continue, the combined effect of *all* greenhouse gases could cause a combined effective concentration to be equivalent to the doubled CO2 concentration by 2030 (World Resources Institute 1990). Of equal concern is the fact that, because of delays in climate response, exactly when the resultant warming would occur is not known.

Because the computer models of climate change have more difficulty in predicting *regional changes* with any reliability, it is difficult to predict specific impacts of the warming. Current wisdom, however, is that the most dramatic effects would be sea level rise; changes in winds and ocean currents; accumulations of ice and snow in polar ice caps; frequency of severe storms; alteration in precipitation patterns that would affect agriculture and water availability; and changes in natural ecosystems.

GLOBAL SOURCES OF GREENHOUSE GAS EMISSIONS

Past and Current Emissions

In assessing how the world arrived at its current state of concern about greenhouse gas emissions, it is useful to examine past emissions. In the case of carbon dioxide, the most important of these, fossil fuel combustion released 51 billion tons, in terms of its carbon content, between 1860 and 1949. Another 130 billion tons of carbon were released by this process in the period from 1950 to 1987. Since 1860, an additional 60 billion tons of carbon are estimated to have been released through land use changes, including deforestation for agricultural purposes. Thus the total anthropogenic release between 1860 and 1987 was approximately 241 billion tons of carbon. Of this, the United States, the European Community, and the Soviet Union are together responsible for approximately two-thirds. China and Japan add another 12 percent. Thus, that part of the past emissions related to fossil fuel combustion was contributed to most heavily by North America and Europe.

As pointed out earlier, CO2 emissions, including those resulting from land use change, are responsible for only about 50 percent of the potential global warming resulting from human activity. Of the other half, CFCs are responsible for approximately 20 percent, methane approximately 16 percent, tropospheric ozone approximately 8 percent, and nitrous oxides approximately 6 percent. Any comprehensive attempt to estimate greenhouse effect contributions by various countries or regions should take these additional sources into account.

To address this issue, the World Resources Institute has recently developed a "Greenhouse Index" that incorporates the contribution of each gas, weighted by its heat-trapping potential, based on annual emissions. Based on this index, the four countries with the highest greenhouse gas net emissions in 1987 were (with percent of total in parentheses) the United States (16.9 percent), USSR (12.0 percent), Brazil (10.5 percent), and China (6.4 percent). Thailand ranked eighteenth among the countries, with a contribution of 1.1 percent. Of Thailand's total of 67 million tons of carbon dioxide heating equivalents (CDHE), by far the largest contribution was CO2 resulting from land use change (41 million tons). Other countries in Asia with more than 1 percent of the world's total are India (3.9 percent), Indonesia (2.4 percent), and Burma (1.3 percent).

Baseline Global Scenario for the Future

There is considerable analytical work underway to analyze future emissions of greenhouse gases and the potential for managing these emissions so as to avoid serious climatic changes. One of the most prominent of these global studies is that of Working Group III of The IPCC. Although there is no formal international agreement on these results, they do provide a reasonable set of scenarios within which to discuss various issues relevant to Thailand. Most of the following description is taken directly from the IPCC Summary Report.

The IPCC scenarios cover the emissions of carbon dioxide, methane, nitrous oxide, and chlorofluorocarbons up to the year 2100. Growth of the economy and population was taken common for all scenarios. Population was assumed to approach 10.5 billion in the second half of the next century. Economic growth was assumed to be 2 percent to 3 percent annually in the coming decade in the OECD countries, and 3 percent to 5 percent in the Eastern European and developing countries. The economic growth levels were assumed to decrease thereafter. In order to reach the required targets, levels of technological development and environmental controls were varied.

The IPCC baseline scenario is defined as follows:

Scenario A (Business-as-Usual):

o Energy supply is coal intensive.
o Achievement of only modest demand-side efficiency increases.
o Carbon monoxide controls are modest.
o Deforestation continues until tropical forests are depleted.
o Agricultural emissions of methane and nitrous oxide are uncontrolled.
o Montreal CFC protocol implemented only partially.

The Working Group simulated the increase in global mean temperature from 1850-1990 due to observed increases in greenhouse gases, and developed predictions of the rise between 1990 and 2100 which would result from the Business-as-usual emissions. Under this scenario, the average rate of increase of global mean temperature during the next century is estimated to be about 0.3 degrees celsius per decade, with an uncertainty range of 0.2 degrees celsius to 0.5 degrees celsius. This will result in a likely increase in global mean temperature of about 1 degree celsius above the present value by 2025, and 3 degrees celsius above today's temperature before the end of the next century. The projected temperature rise through the year 2100 with high, low, and best estimate climate responses, is shown in Figure 12-5. The indicated range of uncertainty in global temperature rise reflects a subjective assessment of uncertainties in the calculation of climate response, but does not include those due to the transformation of emissions to concentrations, nor the effects of greenhouse gas feedbacks.

INTERNATIONAL ACTIONS: CURRENT AND POTENTIAL

During the last few years there have been a great many studies of the effect of global warming. Despite the uncertainties described earlier, there appears to be a consensus that it is unlikely that the effect is not real, or that it has been seriously misjudged.

Although there are some who argue that human adaption to an inevitable warming represents the most viable global strategy, there is an increasing tendency toward consideration of preventative options, based upon societal actions to reduce emissions of greenhouse gases. The discussion of future emissions reductions is now increasingly directed toward the issues of:

By whom?
When?
How?
At what cost?
and more recently, Who pays?

Current Programs and Actions

The past few years have seen several international efforts to develop agendas for action. These are summarized below.

1. The Toronto Conference, June 1988. (Called for 20 percent reduction of CO2 by the year 2005.)
2. The Hamburg Conference, November 1988. (Called for 30 percent reduction by the year 2000.)
3. The Noordwijk Conference on Atmospheric Pollution and Climate Change, the Netherlands, November 1989. (Encouraged the IPCC to include in its First Assessment Report, an analysis of Quantitative targets to limit or reduce CO2 emissions.)
4. The International Panel on Climate Change (IPCC). (Sponsored by the World Meteorological Organization and the United Nations Environmental Programme). Its three Working Groups have submitted reports this year on "Scientific Assessment of Climate Change," "Potential Impacts of Climate Change," and "Formulation of the Response Strategies."

The greenhouse gas issue appears to be the most comprehensive and truely global environmental problem recognized to date. All nations of the world are, at least to some degree, a part of the problem, and all would potentially be able to contribute to its solution.

It is difficult to find another issue which has achieved such rapid prominence on the international scientific and political agenda. Much of the early discussion has been on the scientific aspects of the issue - and it seems unlikely that this scientific debate will end soon. The debate, however, is increasingly turning toward narrower scientific issues such as the degree and timing of the effect, and perhaps more significantly, toward economic and political issues.

One of the key issues fueling the current debate is whether immediate action on reductions is warranted. Unfortunately, there is a consensus that achieving agreement on reductions will be extraordinarily difficult. The costs and the benefits of the reductions are not only poorly understood, but very unevenly distributed among the nations of the world. Early, and quite preliminary, studies of the costs indicate that some countries would incur large costs to bring about small reductions, while others might achieve them relatively inexpensively.

Most observers agree that international negotiations will become increasingly important as the discussions focus more on specific policy alternatives and legal initiatives. Yet there does seem to be a strong consensus among nations that if significant measures must be taken to reduce the emissions of greenhouse gases, they should be developed and implemented within the framework of an international agreement.

To date, most studies have been devoted to the nature and potential of prevention strategies. Much of this has emphasized emissions reductions within individual nations, with some efforts then made to aggregate results across regions (IPCC 1990) or groups of countries, and in a few cases to a global basis (Barnola 1987). Our discussion on this subject is organized as follows:

1. Prevention strategies
2. Economic issues and institutional response strategies

Prevention Strategies

This section presents several strategies in a generic framework, and specifies criteria for choosing or rejecting them. Application of these criteria, discussion of specific issues concerning Thailand, and a quantitative analysis of the scenarios are then presented. The following chapter will discuss some of the international frameworks under consideration.

A number of criteria should be taken into account in selecting policies designed to prevent the increase of greenhouse gases, they include:

1. Technical feasibility; a necessary but not sufficient criterion.
2. Macro-economic impact; e.g., balance of payment considerations.
3. Political and social acceptability; including the inertia of the energy system.
4. Implementation time scale; i.e., the time lag necessary to bring new systems on-line.
5. Ease and effectiveness of implementation; the ability of institutions to implement and respond, for example, to pricing changes.
6. Degree of international dependency; the need for technical or financial assistance from other nations.

The international debate has led to the identification of a number of policy options for reducing greenhouse gas emissions. These policies deal with both energy and non-energy related sources of the gases. In the latter group are CFC production and methane emissions from rice production and livestock.

The major options for reducing energy-related greenhouse gas emissions, especially CO2, are:

1. Reduction of emissions from fossil fuel consumption.
2. Reforestation/aforestation and reduction of deforestation.

There is little doubt that Option 1 will be the major policy debated in the near to mid-term future, since fossil fuel combustion is already the major source of emissions by far, as well as the most rapidly growing. The three mechanisms for a strategy of this type are:

1. Reductions in fossil fuel use through increasing end-use energy utilization efficiencies, and increasing efficiency of energy supply systems.
2. Bringing about shifts in the fuel mix, i.e., shifting from fossil fuels having high emissions of carbon to fuels having low emissions of carbon.
3. The substitution for fossil fuels by alternative forms of energy having no carbon emissions, e.g., solar, wind, hydro-power, or nuclear energy. These are generally referred to as new or renewable energy sources (NRE).

In addition to their baseline scenario described earlier, the IPCC has examined three scenarios which assume progressively increasing levels of controls to reduce the growth of greenhouse gas emissions. The assumptions in these scenarios are as follows:

Scenario B:

- Energy supply shift toward low-carbon fuels.
- Largy demand-side efficiency increases.
- Reversal of deforestation.
- Full implemental of Montreal CFC Protocol.

Scenario C:

- Shift toward renewables and nuclear energy in second half of next century.
- CFCs phased out and agricultural emissions limited.

Scenario D:

o Shift to renewables and nuclear energy in first half of next century.

Under these scenarios, average rates of increase in global mean temperature over the next century are estimated to be roughly 0.2 degrees Celsius per decade (Scenario B), just above 0.1 degree Celsius per decade (Scenario C), and about 0.1 degree Celsius per decade (Scenario D). The results indicate that with the Business-as-Usual Case for comparison, Scenarios C and D greatly reduce the rate of temperature increase by the end of the next century, and significantly reduce the absolute rise in temperature.

Overview of Potential Economic/Institutional Response Strategies Under Discussion

The previous section discussed potential prevention strategies and their impact on emissions and resulting temperature increases. This section will describe some of the main economic and institutional issues related to implementation of these prevention strategies.

It is clear from the preceding discussion that these types of prevention strategies will differ greatly in their degree of applicability and ease of implementation across the broad spectrum of industrialized and developing countries. However, there seems to be general consensus on special roles for the industrialized countries, as typified by two of the findings of the IPCC Working Group III:

1. The major part of emissions affecting the atmosphere at present originates in industrialized countries where the scope for change is greatest. Industrialized countries should adopt domestic measures to limit climate change by adapting their own economies in line with future agreements to limit emissions.
2. Industrialized countries have the responsibility to co-operate with developing countries in international action without standing in the way of the latter's development, by contributing additional financial resources, by appropriate transfer of technology, by engaging in close cooperation concerning scientific observation, by analysis and research, and finally by means of technical co operation geared to forestalling and managing environmental problems.

Likewise, specific findings were expressed for developing countries:

1. Emissions from developing countries are growing and may need to grow in order to meet their development requirements and thus, over time, are likely to represent an increasingly significant percentage of global emissions. Developing countries have the responsibility, within the limits feasible, to take measures to suitably adapt their economies.
2. Sustainable development requires proper concern for environmental protection as the necessary basis for continuing economic growth. Continental economic

> development will increasingly have to take into account the issue of climate change. It is imperative that the right balance between economic and environmental objectives be struck.

However, as of late August 1990, there remained disagreements among major industrial nations about the need for and desirability of specific targets and obligations to control net emissions. Some of these countries, notably the United States, have serious concerns about the economic costs of achieving targets.

It appears that international negotiations will take considerable time to hammer out. Among the key issues yet to be resolved are the specific criteria, timing, and legal form of any obligations. Of key importance is the request of the developing countries for additional financial resources, and for the transfer of technology on a preferential basis. It is still unclear whether new or existing international institutional bodies will form the framework for the development and implementation of such policies.

Despite the lack of any obligatory agreement on emission reductions, the IPCC recommended the examination of potential mechanisms including; technology development and transfer, economic market mechanisms, financial mechanisms, tradable emissions permits, standards, environmental impact assessments, legal and institutional mechanisms, and public information and education. It is likely that future discussions will focus on the efficacy and political acceptability of arrangements incorporating one or more of these mechanisms. The following discussion is limited to economic mechanisms.

Economic Mechanisms

Economists have long advocated the use of economic instruments for the implementation of environmental policy (IEA 1989). Such instruments are expected to provide efficient, effective, and flexible options for achieving policy objectives. They also create incentives to develop improved and cleaner technologies. Such incentives may be lacking in the case of regulations, which have traditionally been used as the basic instrument for implementing environmental policy. Regulatory approaches have the advantage that administrative authorities are more familiar with them, and they are often considered to be more "direct," more controllable, and more certain in outcome. With the great diversity of countries involved in the global warming issue, it is unlikely that economic instruments would be applicable in all circumstances.

However, in many industrialized countries there are a growing number of examples of their use in programs for reducing environmental degradation. Examples include emissions fees or charges, subsidies, emissions rights trading, and enforcement incentives, e.g., financial sanctions. Of these, fees and emissions rights trading are discussed below, as there is likely to be a general understanding of the other two.

Charges (Fees or Taxes)

Charges may be thought of as a price paid by the polluter for his pollution. In the case of greenhouse gases, effluent charges would likely be imposed on the emission's contribution to climate change, based on the quantity and type of gas released. Their intended impact would be an incentive to limit or reduce emissions, and to develop effective means of doing so. The incentive impact depends strongly on the cost and price changes brought about by the charge. Such charges would also have a redistributive effect since the collected revenue could provide substantial funds for further emissions abatement, research, or lowering of other taxes. Concerns with a charge-based approach include deciding the basis and size of the charge, and uncertainty as to whether it will reduce emissions to the desired target.

There is considerable research underway to examine alternative systems of effluent charges, generally called "carbon taxes," for greenhouse gas reduction. For example, Willam Nordhaus of Yale University has estimated that an internationally applied tax of US$5-10 per ton of carbon emissions would be adequate to bring about a reduction of roughly 13 percent (Nordhaus 1990). Reduction on the order of 45 percent would be obtained from US$100 tax level. He argues that the lower tax brings about the reductions at a modest cost, resulting in net global benefits. The US$100 per ton tax, although bringing about a greater carbon reduction, would impose a net negative cost on the global economy, because the further reductions would be much more costly. Nordhaus also makes a strong case for introducing the taxes gradually to permit efficient shifts of capital.

Emissions Trading

The use of emissions trading is an alternative to the system of emissions charges. Within this framework, emitters are subject to emissions standards as with normal regulatory control programs. However, if an emitter releases less than allowed by the standard, the entity can sell or trade the difference between its actual and allowable emissions. The receiving entity then has the right to emit more than allowed by its original limitation. The anticipated benefits of this mechanism are cost reductions in meeting a given target because of (1) maximization of comparative trade advantages between trading partners, and (2) creation of economic incentives for the development of more efficient energy systems. To date, emissions trading in the field of air pollution has been widely applied only in the United States. Evidence exists that trading is working, but controversy remains about its impact on environmental quality. Its main advantages appear to have been in fostering economic efficiency. The IPCC raises concerns about the uncertainty of the potential scope and size of the market in which permits would be traded, and the need for the development of an international administrative structure which does not currently exist.

One of key issues in both of the above market mechanisms concerns the cost of the energy efficiency and supply shift measures needed to bring about the emissions reductions. The costs would clearly vary from country to country. For example, Yamaji estimates that in already energy-efficient Japan, reductions would cost several hundred to a thousand dollars per ton (Yamaji et al. 1990).

Manne and Richels have attempted to analyze the costs (but not the benefits) in terms of GDP loss for several countries and regions of the world, under a variety of assumptions about target reductions. Their results indicate that holding global emissions at current levels implies an equilibrium tax of US$250 per ton of carbon. If one region or country were to sell only 100 million tons (e.g, 10 percent of the United States emissions) of carbon emissions rights to another, this tax rate would imply an annual financial transfer of US$25 billion. They also point out that there are significant regional differences in the time path to the long run equilibrium carbon tax level, indicating significant opportunities for international trading of emissions rights. At a given point in time, nations which find it difficult to adjust to their carbon limits may be willing to purchases rights form countries experiencing less difficulty (Manne and Richels 1990).

Table 12-1 Summary of Key Greenhouse Gases Affected by Human Activities

	Carbon Dioxide	Methane	CFC-11	CFC-12	Nitrous Oxide
Atmospheric Concentration	ppmv	ppmv	pptv	pptv	ppbv
Pre-Industrial (1750-1800)	280	0.8	0	0	288
Present Day (1990)	353	1.72	280	484	310
Current Rate of Change per Year	1.8 (0.5%)	0.015 (0.9%)	9.5 (4%)	17 (4%)	0.8 (0.25%)
Atmospheric Lifetime (Years)	(50-200) *	10	65	130	150

Note: ppmv = parts per million by volume
ppbv = parts per billion (thousand million) by volume
pptv = parts per trillion (million million) by volume
* = The way in which CO2 is absorbed by the oceans and biosphere is not simple and a single value cannot be given; refer to the main report for further discussion

Source: IPCC Working Group I

Chapter 13

Global Climate Change: Implications for Thailand's Energy Systems

This chapter deals with the problem of global climate change in the context of Thailand. The first section covers the identification of the country's sources of greenhouse gas emissions as well as estimations of future contributions to global emissions. Details of carbon dioxide releases due to changes in the pattern of land use and fuel consumption are presented. Some crude estimates of methane emissions from rice paddy fields are included. The second section presents the results of scenario analyses illustrating some implications of international movements on atmospheric greenhouse gas reduction for Thailand's energy systems. The final section of this chapter lays out the basis for the country's response strategies to these movements.

THAILAND'S GREENHOUSE GAS EMISSIONS: SOURCES AND TRENDS

Major sources of Thailand's greenhouse gas emissions are changes in patterns of land use, and consumption of energy including both fossil and renewable fuels. Changes in the pattern of land use are basically the transformation of forests into non-forest land, leading to a drastic drop in the carbon stored in standing biomass and soils. The amount of carbon lost then adds to the atmosphere in the form of carbon dioxide through oxidation. In 1988, this process was estimated to release 35 million tons of carbon, accounting for 60 percent of the country's total carbon release. Another source concerning land use is rice growing, particularly wet rice. Rice paddy fields release methane which is also an important greenhouse gas. In Thailand a large portion of the country's area is devoted to rice production, about 18 percent to 20 percent in the 1980s, and wet rice accounts for 90 percent of the total rice planted area. The estimates of released methane during that period were some 10-12 million tons of carbon equivalence annually. A final main source of greenhouse gas emissions is the energy conversion and consumption precess which produces a large amount of CO_2. The CO_2 emissions in terms of carbon from this source were estimated at 16, 16, 20, and 23 million tons of carbon in 1979, 1981, 1986, and 1988, respectively. An increasing rate of fuel carbon emissions and slowed rate of deforestation have made fuel carbon emissions greater than the emissions by deforestation in 1989. It should be noted that Thailand is considered a small user of CFCs. Thailand's consumption per capita in 1988 was 0.07 kilograms, while the corresponding figures for the United States, Europe, Japan, and Malaysia were 1.2, 0.9, 0.9, and 0.2, respectively (Department of Industrial Works 1990).

Since the most serious current proposals seem to concern the reduction of CO2, this section is devoted to the estimation and discussion of CO2 emissions from various sources as well as their trends. Some rough estimates of CH4 released from rice fields are included.

Carbon Dioxide Released by Deforestation

While fossil fuel burning is considered the most prominent source of CO2 emissions in industrialized countries, deforestation has been the major contributor of CO2 to the atmosphere in Thailand. If CO2 emissions from deforestation and fossil fuel burning are combined, Thailand, in 1987, ranked as the 13th largest CO2 emitter in the world after Mexico. These top 13 countries were responsible for 70 percent of the world net carbon released to the atmosphere (World Resorces 1990/91).

Thailand lost its forest area very rapidly during the 1960s and 1970s (3 percent annually). In the early 1980s, though the deforestation rate was somewhat lower (2 percent), the annual loss was still as high as 240,000-480,000 hectares (1.5-3.0 million rai). The figure dropped to approximately 1 percent during 1987-1988, and from 1988 to 1989 it declined further to 0.3 percent (about 39,000 hectares) due to the logging ban which took effect in February, 1988.

Relationships between deforestation and atmospheric carbon are not easy to quantify. Though most global climate-related studies have mentioned such relationships, not many have explicitly quantified them. One recent study provides detailed information on this issue, the 1989 study of the International Project for Sustainable Energy Paths (IPSEP). The study suggests that (1) deforestation contributes to net increases in atmospheric carbon, (2) carbon stored in vegetation and soils in a tropical forest is in the range of 270-370 tons per hectare, and (3) a drop in carbon due to tropical deforestation is as large as two thirds of the amount originally stored. In this study it is assumed that carbon lost from vegetation and soils adds to the atmospheric carbon, and that on average the rate of carbon released is 246 (two thirds of 370) tons per hectare per year. The upper limit of the range is taken in order to capture some carbon releases from forest degradation. Otherwise, the carbon releases would be understated.

Estimates of CO2 additions to the atmosphere caused by deforestation are shown in Table 13-1. During the 1960s and 1970s Thailand's deforestation contributed more than 100 million tons of carbon to the atmosphere annually. The figures dropped to approximately 60 million tons during 1983-1986, and became much lower (approximately 35 million tons) in 1988. In 1989, it was estimated to be as low as 10 million tons. The downward trend follows a slowed rate of deforestation.

Carbon Dioxide Released Due to Energy Consumption

According to the report by the NEA energy consumption, including renewable energy, has increased at a rate of 4.6 percent per annum from 1981 to 1986, and rose sharply to 8.4 percent during 1986-1988. In 1988, total primary energy demand was 23 million tons of crude oil equivalent. The CO2 emission due to such consumption was estimated at 86 million tons (23 million tons of carbon). It should be noted that our figure gives a much larger amount of carbon emission than estimated elsewhere because we have included renewable energy, which is basically from biomass burning (table 13-2). Without this biomass component the estimates of carbon emission in 1988 would be lowered by 30 percent.

Our projection to the year 2011 indicates that the energy consumption of the country will grow at a compound rate of about 6 percent. This also implies an increasing amount of CO2 emissions. From the beginning of the Eighth National Development Plan (1996) on, the rate of emission would be larger due to an increasing proportion of coal and lignite consumption in the future energy mix of utilities, and to the growing energy demand of the industrial sector. Table 13-2 shows estimates of future emissions.

CO2 emissions are unevenly produced by various economic sectors. Prior to 1981 major sources of CO2 emissions were the residential, industrial, and transportation sectors. Their emission shares were about 33 percent, 24 percent, and 22 percent of the country total, respectively. Since the end of the Fifth Plan (1986), the transportation sector as a source of CO2 has become dominant. Its share of emissions was 29 percent in 1986, and rose dramatically to 38 percent in 1988. Estimates for the year 2011 show increasing emissions of the transportation sector with an annual compound growth rate of about 6.6 percent. However, the CO2 emissions share of the power sector would become the second largest at the beginning of the Seventh Plan (1991), due to high levels of lignite utilization in electricity generation. The emission share of this sector is expected to be as large as 27 percent in 1991, and 30 percent in 1996. By 1996 the power sector's share would become very close to that of the transportation sector, and would be the greatest soon thereafter, unless major shifts in fuel mix and effective emission control systems were adopted. A summary of sources and trends are illustrated in Figure 13-1.

Table 13-3 shows a comparison of CO2 emissions resulting from the release of carbon through fuel consumption and deforestation. The ratios of the emissions from deforestation to the emissions from fuel burning were roughly 7.7, 7.0, 3.0, and 1.5 in 1979, 1981, 1986, and 1988, respectively. The decreasing ratios are the result of increased fossil fuel combustion and the slowing down of deforestation. The amount of carbon released from deforestation was less than 40 percent of fuel carbon in 1989. In the forseeable future (during the Seventh to the Tenth Plans) the carbon added to the atmosphere would be mainly from the fuel burning of the power, industrial, and transportation sectors. This implies a growing significance of fossil fuel consumption as a source of the country's carbon production during the next two decades.

Methane Releases From Rice Paddy Fields

Methane (CH4) releases are basically caused by the anaerobic fermentation of organic waste which can take place in rice fields, animal husbandry, sewage treatement, biogas pits and wetlands. Among these, rice fields are considered the most important sources. It should be noted that only wet rice production contributes to CH4 releases, dry rice does not.

In general, estimations of CH4 from rice fields are made based upon field monitoring or experiments. The IPSEP report stated that measurements taken in Spain showed deduced CH4 release rates ranging between 2-14 milligrams per square meter per hour, and that rates displayed strong seasonal variations with maximum values at the end of the flowering stage, and minimum values during the tilling stage and shortly before harvest. Khalil and Rasmussen (1990) reported that the average rate of CH4 flux in China was estimated at 55 mg/m2/hour.

To obtain crude estimates of CH4, this study assumes that CH4 flux is 2 mg/m2/hour. This provides us with a lower limit of emission. From this rough estimation we may conclude that in 1988 Thailand's rice fields released at least 550,000-

700,000 tons of CH4, or about 10-12 million tons of carbon equivalence annually (table 13-4). The World Resources 1990/91 estimate of Thailand's methane emission was 0.9 million tons of carbon equivalence in 1987. In the future, the figure is expected to be lower because of changes in land use from the production of rice to other crops.

IMPLICATIONS FOR THAILAND'S ENERGY SYSTEMS

As described in Chapter 12, some preventive strategies have been discussed internationally. It is crucial for Thailand to understand what these strategies would mean to its energy systems if they were adopted as carbon dioxide reduction measures. The answers to these policy questions lie in the results of the study Scenarios S3, S4, and S5.

Shift in Fuel Mix Scenarios (S3)

In the S3 scenarios it was assumed that there were switches of fuel mix in the transportation, industrial, and power sectors. In industries located in Bangkok and the central region, natural gas was substituted for 50 percent of coal, lignite, and fuel oil. In the transportation sector, gasoline and diesel were replaced by LPG by 8.25 percent, 15 percent, 24.75 percent, and 33 percent in 1996, 2001, 2006, and 2011, respectively. In the power sector it was assumed (1) that there was a substitution of natural gas for fuel oil and imported coal in 2001 and thereafter (S3-B-G), and (2) that a nuclear power project was implemented in 2001, and that fuel oil was replaced by natural gas (S3-B-N).

In Scenario S3-B-G the total reductions of carbon dioxide would be approximately 3 percent and 17 percent by the ends of the Seventh and the Tenth Plans. The reduction of carbon dioxide could be much larger in the case of S3-B-N where the nuclear option was chosen, in fact the reduction could reach 31 percent by the end of the National Tenth Plan. Details of carbon dioxide reductions across sectors are presented in Table 13-5. Table 13-6 shows sectoral energy demand and Table 13-7 gives details of energy requirements for electricity generation according to the fuel switches assumed in S3-B-G and S3-B-N.

Energy Efficiency Scenarios (S4)

Energy efficiency measures were incorporated into this model. The basic assumptions were as follows: There were possibilities for achieving efficiency improvements in energy use. As a result, intensity of modern energy use per unit of GDP decreased for all sectors. The reduction of modern energy intensity in industry from the

Base Case (S1) was assumed to be 20 percent by the year 2011. The reductions were assumed to be 5 percent, 10 percent, 15 percent, and 20 percent in 1996, 2001, 2006, and 2011, respectively. In transportation, improvement of efficiency differed by various fuel types. It was assumed that the intensity of diesel and LPG use was reduced by 6.25 percent, 12.5 percent, 18.75 percent, and 25 percent in 1996, 2001, 2006, and 2011, respectively. The corresponding figures for gasoline were 4 percent, 8 percent, 16 percent, and 16 percent. There was also conservation in services and residential and commercial uses of electricity, thus electricity use per unit of GDP improved by 2.5 percent, 5 percent, 7.5 percent, and 10 percent from the Base Case in 1996, 2001, 2006, and 2011. The results of this scenario indicate that efficiency measures would bring about a 13 percent reduction of carbon dioxide from the Base Case (S1) by the year 2011.

Comprehensive Scenarios (S5)

The assumptions of the comprehensive scenarios (S5) include both the assumptions in the efficiency (S4) and the shift in fuel mix (S3) scenarios. The results of (S5) are as follows:

S5-B-G: With some change of fuel mix, in the power sector particularly, we assumed that from the year 2001 onward imported natural gas would be available to substitute for fuel oil and imported coal. As a result, carbon dioxide emissions would be reduced by 29 percent by the year 2011.

S5-B-N: In this scenario, both efficiency improvement assumptions and the adoption of a nuclear option in electricity generation were incorporated into the model. The results indicate a great impact on carbon dioxide reductions (71 percent) in the power sector, leading to a 41 percent reduction of the country's total emissions by the year 2011.

ENVIRONMENTAL IMPLICATIONS

(1) Energy efficiency measures could bring about a 13 percent reduction of carbon dioxide emissions by the year 2011. Of this, 42 percent would be attributed to the transportation sector. Efficiency improvements in the industrial sector could account for up to 26 percent, and another 32 percent reduction could be made in the power sector. Since *efficiency measures per se* contribute about 13 percent of the reduction from the Base Case scenario by the end of 2011, any reduction beyond 13 percent would require a strong decision on switching the fuel mix of the power sector. Fuel shifts in the power

sector are also extremely useful and administratively attractive because the whole electricity generating system is operated by only one agency (EGAT). Controls over power plant emissions could be more desirable if the acid deposition problem were taken into the problem package. EGAT alone would be able to cut emissions up to 20 percent to 30 percent. If a 20 percent reduction of fossil carbon is imposed, EGAT would certainly have to either consider imported natural gas (or LNG) or the nuclear option. This raises the question of how competitive these alternatives are, particularly under the current crisis situation in the Persian Gulf. Though details of cost comparison by technology are beyond the scope of this study, some rough figures are presented below, indicating that LNG is attractive, and that the nuclear option is potentially competitive.

LNG is environmentally attractive because of its low carbon and sulfur content. Economically, it might be a viable energy alternative for the following reasons : (1) There will be an abundant supply, though reserves have not been fully developed. (2) There has been little fluctuation in its price during the past 15 years, and it is believed that future prices should not unexpectedly fluctuate since the transaction is usually made under a long-term contract. (3) Compared to crude oil, LNG has been rather competitive. Table 13-8 shows energy price series from 1975 to 1989 indicating that prices of LNG have been lower than prices of crude oil throughout the period, except in 1986 and 1988. (4) The only costly component in adopting the LNG option is the cost of receiving facilities. However, according to the preliminary finding, such facilities, including a gasification plant and safety control system for a capacity of 2.5 million tons per year (333 million cubic feet per day), would cost about US$ 460 million, leading to an additional fuel cost of US$ 0.50 per million Btu.

In an attempt to analyze the potential of a nuclear power plant, a cost comparison with coal-fired plants was carried out by Delene, Bowers and Shapiro at the Oak Ridge National Laboratory in 1988. The study pointed out that the nuclear option has been noncompetitive when compared to coal in the United States because of its long lead time and high capital, and operating and maintenance costs. However, it might become competitive with advanced water reactor developments. Construction costs might be reduced through modularization and standardization of nuclear power plants. A summary of levelized power generation cost estimates including capital, operation and maintenance (O&M), and fuel and decommissioning are shown in Table 13-9.

Another cost comparison was reported by the OECD (1989). The report reviewed the projected electricity generation costs for the base-load power generation options expected to be available in the medium-term (1995-2000). Basis for comparison was also the cost of advanced water reactors and coal-fired power plants with desulfurization and denitrification systems. The study reports that most countries (OECD countries and some developing countries) concluded the nuclear power would be the least costly option except for some low cost coal regions of Brazil, China, and India.

The discussion above implies that the nuclear option would be sufficient for a 20 percent reduction of fossil carbon. This does not mean that it would be neccessary. For nuclear power to be considered as a viable option for Thailand, a detailed study should be conducted. The cost estimates reported above might not be relevant to Thailand since they vary from country to country depending upon the country's economic parameters, lifetime, local factors, regulatory approach, design, siting, and exchange rates.

(2) The emission reduction could also be acheived via changing the pattern of land use. Reforestation could be an attractive strategy. Though there are some uncertainties in quantification of the relationship between tropical reforestation and carbon absorption, some rough estimations could be made by following the statistics reviewed by the IPSEP (1989) and the most recent statistics reported by the IPCC Working Group II. Assuming that the CO2 absorptive capacity of one rai of forest is 0.4 tons per year, and that the government's forest policy is effectively implemented to reforest an area of one million rai per year, by the end of 2030 Thailand would have an additional 40 million rai of forested area. This would absorb 16 million tons of CO2 annually, and would uptake approximately 300 million tons by the year 2030. The amount of CO2 absorbed by the newly planted trees would be more than enough to stabilize the level of the country's CO2 emission without disturbing energy consumption in other sectors. Reforestation could also bring many benefits other than CO2 reduction, and should therefore be taken into serious consideration by decision makers. In implementing a reforestation policy attention should be paid to the trade-off between land for food crops and forest area, and to ensure that local people participate in and benefit from the programs.

(3) Energy conservation could certainly play an important role in CO2 reductions. It is believed that Thailand has much room to improve the efficiency of its energy use as it seems to have a higher energy consumption per unit GDP than many other countries with the same degree of development.

According to the NEA, the efficient use of energy in the industrial, and commercial and residential sectors could save up to 607 megawatts of electricity. This accounts for 10 percent of the EGAT system generation, or twice the capacity of the lignite power plant Unit 10 soon to be built at Mae Moh. The NEA estimates suggest that it would be less costly to save this amount of energy than to generate it from the new power plant. It would cost only 6,240 baht per kilowatt for the conservation program to be implemented over a payback period of 5 years, while the capital investment of the EGAT lignite-fired power plant would be about 20,000-30,000 baht per kilowatt. For a new plant, such as Mae Moh Unit 12 fully equiped with a wet scrubber system, costs would rise to 30,000-40,000 baht per kilowatt. In summary, improvements in energy use efficiency would bring about four major benefits. First, in the context of the global warming issue, it would reduce CO2 emissions as described above. This would increase the carbon budget for the economy, meaning that Thailand would have more permits to trade if emissions trading rights were adopted to manage the future allocation of responsibility for stabilizing greenhouse gas emissions. Secondly, it would not only reduce the price for new power plant construction, but also induce a reduction of related environmental damage such as SO2 and CO2 emissions from lignite mining and power plants, and damage from hydro-power plant construction. Thirdly, it would lower imported oil bills for power generation, improving the trade balance. Finally, it would induce the developement of more efficient infrastructure, which would be more attractive (and competitive) for foreign investment.

In order to ensure a supply of electricity sufficient for Thailand to achieve its targetted growth and industrialization, while keeping the level of CO2 emissions low, the government should take immediate actions to accelerate the implementation of energy conservation programs. Incentives in various forms should be offered to electricity users. EGAT as a public utility could take a leading role. In the medium-run (5-10 years) where expansion of electricity generation might be inevitable, switches of fuel mix, basically toward extensive use of natural gas and LNG, would be required. The possibility of adopting unconventional sources of energy (wind/solar) should be considered as long-term alternatives. Along with other policy actions, effective measures to increase forest areas should be designed, and proper management of forest areas should be made a long-term goal.

BASIS FOR RESPONSE STRATEGY TO GLOBAL WARMING MOVEMENTS

Most of the recent international conferences, including the Ministerial-Level Conference on Environment and Development in Asia and the Pacific, and the ASEAN Workshop on Global Climate Change, both held in October, 1990, have agreed to support the Intergovernmental Panel on Climate Change (IPCC) as the principle forum for scientific assessment of climate change. This implies a basic recognition of the fact that climate change is a global problem of unique character, and that all countries should adopt principles of equity and a common but differentiated responsibility. Industrialized countries are expected to take the lead and commit themselves to immediate action, and enter into cooperation with developing countries to enable them to address climate change without obstruction to national development goals and objectives. All countries should base their responses on the precautionary principle, that is, environmental measures must anticipate, prevent, and attack the causes of environmental degradation. Lack of certainty should not be used as a reason for postponing preventive measures.

A difficult aspect of formulating an agreement and commitment is the question of how to construct a basis for reduction allocation among countries. There have been many debates over approaches to allocate responsibility. The first approach suggests that allocation be based on the current carbon releases of each country. This would assign a 28 percent share of the global fossil carbon budget to the developing countries. This approach is not widely accepted because in many countries, when externalized costs are ignored, fossil fuels at current prices are significantly cheaper than several of the presently available renewable-based resources, and developing countries will have more difficulty finding access to the technical know-how, financing, and organizational capacities to implement renewable technologies. A second approach suggests that allocation be based on carbon/GDP ratios. All countries would be required to reduce their carbon/GDP ratios by certain percentages by a given year. This is advantageous for many industrialized countries because their current carbon/GDP ratios are much lower than those of developing countries. It does not really provide incentive for the efficient use of the energy or the limiting of emissions, since it allows countries with high growth to have high emissions rate, as long as economic growth can keep pace with emissions growth. The third approach employs carbon per capita. In a given year all countries would be required to achieve the same carbon/population ratio. Some might argue that population projections may not be accurate and cannot provide reliable estimates for future allocation. However, it is generally agreed that population projections are much more stable than GDP. A variation of this approach is allocation in terms of cumulative per capita. This replaces the population by cumulative populations reflecting the change over time, or taking into account intergenerational equity.

Among these, the third approach represents the highest level of equity in allocating the fossil carbon budget, but it would also be the most difficult to accept for industrialized countries because it would not allow them any further burning of fossil fuel unless compensation mechanisms were adopted. An acceptable approach would need a certain degree of flexibility. This is why economic mechanisms, tradable emissions rights, taxation systems, and a climate protection fund are introduced as tools for emissions management.

Thailand has indicated its commitment to protecting the global climate by participating in many international fora. It has been a contracting party to the Vienna Convention for Protection of the Ozone Layer, as well as the Montreal Protocol on Substances that Deplete the Ozone Layer (CFC control). However, it is not clear, at least to the public, what Thailand's position should be. Thailand is less able than industrialized countries to mobilize technical and financial resources to respond to the impacts of climate change. To prevent the change and maintain its goals of development, Thailand must design policies and preventive strategies (discussed in Chapter 12) so as to minimize its own emissions without hindering growth. A discussion of Thailand's position follows.

Thailand's Share of Global Greenhouse Gas Emissions

Thailand emits 1.13 percent of the world net total atmospheric increase of greenhouse gases, 67 million out of 5.9 billion tons of carbon, or about 6.7 percent of the United States emissions (table 13-10). In terms of emissions per capita, Thailand emits 1.3 tons per head, close to the world average of 1.2 tons per head. The per capita emissions of the United States, the United Kingdom, Japan, Malaysia, and South Korea are 4.1, 2.7, 1.8, 1.6, and 0.7 tons, respectively. Among ASEAN countries, Thailand falls between Malaysia, and Indonesia. Note for comparative purposes, that the above figures are calculated using the information reported by the World Resources 1990/91, not the estimates obtained in the previous section of this study (table 13-11).

Structural Change of the Economy

The GDP shares of the nonagricultural sectors, particularly the industrial and service sectors, have grown at an accelerated rate. In 1970, the shares of industry, services, and agriculture were 26 percent, 47 percent, and 27 percent, respectively. In 1989, while the share of agriculture went down to 16 percent, the industrial share rose to 36 percent. The share of services has been quite steady at 47 percent to 48 percent, but is expected to grow with the expansion of the industrial sector. The expansion of industry and services has become a driving force of the economy's growth, and has created a growing demand for fossil energy thus increasing CO2 emissions. Past performance labelled Thailand as one of the most rapidly industrializing countries, with an average growth rate of 6.8 percent from 1970 to 1980, and 7.5 percent from 1980 to 1989. There are very close relationships between economic growth, energy consumption, and the emission of CO2. Rough estimates indicate that the emissions elasticity of GDP is about 0.9, meaning that a 1 percent increase in the GDP induces a roughly 0.9 percent increase in CO2 emissions.

Changes in Land Use Patterns

Future land use patterns are expected to act as constraints to increases of CO2 and methane emissions for two major reasons. As mentioned earlier in this chapter, the deforestation rate has been slowed. This phenomenon has two important implications. First, it directly reduces the CO2 releases from tree cutting. Second, deforestation cannot continue to be the major source of new crop land. This would mean that additional crop land expansion must be made through a reduction of paddy planted area. As a result, Thailand's paddy planted area is expected to decrease due to crop diversification and switches from rice to other crops, fruit trees, livestock, and aquaculture which offer higher profit margins than rice.[1]

Energy Use Efficiency

The energy consumption to GNP ratios shown in Table 13-10 indicate that Thailand is an inefficient user of energy. As a result, its emissions/GNP ratio is higher than many countries. It is in general believed that there is much room for efficiency improvements in Thailand.

In summary, Thailand is a small contributor of greenhouse gases, undergoing structural changes, rapid expansion of industry and services, switches from rice production to other crops, reforestation, a slowed rate of deforestation, and rapid growth.

[1] For details see Chapter 2 of TDRI Research Report #2, Land and Forest: Projecting Demand and Managing Encroachment.

Thailand stands to loose considerably from international agreements which aim to freeze the level of fossil carbon emissions by country.

In contrast, Thailand will benefit from the per capita basis allocation of responsibility, if there is an agreement to fix the level of CO2 emissions per capita at the current world average of 1.2 tons. This can be illustrated by a simple calculation as follows. Assuming that (1) there is no efficiency improvement, (2) deforestation continues at the 1989 rate, (3) there is no reduction of rice planted area, and (4) the economy's growth rate is 8 percent. In this case, Thailand's current emissions quota would be 67 million tons per year, the current population multiplied by world average emissions per capita. Table 13-3 shows that Thailand's emissions would not exceed its current quota for fifteen years. This means Thailand would have approximately 24 million tons, or permits, to trade in 1991, and 10-15 million tons per year during the next 15 years. This is a very conservative calculation. Thailand would have a much larger quota to trade given a 2 percent to 3 percent growth in population, a slowing rate of deforestation with some reforestation (though not fully successful), structural changes from industry to services, a downward trend of rice planted area, and efficiency improvements in energy use. It is thus clear why Thailand should play an active role in international movements to limit greenhouse gas emissions. Moreover, Thailand should protect its interests by giving strong support to the per capita basis for allocation of responsibility with allowance for emissions rights trading.

Table 13-1 Thailand's Carbon Released to the Atmosphere by Deforestation

Year	Forest land (Hectares)	Deforestation (Hectares)	Carbon Released due to Deforestation (Million Tons)
1950	31,712,663	-	-
1951	31,241,856	470,807	116
1952	30,868,295	373,561	92
1953	30,491,196	377,099	93
1954	30,094,483	396,713	98
1955	29,729,743	364,740	90
1956	29,391,512	338,231	83
1957	29,004,798	386,714	95
1958	28,666,724	338,074	83
1959	28,340,338	326,386	80
1960	28,185,017	155,321	38
1961	28,029,601	155,416	38
1962	27,570,229	459,372	113
1963	27,136,124	434,105	107
1964	26,671,658	464,466	114
1965	26,228,889	442,769	109
1966	25,637,102	591,786	146
1967	25,037,072	600,030	148
1968	24,448,424	588,648	145
1969	23,855,587	592,838	146
1970	23,266,739	588,848	145
1971	22,700,334	566,405	139
1972	22,131,635	568,699	140
1973	21,553,421	578,215	142
1974	21,237,697	315,724	78
1975	20,921,973	315,724	78
1976	19,841,700	1,080,273	266
1977	18,651,844	1,189,856	293
1978	17,522,400	1,129,444	278
1979	17,022,877	499,523	123
1980	16,546,998	475,880	117
1981	16,093,188	453,810	112
1982	15,660,000	433,188	107
1983	15,402,779	257,221	63
1984	15,151,274	251,504	62
1985	14,905,324	245,950	61
1986	14,664,774	240,550	59
1987	14,522,561	142,212	35
1988	14,380,349	142,212	35
1989	14,341,687	38,662	10

Note: Assuming that 1 hectare of deforestation releases 246 tons of carbon annually

Source: Forest land
1950-1974 "Land Utilization of Thailand 1950/51-1977/78"
1975-1977 "Agricultural Statistics of Thailand" Crop year 1983/84
1978-1988 "Agricultural Statistics of Thailand" Crop year 1986/87
Office of Agricultural Economics
Ministry of Agriculture & Co-operatives
1989 Bangkok Post, Oct.22, 1990

Table 13-2 Thailand's Carbon Released to the Atmosphere by Fuel Consumption

Year	CO_2 Emission due to Fuel Consumption (Million Tons)	Carbon Released due to Fuel Consumption (Million Tons)
1979	58	16
1981	59	16
1986	73	20
1988	86	23
1991	111	30
1996	152	41
2001	205	56
2006	280	76
2011	389	106

Note: a) 1979-1988 are based on actual fuel consumption reported by the NEA 1991-2011 are based on TDRI projections of fuel consumption

b) CO_2 Emissions are estimated based on the following conversion factors:

0.295 CO_2 g/kcal for petroleum & petroleum products
0.211 CO_2 g/kcal for natural gas
0.366 CO_2 g/kcal for lignite & coal
0.4 CO_2 g/kcal for renewable energy

c) The actual mass of carbon is estimated by dividing the CO_2 emission by 3.664, the ratio of molecular weight of CO_2 to the atomic weight of carbon

Table 13-3 Comparison of Thailand's Carbon Released Due to Fuel Consumption and Deforestation

Year	Carbon Released due to Fuel Consumption a/ (Million Tons)	Carbon Released due to Deforestation (Million Tons)	Total Carbon Released (Million Tons)
1979	16	123	139
1981	16	112	128
1986	20	59	79
1988	23	35	58
1989	26	10	36
1991	30	10 b/	40
1996	41	10 b/	51
2001	56	10 b/	66
2006	76	10 b/	86
2011	106	10 b/	116

Note: a/ Includes fossil and renewable fuels

b/ Assuming that deforestation remains the same as the 1989 figure

Source: Table 13-1 and Table 13-2

Table 13-4 Total Methane Generated from Paddy Fields

Year	Wet Rice Planted area (Hectares)	Case 1 Methane Emission (Tons)	Case 2 Methane Emission (Tons)	Case 1 Carbon Equivalence (t.carbon)	Case 2 Carbon Equivalence (t.carbon)
1961	6,177,920	355,848	444,810	6,699,008	8,373,760
1962	6,657,920	383,496	479,370	7,219,495	9,024,368
1963	6,587,680	379,450	474,313	7,143,330	8,929,163
1964	6,520,160	375,561	469,452	7,070,115	8,837,644
1965	6,531,200	376,197	470,246	7,082,086	8,852,608
1966	7,432,640	428,120	535,150	8,059,560	10,074,450
1967	6,714,400	386,749	483,437	7,280,739	9,100,923
1968	7,138,080	411,153	513,942	7,740,155	9,675,193
1969	7,586,560	436,986	546,232	8,226,463	10,283,078
1970	7,548,640	434,802	543,502	8,185,344	10,231,680
1971	7,430,080	427,973	534,966	8,056,784	10,070,980
1972	7,345,440	423,097	528,872	7,965,005	9,956,256
1973	7,960,800	458,542	573,178	8,632,269	10,790,336
1974	7,881,440	453,971	567,464	8,546,215	10,682,769
1975	8,518,880	490,687	613,359	9,237,421	11,546,776
1976	8,137,440	468,717	585,896	8,823,808	11,029,760
1977	8,555,200	492,780	615,974	9,276,804	11,596,005
1978	9,317,760	536,703	670,879	10,103,684	12,629,605
1979	9,098,880	524,095	655,119	9,866,342	12,332,928
1980	9,116,320	525,100	656,375	9,885,253	12,356,566
1981	9,022,720	519,709	649,636	9,783,758	12,229,698
1982	8,987,360	517,672	647,090	9,745,416	12,181,770
1983	9,298,400	535,588	669,485	10,082,691	12,603,364
1984	9,266,400	533,745	667,181	10,047,992	12,559,990
1985	9,509,920	547,771	684,714	10,312,052	12,890,065
1986	9,270,880	534,003	667,503	10,052,850	12,566,062
1987	8,691,840	500,650	625,812	9,424,970	11,781,212
1988	9,499,520	547,172	683,965	10,300,775	12,875,968

Note: 1 Emission factor : assuming that rate of CH4 flux 2 mg/m^2/hr

2 Case 1 : assuming rice growing season 120 days/year

Case 2 : assuming rice growing season 150 days/year

3 Estimates of methane emissions are converted to carbon equivalence by multiplying methane emissions by 68.6 (methane CO2 heating coefficient) and then dividing by 3.664, the ratio of molecular weight of CO2 to the atomic weight of carbon

Source: 1 Office of Agriculture Economics, Ministry of Agriculture & Co-operatives and

2 World Resources 1990/91

Table 13-5 Comparison of Carbon Dioxide Emission by Sector

(Thousand Tons)

CO2	Base Case			S-2A		S-2B		S-3B-G		S-3B-N		S-4B		S-5B-G		S-5B-N	
	1986	1996	2011	1996	2011	1996	2011	1996	2011	1996	2011	1996	2011	1996	2011	1996	2011
Industry	16365	33897	69607	33897	69607	33897	69607	32377	63185	32377	63185	31981	56163	30613	51347	30613	51347
Agri.	2608	5759	8934	5759	8934	5759	8934	5759	8934	5759	8934	5759	8934	5759	8934	5759	8934
Res.& Com	20416	14803	20195	14803	20195	14803	20195	14803	20195	14803	20195	14803	20195	14803	20195	14803	20195
Transport	20880	51372	119841	51372	119841	51372	119841	51302	119190	51302	119190	49723	98272	49651	96067	49651	96067
Power Gen.	11481	43293	166929	43293	166929	43293	166929	40721	107489	40721	54667	42210	150236	39703	96740	39703	49201
Refinery	1032	3095	3095	3095	3095	3095	3095	3095	3095	3095	3095	3095	3095	3095	3095	3095	3095
Total	72783	152219	388601	152219	388601	152219	388601	148058	322088	148058	269267	147571	336895	143624	276378	143624	228839

Source: Thailand Development Research Institute Estimates (November 1990)

Table 13-6 Total Energy Demand by Energy Sources

(Unit : KTOE)

	Base, S-2A, S-2B			S-3B-G, S-3B-N		S-4B		S-5B-G, S-5B-N	
	1986	1996	2011	1996	2011	1996	2011	1996	2011
Lignite	323	1770	4802	1206	2466	1593	3602	1085	1850
Coal	140	369	1014	243	373	332	761	219	280
Natural Ga	87	855	1135	2062	6180	770	851	1856	4635
Oil	10020	24174	58010	23657	55941	23303	48255	22835	46127
Electricity	1877	5906	17057	5906	17057	5759	15353	5759	15353
Renewable	7056	5970	5436	5970	5436	5970	5436	5970	5436
Total	19502	39044	87454	39044	87454	37726	74257	37724	73680

Source: Thailand Development Research Institute Estimates (November 1990)

Table 13-7 Energy Use in Electricity Generation

(Unit : KTOE)

	Base, S-2A, S-2B			S-3B-G		S-3B-N		S-4B		S-5B-G		S-5B-N	
	1986	1996	2011	1996	2011	1996	2011	1996	2011	1996	2011	1996	2011
Lignite	1122	3407	8808	3407	8808	3407	8808	3322	7927	3322	7927	3322	7927
Nat.Gas	2314	6662	6141	12967	10422	12967	10422	6496	5527	12643	9380	12643	9380
Oil	812	5556	3561	191	0	191	0	5417	3205	186	0	186	0
Import Coa	0	0	29967	0	0	0	0	0	26970	0	0	0	0
Alt.#1	0	0	0	0	24834	0	0	0	0	0	22350	0	0
Total	4248	15625	48477	16565	44063	16565	19229	15234	43629	16151	39657	16151	17306

Source: Thailand Development Research Institute (November 1990)

Table 13-8 Energy Prices, 1975-1989

	LNG cif Japan	EC Western Europe	Natural Gas USA (wellhead)	USA (import)	Crude Oil cif IEA Countries
1975	1.7	1.0	0.4	1.8	1.9
1976	1.8	1.4	0.6	2.6	2.4
1977	2.1	1.7	0.8	2.9	2.6
1978	2.4	1.9	0.9	3.3	2.6
1979	2.8	2.1	1.2	3.9	3.7
1980	5.1	3.0	1.6	4.2	6.0
1981	5.8	3.6	2.0	4.7	6.7
1982	5.7	4.0	2.5	4.8	6.2
1983	5.1	3.8	2.6	4.3	5.5
1984	4.9	3.7	2.7	4.0	5.3
1985	5.0	3.8	2.6	3.1	5.0
1986	3.9	3.6	2.0	2.5	2.7
1987	3.4	2.6	1.7	2.1	3.3
1988	3.2	2.3	1.7	2.0	2.7
1989	3.2	2.1	1.8	2.0	3.2

Note: cif = cost + insurance + freight (average prices)

Source: BP Statistical Review of World Energy (1990)

Table 13-9 Power Generation Cost Estimates

(Unit: 1988 US Dollars)

Plant	Plant Size MW (a)	Mills/kWh a/				
		Capita	O&M	Fuel	Decommissioning	Total
PWRM	1 x 1100	57	13	8	0.6	78
PWRB	1 x 1100	30	9	7	0.6	46
IPWR	1 x 1100	23	9	7	0.6	40
PWRB	2 x 550	32	11	7	0.8	50
IPWR	2 x 550	25	11	7	0.8	44
APWR	2 x 550	23	11	7	0.8	42
Coal	2 x 550	22	6	22	0.1	50

Note: PWRME = present median experience nuclear plant
PWRBE = current better experience nuclear plant
IPWR = improved nuclear power plant
APWR = advanced nuclear power plant
Coal = coal-fired power plant with flue gas desulfurization
a/ All cost figures rounded

Source: Delene, Bowers and Shapiro (1988)

Table 13-10 Net Additions to the Greenhouse Heating Effect,1987

	CO2 Emissions ('000 t.carbon)		Methane Emissions Equivalent CO2 Heating Effect ('000 t.carbon)		1986 CFC Use Equivalent CO2 Heating Effect ('000 t.carbon)		Heating Effect ('000 t.carbon)	
WORLD	3,700,000	100.0%	800,000	100.0%	1,400,000	100.0%	5,900,000	100.0%
ASIA								
Thailand	48,000	1.3%	16,000	2.0%	3,500	0.3%	67,000	1.1%
Malaysia	22,000	0.6%	1,400	0.2%	2,500	0.2%	26,000	0.4%
Indonesia	110,000	3.0%	19,000	2.4%	9,500	0.7%	140,000	2.4%
Singapore	3,400	0.1%	26	0.0%	3,700	0.3%	7,100	0.1%
India	130,000	3.5%	98,000	12.3%	700	0.1%	230,000	3.9%
China	260,000	7.0%	90,000	11.3%	32,000	2.3%	380,000	6.4%
Korea,De	18,000	0.5%	2,300	0.3%	x	0.0%	20,000	0.3%
Japan	110,000	3.0%	12,000	1.5%	100,000	7.1%	220,000	3.7%
AMERICA&EUROPE								
USA	540,000	14.6%	130,000	16.3%	350,000	25.0%	1,000,000	16.9%
UK	69,000	1.9%	14,000	1.8%	71,000	5.1%	150,000	2.5%
Canada	48,000	1.3%	33,000	4.1%	36,000	2.6%	120,000	2.0%
OTHERS	2,341,600	63.3%	384,274	48.0%	791,100	56.5%	3,539,900	60.0%

Source: World Resources 1990/91

Table 13-11 Greenhouse Gas Emission: A Country Comparison

	Net Total a/ Greenhouse Gas Increase ('000 t.carbon)	Population (Thousand)	GNP (Million $US)	Emission per Capita (t.carbon)	Emission per $US GNP (Kg.carbon/$US)
WORLD	5,900,000	4,997,609		1.2	
ASIA					
Thailand	67,000	53,150	45,542	1.3	1.5
Malaysia	26,000	16,264	30,075	1.6	0.9
Indonesia	140,000	172,494	76,038	0.8	1.8
Singapore	7,100	2,616	20,884	2.7	0.3
India	230,000	786,300	248,073	0.3	0.9
China	380,000	1,085,008	313,672	0.4	1.2
Korea,Re	29,000	42,672	113,153	0.7	0.3
Japan	220,000	122,053	1,924,663	1.8	0.1
AMERICA & EUROPE					
USA	1,000,000	242,159	4,516,739	4.1	0.2
UK	150,000	56,160	592,764	2.7	0.3
Canada	120,000	25,963	391,928	4.6	0.3
OTHERS	3,530,900	2,392,770			

Note: a/ Includes carbon dioxide emissions, methane emissions, and CFCs use

Source: World Resources 1990/1991, and World Resources 1987


CO2 Emission
(Base Case)
Million Tons
200
150
100
50
0
1986
1988
1991
1996
2001
2006
2011
Year
Industry
Transport
Agriculture
Power Gen.
Res.& Comm.
Refinery

Figure 13-1

Chapter 14

Conclusions and Policy Recommendations

INTRODUCTION

The previous two chapters have discussed a range of issues relating to global climate change due to greenhouse gas emissions. Chapter 12 described the bases and impacts of the phenomenon, and some of the prevention strategies and programs currently under consideration. Chapter 13 discussed implications for Thailand's energy systems, in particular laying out the CO2 emissions resulting from scenarios based on several prevention strategies. This chapter comments on the results and conclusions and presents a series of policy implications based upon these results.

BASIS OF POLICY RECOMMENDATIONS

The discussion in Chapter 12 laid out the consequences of a global "business-as-usual" scenario, the results of a comprehensive analysis by the Intergovernment Panel on Climate Change (IPCC). It showed a likely increase in global mean temperature of about 1 degree Celsius by 2025, and a 3 degree increase above today's temperature before the end of the next century. The general consensus which is developing around these results is that the realization of this scenario poses an unacceptable risk to mankind, and that means should be developed to prevent a temperature rise of that magnitude.

Although there remain significant disagreements on how soon and how drastic these preventive actions should be, the international community is moving ahead rapidly to consider specific measures of the types discussed in Chapter 12. The three prevention scenarios considered by the IPCC vary in the severity of their measures and in their influence on the rate of temperature increase. It seems likely that both the international community and many individual countries will proceed with caution, recognizing the uncertainty of the scenarios but nevertheless trying to adopt strategies which will provide them with some insurance against their realization, while at the same time trying to minimize the "insurance premium".

The current consensus seems to be that the industrialized countries must indeed bear the brunt of the responsibility for the current situation, as documented in Chapter 12 and as discussed in the IPCC declarations. It is likely that any future conventions will recognize the desirability of continued economic growth by developing countries and the necessity of concurrent growth in their energy use. The industrialized countries will likely try to develop attainable targets and programs for reduction of their greenhouse gas emissions, and also try to set up mechanisms for technical and capital assistance for developing countries to minimize their own emissions without hindering growth.

In general, because developing countries as a group are less able than industrialized countries to marshal technical and financial resources to respond to the physical and socioeconomic impacts resulting from a global climate change, it is in their interest to prevent the change while still maintaining their desired pattern of development. The challenge for Thailand is to establish policies which fit within an overall prevention strategy and are robust to policy adjustments in global strategies which may take place in the future as uncertainties about climate change are gradually reduced.

The policies to be considered by Thailand fall into the following categories:

1. National strategies for preventing greenhouse gas emissions
2. Responses to international or regional strategies, protocols, programs, etc, for dealing with global climate change

NATIONAL EMISSIONS PREVENTION STRATEGIES

As specified earlier, the major options for the reduction of greenhouse emissions are:

- Reduction of emissions from fossil fuel consumption
- Reforestation/aforestation and reduction of deforestation

Reduction of Emissions from Fossil Fuel Consumption

The primary options of this type are efficiency increases, shifts to low-carbon fossil fuels, and the substitution for fossil fuels by alternative forms of energy. Variations of these options were explicitly analyzed in the scenarios discussed in Chapter

13 and the results were summarized in Table 13-5 showing the changes in carbon emissions that were associated with each scenario, relative to the Base Case scenario.

Energy Efficiency Measures

The energy efficiency measures studied in these scenarios were intended to incorporate a variety of technical, economic, and management interventions in the industrial, transportation, and residential/commercial sectors. As described in Chapter 3, these policies can be considered "moderate intervention" and represent cost effective measures which would occur through market procedures if certain institutional barriers, such as lack of information or capital shortages, were removed. Table 13-5 indicates that these end-use efficiency measures would lead to an approximately 9 percent reduction of carbon emissions by the year 2011.

Based on an international comparison of efficiencies of energy use in the above sectors, Thailand should have no major difficulties in achieving the assumed improvements if efficiency programs are carried out along the lines described by the Energy Conservation Center of Thailand, published in Energy Policy Journal NO. 9. It should be emphasized again that they also depend on appropriate pricing structures and policies; prices must not only incorporate the environmental costs but also address inefficient subsidies and cross-subsidies.

Shifts to Low-Carbon Fossil Fuels

As shown in Table 13-5 the shift from coal to natural gas or LNG as a fuel for the large number of new power plants required in the period from 2001 to 2011 would have a significant impact on carbon emissions, reducing emissions in 2011 by approximately 20 percent from the Base Case. From a purely environmental perspective it is an attractive option since it also effectively addresses the issue of acid rain, as discussed in detail in Chapter 9.

Economically it might be a viable option due to its potentially abundant supply, small fluctuation in price, and most importantly its price competitiveness compared to oil. Adopting the LNG option would also require construction of a gasification plant. However, this would cost about US$460 million, much less than the cost of emission controls on a 300 MW lignite-fired power plant.

Substitution of Alternative Forms of Energy

A third approach to substantially reducing greenhouse gas emissions over the longer run is the development and implementation of alternative forms of energy, e.g., hydro-power, nuclear power, and solar energy. Because of the emerging consensus that the few remaining hydro-power resources in Thailand should not be tapped, primarily because of environmental and social concerns, nuclear and solar power would appear to be the two primary candidates. As shown in Table 13-15, the substitution of non-carbon alternatives (in Scenarios S3-A-N and S4-A-N nuclear power was assumed) as fuel for the coal-fired plants added after 2001, would reduce carbon emissions by approximately 20 percent to 30 percent in the year 2011. This is a very substantial reduction which deserves careful consideration within the spectrum of potential strategies.In the case of nuclear power, though it might be competitive in the future, there are obviously both strong concerns and perhaps constraints concerning the introduction of this technology into Thailand's future energy systems. Although the technology is clearly benign with respect to greenhouse gas emissions, it introduces other significant environmental and safety issues. At a minimum there are likely to be problems with political concerns as well as public acceptance. In addition, a long-term commitment to nuclear power has major implications for technology transfer to Thailand, including the country's increased dependence on advanced foreign technology. Given these issues as well as the inherent complexity of the technology, it is unlikely that any large scale program would be able to provide significant emissions reduction benefits until several years into the next century.

Although solar photovoltaics (PV) appear to be environmentally benign and would also greatly reduce the carbon emissions in the above mentioned scenarios, the cost of electricity generated is usually beyond the price necessary to compete with current systems. However, the price of PV cells has fallen dramatically in the past 15 years, and in the solar industry there is optimism that the decrease will continue and eventually reach the range where it can compete with conventional power generation systems. Nevertheless, PV systems now prove cost effective only in limited markets, for example, in providing power for machinery and villages removed from utility grids. Despite the current barriers to penetration of the above two technologies, their benefits in emissions reductionsare significant enough that they should be examined carefully in the range of power options.

Reforestation and Reduction of Deforestation

Our estimates indicate that the amount of carbon given off annually by deforestation is much larger than that released by fossil fuel consumption. Slowing the rate of deforestation has brought the net total carbon release down from 139 million tons in 1979 to 58 million tons in 1988. The effect of the logging ban has pushed the figure down further to 36 million tons in 1989. If the future rate of deforestation remains the same as the 1989 figure (below 40,000 hectares per year), Thailand's total carbon releases would not exceed 100 million tons until sometime during the Tenth Plan (2006-2011). Since 1989 the main source of carbon releases has been emissions by fossil fuel consumption. The acceleration of industrialization is driving the rate of fossil carbon emissions to grow more rapidly than in the past.

To keep the emission levels low while allowing the growth of fossil fuel consumption, Thailand should see tree planting as an attractive means. In fact this suggestion could be more justifiable if it is also seen as a means to increase agricultural productivity. It is obvious that an increase of not more than 1 million rai a year of forest covered area is required to offset all fossil carbon emissions in the next two decades. The many problems facing the implementation of the prevailing reforestation programs should not reduce the significance of the policy. The only requirement is to ensure that local people participate in and benefit from the programs.

RESPONSE TO INTERNATIONAL PROGRAMS AND ARRANGEMENTS

Chapter 12 gave a summary of potential international economic/institutional strategies under consideration in response to the threat of global climate change. This section discusses criteria and options for Thailand's position and response to these strategies. Quite clearly the current situation is very fluid in view of the fact that the IPCC has only recently completed its review of the Working Group reports. However there are a number of cornerstones upon which an international arrangement will likely be developed.

Emissions Limitations

The major part of emissions affecting the atmosphere at present originates in industrialized countries where the scope for change is greatest. Each ton of additional emission by industrialized countries essentially precludes a future emission by a developing country. Thailand should vigorously support the IPCC statement that industrialized countries should adopt domestic measures to limit climate change by adapting their own economies in line with future agreements to limit emissions. Thailand should also support efforts to establish a framework whereby industrialized countries formally develop reduction targets and establish protocols incorporating them.

It is likely that any future international emissions limitations framework will be based at least in part on per capita emissions, i.e., there will be some notion of equity.

Thailand's per capita emissions in 1987 (1.3 tons) were well below those of the industrialized countries and, with the presumed slowed rate of deforestation in Thailand and a likely stabilization or decrease of rice production, are undoubtedly considerably lower today. Therefore it is to Thailand's advantage to participate in and support efforts to establish a protocol incorporating limits on such a basis.

At the same time, it is recognized that emissions from developing countries are growing rapidly and, if present trends continue, within the next few decades will represent the largest portion of global emissions. Therefore Thailand, as well as other developing countries, should actively assume the responsibility to adapt its economy and energy systems and, within feasible limits consistent with the notion of sustainable development, seek to minimize its contributions to global emissions.

International Cooperation on Technology Development and Transfer for Managing Greenhouse Gas Emissions

The IPCC suggested that industrialized countries have a responsibility to cooperate with developing countries in international action without standing in the way of the latter's development. They can do so by contributing financial resources, by appropriate transfer of technology, by engaging in close cooperation concerning scientific observation, by analysis and research, and finally by means of technical cooperation geared to forestalling and managing environmental problems. Thailand stands to benefit from the development of specific actions and programs through which this responsibility could be manifested.

Economic Mechanisms for Emissions Reductions

In Chapter 12 it was pointed out that there is considerable discussion underway concerning the desirability of devising economic mechanisms for bringing about the targeted emissions reductions. There is underlying reason to such a desire, when one considers the complexity of designing (and implementing) a regulatory system based upon norms and standards. The carbon tax and the associated idea of emissions trading rights are two of the most prominent candidates. Despite the problems which would inevitably be associated with a market-based system, it could offer advantages to developing countries such as Thailand, which have far lower emissions per capita than industrialized countries, have rapidly growing economies and energy systems, and have options for a variety of emissions strategies. It is not unreasonable to expect that the development of such a system could eventually provide Thailand the opportunity to sell or trade emissions rights to a country experiencing severe difficulties in controlling its own emissions.

Because marketable permit approaches have been shown to produce cost savings without decreasing environmental quality, these mechanisms are likely to be used more widely in the future. As the marginal cost of pollutant removal (e.g., CO2 reduction) increases, and as monitoring costs decrease (through improved techologies and information systems), the use of economic mechanisms are likely to further increase. In addition, as experience in industrialized countries grows, the demonstration effect may also stimulate their use.

It is unlikely that a system of the above type will be implemented in the very near future. However, because the eventual development of such a system could have distinct advantages for Thailand, as well as having the broader potential of bringing about a more efficient reduction process globally, Thailand should participate in and encourage the discussion and development of market-based frameworks and mechanisms of this type.

Part VI

Conclusion And Policy Recommendations

Chapter 15

Conclusion and Policy Recommendations

The foregoing analyses in Chapters 3-14 identified three major environmental issues that are of particular concern. They included:

1. The impacts of air pollution and management policies on Thailand's urban energy/environment systems.
2. The acid rain problem in Thailand and its relationship to the Asia Region.
3. Global climate change due to greenhouse gas emissions and its implications for Thailand's future energy systems.

These issues arise from the severe environmental threats that now face Thailand. The main theme discussed is the problem of gaseous emissions brought about by significant increases in energy consumption during the past years. Strong economic development, and changes in the structure of the economy towards increased industrialization and urbanization are some of the major factors explaining the rapidly increasing rate of energy demand. These factors can be summarized as follows.

Expansion of the Economy

Thailand has undergone very rapid economic expansion, especially during the past few years. Following the introduction of the Sixth Plan in 1986, a favorable economic environment helped to accelerate the country's export promotion drive. The collapse of world oil prices, high growth rates of investment, and strong expansion of the tourist industry are among the favorable factors that have sustained Thailand's economic development in recent years. These, together with Thailand's comparative advantages in natural resource base, low labor cost, and conservative fiscal and monetary policies, have helped sustain double-digit economic growth for three consecutive years.

Increased Urbanization

Thailand has rapidly transformed from a rural towards an industrialized/urbanized economy. The concentration of economic activities in the Bangkok area, particularly those in the commercial and industrial sectors, have attracted a continuous flow of rural migrants to the city. This migration, along with the natural increase, has caused population in the Bangkok area to grow at a rate exceeding that of the national average.

Industrialization and urbanization lead to a greater demand for energy. More energy is required to fuel the industrial plants and to provide motorized transportation service to the public. Furthermore, as the spatial extent of the urban area grows, so does demand for more motorized transportation.

Expanded Electricity Service

The increasing demand for electricity is attributed to economic expansion. In the residential sector, higher incomes have led to greater demand for electrical appliances, not only in the metropolitan but also in the rural areas. A recent survey of electricity utilities showed that the share of households in Bangkok having energy-intensive appliances, such as air conditioners, reached 30 percent in 1989. In rural areas, the government s rural electrification program has increased the number of villages with access to electricity to nearly 90 percent in 1990. Expanded electricity service had led to significant growth in electricity consumption in the provinces. Total electricity demand in Thailand has been growing at 13 percent to 14 percent annually for three consecutive years.

STRUCTURE OF FUTURE ENERGY DEMAND

This study predicts that strong economic growth and the industrialization/urbanization process will continue into the future. As a result, the demand for primary energy (electricity generation, etc.) and final energy (industry, homes, etc.) will continue to grow. According to Table 15-1, primary energy demand will increase at an annual average rate of 8 percent from 1988 to 2006. However, there will be a shift of energy use to petroleum and lignite/coal where the 2006 shares will be 56 percent and 31.8 percent, respectively. Demand for lignite and coal will be strongest during this period. Since the development of indigenous natural gas, a low-carbon fuel, could not meet EGAT's energy requirements, EGAT's Power Development Plan calls for the increasing use of lignite and coal for power generation. The share of natural gas in total energy demand will fall from 32.7 percent in 1988 to 11.3 percent in 2006.

Although the market share of petroleum is expected to be lower in 2006 than it was in 1988, its consumption will continue to dominate the country's energy demand well into the future. The uses of petroleum in final energy demand consist of diesel fuel and gasoline for transportation, and fuel oil for industrial uses. These fuels will continue to be the main energy sources for these economic sectors in the future, while lignite, coal, natural gas, and compressed natural gas (CNG) will have only slight market shares.

The future energy consumption pattern as shown in Table 15-1 indicates that the country will be increasingly dependent on high-carbon and high-sulfur fuels like lignite, diesel, and fuel oil. This could cause serious environmental impacts should these fuels be used at an increasing rate. Furthermore, the future environment could be deteriorated even more given the following conditions.

Inefficient Land Use Planning

Land use planning in Thailand has been inefficient. Government policies to establish zoning for residential, commercial, and industrial sectors have often run into opposition from powerful land developers. In addition it takes a long time to draw up land use plans for a particular area, whereas land developments, particularly in Bangkok and other major cities, have been rapidly changing. Unless land use planning becomes effective, excessive development of some areas, or other inappropriate land developments, could lead to traffic problems and wasteful uses of energy.

Lack of Infrastructure

There is a severe lack of infrastructure in the BMR particularly concerning transportation. The JICA study indicates that traffic conditions in Bangkok are reaching a chronic state, as the average speed of traffic in Bangkok's central business district has fallen to 8 kilometers per hour. Despite the government's effort to build more roads and a mass transit system in Bangkok, the report found that average speeds in the area will not be significantly improved.

Regulated Energy Prices

The government continues to regulate prices for most domestic energy products. Some of the products, like LPG, have been partially subsidized while taxes levied on the others, like lignite, have been very low. The use of LPG should be encouraged because of its low-carbon, low-sulfur characteristics while the increased use of lignite, particularly in urban industrial areas, will have a devastating impact on the urban environment.

Energy Demand

Thailand has an unusually high proportion of energy demand for transportation, compared to most other countries in the region. The 1989 share of the transportation sector in total final energy demand was 56 percent, having been 46 percent in 1973.

According to ADB statistics, Thailand's transportation share was the highest among the 13 Asian nations including Korea (15 percent), Taiwan (16 percent), Malaysia (36 percent), and Indonesia (30 percent).

Our analysis of Thailand's transportation sector shows that energy has been heavily used in "personal" passenger transport. The share of fuel use in private passenger cars, motorcycles taxis, and pickups is 49 percent of the total final energy demand, whereas fuel consumption in mass transit, such as buses, accounts for only 14 percent of the total. The freight sector is dominated by trucks, which account for 20 percent of final energy demand, while the mass transport modes, i.e., rail and cargo ships, demand only 2 percent and 6 percent, respectively. Heavy use of "personal" transport modes results in high energy demand for transportation since energy is used inefficiently.

The lack of infrastructure, proper land use planning and inefficient use of energy partly explain the growth of energy intensity in Thailand. Energy intensity has risen from 39 tons of oil equivalent per million baht of GDP in 1982 to 45 tons of oil equivalent at present. The opposite trend is seen in developed countries, such as Japan and the United States, where energy intensity has been declining during this period. Unless the conditions are improved, energy consumption in Thailand will grow strongly as the economy continues to move up its development path. Meanwhile, the level of toxic air emissions resulting from energy consumption will continue to grow linearly with the increased use of energy.

FUTURE AIR POLLUTION LEVELS

Table 15-2 highlights projections of emissions in the years 2006 and 2011 under the Base Case scenario. The scenario assumes continued expansion of the economy as explained in Chapter 4. Although this is essentially a do-nothing case, the scenario incorporates pollution abatement programs which are currently being planned by the government, such as the reduction of lead in gasoline to 0.15 grams per liter and the cut of 50 percent in the sulfur content of diesel fuel by 1993. However, it includes no pollution control requirements for major pollutants. Although this is the worst case scenario, it provides only a conservative estimate of future emission loads because we assume stabilization of modern energy intensity in most economic sectors, and the decline in noncommercial intensity over the period.

According to Table 15-2, Thailand will be experiencing high emission levels of sulfur and carbon. Total SO2 emission from all sources was 552,000 tons in 1988. By 2011, the level of SO2 emissions is expected to grow to over 3 million tons. Most of the SO2 emission in 1988 came from the use of lignite and fuel oil in power generation. However, government policy to promote the use of lignite in power plants will significantly raise the share of SO2 emissions from power plants, from 44 percent in 1988 to 60 percent by 2011.

Furthermore, the use of high-carbon fuels like lignite will also raise the level of CO2 emission. In 1988, CO2 emissions originating from all energy sources totaled 86 million tons. The level of CO2 emissions is expected to reach 389 million tons by 2011. The share of CO2 emissions from power generation will grow from 19 percent in 1988 to 43 percent by 2011, mainly as a result of increased use of lignite as mentioned.

On the other hand, emissions of HC, NOx, and CO originate mainly from the transportation sector. Of the 810,000 tons of HC emitted in 1988, 41 percent came from transport. The level of HC emissions is expected to reach 1.7 million tons in 2011, 88 percent of which will come from transportation.

The emission of NOx in 1988 was 400,000 tons. This will rise to 2 million tons by 2011. The share of the transportation sector in NOx emission was 67 percent in 1988, and will decline slightly in relative terms to 60 percent in 2011 because of the stronger growth of NOx emissions from the power sector during that period.

The level of CO emission also exhibits a strong growth over the next twenty year period. CO emission was 2 million tons in 1988 and is expected to rise to 8.4 million tons by 2011. Most of the CO emission came from the transportation sector, a share of 87 percent in 1988. This share will increase to 96 percent by 2011. As for lead, the level of emission was 1,000 tons in 1988 and will rise to 2,000 tons by 2011. Nearly all of the lead emissions come from transportation.

Finally, the industrial sector is the major contributor of SPM emission which, in 1988, reached the level of 514,000 tons. The level of SPM is expected to reach 1.6 million tons by 2011. The share of the industrial sector was 40 percent in 1988 and is projected to reach 67 percent in 2011.

The level of projected future emissions in Table 15-2 creates a bleak outlook and indicates disturbing trends for environmental conditions in Thailand. Inefficient use of energy without due regards to the environment will expose a large number of the country's population to serious health consequences. The results of the study in Chapter 5 indicate heavy concentrations of SPM, CO, NOx, and lead in Bangkok. As the current air quality conditions in the Bangkok area are near or have failed to meet NEB and international standards for health, the doubling, or in some cases quadrupling, of emissions will have severe health impacts. A significant increase in these emissions beyond the already critical level will create a very serious health problem for the population.

The problem of acid rain is equally serious. Chapters 8-11 raised concerns about air quality around the lignite power plants at Mae Moh. Future growth of lignite consumption there will worsen the air quality and increase the prospect of environmental damage from acid rain.

POLICY MEASURES

The recommended policies for energy emission controls are consistent with other TDRI studies on the environment (The Greening of Thai Industry: Producing More and Polluting Less, 1990). These policies must adhere to the following principles:

The Ambient Air Qualities Targets

An effective environmental quality control policy should be one that leads to a desirable ambient air quality target. In this regard, we have explored a comprehensive list of policy measures that would offer effective emission controls. These measures are as follows:

S1 - Base Case - no pollution control requirements

S2 - Fuel- and technology-based pollution controls

S3 - Fuel shift toward low-carbon, low-sulfur

S4 - Enhanced fuel consumption efficiency standards

S5 - Comprehensive controls - implementation of S2, S3, S4, and S^* traffic demand control (Transportation only)

Policy S2 emphasizes fuel- and technology-based pollution controls on energy sources and energy-using equipment including new vehicles, boilers, and others that will be installed or purchased in the future. The impact of this measure would be a reduction in emissions, such as lead from cars, and SO_2 and NOx from power plants and industrial boilers, under a given level of control technology.

The change in fuel mix, S3, would be designed to minimize consumption of high-carbon, high-sulfur fuels and to provide viable alternatives to further reduce hazardous emissions including lead.

The third measure, S4, seeks to improve fuel consumption efficiency by reducing energy intensities. This alternative is achievable by using pricing and equipment efficiency standard control mechanisms.

The last alternative, S5, reflects a full commitment to pollution control, where all of the above mentioned measures would be implemented within a specified time frame. Policy S* is proposed for urban transportation demand control only. This alternative is designed to improve traffic flow in Bangkok which would lead to substantial fuel savings and reductions in emissions.

The criteria for the selection of these alternatives is their effectiveness in stabilizing emissions at today's level, given the technical constraints considerations. Our main objective is that we should at least be able to maintain the existing air quality standards in the face of rapidly increasing energy consumption. Although there may be several other possible emission control measures, we believe the study has provided a reasonable range of feasible alternatives that could be implemented in the Thai context and could effectively stabilize the emissions at reasonable costs to consumers (see below).

The Least-Cost Principle

This study advocates the use of a least-cost approach in proposing environmental control policies. According to this approach the most beneficial policies are those that achieve a given ambient target at the least possible cost to the economy. Although time limitations preclude full least-cost evaluation in this study, we have attempted to provide cost estimates for each of the proposed measures. These are indicative cost figures only, as the total cost figures would require further in-depth study.

The Polluter-Pays-Principle

This study also advocates the polluter-pays-principle. This principle, generally accepted among industrialized countries, requires that the polluters (industries, power companies, etc.) and their beneficiaries (consumers) pay for the cost of related anti-pollution measures. The application of this principle would help to internalize environmental costs. In the case of transportation it means the costs are incorporated in fuel prices (through fuel standards, fuel shifts, and efficiency improvements measures), into vehicle prices (through emission controls and efficiency standards measures), and into road use fees (through area control measures).

In the case of industrial air pollution, the costs should be incorporated into fuel prices, whereas in the case of power generation the costs should be incorporated into electricity prices to provide appropriate pricing signals to consumers. These pollution control measures will be imposed on the fuel sources and the polluting sources.

SPECIFIC POLLUTION CONTROL POLICY MEASURES

To summarize, this study proposes a consistent set of policy measures for the control of air pollution and greenhouse gas emissions in transportation, industry, and power generation.

There are two alternatives in some of the measures examined. For example, option S3-A proposes a 25 percent share of light vehicles running on LPG. Alternatively, we also examine the case S3-B where all light vehicles are running on LPG. In the case of power sector, fuel shift options with and without nuclear power are tested.

The results of the study show that unless a comprehensive control is used, the level of emissions will continue to rise quickly. Results of the model in the previous chapters clearly indicate that the implementation of either policy S2, S3, or S4 would not be sufficient to contain emissions at today's level. In the case of Bangkok air pollution, where the problems of CO and SPM emissions are already serious, the level of emission of CO and SPM will be twice as high as today's level by 2006 if policy options S2, S3, or S4 are implemented selectively. Because the ambient air quality in Bangkok for these emissions already fails to meet NEB and international standards, a more stringent control option, i.e., a comprehensive control policy, is required. As for acid rain, the level of SO2 emission in 2011 will be 60 percent higher than today's level under a stringent fuel control and technology-based control option for Mae Moh (S2-B). A comprehensive policy option which would include a significant fuel shift towards low-sulfur fuels, would maintain SO2 emission at a level only slightly higher level than it is today.

The evaluation of model results for other emissions points to the need for a comprehensive emission controls policy in order to avoid further degradation of environmental quality from its already critical level. In this regard, the study has proposed specific environmental control recommendations for each of the economic sectors, and specific time frames that would lead to the eventual implementation of a comprehensive pollution control policy.

The suggested time frame for each of the proposed options is as follows:

S2 Fuel/Technology-Based - short-term: within 3-4 years from 1990

S3 Fuel Shift - medium-term: within 5-7 years from1990

S4 Efficiency Improvement - medium-term: within 5-7 years from 1990

S5 Comprehensive - long-term: within 8-10 years from 1990

Details of the specific emission controls recommendations above are presented in Table 15-3.

Transportation[1]

To protect urban air quality from degradation, the government should mandate the use of lead-free gasoline in new cars beginning in 1993. Although the reduction of lead content to 0.15 grams per liter in 1993 will stabilize lead emission in the Bangkok area, the presence of lead in gasoline prohibits the use of catalytic converters in vehicles to trap SPM, CO, HC, and NOx emissions. As indicated earlier, the levels of SPM and CO emission in Bangkok have already reached a critical level. The introduction of lead-free fuel should be initiated as soon as possible to enable the use of the catalytic converters.

Modification of the refining process to produce lead-free gasoline will take 2-3 years. The government should formulate a policy for the production of lead-free gasoline by local refineries in addition to the production of low-lead fuel (0.15 grams per liter) being planned. Such a policy should be implemented as soon as possible because it will affect the design of new greenfield refineries to be constructed during Seventh Plan. Meanwhile, the government should establish a time frame to phase out leaded gasoline. This may not take very long since a preliminary survey by Shell indicates that only 12

[1] The government is introducing three measures to be enforced in 1993.

1. Reduce lead in gasoline to 0.15 grams per liter.
2. Reduce sulfur in diesel fuel to 0.5 percent (by weight).
3. Reduce refining temperature of diesel fuel from 368 degree to 357 degrees celsius at the 90 percent point. The fuel will be lighter and produce less smoke. This measure will be carried out in 1995.

percent to 15 percent of the existing car fleet (mostly older cars) require leaded gasoline for their engines. The rest of the fleet could immediately switch to lead-free fuel.

Initially, lead-free gasoline should be of mid-range grade (having octane of 92 RON). This should be an optimum octane level since both Shell and the Ministry of Commerce survey results indicate that 75 percent of the existing car fleet could run efficiently at this octane level.

Removing lead from gasoline will raise the price by about 0.5 baht per liter, and the cost of a catalytic converter amounts to only 3 percent to 4 percent of a new car price. Thus, the costs are relatively low and should be passed on to consumers. However the study recommends that the government equalize the prices of leaded and unleaded grades to promote the use of lead-free fuel in new and old vehicles (and to prevent "cheating" by new vehicle owners). The price of leaded gasoline would therefore be raised to match the unleaded grade, so that the users of leaded fuel help pay for the cost of lead removal. This would comply with the polluter-pays-principle and serve to discourage the use of leaded gasoline. The study also recommends that the level of sulfur in diesel fuel be reduced to 0.25 percent (by weight) rather than the 0.5 percent level targeted by the government. The 0.25 percent level conforms with international standards.

Currently, about 25 percent of total SO2 emissions come from the transportation sector. The reduction of sulfur in diesel fuel to 0.25 percent would significantly slow down the increase of SO2 emissions resulting from the expected high growth of diesel fuel consumption in the future.

In addition, the government should establish a time frame to further reduce sulfur content in diesel fuel to enable the use of particulate traps in diesel engines. This will result in significant reduction of SPM emissions.

Removing sulfur in diesel fuel will raise diesel prices by only about 0.2 baht per liter. This cost should be passed on to consumers of diesel fuel.

Within the medium-term time frame the government should aim to promote low-carbon fuel consumption and energy efficiency improvements. First, the policy to phase out leaded gasoline should continue as lead-free gasoline is making significant inroads toward full utilization. Second, by using price incentives, the government should encourage an increased use of LPG in vehicles and light trucks to slow consumption of gasoline and diesel fuel. Third, Bangkok's bus fleet should be gradually converted to run on CNG as that fuel becomes available in various parts of the city as a result of the proposed PTT's pipeline network.

As for efficiency improvements, efficiency standards on new passenger cars should be established. The goal is to reduce the current fleet-wide average fuel consumption of 11 liters per 100 kilometers to 8 liters per 100 kilometers (the United States standards) in the medium- to long-term time frame. An increase in fuel prices would be as effective as the setting of standards in attaining the efficiency target but less costly to the economy. Experience elsewhere has shown that proper fuel pricing will raise fleet efficiency as consumers demand more efficient cars with smaller engines.

Within the long-term time frame (8-10 years) the government should aim to achieve the proposed pollution control targets. All vehicles should be running on lead-free gasoline, LPG, or low-sulfur diesel fuel. Emission control standards should be established. At least 25 percent fleet-wide efficiency gains should be achieved. Transport demand controls should be established.

Industrial Sector

The second major source of urban air pollution is the industrial sector. Within the short-term time frame, we propose that the government establish fuel standards for low speed diesel and fuel oil. Maximum sulfur content in the fuels should not exceed 2 percent. This policy should effectively reduce SO2 emissions from existing industrial plants, many of which are medium and small scale. Enforcing emission control standards on the boilers in older plants, particularly the smaller ones, is impractical and could be relatively costly. However, emissions standards should be established for new and replacement boilers, particularly those that will be used in Bangkok and other urban areas.

The cost is low as the removal of sulfur from the fuels to meet this standard will raise the fuel cost by 0.1-0.15 baht per liter.

In the medium-term, the government should encourage the use of natural gas in industrial plants in the Bangkok area. The planned natural gas pipeline expansion in Bangkok should be accelerated. The government should provide price and tax incentives to encourage industrial plants to use natural gas. On the contrary, the use of lignite in urban areas should be discouraged by imposing significant fees on its use. Furthermore, the government should establish a time frame to further reduce sulfur in fuel oil to 1 percent.

Power Sector

The government policy to reduce sulfur in fuel oil and establish emissions standards for industrial plants will reduce acid rain precursor emissions. This study recommends that the government establish equipment performance standards for SO2 and NOx for new lignite power plants within a 2-3 year time frame. The target is to reduce SO2 and NOx emissions at the lignite plants by 90 percent and 40 percent of the uncontrolled level, respectively. These so-called "Phase I" standards mentioned in Chapter 11 are equivalent to the new source performance standards implemented in the United States in 1971. Thus, the proposed recommendation is relatively less stringent than the standards that are being enforced in Japan, Europe, and North America.

This "Phase I" standard will raise the power generation cost of a new lignite (300 MW) plant by 25 percent to 36 percent. However, the levelized cost over the entire generation system will be increased by only 3 percent to 4 percent. This added cost should be passed on to consumers.

In the medium-term, the government should set a time frame for "Phase II" standards which will further reduce SO2 by 95 percent from the uncontrolled level. Although the Phase II standards will still be less stringent than the existing standards in most developed countries, it will substantially reduce acid rain precursor emissions from future power plants, and minimize potential damage resulting from these emissions.

In addition, the government should promote the use of natural gas in power generation to replace imported coal which is being planned by EGAT. The additional supply of natural gas (beyond that being produced domestically) could come from imports in the form of LNG, and from neighboring countries (via pipeline) in the form of joint natural gas development.

A broader fuel switch policy should examine the use of nuclear power generation. Serious evaluation of the nuclear option in terms of technology, pricing, waste disposal, and public acceptance should be carried out in the medium-term time frame. A fuel shift policy for power generation, together with the establishment of emissions standards at the lignite plants, will effectively reduce acid rain precursors in Thailand. However, a significant use of natural gas and the introduction of nuclear technology in Thailand will require in-depth considerations on various economic and technical factors such as the source of supply, fuel price, transportation cost, and the scope of technological transfer.

Although these considerations are beyond the scope of this study, we recommend that serious assessments of these possibilities be initiated within the medium-term time frame.

Greenhouse Gas Emissions

The above mentioned policies to improve fuel consumption efficiency and to change fuel mixes toward low-carbon fuels, such as LPG and natural gas, will effectively reduce CO2 emissions from fossil fuel consumption. According to our study, comprehensive environmental control measures (with a nuclear fuel option that meets 30 percent of EGAT's energy requirement) will cut CO2 emission from energy consumption by 40 percent from the Base Case by the year 2011.

However, an effective greenhouse gas control policy must also consider the pattern of land use. This study has found that reforestation could effectively absorb significant amounts of CO2 emissions. If a reforestation program of one million rai per year is implemented, 16 million tons of CO2 would be absorbed annually. This is enough to absorb all of the incremental emissions originating from energy utilization which, on average, will grow by 13 million tons per year under the Base Case. That is, if the reforestation policy is carried out successfully as mentioned, the level of CO2 emissions in the country will stabilize despite high growth of energy demand. However, in light of the difficulties associated with reforestation programs, major reductions in CO2 may have to come from a comprehensive emission controls policy, to be supplemented by reforestation programs. This would be the most effective greenhouse gas policy for the country. Successful implementation of this policy will strengthen Thailand's position in responding to the international calls for greenhouse gas reductions. Furthermore, the combined policies would ensure that Thailand could maintain its CO2 emission within the proposed quota system established on an emissions per capita basis.

In addition to the above policy measures, the government should initiate research programs to develop non-conventional forms of energy such as solar, wind, and biomass. These are clean renewable resources that could be used to substitute for fossil fuels in the long run. The solar option should be seriously explored as research in solar cells has made significant progress in recent years. Solar energy will be most suitable for electricity supply in various remote areas of the country. It also has high potential for many other applications. We believe there is a good prospect for solar becoming a major source of electricity supply in the future.

Energy conservation measures should be seriously carried out. Energy conservation, including proper pricing of all fuels, will lead to more efficient use of energy and is one of the most effective tools to control long-term energy pollution emissions.

Finally, the study recommends that Thailand take an active role in international discussious which aim to limit global greenhouse gas emissions. Given that Thailand is a relatively small contributor of CO2 in total global greenhouse gas emissions, it should object to an agreement that aims to freeze the level of the emissions. On the other hand, Thailand would "benefit" from a policy to control the level of greenhouse gas on the basis of emissions per capita. In other words, an annual emission "quota" would be established, the amount of which Thailand could easily meet. This is because our current emissions per capita of 1.3 tons is about the same as that of the world average of 1.2 tons. On this basis, the current emission quota for Thailand would be 67 million tons per year, current population multiplied by world average emissions per capita. Our calculations show that the country's current and future emissions will be lower than the quota for the next fifteen years, given that the proposed policy measures, including reforestation programs, are carried out. This means Thailand will have a substantial amount of excess quota to trade. Thus, it is important that we support the international greenhouse gas control agreement based on a per capita system while actively carrying out the comprehensive emission control measures as proposed.

Table 15-1 Energy Demand in Thailand

(Unit: KTOE)

	1988	% Share	2006	% Share	2011	% Share
Primary Commercial						
Natural Gas	5,096	23.7	9,733	11.3	9,733	11.3
Lignite/Coal	2,246	10.4	27,358	31.8	44,591	51.8
Hydro	346	1.6	664	0.8	664	0.8
Petroleum	13,850	64.3	48,320	56.1	63,456	73.7
Total	21,538	100.0	86,075	100.0	118,444	137.6
Final Energy						
LPG	898	5.6	3,946	6.6	5,427	6.6
Gasoline	2,168	13.5	7,311	12.2	9,732	11.9
Diesel	6,262	39.1	20,460	34.1	26,814	32.7
Jet/Kerosene	1,564	9.8	4,911	8.2	6,554	8.0
Fuel Oil	1,855	11.6	6,244	10.4	9,483	11.6
Lignite/Coal	807	5.0	4,020	6.7	5,816	7.1
Natural Gas	60	0.4	1,135	1.9	1,135	1.4
Electricity	2,406	15.0	11,937	19.9	17,057	20.8
Total	16,020	100.0	59,964	100.0	82,018	100.0

Source: National Energy Administration
National Energy Policy Office
Electricity Generating Authority of Thailand
Thailand Development Research Institute (1990)

Table 15-2 Energy Emissions by Sector, by Type

(Unit: 1000 Ton per Year)

Emission	1988	Share by Sector (%)			2011	Share by Sector (%)		
		Ind.	Tran.	Power		Ind.	Tran.	Power
HC or VOC	813	1.5	41.2	0.1	1,693	1.4	88.1	0.4
NOx	401	10.8	66.6	11.8	2,077	11.6	60.0	26.4
SO2	552	26.4	23.1	44.4	3,186	26.8	10.8	60.3
CO	2,054	2.5	87.2	0.3	8,404	1.6	95.7	0.4
CO2	86,338	21.1	31.8	18.8	388,600	17.9	30.8	42.9
SPM	514	40.2	17.9	3.4	1,596	67.1	25.6	2.7
Lead	1	-	100.0	-	2	-	100.0	-

Source: Thailand Development Research Institute (1990)

Table 15-3 Summary of Proposed Mitigating Measures and Their Time Frame

I. Short-Term (3-4 Years from 1990)

Introduction of Fuel/Emission Control Standards (S2)

1. Transportation

1.1 Setting Fuel Standards

Introduce lead-free gasoline for new cars.

Reduce sulfur in diesel fuel to 0.25 percent.

Begin to phase out leaded gasoline.

1.2 Setting Emissions Standards

Mandate manufacture of new vehicles requiring unleaded gasoline.

Establish emissions standards and control technologies for all new vehicles.

1.3 Policy Cost

Removing all lead in gasoline will raise prices by 0.5 baht/liter.

Removing sulfur in diesel will raise the price by 0.2baht/liter.

A catalytic converter costs 3-4 percent of new car cost.

2. Industrial Sector

2.1 Setting Fuel Standards

Set maximum sulfur content at 2 percent for fuel oil.

2.2 Setting Emissions Standards

Set new equipment performance standards for new and replacement boilers (particularly in the BMR).

Set standard control levels for solvents and VOC emissions.

2.3 Policy Cost

Removing sulfur in fuel oil to meet the new standards will raise prices by 0.1-0.15 baht/liter.

Table 15.3 (Continued)

I. Short-Term (3-4 Years from 1990)

3. Power Sector

3.1 Setting Emissions Standards for New Lignite-Fired Facilities:

90 percent reduction for SO_2

40 percent reduction for NO_x

3.2 Policy Cost:

Will raise total cost at plant by 23 percent to 36 percent.
Will raise power system cost by 3 percent to 4 percent.

4. Greenhouse Gas Emissions

In addition to measures stated in 1-3 above, the following actions should be taken to reduce greenhouse gas emissions.

4.1 Accelerate energy conservation drive.

4.2 Accelerate reforestation effort.

4.3 Take a leading role in international movements to establish allocation of greenhouse gas emissions on a per capita basis.

4.4 Support the proposed establishment of an "International Environmental Fund" to control greenhouse gases, the proceeds of which will be used for reforestation programs in participating countries, including Thailand.

5. Other Short-Term Measures

5.1 Improvement of mass transit systems and urban infrastructure investment.

5.2 Improvement of city zoning and land use planning.

5.3 Establish systematic pollution monitoring and evaluation process on a continuous basis.

5.4 Establish regulatory emissions standards for all types ofboilers.

Table 15-3 (Continued)

II. Medium-Term (5-7 Years from 1990)

A drive toward low-carbon fuels and enhanced energy efficiency (S3, S4)

1. Transportation

1.1 Fuel Shift (S3)

Conversion of at least 25 percent of new passenger cars and light truck to run on LPG.

Conversion of new Bangkok bus fleet to run on CNG.

Continue to phase out leaded gasoline.

1.2 Efficiency Standards (S4)

Set efficiency targets and coresponding time frames for new vehicles. This could be achieved by setting new vehicle standards and/or proper fuel pricing.

1.3 Policy Cost

Converting existing gasoline engines to run on LPG will raise car prices by 3 percent.

Cars with engines for CNG will cost 3-4 percent more than to those with gasoline engines.

Conversion of diesel to LPG engines will lower car prices.

Efficiency standards will result in a car fleet with smaller engine sizes. Vehicle costs and operating costs will thus be lowered.

2. Industrial Sector

2.1 Fuel Shift (S3)

Raise NG fuel share to 15 percent of energy use in industrial plant in urban areas.

Implement a pricing policy to discourage use of lignite in industry in urban areas.

2.2 Efficiency Standards (S4)

Set efficiency targets and corresponding time frames for new industrial plants. Energy intensity will be reduced by 10 percent to 15 percent in ten years, and 20 percent to 25 percent percent in fifteen years.

Table 15-3 (Continued)

II. Medium-Term (5-7 Years from 1990)

2.3 Policy Cost

NG price is currently 85 percent higher than lignite, and is 15 percent lower than fuel oil.

Efficiency gain targets will result in higher capital costs for new facilities. However, in the long run the additional costs will be recovered from fuel savings.

3. Power Sector

3.1 Fuel Shift (S3)

Actively promote the use of imported natural gas to replace fuel oil and imported coal.

Seriously explore the feasibility of building nuclear power plants in Thailand.

3.2 Policy Cost

The use of imported natural gas will raise fuel price to EGAT (including facilities) by 32 percent over the current NG price. However, the price will be 20 percent lower than fuel oil.

Nuclear power plants have roughly the same electricty production cost as coal/lignite-fired plants with moderate SO2 control.

4. Greenhouse Gas Emissions

In addition to measures stated in 1-3 above, the following actions should be taken to reduce greenhouse gas emissions.

4.1 Accelerate energy conservation drive.

4.2 Accelerate reforestation effort.

4.3 Promote the use of low-carbon fossil fuels like CNG and LPG in industrial and transportation sectors.

4.4 Develop non-conventional renewable resources like solar, wind, and others to substitute for fossil fuel consumption.

5. Other Medium-Term Measures

5.1 Implementation of area control in CBD.

5.2 Continue improving mass transit and infrastructure development.

Table 15-3 (Continued)

III. Long-Term (8-10 Years from 1990)

Achieving Comprehensive Pollution Control Measures

1. Transportation

   1.1 Fuel Standards

   All lead-free gasoline and very low-sulfur diesel.

   1.2 Emissions Standards

   Achieving international control standards on vehicles.

   1.3 Fuel Shifts

   All cars run on lead-free gasoline, LPG or low-sulfur diesel. BMA buses run on CNG.

   1.4 Efficiency Gains

   Attain 25 percent fleet-wide efficiency gain.

   1.5 Demand Control

   Area control fully enforced.

   Mass transit programs in place.

   Land-use planning fully enforced.

2. Industrial Sector

   2.1 Fuel Standards

   Maximum 1 percent sulfur in fuel oil.

   2.2 Emissions Standards

   Standards are strictly enforced. Attain a minimum 50 percent, 25 percent, and 99.8 percent reductions in SO2, NOx, and SPM, respectively.

   2.3 Fuel Shifts

   20 percent share of NG use in industry.

   2.4 Efficiency Gains

   Attain at least 20 percent to 25 percent reduction in energy intensity.

Table 15-3 (Continued)

III. Long-Term (8-10 Years from 1990)

3. Power Sector

   3.1 Emissions Standards

   Attain at least 95 percent and 40 percent, reductions in SO2 and NOx, respectively in all coal/lignite-fired power plants.

   3.2 Fuel Shift

   Attain 75 percent NG consumption in total power sector fuel demand (no nuclear), or 30 percent (with nuclear). No use of fuel oil or imported coal.

4. Greenhouse Gas Emissions

   4.1 Attain international standards on energy consumption efficiency.

   4.2 Well developed unconventional renewable energy (solar, wind, and others) for commercial purposes.

Part VII

Appendices

Appendix A-1 Proposed Industrial Emission Standard by Industrial Environment Division, Ministry of Industry

No.	Substance	Sources	Proposed Standard Values
1	Particulate	- Boiler & furnance	
		Heavy oil as fuel	0.3 g/Nm3
		Coal as fuel	0.5 g/Nm3
		- Steel manufacturing	400 mg/Nm3
		- Cement plant and calcium carbide plant	400 mg/Nm3
		- Rock and gravel aggregate plant (production capacity more than 50,000 tons per year)	400 mg/Nm3
		- Other source	500 mg/Nm3
2	Smoke opacity	Boiler and furnance	not exceed 40% Ringlemann scale
3	Aluminium	Furnace or smelter	(dust) 300 mg/Nm3 (Al) 50 mg/Nm3
4	Alcohol	any source	0.05 lb/min
5	Aldehyde	any source	0.05 lb/min
6	Ammonia	gas plant	25 ppm
7	Antimony	any source	25 mg/Nm3
8	Aromatics	any source	0.05 lb/min
9	Asbestos	any source	27 ug/Nm3
10	Arsenic	any source	20 mg/Nm3
11	Beryllium	any source	10 ug/Nm3
12	Carbonyls	Burning refuse	25 ppm
13	Chlorine	any source	20 mg/Nm3
14	Ethylene	from production or by usage	0.03 lb/min
15	Ester	any source	0.05 lb/min
16	Fluorine	any source	0.3 lb/ton P2O5
17	Hydrogen Chloride	any source	200 mg/Nm3
18	Hydrogen Fluoride	any source	10 mg/Nm3
19	Hydrogen Sulphide	any source	100 ppm
20	Cadmium	any source	1.0 mg/Nm3
21	Copper	any source	dust 300 mg/Nm3 (Cu) 20 mg/Nm3
22	Lead	any source	dust 100 mg/Nm3 (Pb) 30 mg/Nm3
23	Mercury	any source	0.1 mg/Nm3
24	CO	any source	1,000 mg/Nm3
25	SO2	H2SO4 production	500 ppm
		Other activities:	
		- Bangkok and its vicinities	400 ppm
		- other area	700 ppm
26	NOx	Combustion source	1,000 mg/Nm3
		HNO3 production	2,000 mg/Nm3
		any others	
27	Nitric acid	any source	70 mg/Nm3
28	Organic Material	any source	0.01 ld/min
29	Phosphoric acid	any source	3 mg/Nm3
30	Sulfur trioxide	any source also in combination with H2SO4	35 mg/Nm3 as H2SO4
31	Sulfur acid	any source	35 mg/Nm3

Source: Ministry of Industry

Appendix B1-1 Costs/Benefits of Emission Control Scenario (S2)

(Gasoline Engine)

	Refinery Upgrading and the Use of Additive (10% Blend)	
	Ethanol	MTBE
Emission	**% Reduction (-) or increase (+) from S1**	
CO	-25	-25
NOx	-15/+8	-16
HC (non-methane)	-8/+50	-10
Cost		
Fuel cost(Baht/liter) *	0	+(0.4-0.5)
Vehicle cost **		
Engine modification	0	0
Use of catalytic converter	+	+
Advantages		
	1. High octane (129 RON,96 MON) 2. Renewable resource.(can be made from various agricultural products) 3. No engine/fuel distribution modification 4. Reduce CO emission	1. High octane (119 RON,103 MON) 2. A derivertive of methanol, can be made from natural gas and other feedstocks 3. No engine/fuel distribution modification 4. Reduce CO emission 5. Less water soluble than ethanol
Disadvantages		
	1. May increase NOx, HC emissions 2. Future supply uncertain 3. Less energy per liter 4. Water soluble	1. Regional supply uncertain 2. Relatively expensive 3. Less energy per liter

Note: * + = Incremental cost to gasoline,
0 = about the same as current gasoline price
** 0 = same, - = cheaper, + = more expensive compared to leaded gasoline.

Sources: Renewable Fuels Foundation (1988)
ARCO Chemicals Company (1988)
Sierra Research, INC. (1990)
Ministry of Science, Technology and Energy

Appendix B1-2 Costs/Benefits of Fuel Switch Scenario (S3)

	LPG	CNG	Pure/Near Pure Methanol/Ethanol	Electric/ Solar-Hydrogen
Emission				
CO	-95	-95	n.a.	Virtually
NOx	-47	-47	unconclusive	No emissions
HC (non-methane)	-72	-90		
Cost				
Fuel cost(B/lt) *	-4.3	-4.2	0	+
Vehicle cost **				
Engine modification	+	+	+	+
Catalytic converter	+	+	+	+
Retail station cost	+	+	+	+
Advantages	1. Reduce CO,HC,NOx 2. Low fuel cost 3. High octane 4. Sufficient supply in Bangkok and most urban areas	1. Reduce reactive HC 2. Low fuel cost 3. High octane 4. Sufficient supply in Bangkok	1. Reduce CO emission 2. Renewable Resource (ethanol) 3. Can be produced from various feed stock (methanol)	1. Low emissions from vehicle source 2. Renewable (Solar-hydrogen)
Disadvantages	1. Less energy limited driving range 2. Need some engine modification 3. High distribution costs 4. May need to import	1. Less energy limited driving range 2. Need engine modification 3. Long refueling time 4. High distribution costs	1. Supply/price uncertain Highly toxic and 2. emits formaldehyde (methanol) 3. Requires engine modification 4. Uncertain about long term environmental impacts	1. Technology unlikely to be available for 10-15 years 2. Limit driving range and long recharge time (Electric)

Note: * + = incremental cost to gasoline, 0 = about the same as current gasoline price, - = lower
** 0 = Same, - = Cheaper, + = More Expensive Compared to leaded Gasoline.

Sources: Renewable Fuels Foundation (1988)
ARCO Chemical Company (1988)
Sierra Research, INC. (1990)
Ministry of Science, Technology and Energy

Appendix B2 Transportation Scenario Assumptions for the Year 2006

Trip Generation	43	million single mode trips: allocation to the 19 districts shown in Table 5-7.
Mean Speed in 198	24	kph in zones 11,12,13,14,15,17,18 and 19.
	16	kph in zones 5,7,8,9,10, and 16.
	8	kph in zones 1,2,3,4 and 6.
Mean Speed in 200	24	kph in zones 19.
	16	kph in zones 11,12,13,14,15,16,17, and 18.
	8	kph in zones 1,2,3,4,5,6,7,8,9, and 10.

Exceptions: Scenario S6a, 16 kph in zones 1 and 4.
Scenario S6b, 24 kph in zones 11,12,13,14,15,16,17,18, and 19.
16 kph in zones 1,2,3,4,5,6,7,8,9, and 10.

	S1	S2	S3	S4a,b	S5	S6a	S6b
Emission Controls	Tech 2	Tech 4	Tech 4	Tech 4	Tech 4	Tech 4	Tech 4
Auto Fuel Efficiency	as is	as is	lpg eff.	8l/100km	8l/100km	as is	as is
Percent Private Trips	0.56	0.56	0.56	0.56	0.56	0.56	0.40
Percent Motor Trip Reduction in Zones 1 & 4	0	0	0	0	40	40	0
Fuel Substitution	no	no	yes	no	yes	no	no

Note: Other assumptions are:
1. Trip lengths by mode are held constant across all scenarios as shown in spreadsheet model.
2. Load factors by mode are held constant across all scenarios as shown in spreadsheet model.

Appendix C-1 COMPARISON OF CAPITAL INVESTMENT

% SO2 REDUCTION	TOTAL INVESTMENT COST(M.US $)		
	CASE # 1	CASE # 2	CASE # 3
22.9	-	74.721	-
29.6	72.473	-	-
29.9	-	-	106.227
34	-	-	110.381
47.1	-	105.115	-
50.3	89.745	-	-
50.6	-	-	128.529
79.3	106.355	-	-
87.6	110.853	-	-
89	-	-	167.259

Note: Include NOx, ESP

Source: Thailand Development Research Institute (1990)

Appendix C-2 REDUCTION + UNIT 10 PLANT COST

% SO2 REDUCTION	REDUCTION COST + UNIT 10 PLANT COST (M.US$)		
	CASE # 1	CASE # 2	CASE # 3
22.9	-	365.441	-
29.6	363.193	-	-
29.9	-	-	396.947
34	-	-	401.101
47.1	-	395.835	-
50.3	380.465	-	-
50.6	-	-	419.249
79.3	397.075	-	-
87.6	401.573	-	-
89	-	-	457.979

Note: Total cost of Unit 10 plant = us$ 294,584,615.38
Esp cost = us$ 3,966,666.67
Tc - Esp cost = us$ 290.72

Source: Electricity Generating Authority of Thailand (1988)
Thailand Development Research Institute (1990)

Appendix C-3 SO2 REDUCTION COST SHARE IN UNIT 10 PLANT

% SO2 REDUCTION	SO2 REDUCTION COST SHARE IN UNIT 10 PLANT (%)		
	CASE # 1	CASE # 2	CASE # 3
22.9	-	20.45	-
29.6	19.95	-	-
29.9	-	-	26.76
34	-	-	27.52
47.1	-	26.56	-
50.3	23.59	-	-
50.6	-	-	30.66
79.3	26.78	-	-
87.6	27.6	-	-
89	-	-	36.52

Source: Thailand Development Research Institute (1990)

Appendix C-4 COMPARISON OF OPERATION COST VS. % OF SO2 REDUCTION

% SO2 REDUCTION	LEVELIZED ANNUAL REVENUE REQUIR ($/KWH)		
	CASE # 1	CASE # 2	CASE # 3
22.90	-	0.01154	-
29.60	0.01235	-	-
29.90	-	-	0.01679
34.00	-	-	0.01766
47.10	-	0.01753	-
50.30	0.01725	-	-
50.60	-	-	0.02135
79.30	0.02328	-	-
87.60	0.02494	-	-
89.00	-	-	0.03124

Source: Thailand Development Research Institute (1990)

Appendix C-5 COMPARISON OF ANNUAL OPERATING COST EFFECTIVE VS. SO2 REDUCTION

% SO2 REDUCTION	ANNUAL OPERATING COST($/TON)		
	CASE # 1	CASE # 2	CASE # 3
22.9	-	880.2	-
29.6	727.46	-	-
29.9	-	-	980.48
34	-	-	904.97
47.1	-	649.02	-
50.3	598.64	-	-
50.6	-	-	735.91
79.3	512.31	-	-
87.6	496.91	-	-
89	-	-	612.3

Note: Include NOx, ESP

Source: Thailand Development Research Institute (1990)

Appendix C-6 WATER REQUIREMENT VS. SO2 REDUCTION

% SO2 REDUCTION	WATER REQUIRMENT (M^3)		
	CASE # 1	CASE # 2	CASE # 3
22.90	-	944,659	-
29.60	157,019	-	-
29.90	-	-	675,536
34.00	-	-	754,636
47.10	-	961,024	-
50.30	212,526	-	-
50.60	-	-	1,071,947
79.30	289,898	-	-
87.60	311,992	-	-
89.00	-	-	1,812,036

Source: Thailand Development Research Institute (1990)

Appendix C-7 INVESTMENT COST AT 5O % SO2 REDUCTION

CONTROL TECHNOLOGY	TOTAL SYSTEM COST ($/KW)	LEVELIZED REVENUE REQUIRMENT (MILLS/KWH)	SO2 COST EFFECTIVE ($/TON)	NOX COST EFFECTIVE ($/TON)	PARTICULATE COST EFFECTIVE ($/TON)	WATER REQUIREMENT (M^3/YR)
CASE # 1	299.18	17.25	598.64	4,305.45	104.20	212,526
CASE # 2	350.38	17.53	649.02	4,376.84	105.89	961,024
CASE # 3	428.43	21.35	735.91	5,328.46	128.80	1,071,947

Source: Thailand Development Research Institute (1990)

Appendix D-1 GDP Projection by Economic Sector (1972 Price)

(Unit: Million Baht)

Whole Region	1986	1988	Projected 1991	1996	2001	2006	2011
Mining	9719	12790	20362	32745	48708	71337	106535
Manufacturing	87512	115507	159728	251612	363292	519609	761784
-Food & Beverage	27583	32734	43311	60437	77135	97181	125027
-Textile	24966	34436	47971	77915	117272	174777	266101
-Sawmill & Wood	2398	3094	4234	6632	9503	13633	20236
-Paper & Printing	3013	3605	4919	7201	9633	12680	16986
-Chemical	10832	13778	19326	30983	45649	67291	102262
-Nonmetal	3323	4647	6190	9684	14021	20178	29785
-Basic Metal	1473	1614	2161	3061	3961	5043	6535
-Others	13924	21599	31618	55699	86118	128825	194853
Construction	16159	22206	39608	70556	86938	96901	110891
Total Industry	113390	150503	219699	354913	498938	687847	979210
Agriculture	78775	86642	94784	108620	125547	145365	168497
Service & Comm.	197092	246760	338151	549909	774129	1048442	1432692
Transport	24135	28563	37067	54066	72061	94501	126125
Total GDP	413392	512468	689701	1067507	1470675	1976156	2706524

Source: TDRI's preliminary projection under a high growth scenario

Appendix D-2 List of Provinces in the Region

North	Chieng Mai, Mae Hong Son, Lamphun, Lampang, Chiang Rai, Phayao, Phitsanulok, Phichit, Tak, Kamphang Phet, Sukhothai, Phare, Nan, Uttaradit, Lob Buri, Sing Buri, Phetchabun, Nakhon Sawan, Uthai Thani, Chai Nat
Northeast	Udon Thani, Nong Khai, Knon Kaen, Loei, Sakhonnakorn, Nakhon Phanom, Ubon Ratchathani, Yasothon, Roi Et, Kalasin, Maha Salakham, Sisa Ket, Mukdahan, Nakhon Ratchasima, Chaiyaphum, Buriram, Surin
South	Phetchaburi, Prachuap Khiri Khan, Ratchaburi, Samut Songkram, Chaumphon, Ranong, Nakhon Sri Thammarat, Trang, Krabi, Surat Thani, Phuket, Phang Nga, Yala, Pattani, Narathiwat, Songkhla, Satun, Phatthalung
Central	Phra Nakhorn Sri Ayutthaya, Ang Thong, Saraburi, Nakhon Nayok, Phachin Buri, Chon Buri, Chachoengsao, Rayong, Chanthaburi, Trat, Suphan Buri, Kanchanaburi
BMR	Bangkok & Thonburi, Nontanburi, Samutprakarn, Nakhon Pathom, Samut Sakhon

Appendix D-3 Regional GDP Projection

(Unit: Million Baht in 1972 price)

Bangkok Region			Projected				
	1986	1988	1991	1996	2001	2006	2011
Mining	451	584	1002	1659	2557	3813	5726
Manufacturing	63137	84922	116537	184016	269849	390834	578886
-Food & Beverage	16257	19398	26084	37347	48453	61877	80491
-Textile	22231	30674	42878	69815	105224	157007	239289
-Sawmill & Wood	1665	2155	2981	4730	6844	9912	14848
-Paper & Printing	2222	2496	3343	4865	6490	8517	11377
-Chemical	7259	9467	12546	18571	28815	44537	70671
-Nonmetal	973	1453	1835	2795	4063	5826	8506
-Basic Metal	1266	1367	1330	1824	2603	3598	4991
-Others	11265	17912	25538	44069	67358	99560	148714
Construction	6832	9686	15388	25211	29538	31238	33847
Total Industry	70420	95192	132927	210886	301944	425885	618459
Agriculture	6605	7611	8307	9522	10992	12708	14704
Service & Comm.	103654	134312	187052	312899	452374	628134	878559
Transport	14765	17671	23489	35123	47602	63343	85623
Bangkok GDP	195444	254786	351775	568430	812912	1130070	1597345

Central Region			Projected				
	1986	1988	1991	1996	2001	2006	2011
Mining	3405	4408	7561	12521	19299	28779	43216
Manufacturing	12631	16279	24617	40756	56654	78125	110471
-Food & Beverage	4819	5905	8363	12399	16445	21469	28549
-Textile	1616	2347	3378	5614	8556	12908	19891
-Sawmill & Wood	243	314	414	621	861	1194	1712
-Paper & Printing	359	505	720	1067	1437	1902	2564
-Chemical	3328	3992	6393	11946	16164	21786	30148
-Nonmetal	1122	1665	2444	3998	5659	7901	11232
-Basic Metal	207	247	831	1237	1358	1445	1543
-Others	938	1304	2073	3873	6175	9520	14833
Construction	1340	1900	3019	4946	5795	6128	6640
Total Industry	17376	22587	35196	58223	81747	113032	160326
Agriculture	13290	15314	16714	19158	22117	25570	29586
Service & Comm.	22292	28886	40229	67294	97291	135091	188949
Transport	1975	2364	3143	4699	6368	8474	11455
Central GDP	54934	69151	95281	149374	207524	282167	390316

Source: TDRI's preliminary estimation

Appendix D-3 Regional GDP Projection (continued)

(Unit: Million Baht in 1972 price)

North Region	1986	1988	Projected 1991	1996	2001	2006	2011
Mining	2169	3087	6319	12241	19807	31005	48875
Manufacturing	3811	4743	6371	9539	13439	19174	28554
-Food & Beverage	2263	2609	2937	3264	3466	3623	3858
-Textile	56	79	112	185	282	423	651
-Sawmill & Wood	229	295	399	615	870	1233	1808
-Paper & Printing	136	191	271	402	541	716	965
-Chemical	51	69	98	150	236	372	601
-Nonmetal	427	583	998	1892	3112	5048	8339
-Basic Metal	0	0	0	0	0	0	1
-Others	649	917	1557	3032	4931	7757	12331
Construction	2794	3751	8059	15951	20760	24389	29356
Total Industry	8775	11582	20750	37731	54006	74569	106785
Agriculture	21078	22336	23827	26494	29872	33731	38119
Service & Comm.	23409	27713	36443	55230	72599	91653	116554
Transport	2370	2739	3031	3612	4072	4508	5070
North GDP	55632	64370	84052	123067	160549	204461	266528

Northeast Region	1986	1988	Projected 1991	1996	2001	2006	2011
Mining	1086	1379	1916	3166	4017	4929	6092
Manufacturing	4743	5684	7203	10098	13519	18102	25088
-Food & Beverage	2606	2890	3482	4180	4765	5347	6112
-Textile	1032	1293	1539	2193	3046	4190	5886
-Sawmill & Wood	99	127	169	256	358	501	725
-Paper & Printing	170	239	339	503	677	897	1208
-Chemical	43	57	72	94	140	210	321
-Nonmetal	240	318	331	416	553	724	966
-Basic Metal	0	0	0	0	0	0	0
-Others	553	761	1272	2456	3979	6234	9869
Construction	2955	4011	8138	15642	20070	23243	27579
Total Industry	8784	11074	17257	28907	37605	46275	58759
Agriculture	20953	22035	24773	28581	33119	38434	44638
Service & Comm.	25464	29862	39747	60308	78384	97845	123032
Transport	2213	2564	3092	4145	5191	6383	7972
Northeast GDP	57414	65535	84869	121940	154299	188936	234400

Source: TDRI's preliminary estimation

Appendix D-3 Regional GDP Projection (continued)

(Unit: Million Baht in 1972 price)

South Region			Projected				
	1986	1988	1991	1996	2001	2006	2011
Mining	2608	3332	3564	3157	3028	2809	2625
Manufacturing	3190	3879	5000	7202	9831	13374	18786
-Food & Beverage	1638	1931	2445	3247	4006	4864	6017
-Textile	30	44	64	108	165	249	385
-Sawmill & Wood	162	204	271	409	569	793	1143
-Paper & Printing	126	174	246	364	489	648	872
-Chemical	152	193	216	223	294	386	520
-Nonmetal	562	627	581	582	633	679	741
-Basic Metal	0	0	0	0	0	0	0
-Others	519	705	1177	2270	3675	5755	9106
Construction	2237	2857	5004	8806	10776	11903	13470
Total Industry	8034	10068	13568	19166	23635	28087	34881
Agriculture	16848	19346	21163	24865	29447	34923	41451
Service & Comm.	22273	25987	34680	54178	73482	95719	125599
Transport	2811	3225	4313	6488	8827	11793	16004
South GDP	49967	58626	73724	104696	135391	170522	217935

Source: TDRI's preliminary estimation

Appendix D-4 Statistical Energy/GDP Intensities (1982-1989)

Total Energy/GDP Intensity

(Unit : KTOE / 1972 Million Baht GDP)

Year	31	32	33	34	35	36	37	38&39	Total	Mining	Cons.	Total	Agri.	Res.&Co.	Tran.
1982	0.1143	0.0203	0.0249	0.0495	0.0293	0.3683	0.0995	0.0235	0.0668	0.0092	0.0078	0.0528	0.0167	0.0379	0.2009
1983	0.1017	0.0200	0.0167	0.0594	0.0270	0.3145	0.1292	0.0192	0.0592	0.0128	0.0049	0.0470	0.0149	0.0359	0.2242
1984	0.0979	0.0203	0.0172	0.0535	0.0267	0.2940	0.1842	0.0214	0.0601	0.0090	0.0057	0.0469	0.0139	0.0342	0.2321
1985	0.1005	0.0192	0.0231	0.0611	0.0267	0.3430	0.1128	0.0263	0.0637	0.0075	0.0075	0.0499	0.0107	0.0337	0.2326
1986	0.0979	0.0180	0.0221	0.0564	0.0242	0.3208	0.1303	0.0253	0.0599	0.0055	0.0076	0.0478	0.0112	0.0316	0.2912
1987	0.0929	0.0170	0.0254	0.0618	0.0242	0.3199	0.1455	0.0197	0.0549	0.0047	0.0064	0.0443	0.0106	0.0305	0.2460
1988	0.0829	0.0175	0.0275	0.0682	0.0273	0.2899	0.1437	0.0213	0.0525	0.0038	0.0044	0.0413	0.0096	0.0270	0.3229
1989	0.0943	0.0184	0.0256	0.0738	0.0313	0.3431	0.1529	0.0169	0.0580	0.0035	0.0039	0.0446	0.0179	0.0253	0.3192

Electric/GDP Intensity

Year	31	32	33	34	35	36	37	38&39	Total	Mining	Cons.	Total	Agri.	Res.&Co.	Tran.
1982	0.0054	0.0076	0.0048	0.0125	0.0056	0.0289	0.0423	0.0123	0.0089	0.0000	0.0000	0.0068	0.0000	0.0044	0.0000
1983	0.0060	0.0084	0.0049	0.0195	0.0098	0.0282	0.0512	0.0062	0.0089	0.0000	0.0000	0.0068	0.0001	0.0047	0.0000
1984	0.0059	0.0088	0.0048	0.0205	0.0106	0.0262	0.0525	0.0062	0.0091	0.0000	0.0000	0.0068	0.0001	0.0049	0.0000
1985	0.0065	0.0084	0.0054	0.0126	0.0101	0.0305	0.0385	0.0097	0.0097	0.0000	0.0000	0.0073	0.0001	0.0051	0.0000
1986	0.0060	0.0071	0.0054	0.0093	0.0094	0.0319	0.0543	0.0139	0.0099	0.0000	0.0000	0.0076	0.0001	0.0051	0.0000
1987	0.0065	0.0067	0.0053	0.0096	0.0097	0.0303	0.0608	0.0106	0.0095	0.0000	0.0000	0.0075	0.0001	0.0055	0.0000
1988	0.0068	0.0069	0.0068	0.0147	0.0106	0.0312	0.0682	0.0077	0.0096	0.0000	0.0000	0.0073	0.0001	0.0053	0.0000
1989	0.0072	0.0076	0.0079	0.0145	0.0119	0.0350	0.0652	0.0064	0.0099	0.0000	0.0000	0.0074	0.0001	0.0054	0.0000

Note: 31 = Food; 32 = Textile; 33 = Wood; 34 = Paper; 35 = Chemical
36 = Non-metal; 37 = Basic Metal; 38&39 = Others; Cons. = Construction; Agri. = Agriculture
Res.&Co. = Residential & Commercial; Tran. = Transport

Appendix D-4 Statistical Energy/GDP Intensities 1982-1989 (continued)

Trend of Renewable Energy/GDP Intensity

(Unit : KTOE / 1972 Million Baht GDP)

Year	31	32	33	34	35	36	37	38&39	Total	Mining	Cons.	Total	Agri.	Res.&Co.	Tran.
1982	0.0946	0.0000	0.0127	0.0000	0.0086	0.0461	0.0000	0.0001	0.0333	0.0000	0.0000	0.0253	0.0000	0.0303	0.0000
1983	0.0827	0.0000	0.0103	0.0000	0.0070	0.0378	0.0000	0.0002	0.0280	0.0000	0.0000	0.0214	0.0000	0.0281	0.0000
1984	0.0792	0.0000	0.0101	0.0000	0.0073	0.0340	0.0000	0.0001	0.0278	0.0000	0.0000	0.0209	0.0000	0.0268	0.0000
1985	0.0786	0.0000	0.0095	0.0000	0.0075	0.0452	0.0000	0.0066	0.0293	0.0000	0.0000	0.0221	0.0000	0.0261	0.0000
1986	0.0774	0.0000	0.0092	0.0000	0.0074	0.0445	0.0000	0.0000	0.0273	0.0000	0.0000	0.0210	0.0000	0.0237	0.0000
1987	0.0722	0.0000	0.0121	0.0000	0.0056	0.0388	0.0000	0.0000	0.0228	0.0000	0.0000	0.0179	0.0000	0.0220	0.0000
1988	0.0628	0.0000	0.0103	0.0000	0.0050	0.0318	0.0000	0.0000	0.0199	0.0000	0.0000	0.0153	0.0000	0.0186	0.0000
1989	0.0744	0.0000	0.0087	0.0000	0.0060	0.0256	0.0000	0.0000	0.0230	0.0000	0.0000	0.0173	0.0000	0.0166	0.0000

Trend of Fossil Fuel/GDP Intensity

Year	31	32	33	34	35	36	37	38&39	Total	Mining	Cons.	Total	Agri.	Res.&Co.	Tran.
1982	0.0143	0.0127	0.0074	0.0370	0.0151	0.2932	0.0571	0.0112	0.0246	0.0092	0.0078	0.0207	0.0166	0.0033	0.2009
1983	0.0130	0.0116	0.0015	0.0398	0.0102	0.2485	0.0780	0.0128	0.0224	0.0128	0.0049	0.0189	0.0148	0.0031	0.2242
1984	0.0128	0.0115	0.0022	0.0330	0.0087	0.2338	0.1317	0.0151	0.0233	0.0090	0.0057	0.0192	0.0139	0.0027	0.2321
1985	0.0154	0.0108	0.0081	0.0485	0.0091	0.2673	0.0743	0.0100	0.0247	0.0075	0.0075	0.0205	0.0106	0.0030	0.2326
1986	0.0144	0.0109	0.0075	0.0471	0.0074	0.2444	0.0760	0.0114	0.0228	0.0055	0.0076	0.0191	0.0111	0.0032	0.2912
1987	0.0142	0.0103	0.0080	0.0522	0.0088	0.2508	0.0847	0.0091	0.0226	0.0047	0.0064	0.0189	0.0106	0.0036	0.2460
1988	0.0133	0.0105	0.0103	0.0535	0.0117	0.2268	0.0756	0.0136	0.0230	0.0038	0.0044	0.0186	0.0096	0.0031	0.3229
1989	0.0127	0.0108	0.0090	0.0593	0.0134	0.2825	0.0878	0.0105	0.0251	0.0035	0.0039	0.0198	0.0178	0.0033	0.3192

Note : 31 = Food; 32 = Textile; 33 = Wood; 34 = Paper; 35 = Chemical; 36 = Non-metal; 37 = Basic Metal; 38&39 = Others; Cons. = Construction; Agri. = Agriculture; Res.&Co. = Residential & Commercial; Tran. = Transport

Appendix D-5 Fuel Mix Pattern by Sector in 1988

(Unit : Percent)

Sector	Fossil energy									Renewable energy		
	Coal	Lignite	LPG	Gaso-line	Jet/ Kero	Diesel/ Dist.	Fuel oil	Nat.gas	Total Fossil	Bagasse & Husk	Fuel wood & Charcoal	Total Renew.
Mining	0.00%	0.00%	0.00%	0.00%	0.00%	77.55%	22.45%	0.00%	100.00%	0.00%	0.00%	0.00%
Construction	0.00%	0.00%	0.00%	0.00%	0.00%	81.63%	18.37%	0.00%	100.00%	0.00%	0.00%	0.00%
Manufacturing												
Food	0.00%	20.41%	1.15%	0.00%	0.00%	16.06% 1/	62.38%	0.00%	100.00%	84.09%	15.91%	100.00%
Textile	0.00%	2.57%	2.75%	0.00%	0.00%	1.99% 1/	92.69%	0.00%	100.00%	0.00%	0.00%	0.00%
Wood	0.00%	0.00%	0.00%	0.00%	0.00%	6.25% 1/	93.75%	0.00%	100.00%	0.00%	100.00%	100.00%
Paper	9.84%	51.95%	0.00%	0.00%	0.00%	3.63% 1/	34.58%	0.00%	100.00%	0.00%	0.00%	0.00%
Chemical	10.00%	0.00%	1.88%	0.00%	0.00%	10.26% 1/	38.17%	39.69%	100.00%	0.00%	100.00%	100.00%
Non-metal	10.00%	56.10%	3.03%	0.00%	0.00%	3.12% 1/	13.90%	13.85%	100.00%	12.16%	87.84%	100.00%
Basic metal	16.00%	0.00%	7.38%	0.00%	0.00%	8.20% 1/	68.42%	0.00%	100.00%	0.00%	0.00%	0.00%
Others	0.00%	1.54%	9.90%	0.00%	0.00%	11.26% 1/	77.30%	0.00%	100.00%	0.00%	0.00%	0.00%
Agriculture	0.00%	0.00%	0.36%	5.92%	0.12%	93.48%	0.12%	0.00%	100.00%	0.00%	0.00%	0.00%
Res & Comm.	0.00%	0.00%	94.36%	0.00%	3.81%	0.00%	1.83%	0.00%	100.00%	5.80%	94.20%	100.00%
Transport	0.00%	0.00%	0.53%	23.73%	16.27%	56.23%	3.24%	0.00%	100.00%	0.00%	0.00%	0.00%

Source: National Energy Administration

Note: 1/ include mainly diesel and some gasoline and kerosene

Appendix D-6 EGAT's Electricity Generation and Fuel Requirements

(Unit : Million Kwh)

Type of Plant	1986	1988	1991 (Forecast)	1996 (Forecast)	2001 (Forecast)	2006 (Forecast)	2011 (Forecast)
Hydro	5051	3583	4147	5905	7018	7097	7097
%	20.4	11.2	8.6	7.8	6.5	4.7	3.3
Natural Gas	10270	18203	19650	30644	28718	29145	29145
%	41.4	57.0	40.9	40.3	26.6	19.3	13.5
MMscf	258.0	462.0	531.0	742.9	684.9	684.8	684.8
Heavy Oil	3281	2856	12792	24584	28916	15968	15968
%	13.2	8.9	26.6	32.3	26.8	10.6	7.4
Million litre	858.0	754.0	3241.6	5902.5	6924.0	3783.5	3783.5
Diesel Oil	11	15	30	0	0	0	0
%	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Million litre	5.0	7.0	16.7	0.0	0.0	0.0	0.0
Lignite	5402	6789	10654	14275	33484	36602	36602
%	21.8	21.3	22.2	18.8	31.0	24.3	17.0
Million tons	4.5	5.8	10.4	13.8	32.2	35.3	35.3
Import Coal	0	0	0	0	9200	61357	126068
%	0.0	0.0	0.0	0.0	8.5	40.7	58.5
Million tons	0.0	0.0	0.0	0.0	3.4	23.3	48.0
Purchase	764	480	740	705	705	705	705
%	3.1	1.5	1.5	0.9	0.7	0.5	0.3
Total	24779	31926	48013	76113	108041	150874	215585
%	100	100	100	100	100	100	100

Source: EGAT based on PDP 90-02

Appendix D-7 Local Refinery Production

(Unit : KBD)

	1986	1988	1991	1996
WHOLE REGION				
LPG	4.29	5.29	6.84	22.52
Mogas (Gasoline)	37.92	44.23	54.57	107.22
Naphtha	0.00	0.00	0.00	31.50
Distillate	85.68	86.61	114.77	266.01
Jet/Kerosene	22.36	25.08	35.60	72.38
Diesel	63.32	61.53	79.17	193.63
Fo/Asp	40.64	44.40	67.78	63.41
Fuel Oil	37.72	41.62	64.24	60.14
Asphalt	2.92	2.78	3.54	3.27
Aro.Feedstock	0.00	0.00	0.00	16.06
Long Residue	0.00	0.00	-20.34	0.00
Total Products	168.53	180.53	223.62	506.72
Crude Run	173.65	184.10	228.03	520.56

Source: 1986 figures from Oil and Thailand, NEA
1988-1995 figures from NEPO.
1996-2011 figures are assumed to be the same as of 1995

Appendix D-8 Gas Separation Plant Production

Capacity	Production				
	Methane (MMCFD)	Ethane (Ton/y)	Propane (Ton/y)	LPG (Ton/y)	NGL (Ton/y)
Unit I (350 MMCFD)	250	316,000	197,000	229,000	82,000
Unit II (250 MMCFD)	220	72,000	118,000	191,000	61,000

Source: Petroleum Authority of Thailand

Appendix D-9 Demand and Supply of Natural Gas

(Unit : MMCFD)

YEAR	SUPPLY				DEMAND			AVAILABLE TO EGAT
	UNOCAL	PTTEP	ESSO	TOTAL	FEEDSTOC	INDUSTRY	TOTAL	
1990	564	0	0	564	115	31	146	418
1991	650	0	40	690	132	48	180	510
1992	650	0	40	690	132	63	195	495
1993 a/	650	0	(80)40	(730)690	132	83	215	(515)475
1994	600	150	150	900	132	143	275	625
1995	600	200	200	1000	167	153	320	680
1996	600	250	250	1100	203	172	375	725
1997	600	250	250	1100	203	187	390	710
1998	600	300	250	1150	203	202	405	745
1999	600	350	250	1200	274	216	490	710
2000	600	350	250	1200	274	226	500	700
2001	600	350	250	1200	274	241	515	685
2002	600	350	250	1200	274	241	515	685
2003	600	350	250	1200	274	241	515	685
2004	600	350	250	1200	274	241	515	685
2005	600	350	250	1200	274	241	515	685

Source: Petroleum Authority of Thailand, as of April 19, 1990

Note: a/ Gas Supply from ESSO was adjusted to 80 MMCFD, due to the addition of Nam Phong Combined Cycle Block 2 in January 1993.

Appendix D-10 Petroleum Product Quality

Liquefied Petroleum		Limits	Test Methods
Lapour Pressure at 37.8 C (kg/cm)	Max	14.06	ASTM D 1267
95% Boiling Point at 760 m.m.Hg C	Max	2.2	ASTM D 1837
pertane and Heaviers vol % (Vaport)	Max	2	ASTM D 2163
Copper Strip Corrosion	Max	Copper No.1	ASTM D 1838
Total Sulphur (Before Adding Odorous)	Max	0.343	ASTM D 2784
Agent To Gas g/m(at 15.6 C and 1.03 kg/m)			
Residue ofter evaporation 100 ml.	Max	0.05	ASTM D 2158
No water		-	
Odor		Marketable	
Regular Gasoline		**Limits**	**Test Methods**
Octane Number Reseach Method (F-l)	Min	82.60	ASTM D 2699
Lead Content	Max	0.45	ASTM D 3341
Reid Vapour Pressure at 37.8 C, kPa	Max	62.00	ASTM D 323
Existent Gum, g/100ml	Max	0.005	ASTM D 381
sulphur content, % wt.	Max	0.20	ASTM D 1266
Copper Strip Corrosion (50 C,3 hrs.)	Max	Copper No.1	ASTM D 130
Distillation			ASTM D 86
10% evaporation, C	Max	75.00	
50% evaporation, C	Max	75.00	
C	Max	125.00	
90% evaporation, C	Max	190.00	
End Point, C	Max	215.00	
Residue, % vol.	Max	2.00	
Premium Gasoline		**Limits**	**Test Methods**
Octane Number Reseach Method (F-l)	Min	94.60	ASTM D 2699
Lead Content	Max	0.45	ASTM D 3341
Reid Vapour Pressure at 37.8 C, kPa	Max	62.00	ASTM D 323
Existent Gum, g/100ml	Max	0.005	ASTM D 381
sulphur content, % wt.	Max	0.20	ASTM D 1266
Copper Strip Corrosion (50 C,3 hrs.)	Max	Copper No.1	ASTM D 130
Distillation			ASTM D 86
10% evaporation, C	Max	75.00	
50% evaporation, C	Max	75.00	
C	Max	125.00	
90% evaporation, C	Max	190.00	
End Point, C	Max	215.00	
Residue, % vol.	Max	2.00	

Source: Department of Commercial Registration (DCR)

Appendix D-10 Petroleum Product Quality (continued)

High Speed Diesel		Limits	Test Methods
Specific Gravity at 15.6/15.6 C	Min	0.82	ASTM D 1298
	Max	0.90	
Calculated Cetane Index or	Min	47.00	ASTM D 976
Cetane Number			ASTM D 613
Knematic Viscosity at 40 C, cst	Min	1.80	ASTM D 445
	Max	5.00	
Pour Point, C	Max	10.00	ASTM D 97
Sulphur Content, % wt.	Max	1.00	ASTM D 129
Copper Strip Corrosion (50 C, 3 hrs.)	Max	Copper No.1	ASTM D 130
Conradson Carbon Residue, % vol.	Max	0.05	ASTM D 189
Water and Sediment,% vol.	Max	0.05	ASTM D 2709
Ash, % wt.	Max	0.01	ASTM D 482
Flash Point, Pensky-Martens	Min	52.00	ASTM D 93
Clsed Tester, C			
Distillation			ASTM D 86
90% recovered, C	Max	370.00	
Colour, ASTM	Max	4.00	ASTM D 1500
Low Speed Diesel		**Limits**	**Test Methods**
Specific Gravity at 15.6/15.6 C	Max	0.92	ASTM D 1298
Calculated Cetane Index or	Min	45.00	ASTM D 976
Cetane Number			ASTM D 613
Knematic Viscosity at 40 C, cst	Max	8.00	ASTM D 445
at 50 C	Max	6.00	
Pour Point, C	Max	16.00	ASTM D 97
Sulphur Content, % wt.	Max	1.50	ASTM D 129
Water ans Sediment, % vol.	Max	0.30	ASTM D 2709
Ash, % wt.	Max	0.02	ASTM D 482
Flash Point, Pensky-Martens			ASTM D 93
Clsed Tester, C	Min	52.00	
Colour, ASTM	Min	4.50	ASTM D 1500
	Max	7.50	
Kerosene		**Limits**	**Test Methods**
Specific Gravity at 15.6/15.6 C	Max	0.84	ASTM D 1298
Smoke Point, mm	Min	22	ASTM D 1322
Flash Point, Tag Closed Tester, C	Min	38	ASTM D 56
Sulphur Content, % wt.	Max	0.2	ASTM D 1266
Copper Strip Corrosion (50 C, 3hrs.)	Max	Copper No.1	ASTM D 130
Distillation			ASTM D 86
10% recovered, C	Max	205	
End Point, C	Max	300	

Source: Department of Commercial Registration (DCR)

Appendix D-10 Petroleum Product Quality (continued)

Fuel Oil		Type 1	Type 2	Type 3	Type 4	Type 5	Test Methods
Specific Gravity at 15.6/15.6 C	Max	0.985	0.99	0.995	0.995	0.995	ASTM D 1298
Kinematic Viscosity at 50 C, c	Min	7	81	181	231	-	ASTM D 445
	Max	80	180	230	280	-	
Flash Point, Pensky-Martens	Min	60	60	60	60	60	ASTM D 93
Close Tester, C		24	24	30	30	57	ASTM D 97
Pour Point C	Max	3	3.5	3.5	3.5	3	ASTM D 129
Sulphur Content, % wt.	Max	10,000	9,900	9,900	9,900	9,900	ASTM D 240
Gross Heast of Combustion, C	Min	0.1	0.1	0.1	0.1	0.1	ASTM D 482
Ash, % wt.	Max	1.0	1.0	1.0	1.0	1.0	ASTM D 1796
Water and Sediment, % vol.	Max	8.0	-	-	-	-	ASTM D 1500
Colour, ASTM	Min						

Source: Department of Commercial Registration (DCR)

Appendix D-11 Mae Moh Lignite Quality

Sulfur content (percent)	2.3 - 3.0
Ash content (percent)	18 - 27
Moisture content (percent)	30 - 34
Calorific value (Kcal/kg)	2400 - 2900

Source: Electricity Generating Authority of Thailand

Appendix D-12 Natural Gas Composition

	Percent by Volume
CO2	15
C1	67
C2	0.9
C3	5
C4	2
C5	0.4
H2O	0.02
N2	1.4
S	0.05
Calorific value	1000 BTU/scf

Source: Petroleum Authority of Thailand

Appendix D-13 Quality of Industrial Lignite

Sulfur content (percent)	0.6 - 2.25
Ash content (percent)	2 - 37
Moisture content (percent)	15 - 36
Calorific value (Kcal/kg)	2900 - 5700

Source: National Energy Administration

Appendix D-14 National Ambient Air Quality Standard

Pollutants	1 hr average value mg/m3	8 hr average value mg/m3	24 hr average value mg/m3	1 yr average value mg/m3	Methods of Measurement
Carbon Monoxide (CO)	50	20	-	-	Non-Dispersive Infrared Detection
Nitrogen Dioxide (NO2)	0.32	-	-	-	Gas Phase Chemiluminescence
Sulfur Dioxide (SO2)	-	-	0.3	0.1 *	Pararosaniline
Suspended Particulate Matter (SP	-	-	0.33	0.1 *	Gravinetric
Photochemical Oxidant (O3)	0.2	-	-	-	Chemiluminescence
Lead (Pb)	-	-	0.01	-	Wet Ashing

Note: * = Geometric mean value

Source: (1) Standard: Notification of office of the National Environment Board, No.2, dated November 6, B.E. 2524, published in the Royal Goverment Gazette, Vol.98, Part 197, dated December 1, B.E. 2524 (1981) p. 4322-4323.

(2) Methods of Measurement: Notification of the Ministry of Science, Technology and Energy, issued under Improvement and Conservation of National Environment Quality Act B.E. 2518, B.E. 2521, published in the Royal Government Gazette, Vol.98, Part 197, dated December 1, B.E. 2524 (1981) p.4299-4306.

Appendix D-15 Emission Standard

(a) In order to avoid industrial nuisance problems, the intensity of smoke at the mouth of the stack shall not exceed 40 percent of total blackness by the Ringlemann scale except for the short periods of time during starting of operation, soot blowing, or other malfunctions of the soot control system.

Penalty : According to Factory Act No.2, B.E.2518(1975) which rules that violator are subjected up to one month imprisonment or fined not more than 10,000 baht or both.
Soure : Notification of the Ministry of Industry No.4, B.E. 2514(1971) issued under the Factory Act B.E. 2512(1969) dated August 11, B.E.2514(1971), published in the Royal Government Gazette, Vol.86(Special issue) dated August 14, B.E. 2514(1971)

(b) Motor Vehicle Emission Standards.

Organization	Parameters	Emission Standards		Measuring Methods (summary)
		Measuring Systems	Maximum Permissible Limit (%)	
(1) ONEB (Office of the National Environment Board)	Black Smoke	Bosch	40	1) No-load acceleration at 3/4 of maximum rotating speed. Use maximum value of the two measurements. or
		Hartridge	52	2) On test bench, running with full-load at 60 % of the maximum rotating speed. Use average value of the two measurements.
	CO	Non-Dispersive Infrared Detection	6	1) Idling 2) Average value of the two measurements
(2) The Police Department	Black Smoke	Smoke meter	40	At proper rotating speed
(3) Department of Land Transport	Black Smoke	Bosch	40	The same as ONEB.
		Hartridge	52	The same as ONEB.
	CO	Non-Dispersive Infrared Detection	6	The same as ONEB.

Source:
(1) ONEB Standard: Notification of Office of the National Environment Board, Dated December 14, B.E. 2522(1979) published in the Royal Government Gazette, Vol.97, Part 35, dated March 4, B.E. 2523(1980) P. 736-737.

Appendix D-16 Air Quality near Major Streets in Bangkok and Other Major Cities

Pollutants	Site Measured	Range of Max Values (mg/cu.m)	Standard (mg/cu.m)
Carbon monoxide (8 hour)	Bangkok	27-37	20
	Chiang Mai	16-18	
	Haad Yai	6-27	
Suspended Particulate Matter (24 hour)	Bangkok	0.23-1.05	0.33
	Chiang Mai	0.41-0.47	
	Haad Yai	0.42-0.45	

Source: National Evironmental Board (1985)

Appendix D-17 Existing Air Quality along Proposed Ekkamai-Ram Inthra Expressway Route (Average of 5 measurements, 1987)

(Unit : mg/cu.m.)

Measurement Site	SPM 24 hr.	CO Max./hr.	Pb 24 hr.
Sacred Heart Convent School	0.187	6	0.00115
Military Flat, Sukhumvit Soi 66	0.244	6.3	0.00205
Soi Ruam Rudi 2	0.247	8.1	0.00442
Sukhumvit Bowl, Ekkamai Road	0.206	9.9	0.00261
Lat Phrao Road Soi 71	0.244	14.7	0.00163
Bangkok Bank, Ram Inthra Road	0.175	5.2	0.00082
NEB Standard	0.33	50	0.01(max)

Source: Ekkamai-Ram Inthra Expressway Final Report

Appendix D-18 Summary of Air Pollution Data in Bangkok for 1989

(Unit : mg/cu.m)

Location	CO	SPM	Lead	
	[max hrly av]	[24hr av]	[av]	[max]
1.Ratcha Prarop Rd.	15.87	0.81	0.0020	0.0027
2.Yao-Wa-Rat Area	13.76	0.56	0.0023	0.0044
3.Lan Luang Rd.	9.65	0.35	0.0019	-
4.Bamrung Muang Rd.	28.40	0.46	0.0038	-
5.Sukhumvit Rd (Meteorological Department)	8.12	0.49	0.0017	-
6.Bang Lum Poo area	14.23	0.25	0.0012	0.0018
7.Phahon Yothin Rd.	27.80	0.39	0.0012	0.0017
8.Silom Rd.	31.47	0.58	0.0031	0.0043
9.Si Phraya	13.92	0.39	0.0028	0.0062
10.Ban Somdet Police Station	18.05	0.38	0.0018	0.0036
11.Somdet Phra Pin Khlao Hospital	7.05	0.19	0.0006	0.0011
12.Chula Hospital	6.21	0.16	0.0009	0.0014
13.Police Department, Rama IV Rd.	10.81	0.34	0.0013	0.0023
14.Ramkamhaeng Rd.	9.96	0.40	0.0017	0.0025
15.Land Development Dept.,Bang Kaen	-	0.18	-	-
16.Legal Enforcement Dept.	-	0.22	-	-
NEB Standards	50.00	0.33	0.0100 [max]	

Source: National Environmental Board

Appendix D-19 Acid Rain Result : ONEB Station

	Rain		Soil pH
	pH	Acedity (mg/l as CaCO3)	
18 June '87	6.3	7.3	7.3
19 June '87	6.7	5.9	6.4
23 June '87	-	-	6.4
24 Aug '87	-	-	6.6
24 Aug '87	6.8	8.2	7.4
2 Sep '87	5.7	4.3	8.1
10 Sep '87	6.8	1.8	6.8
16 Sep '87	4.5	2.1	6.9
25 Sep '87	-	-	6.6
1 Oct '87	7.2	7.4	6.9
2 Oct '87	5.0	9.2	7.1
13 Oct '87	4.5	8.0	6.2
14 Oct '87	6.8	-	6.3
26 Oct '87	-	-	7.9
24 Nov '87	-	-	7.5
18 Dec '87	-	-	6.9
5 Jan '88	-	-	7.2
15 Feb '88	-	-	7.1
10 Mar '88	-	-	7.25
7 Apr '88	-	-	8.0
18 May '88	-	-	7.5
6 June '88	-	-	7.3
7 June '88	6.5	0.6	7.3
27 Jul '88	-	-	7.8
22 Aug '88	-	-	7.5
30 Sep '88	4.1	14.9	7.6
14 Oct '88	-	-	7.6
19 Dec '88	-	-	7.5
31 Jan '89	-	-	7.3
28 Feb '89	-	-	7.2
29 Mar '89	6.2	3.1	8.0
12 Apr '89	-	-	8.0
29 May '89	-	-	7.5
June '89	-	-	6.8
7 July '89	4.1	5.1	8.5
22 Aug '89	-	-	8.1
Sep '89	-	8.6	7.4
6 Oct '89	-	6.0	7.6
28 Oct '89	-	-	7.7

Source: National Environmental Board

Appendix D-20 Emission Factor by Fuel Type

(Unit : gm emission/unit fuel)

Combustible Fuel Type	Energy Units Grams Emissions/Unit						Lead(Pb) gm/litre		CO_2
	Units	HC or VOC	CO	NOx	SO_2	SPM·	0.4 g.	0.15 g	gm/Kcal
GASOLINE									
-Transport Average	Liters	72.5	565	14.1	1.95	18	0.4	0.15	0.295
AVIATION FUEL and KEROSENE	Liters								
-Commercial Jet Fuel		50	40	30	2.93	1			0.295
-Residential Fuel Use		0.4	0.6	2.3	2.93	0.1			0.295
DIESIL FUEL (Distillate or Light)	Liters								
-Transport & Engine Average		6.1	18.3	28.2	3.80	6.3			0.295
-Commercial/Industrial Furnace		0.04	0.6	3.8	17.00	0.5			0.295
LPG									
-Light Vehicles (LPG or CNG)	Liters	0.2	1	2.5	3.4E-03	0.1			0.295
-Residential (Cooking, etc)		0.2	0.5	1.8	3.4E-03	0.03			0.295
-Commercial/Industrial		0.05	0.3	1.25	3.4E-03	0.03			
NAT. GAS									
-Commercial/Industrial	scf	2.0E-03	1.5E-02	8.0E-02	4.8E-05	1.5E-03			0.211
-Utility Power Plant		1.0E-03	1.8E-02	1.2E-01	4.8E-05	1.5E-03			0.211
FUEL OIL (RESIDENTIAL or HEAVY)	Liters								
-Small Industrial/Commercial		0.08	0.6	6.6	57.00	3.02			0.295
-Utility Power Plant		0.1	0.6	8	57.00	4.13			0.295
Imported Coal	Kg.								
-Small Industrial		0.1	3	10	9.50	56			0.366
-Utility Power Plant		0.04	0.3	7.5	9.75	70			0.366
LIGNITE	Kg.								
-Utility Power Plant		0.04	0.3	4	37.50	75			0.366
-Industry		0.1	3	10	26.60	60			0.366
BAGASSE & PLANT RESIDUE	Kg.	1	4	0.6	0.3	8			0.4
WOOD COMBUSTION									
-Residential Fuel	Kg.	40	100	3	0.5	16			0.4
-Industrial Fuel	Kg.	0.7	2	1.2	0.5	4			0.4

Source: 1. U.S. EPA 2. API 42 & NAPAP inventory
3. WHO 4. TDRI
5. U.S. DOE 6. OECD

Appendix D-21 Regional Land Area

(Unit : Square Km.)

Province	Area	Province	Area	Province	Area	Province	Area
North		**Northeast**		**Central**		**South**	
Chiengmai	22848.37	Udonthani	18149.44	Ayutthaya	2473.56	Phetchaburi	6356.92
Mae Hong So	12509.20	Nong khai	7222.65	Angthong	981.10	Prachuapkhirikhan	6367.62
Lumphune	4407.00	Kgonkaen	11436.14	Saraburi	3818.50	Ratchaburi	5290.20
Lamphang	12517.63	Loei	10787.78	Nakhonnayok	1879.29	Samutsongkhram	400.22
Chiengrai	12191.96	Sakonnakhon	10406.75	Prachinburi	12144.02	Chumphon	6185.00
Payal	6364.00	Nakhonphanom	5458.97	Aranyaprathet	0.00	Ranong	3425.00
Pisanuluk	9701.07	Ubonratchatoni	20458.65	Chonburi	4484.46	Nakhonsi	
Pichit	5020.59	Yasothon	4348.00	Chachoengsao	5433.63	Thammarat	10168.92
Tak	43062.96	Roiet	7715.30	Rayong	3402.19	Trang	5216.66
Kamphangphe	10202.30	Kalasin	7577.60	Canthaburi	6052.17	Krabi	5307.50
Sukothai	6965.41	Mahasorokham	5306.31	Trat	2819.00	Suratthani	12811.06
Phrae	6394.39	Sisaket	9494.32	Suphanburi	5486.53	Phrket	538.72
Nan	12998.41	Mukdahan	4543.65	Kanchanaburi	20348.77	Phangnga	4009.77
Uttaradit	7146.96	Nakhonratchasima	21123.65			Yala	4716.54
Lopburi	6161.29	Chaiyaphum	10788.36			Pattani	2102.79
Singburi	841.10	Buriram	10312.44			Narathiwat	4660.04
Phetchabun	11951.08	Surin	8828.80			songkhla	7436.76
Nakhonsawan	10126.00					Satun	2786.80
Uthaithani	6733.46					Phatthalung	3530.08
Chainat	2635.58						
Total	210778.76	**Total**	173958.81	**Total**	69323.227	**Total**	91310.59

Province	Area	Province	Area
BMR			
BKK	1565.56	**Whole Region**	552987.70
Nonthaburi	654.32		
Samutprakan	870.20		
Pathumthani	1524.84		
Nachonpatho	2150.18		
Samutsakhon	851.22		
Total	7616.33		

Source: Department of Local Administration, June 1987

Appendix D-22 Conversion Factors

Type of Energy and Fuel	Unit	kcal/Unit	Density (kg/lt)	toe/10^6 Unit	MJ/Unit	10^3 BTU/Unit
1.Crude Oil	lt.	8680	0.86	860.00	39.33	34.44
2.Condensate	lt.	7900		782.72	33.07	31.35
3.Natural Gas						
3.1 Wet	Scf.	248		24.57	1.04	0.98
3.2 Dry	Scf.	244		24.20	1.02	0.96
4.Petroleum Products						
4.1 LPG	lt.	6360	0.57	630.14	26.62	25.24
4.2 Gasoline	lt.	7520	0.72	745.07	31.48	29.84
4.3 Aviation Fuel	lt.	8250	0.80	817.40	34.53	32.74
4.4 Kerosene	lt.	8250	0.80	817.40	34.53	32.74
4.5 Diesel	lt.	8700	0.85	861.98	36.42	34.52
4.6 Fuel Oil	lt.	9500	0.97	941.24	39.77	37.7
4.7 Bitumen	lt.	9840	1.03	974.93	41.19	39.05
4.8 Petroleum Coke	kg.	8400	1.35	832.26	35.16	33.33
5.Electricity	kWh.	860		85.21	3.60	3.41
6.Coal (import)	kg.	6300		624.19	26.37	25
7.Coke	kg.	6600		653.92	27.63	26.19
8.Anthracite	kg.	7500		743.09	31.40	29.76
9.Lignite						
9.1 Li	kg.	4400		435.94	18.42	17.46
9.2 Krabi	kg.	2600		257.60	10.88	10.32
9.3 Mae Moh	kg.	2500		247.70	10.47	9.92
9.4 Chae Khon	kg.	3610		357.67	15.11	14.32
10.Fuel Wood	kg.	3820		378.48	15.99	15.16
11.Charcoal	kg.	6900		683.64	28.88	27.38
12.Paddy Husk	kg.	3440		340.83	14.40	13.65
13.Bagasse	kg.	1800		178.34	7.53	7.14
14.Hydroelectric	kWh.	2236		221.54	9.36	8.87
15.Oil Shale	kg.	1000		99.08	4.19	3.97
16.Solar Energy	sq.m/yr.	58.133lt.coe		49994.40	2112.23	2002.23
17.Wind Energy	1 windmil/yr.	100lt.coe		89000.00	3633.45	3444.22
18.Biogas	cu.m	4770		472.60	19.97	18.93
19.Garbage	kg.	1160		114.93	4.86	4.6
20.Saw dust	kg.	2600		257.60	10.88	10.32
21.Agr. Waste	kg.	3030		300.21	12.68	12.02
22.Human Labor	hr.	65		6.44	0.27	0.26
23.Animal Labor	hr.	320		31.71	1.34	1.27
24.Methanol	lt.	4065		402.75	17.02	16.13
25.Ethnol	lt.	5055		500.84	21.16	20.06
26.Calcium Carbide	kg.	4840		479.54	20.26	19.21

Source: National Energy Administration

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