

# Country Synthesis Report on Urban Air Quality Management

## »» Singapore

Discussion Draft, December 2006



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Urban Air Quality Management

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The Study was led by the CAI-Asia Secretariat and the information contained in this report was developed by the CAI-Asia Secretariat with inputs by a range of organizations and air quality experts from across Asia and elsewhere.

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# Abbreviations

ADB	Asian Development Bank	m	meter
APEC	Asia-Pacific Economic Cooperation	MRT	Mass Rapid Transit
AQ	air quality	MEWR	Ministry of Environment and Water Resources
AQG	air quality guidelines	NEA	National Environment Agency
AQM	air quality management	NEEC	National Energy Efficiency Committee
CAI-Asia	Clean Air Initiative for Asian Cities	O <sub>3</sub>	Ozone
CCS	Central Control System	PCD	Pollution Control Department
CO	Carbon monoxide	PM <sub>10</sub>	particulate matter with diameter equal or less than 10 micrometers
EC	European Commission	PM <sub>2.5</sub>	particulate matter with diameter equal or less than 2.5 micrometers
EDB	Economic Development Board	PSI	Pollution Standards Index
EPCA	Environmental Pollution Control Act	SO <sub>2</sub>	Sulfur dioxide
ER	emergency room	TSP	total suspended particulate
ERP	electronic road pricing	µg/m <sup>3</sup>	micrograms per cubic meter
g/l	gram per liter	US EPA	United States Environment Protection Authority
GDP	gross domestic product	WHO	World Health Organization
HC	hydrocarbon		
IACEE	Inter-Agency Committee on Energy Efficiency		
km	kilometer		
km <sup>2</sup>	square kilometer		
LRT	Light Rapid Transit		
LTA	Land Transport Authority		

Note: “\$” means “US dollar” in this publication.

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# General Information

## Geography and Climate

Singapore is a one-city country located at the southernmost tip of the Malayan peninsula, between Malaysia and Indonesia. It comprises the main island of Singapore and 63 islets within its territorial waters. The main island is approximately 42 kilometers (km) from east to west and 23 km from north to south, giving a total area of 699.4 square kilometers (km<sup>2</sup>) [Land Transport Authority (LTA) 2006a]. It contains approximately 10 km<sup>2</sup> of water bodies and 193 km<sup>2</sup> of coastline. The landscape is predominantly made up of lowland hills, the highest being the Bukit Timah Hill at 166 m to the northwest of the city, and the lowest area being the Singapore Straits (Library of Congress 2006).

Singapore has a tropical climate. Its average daily temperatures range from a minimum of 23°C to a maximum of 34°C while average humidity is at 84%. There is no distinct wet or dry season although maximum rainfall occurs in December and April with drier months in February and July.

## Urbanization and Population

Singapore is a highly urbanized country, with an urbanization rate of 100%. The total population of Singapore in 2005 [Economic Development Board (EDB) 2005] was estimated at 4.4 million with a population density at 6,222 persons per km<sup>2</sup>. Age distribution of the population is as follows: below 15-year old bracket, 20.1%; 15– 64 years old, 71.9%; and last, people ages 65 and over, only 8%. In 2005, the resident population growth rate was 1.9%. Birth rate and death rate of 10.1 persons and 4.3 persons for every 1,000 persons respectively, were posted in 2004.

## Economy and Industry

Singapore's manufacturing and services industries are considered the "twin pillars of growth" in the country's highly competitive economy (EDB 2006). The manufacturing and services sectors contributed 27.3% and 67.4% of the gross domestic product (GDP) respectively in 2005. The growth rate of Singapore's GDP grew 6.4% in 2005, slower than the 8.7% growth in 2004. Both manufacturing and services sectors grew moderately during the year (Ministry of Trade and Industry 2006). The following are Singapore's primary industries listed in order of value: electronics, chemicals, oil drilling equipment, petroleum refining, rubber processing and rubber products, processed food and beverages, ship repair, and offshore platform construction (EDB 2005). Now on its 45<sup>th</sup> year of operations, EDB identifies three new growth areas to further improve the country's economy and assets. These three areas are: industrial biotechnology; alternative energy; and new minerals, metals, and materials. Peter Cramer, a German company, will be opening one of the first biodiesel plants in the island. Local and foreign companies alike have dedicated investments toward manufacturing fuel cells. Together with China's Yunnan Tin, Singapore's KJB International established the country's first tin purification plant that produces 99.99% tin that will supply 10% of the global market. Aside from the identified potential growth areas, pharmaceutical, chemical, and petrochemical plants continue to increase and more than 3,500 applications to locate industries in selected industrial estates have been received in the past 5 years (Ministry of Environment and Water Resources [MEWR] 2005).

## Energy

Due to lack of indigenous energy resources, Singapore relies completely on imports to meet its own energy requirements. Despite this, Singapore hosts a large petroleum refining industry and is among the world's top three crude refining and trading hubs (Library of Congress 2006). In 2004, refined petroleum and chemical products accounted for 16% of manufacturing value added. For domestic use, Singapore relies predominantly on oil (57%) but the use of natural gas is increasing.<sup>1</sup> Oil and gas together accounted for almost 99% of the total primary energy supply in 2005. Most imported energy sources were used as feedstock for the refining and petrochemical industries and for power generation (APEC 2006).

For power generation, Singapore relies predominantly on natural gas that is piped in from Indonesia but some oil is also used. Since January 1992, natural gas from Malaysia has been used for electricity generation as a first step toward energy supply diversification. New sources of natural gas became available when Singapore signed agreements with Indonesia for the supply of natural gas from West Natuna and South Sumatra in 2001 and 2003 respectively (Department of Statistics 2005).

Demand for electricity grew at an average of 5.6% annually from 1995 to 2005 (ADB 2006). To meet this demand, Singapore has an installed power generation capacity that consists of natural gas-fired combined cycle plants, oil-fired steam plants and a natural gas-fired cogeneration plant.

In 2005, total final energy consumption for the refined petroleum and chemical products industry was about 4,000 kilotons of oil equivalent (ktoe). Residential and commercial sectors consumed about one quarter of the total energy, followed by the transport sector with about one fifth and industry, which consumed the rest. (NEA 2006a)

<sup>1</sup> Domestic use excludes consumption of oil products by refineries, non-energy uses of fuels (including petrochemicals feedstock), and consumption of jet fuels for international civil aviation.

Energy efficiency and the use of clean energy are actively promoted and pursued at a national level through the National Climate Change Committee, which comprises representatives from 45 organizations (Department of Statistics 2005).

## Transportation

In 2005, Singapore had 754,992 motor vehicles, of which 139,434 were motorcycles (LTA 2006a). Private car ownership is rather low at 11.3 cars per 100 residents (LTA 2006a). The government has introduced a number of measures to improve public transport and avoid congestion of the existing road network. The Vehicle Quota System (where rights to own vehicles are auctioned off) and electronic road pricing (ERP) (where short-range radio communications system is used to charge ERP from in-vehicle smart cards whenever vehicles pass a pricing point (LTA 2006b) and the off-peak car scheme) are just some of these measures.

Singapore has an efficient public transportation network that serves the entire island at reasonable fares through various public transport alternatives. This includes the Mass Rapid Transit (MRT) system, Light Rapid Transit (LRT) system, buses, and taxis.

The MRT system operates a network of trains serving 110 stations (Loh 2006). The average daily ridership for rail (both MRT and LRT) has seen increases from 1,333,000 passenger trips in fiscal year (FY) 2004 to 1,409,000-passenger trips in FY2005. Passenger trips for buses and taxis have likewise increased during the same period and have a combined ridership of 3,776,000 in FY2005 (Department of Statistics 2005).

The National Environment Agency (NEA) of the MEWR actively promotes the use of environment-friendly or "green" vehicles through tax incentives and rebates with the objective of improving air quality (AQ). Green vehicles such as hybrid, fuel cell, and compressed natural gas vehicles emit little or no pollutants such as fine particulates or particulate matter with diameter equal or less than 10 micrometers (PM<sub>10</sub>), Sulfur dioxide (SO<sub>2</sub>), Carbon monoxide (CO), and hydrocarbons (HC). Green vehicles also emit less carbon dioxide (CO<sub>2</sub>), a greenhouse gas, than petrol-driven or diesel-driven vehicles.

» Part Two

# Sources of Air Pollution

The main sources of air pollution in Singapore are from the burning of fossil fuels for energy generation in industries, power stations, and in the transportation sector. Other sources include open burning of waste materials and transboundary smoke haze (NEA 2006a).

## » Part Three

# Status of Air Quality

## Air Quality Monitoring

The ambient AQ in Singapore is routinely monitored by 14 air monitoring stations sited across the island. Over the past 20 years Singapore has maintained an impressive environmental record, despite an increase in industrialization and urbanization. The success in maintaining a clean and safe environment has largely been due to regular monitoring and assessment of the quality of ambient air. Results of air monitoring have aided in the development and review of pollution control measures that specifically address the pollutant of concern and its source (NEA 2006a).

Ambient AQ monitoring in Singapore was initiated in 1972. Today, it is routinely undertaken by NEA Pollution Control Department (PCD). The objectives of the monitoring program are to monitor ambient AQ trends so that timely policy decisions can be made to prevent air pollution problems and to assess the adequacy and effectiveness of pollution control programs. Singapore has an effective AQM program, which is due in part to regular monitoring, assessment, and effective interventions to improve the quality of ambient air.

NEA monitors the ambient AQ through the telemetric air quality monitoring and management system (TAQMMS). This comprises a network of remote air monitoring stations linked to a Central Control System (CCS) via dial-up telephone lines. There are 14 remote air monitoring stations in the network; of which, 11 stations monitor ambient AQ and two stations monitor roadside AQ (MEWR 2005a).

The air monitoring stations are strategically located to accurately monitor AQ at different parts of the island. Ambient stations are classified as urban, industrial, and sub-urban, depending on the activities in the area where they are located. The two roadside stations are situated near busy roads or expressways and are used to assess the effectiveness of NEA's vehicular emission program. Automatic analyzers

and equipment are deployed at the stations to measure the concentrations of major air pollutants, such as SO<sub>2</sub>, CO, O<sub>3</sub>, PM<sub>10</sub>, and NO<sub>x</sub>.

Data transmitted by the air monitoring stations in the network is automatically processed at CCS to give real time updates on air quality. CCS is also equipped to carry out numerical modeling for simulation of various air pollution scenarios. Using a remote operating system such as this provides an efficient means of obtaining AQ data with minimal use of manpower.

AQ monitoring methods used in Singapore are based on the United States Environmental Protection Agency (US EPA) reference methods and are analyzed using the methods presented in Table 3.1 (Chin 2002).

TABLE 3.1

**Methods of Measuring Different Pollutants**

Pollutant	Method of Measurement
SO <sub>2</sub>	Pulsed fluorescence
NO <sub>x</sub>	Chemiluminescence
O <sub>3</sub>	Ultraviolet photometry
CO	Nondispersive infrared spectrometry
PM	(1) Continuous filter-based mass measurement (2) Beta attenuation
Pb	High-volume sampling followed by atomic absorption spectroscopy

CO = Carbon monoxide; NO<sub>x</sub> = Nitrogen oxides; O<sub>3</sub> = Ozone; Pb = Lead; PM = Particulate Matter; SO<sub>2</sub> = Sulfur dioxide

Source: Chin, Koh Yong. 2002. Air Quality Monitoring in Singapore. Paper Presented at the Better Air Quality (BAQ) Workshop 2002. Hong Kong, 16–18 December. Available: [www.cse.polyu.edu.hk/~activi/BAQ2002/BAQ2002\\_files/Proceedings/Subworkshop2/sw2a-6Koh\\_paper.pdf](http://www.cse.polyu.edu.hk/~activi/BAQ2002/BAQ2002_files/Proceedings/Subworkshop2/sw2a-6Koh_paper.pdf).

Regular inspections and spot checks of stationary pollution are conducted to ensure that pollution control equipment of industries are maintained and operated properly. In 2003,

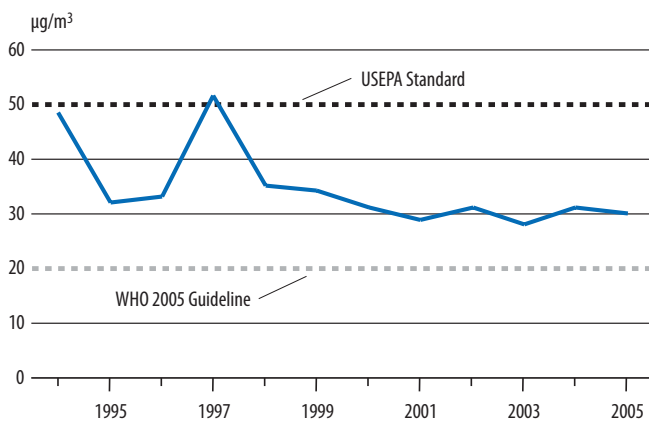
644 fuel analyses and smoke observations of chimneys were conducted. Of these, 42 failed to comply with the prescribed standards. The offenders were prosecuted and required to take remedial action. In 2003, NEA received 480 complaints pertaining to air pollution, of which 113 cases were substantiated. The main causes were primarily due to poor machine maintenance, improper operation, and/or overloading of pollution control equipment. The owners or occupants were required to take remedial actions to comply with the allowable limits.

## Air Quality Data

Particulate matter (PM) is the most important air pollutant for Singapore. Comparing the ambient concentrations of pollutants in Singapore with US EPA guidelines indicates that PM with diameter less than or equal to 2.5 micrometers ( $PM_{2.5}$ ) is the major pollutant of concern. The 2005 average level of PM with diameter less than or equal to 10 micrometers ( $PM_{10}$ ), on the other hand, complies with Singapore standards that are based on US EPA standards but will not be able to meet the new draft 2005 World Health Organization (WHO) updated guidelines. All other pollutants have relatively very low concentrations.

FIGURE 3.1

### Annual Average $PM_{10}$ Concentration in Singapore, 1994–2005



$PM_{10}$  = particulate matter with diameter equal or less than 10 micrometers; US EPA = United States Environment Protection Agency; WHO = World Health Organization;  $\mu\text{g}/\text{m}^3$  = micrograms per cubic meter

Source: Ministry of Environment and Water Resources (MEWR). 2005a. Towards Environmental Sustainability. *State of the Environment Report 2005*. Singapore. Available: <http://app.nea.gov.sg/cms/htdocs/article.asp?pid=2507>.

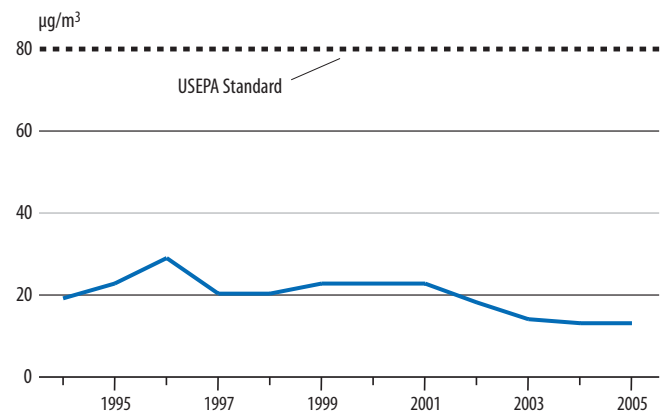
\_\_\_\_\_. 2006. *Key Environmental Statistics 2006*. Available: [www.mewr.gov.sg/soe/kes2006.pdf](http://www.mewr.gov.sg/soe/kes2006.pdf).

The average annual  $PM_{2.5}$  in Singapore of  $21 \mu\text{g}/\text{m}^3$  for 2004 exceeded the US EPA standard of  $15 \mu\text{g}/\text{m}^3$  and the 2005 WHO updated guideline of  $10 \mu\text{g}/\text{m}^3$ . The increases in  $PM_{10}$  in 1994 and 1997 were due to the recurring regional haze in those periods.

$SO_2$  concentrations have remained relatively constant in recent years. In 2005, the average level was  $14 \mu\text{g}/\text{m}^3$ , considerably lower than the US EPA standard of  $80 \mu\text{g}/\text{m}^3$ . See Figure 3.2.

FIGURE 3.2

### Annual Average $SO_2$ Concentration in Singapore, 1994–2005



$SO_2$  = Sulfur dioxide; US EPA = United States Environment Protection Agency; WHO = World Health Organization;  $\mu\text{g}/\text{m}^3$  = micrograms per cubic meter.

Source: Ministry of Environment and Water Resources (MEWR). 2005a. Towards Environmental Sustainability. *State of the Environment Report 2005*. Singapore. Available: <http://app.nea.gov.sg/cms/htdocs/article.asp?pid=2507>.

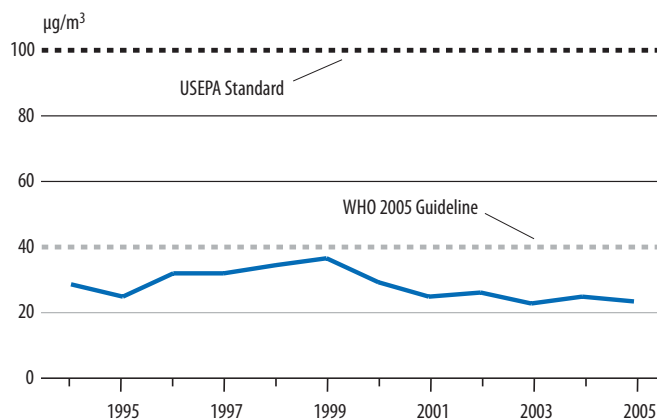
\_\_\_\_\_. 2006. *Key Environmental Statistics 2006*. Available: [www.mewr.gov.sg/soe/kes2006.pdf](http://www.mewr.gov.sg/soe/kes2006.pdf).

$NO_2$  concentrations increased slightly through the latter part of the 1990s but improved after 2000. The average level of  $NO_2$  in 2005 was  $25 \mu\text{g}/\text{m}^3$ , lower than the WHO guideline of  $40 \mu\text{g}/\text{m}^3$  and much lower than the US EPA guideline of  $100 \mu\text{g}/\text{m}^3$ . See Figure 3.3.

O<sub>3</sub>, which was emitted mainly from mobile sources, had an ambient air 8-hourly average level of  $0.5 \text{ mg}/\text{m}^3$  in 2005. The annual average of 8-hour averages for the past 10 years was well below the WHO guideline and US EPA standard. See Figure 3.4.

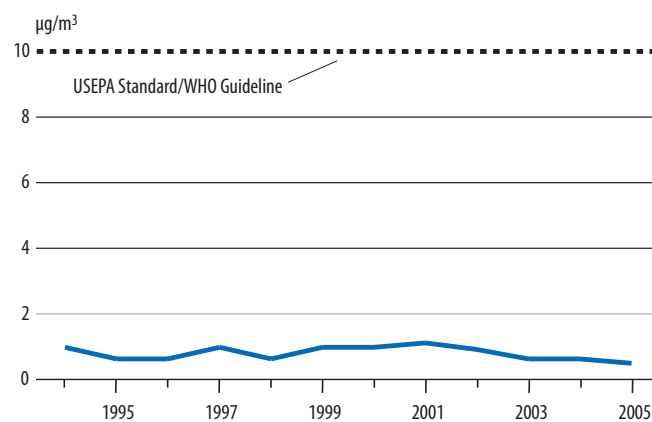
Pb levels in petrol were reduced progressively since the 1980s. In January 1991, unleaded petrol was introduced in Singapore and leaded petrol was phased out on 1 July 1998. Significant reductions in Pb concentration were seen over this time frame, where roadside Pb levels dropped from  $1.4 \mu\text{g}/\text{m}^3$  to

FIGURE 3.3

**Annual Average NO<sub>2</sub> Concentration in Singapore, 1994–2005**

NO<sub>2</sub> = Nitrogen dioxide; US EPA = United States Environment Protection Agency; WHO = World Health Organization; µg/m<sup>3</sup> = micrograms per cubic meter.  
 Source: Ministry of Environment and Water Resources (MEWR). 2005a Towards Environmental Sustainability. *State of the Environment Report 2005*. Singapore. Available: <http://app.nea.gov.sg/cms/htdocs/article.asp?pid=2507>.  
 \_\_\_\_\_. 2006. *Key Environmental Statistics 2006*. Available: [www.mewr.gov.sg/soe/kes2006.pdf](http://www.mewr.gov.sg/soe/kes2006.pdf).

FIGURE 3.4

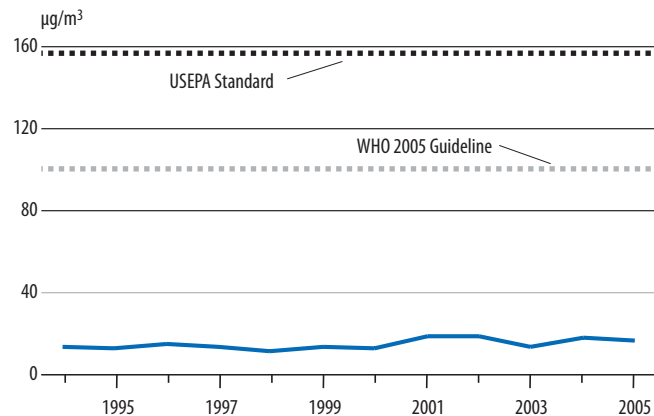
**Annual Average CO Concentrations in Singapore, 1994–2005**

CO = Carbon monoxide; mg/m<sup>3</sup> = milligrams per cubic meter; US EPA = United States Environment Protection Agency; WHO = World Health Organization  
 Source: Ministry of Environment and Water Resources (MEWR). 2005a Towards Environmental Sustainability. *State of the Environment Report 2005*. Singapore. Available: <http://app.nea.gov.sg/cms/htdocs/article.asp?pid=2507>.  
 \_\_\_\_\_. 2006. *Key Environmental Statistics 2006*. Available at: [www.mewr.gov.sg/soe/kes2006.pdf](http://www.mewr.gov.sg/soe/kes2006.pdf).

around 0.1 µg/m<sup>3</sup> and remained below that level since 1992. The WHO guideline for annual average Pb levels is 0.5 µg/m<sup>3</sup> and Singapore currently complies with this value.

O<sub>3</sub> levels are not problematic in Singapore. The annual average of 8-hour averages was well below the WHO guideline and US EPA standard. See Figure 3.5.

FIGURE 3.5

**Annual 8-hour Average O<sub>3</sub> Concentrations, 1994–2005**

O<sub>3</sub> = Ozone; US EPA = United States Environment Protection Agency; WHO = World Health Organization  
 µg/m<sup>3</sup> = micrograms per cubic meter.  
 Source: Ministry of Environment and Water Resources (MEWR). 2005a Towards Environmental Sustainability. *State of the Environment Report 2005*. Singapore. Available: <http://app.nea.gov.sg/cms/htdocs/article.asp?pid=2507>.  
 \_\_\_\_\_. 2006. *Key Environmental Statistics 2006*. Available: [www.mewr.gov.sg/soe/kes2006.pdf](http://www.mewr.gov.sg/soe/kes2006.pdf).

## Reporting of AQ Information

Since 1991, the Pollutant Standards Index (PSI) has been used to report daily air pollutant concentrations and to advise the public about the general health effects associated with different pollution levels. PSI converts the measured respirable suspended particulate (PM<sub>10</sub>), SO<sub>2</sub>, CO, NO<sub>2</sub>, and O<sub>3</sub> concentrations to a number on a scale of 0–500. Intervals on the PSI scale are related to the potential health effects of the daily measured concentrations of five major pollutants. The index value of 100 corresponds to the short-term (24 hours or less) National Ambient Air Quality Standard (NAAQS) set by the US EPA to represent the concentration for each pollutant below which adverse health effects have not been observed. A PSI level in excess of 100 means that a pollutant is in the unhealthy range on a given day, while a PSI level less than 100 means that the pollutant reading is in the satisfactory range. Table 3.2 presents the PSI intervals and the terms describing the AQ levels. The daily PSI is made available on the websites of NEA and NEA Meteorological Service; or through NEA Call Centre. (NEA 2006a).

AQ in terms of PSI is summarized in Figure 3.6. In 1994 and 1997, AQ was affected by the trans-boundary smoke haze from land and forest fires in nearby Indonesia (Chin 2002).

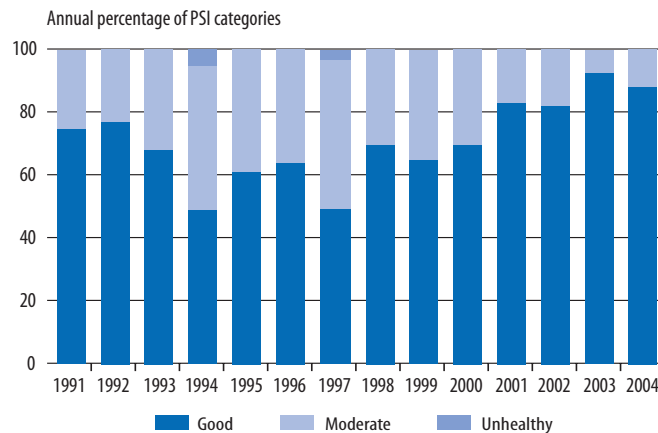
TABLE 3.2

**Singapore Pollutant Standards Index**

Index	Air quality
0–50	Good
51–100	Moderate
101–200	Unhealthy
201–300	Very Unhealthy
>300	Hazardous

Source: National Environment Agency. 2006c. Frequently Asked Questions on the Haze. In NEA Website. Available: <http://app.nea.gov.sg/cms/htdocs/article.asp?pid=1253>.

FIGURE 3.6

**Singapore's Air Quality, in terms of PSI**

PSI = Pollutant Standards Index.

Source: Ministry of Environment and Water Resources (MEWR). 2005a Towards Environmental Sustainability. *State of the Environment Report 2005*. Singapore. Available: <http://app.nea.gov.sg/cms/htdocs/article.asp?pid=2507>.

Looking at the PSI trend, Singapore has continued to enjoy good ambient AQ in the past few years. In 2004, Singapore achieved PSI readings of AQ in the “Good” range for 88% of the year and remaining year being “moderate” (MEWR 2005a). During the two years when Singapore had AQ in the “unhealthy” range (in 1994 and 1997), Singapore was affected by smoke haze from fires in Indonesia that blanketed much of Southeast Asia.

In addition to daily PSI reports, MEWR reports its annual environment statistics through available publications in print and online (MEWR 2006). For its clean air component, annual averages of PM<sub>10</sub>, SO<sub>2</sub>, CO, NO<sub>2</sub>, and O<sub>3</sub> concentrations are presented against US EPA standards.

# Impacts of Air Pollution

## Health Impacts

A number of studies have assessed the impacts of air pollution on the health of residents. Most studies focused on the effects of haze and  $PM_{10}$ .

In 1997, Singapore was greatly affected by regional haze from end of August to the 1<sup>st</sup> week of November. During this period, a 30% increase in outpatient attendance was observed coinciding with haze episodes. Increases of 12% in incidence of upper respiratory tract illness, 19% in asthma, and 26% in rhinitis were associated with the increase in  $PM_{10}$  levels from 50–150  $\mu\text{g}/\text{m}^3$ . Likewise, haze-related accidents were observed. Overall, however, the 1997 haze episode is still considered as mild because there was no associated change in hospital admissions and mortality (Emmanuel 2000).

Singapore is concerned about factors that can affect asthma patients due to its prevalence. One out of five children has asthma (Chew et. al. 1999a) and another one out of five reports suffering from asthma without undergoing formal diagnosis (Goh et. al. 1996).

Linkages between ambient air pollution levels in the city and asthma exacerbation were established by a 5-year time-series study conducted by the Department of Pediatrics, National University of Singapore. It is very interesting to note that despite ambient concentrations of  $SO_2$ , total suspended particulates (TSP),  $NO_2$ , and  $O_3$  falling within the prescribed guidelines of WHO, the study was still able to establish a positive correlation between levels of each of these pollutants and emergency room (ER) visits due to asthma for 3- to 12-year old patients. The study observed that there was an increase of 2.9 ER visits for every 20  $\mu\text{g}/\text{m}^3$  increase in  $SO_2$

concentration one day after days that levels were above 68  $\mu\text{g}/\text{m}^3$ . Likewise, an increase of 5.8 ER visits for every 20  $\mu\text{g}/\text{m}^3$  increase in TSP concentration one day after days that levels were above 73  $\mu\text{g}/\text{m}^3$ . The findings of the study suggested that asthmatic children are susceptible to increases in pollutant concentration despite the ambient levels still being within the acceptable levels. However, the correlation was not observed in children and young adults aged 13–21 years.

Effects of atmospheric pollution in Singapore on cardiopulmonary health were also studied in 1998. Blood analyses for army cadets who were exposed to  $PM_{10}$  from the Asian fires in 1998 have shown elevated levels of pro-inflammatory cytokines. The study suggested that particulate exposure must have stimulated the human alveolar macrophages of the exposed cadets to produce these cytokines. These cytokines are postulated to induce a systemic response which has an important role in the pathogenesis of the cardiopulmonary effects associated with air pollution (Van Eeden 2001).

## Economic impacts

Although ambient air concentrations in Singapore have always met the international standards set by US EPA and WHO, the economic cost of air pollution on human health in Singapore can still be considered significant. A study by the National University of Singapore has estimated that the total economic cost of particulate air pollution for Singapore is US\$3.662 million, which was approximately 4.31% of GDP in 1999. This was based on a damage-function/dose response approach on morbidity and mortality effects (Quah and Boon 2003).

# Air Quality Management

## Legislation and Mandate

Since 1971, a variety of laws have been passed regarding clean air, focusing on vehicular pollution and large-scale industrialization. The 1971 Air Act was passed together with several other rules and regulations aimed at preventing and controlling air pollution. This legislation was passed primarily due to pressure from health authorities regarding the ill effects of air pollution on the population (Singapore Parliamentary Debates 1971–1972).

Air pollution control is regulated under the 1999 Environmental Pollution Control Act (EPCA) and its subsidiary regulations. The 2000 Environmental Pollution Control (Air Impurities) Regulations stipulate emission standards for air pollutants which repeals the original set of Clean Air Standards in place since 1978. EPCA consolidates previous laws on air, water, and noise pollution and therefore provides a more comprehensive legislative framework for the control of environmental pollution. These air pollution laws and regulations control emissions from the following categories: a) stationary sources, such as power stations, oil refineries, and industries; b) mobile sources, such as motor vehicles; and c) other sources such as waste burning.

NEA is a statutory board formed in July 2002 under the MEWR which focuses on the implementation of environmental policies. Of the three divisions under NEA, the Environmental Protection Division plays a major role in protecting the environment as it takes charge of programs that monitor, reduce, and prevent environmental pollution. The tasks of NEA on air pollution control are the responsibility of PCD under the Environmental Protection Division. NEA PCD ensures that environmental factors are incorporated into land use planning development and building control, air, hazardous waste, toxic wastes and water pollution control. The department is likewise responsible for the formulation and implementation of joint programs with neighboring countries with regard to trans-

boundary pollution. In June 2006, NEA represented Singapore when it joined the Renewable Energy and Energy Efficiency Partnership (REEEP), a multi-stakeholder alliance “focused on the development and support of legislative and regulatory frameworks to accelerate the marketplace for renewable energy and energy efficiency (NEA and REEEP 2006).

The National Energy Efficiency Committee (NEEC) is one of the agencies actively engaged in implementing the activities to achieve or maintain Singapore’s clean air. This office traces its origin from the previous Inter-agency Committee on Energy Efficiency (IACEE) of the Ministry of National Development. The restructuring of IACEE in 2001 gave birth to the new NEEC. The following are just some of the key initiatives of NEEC on energy efficiency that have relevant impact on the implementation of the Singapore Green Plan 2012 program for clean air: power generation sector improvements, which included switch to natural gas and adoption of more energy efficient combined cycle technologies; promotion of the use of energy-efficient appliances such as refrigerators and air conditioners through energy labeling.

## Air Quality Standards

US EPA Primary AQ Standards and WHO AQG are used as guidelines in the evaluation of the ambient AQ in Singapore, in lieu of its own set of legislated standards. The standards are summarized in Table 5.1.

TABLE 5.1

**US EPA Air Quality Standards and WHO Air Quality Guidelines**

Pollutant	Averaging Time	US EPA NAAQS	WHO AQG (2000)	WHO AQG (2005 Update)
SO <sub>2</sub>	Annual mean	80 µg/m <sup>3</sup>	50 µg/m <sup>3</sup>	–
	24 hours	365 µg/m <sup>3</sup>	125 µg/m <sup>3</sup>	20 µg/m <sup>3</sup>
	10 minutes	–	–	500 µg/m <sup>3</sup>
NO <sub>2</sub>	Annual mean	100 µg/m <sup>3</sup>	40 µg/m <sup>3</sup>	40 µg/m <sup>3</sup>
	1 hour	–	200 µg/m <sup>3</sup>	200 µg/m <sup>3</sup>
CO	1 hour	40 mg/m <sup>3</sup>	30 mg/m <sup>3</sup>	–
	8 hours	10 mg/m <sup>3</sup>	10 mg/m <sup>3</sup>	–
O <sub>3</sub>	1 hour	235 µg/m <sup>3</sup>	–	–
	8 hours	157 µg/m <sup>3</sup>	120 µg/m <sup>3</sup>	100 µg/m <sup>3</sup>
PM <sub>10</sub>	Annual mean	50 µg/m <sup>3</sup>	–	20 µg/m <sup>3</sup>
	24 hours	150 µg/m <sup>3</sup>	–	50 µg/m <sup>3</sup>
Pb	Annual mean	–	0.5 µg/m <sup>3</sup>	–
	3 months	1.5 µg/m <sup>3</sup>	–	–

AQG = Air Quality Guidelines; CO = Carbon monoxide; NAAQS = National Ambient Air Quality Standards; NO<sub>2</sub> = Nitrogen dioxide; O<sub>3</sub> = Ozone; Pb = Lead; PM<sub>10</sub> = particulate matter with diameter less than or equal to 10 micrometers; SO<sub>2</sub> = Sulfur dioxide µg/m<sup>3</sup> = micrograms per cubic meter; US EPA = United States Environmental Protection Agency; WHO = World Health Organization.

Source: United States Environmental Protection Agency. National Ambient Air Quality Standards. Available: [www.epa.gov/air/criteria.html](http://www.epa.gov/air/criteria.html).

World Health Organization. 2005. WHO Air Quality Guidelines Global Update 2005 Meeting Report. Bonn, Germany, 18–20 October. Available: [www.euro.who.int/Document/E87950.pdf](http://www.euro.who.int/Document/E87950.pdf).

## Management of Mobile Sources

A range of measures is currently being undertaken in Singapore to control PM<sub>2.5</sub> emissions from diesel vehicles including (NEA 2006a):

- Adoption of stringent Euro 4 exhausts emission standards for new diesel vehicles effective 1 Oct 2006;
- Introduction of ultra low sulfur diesel effective 1 Dec 2005;
- Use of chassis dynamometer smoke test for periodic mandatory inspection of diesel vehicles by vehicle inspection centers effective 1 Jan 2007; and
- Enforcement against smoky vehicles by PCD.

Since January 2001, all petrol- and diesel-driven vehicles were required to comply with the Euro 2 (European Commission [EC] Directive 96/69/EC) exhaust emission standards. From 1 July 2003, all motorcycles/scooters were required to comply with the exhaust emission standard as specified in EC Directive 97/24/EC before they can be registered for use in Singapore. From 1 Oct 2006, all new diesel-driven vehicles must comply with the more stringent Euro 4 exhaust emission standard

as specified in EC Directive 98/69/EC for passenger cars and light commercial vehicles with maximum laden weight (MLW) of 3,500 kg or less, and EC Directive 1999/96/EC for heavy vehicles with MLW of more than 3,500 kg before these vehicles can be registered for use in Singapore (NEA 2006a). See Table 5.2.

In addition to emission standards, all vehicles are subject to periodic mandatory inspections to ensure their compliance. NEA takes stringent enforcement actions against smoky vehicles. Clause 19 of the Environmental Pollution Control (Vehicular Emissions) Regulations 1999 stipulates that it is an offense for any person to use or permit the use of any smoky vehicle on the road. It is the responsibility of every vehicle owner to ensure that the vehicle is in good condition before using it on the road. For 2-stroke motorcycles, the cause of white smoke emission is usually due to the addition of lubricating oil in excess of the amount specified in the vehicle manufacturer's manual.

NEA has gradually required the use of cleaner fuel, such as the removal of tetraethyl Pb in petrol. Pb in petrol has been progressively reduced from 0.84 g/l to 0.15 g/l since 1 June 1987. In January 1991, unleaded petrol was introduced in

TABLE 5.2

**Singapore Motor Vehicle Exhaust Emission Standards**

Type of Vehicle	Emission Standard	Implementation
Petrol vehicle	All new petrol vehicles are required to comply with the EC Directive 96/69/EC.	1 January 2001
Diesel vehicle	All new diesel passenger cars are required to comply with the EC Directive 96/69/EC.	1 January 2001
	All new light commercial vehicles 3.5 tons or below are required to comply with the EC Directive 96/69/EC.	1 January 2001
	All new heavy-duty vehicles exceeding 3.5 tons are required to comply with the EC Directive 91/542/EEC Stage II.	1 January 2001
	All new diesel passenger cars and light commercial vehicles 3.5 tons or below are required to comply with the EC Directive 98/69/EC (2005 limits)	1 October 2006
	All new heavy-duty vehicles exceeding 3.5 tons are required to comply with the EC 1999/96/EC (2005 limits)	1 October 2006
Motorcycle and scooter	All new motorcycles and scooters are required to comply with the European Directive 97/24/EC.	1 July 2003

EC = European Commission; NEA = National Environment Agency

Source: NEA 2005.

Singapore and leaded petrol was phased out by 1 July 1998. To further reduce emission from diesel vehicles, the permissible level of sulfur in diesel was gradually reduced over the years. Since 1 March 1999, the sulfur content of diesel had been reduced from 0.3% to 0.05% by weight. A further reduction of the sulfur content in diesel to 0.005% by weight was introduced effective 1 Dec 2005. The introduction of this ultra-low sulfur diesel paves the way for the implementation of Euro 4 emission standard for diesel vehicles that took effect from 1 Oct 2006. Reduction in sulfur content in diesel has helped reduce the levels of SO<sub>2</sub> and PM emissions from diesel-driven vehicles. Green vehicle tax incentives have been introduced to promote their use and to encourage the replacement of diesel vehicles that emit negligible PM.

## Management of Stationary and Area Sources

For industry, a key measure to reduce PM<sub>2.5</sub> emissions has been to encourage the greater use of natural gas in place of fuel oil and diesel in industrial boilers and power stations. To date, more than 70% of electricity is generated from the use of natural gas.

Emissions from stationary and area sources are controlled through PCD in accordance with limits set by EPCA and by guides from the Code of Practice on Pollution Control. All industries that would emit potential air impurities are

required to install their own air pollution control equipment to ensure that the emission limits are met. Monitors are likewise installed to monitor emissions from the stacks of industries. Any fuel burning equipment is allowed to use only fuels with specifications approved by PCD (e.g., fuels used in industries within 100m from residential areas are required to have a sulfur content of not more than 0.005% by weight). The chimneys of fuel burning equipment likewise need to be high enough for safe dispersion in the atmosphere. The chimneys should be at least 15m above ground level or 3m from the roof of the factory, whichever is higher. The heights of surrounding buildings are likewise considered. Moreover, the industries and their monitors are inspected regularly to ensure strict compliance with the standards (NEA 2004b).

Since 1997, industries were also required to conduct source emissions tests regularly. This scheme ensured that industries would monitor their air emissions regularly and promptly implement remedial measures, where necessary, to comply with the national air emissions standards. In 2003, 170 industries had carried out 475 tests comprising of 168 isokinetic tests on PM and 307 tests on gaseous emissions. All companies were able to comply with the national air emission standards.

Singapore offers tax incentives to industries in the form of accelerated depreciation allowances to encourage industries to switch to cleaner equipment such as install replacement energy efficient equipment or energy-saving devices and more efficient pollution control equipment.

# Conclusion

In general, Singapore has a high capability of managing its AQ and, as such, its AQ is among the best in the region. Its form of government made it easy to integrate the AQM agenda into other urban sector and national economic concerns. Their stringent controls on emissions and regulatory measures to address the different sources of pollution have been effective in maintaining AQ at an acceptable level, with PSI readings in the good range for most of the year. Singapore's geography and topography was conducive for air pollutant dispersion but it likewise made it susceptible to trans-boundary haze as

in 1994 and 1997. Except for PM, Singapore does not have a problem keeping their pollutant levels compliant with current US EPA and WHO standards that they use in lieu of their set of standards. With the onset of the 2005 global update to the WHO standards and the current trends of their PM emissions, the possibility of further noncompliance with both PM<sub>10</sub> and PM<sub>2.5</sub> standards increases. However, new measures such as the clean air component of the Singapore Green Plan 2012 that addresses local and regional air pollution may help keep PM and other pollutant levels at bay.

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