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中国空气污染综合管理

INTEGRATED AIR POLLUTION MANAGEMENT IN CHINA

DEVELOPING PARTICULATE MATTER CONTROL

THE WORLD BANK

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Korea Environment Corporation

MEP

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Developing Particulate Matter Control

The World Bank
The Ministry of Environmental Protection, The People's Republic of China

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Acronyms and Abbreviations

Al	Aluminium
APC	Air Pollution Control
API	Air Pollution Index
AQM	Air Quality Management
As	Arsenic
BAM	Beta attenuation monitor
BTH	Beijing-Tianjin-Hebei
Ca	Calcium
CBA	Cost-Benefit Analysis
CAEP	Chinese Academy of Environmental Planning
CMB	Chemical mass balance model
CNMC	China National Monitoring Center
CO	Carbon Monoxide
CRAES	China Research Academy of Environmental Sciences
EPB	Environmental Protection Bureau
ESP	Electrostatic precipitator
EU	European Union
FDG	Flue gas desulfurization
Fe	Iron
FECO	Foreign Economic Cooperation Office (of MEP)
FPM	Fine Particulate Matter
FRM	Federal Reference Method
FYP	Five Year Plan
GDP	Gross Domestic Product
GHG	Green House Gas
GOC	Government of Peoples Republic of China
HOB	Heat only boiler
IMPROVE	Interagency Monitoring of Protected Visual Environments
IT	Interim Target

MEP	Ministry of Environmental Protection
MS	Monitoring station
MW	Mega watts
NH_3	Ammonia
NOx	Nitrogen Oxide or Nitrogen Dioxide
NSP	New Suspension Preheater (Dry Proces Cement Production Line)
OECD	Organisation for Economic Co-operation and Development
PFA	Principal Factor Analysis
PM	Particulate matter
$PM_{2.5}$	PM smaller than 2.5 micrometers
PM_{10}	PM smaller than 10 micrometers
PMF	Positive Matrix Factorization
QA-QC	Quality Control and Assurance
RMB	Renminbi (Chinese currency)
PMF	Positive matrix factorization model
PRD	Pearl River Delta
PWE	Population weighted exposure
SCR	Selective Catalytic Reduction
Si	Silicon
SO_2	Sulphur dioxide
TEOM	Tapered element oscillating microbalance
TSP	Total Suspended Particulate
US	United States
US EPA	United States Environmental Protection Agency
V	Vanadium
VOC	Volatile Organic Compound
WB	The World Bank
WHO	World Health Organization
YRD	Yangze River Delta
Zn	Zinc

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Foreword

The Ministry of Environmental Protection, People's Republic of China and the World Bank have worked together over the last three years to implement the *Integrated Air Pollution Management in China* program. The purpose of the collaboration has been twofold: (1) to propose a national compliance plan on coarse particulate matter (PM_{10}) to help non-compliant cities comply with China's own air quality standards, and to further improve air quality in cities that already comply; and (2) to recommend a monitoring system that will enable China to monitor fine particulate matter ($PM_{2.5}$), which has a comparatively severe human health impact.

As the study shows, most cities in China have over the last decade improved their air quality. A nationwide monitoring system that includes PM_{10} monitoring has been established that now covers about 95 percent of all 655 cities in China. Average PM concentrations have been reduced substantially throughout the country, AQM regulations have been put in place, national and local campaigns have been carried out to improve air quality, investment plans to improve air quality have been implemented, and overall public awareness regarding air quality has increased due to improved environmental information systems. With the help of these initiatives, Chinese cities today are cleaner places to live in and have substantially better air quality than they did five, ten, or fifteen years ago.

Nevertheless, much more work is needed before all Chinese cities attain air quality standards that comply with China's own standards and air quality standards recommended by the World Health Organization. As the study shows, it has taken cities in the United States and Europe many years, even generations, to improve their air quality to today's comparatively clean levels. China is progressing very quickly. At this stage, however, there are few remaining easy policy options that can be quickly applied to achieve the best air quality standards. Only very careful planning and implementation of a large number of air pollution abatement measures—within an effective regulatory framework, which this program also has supported through its advice on the new *Administrative Measures and Technical Guidelines for Urban Air Quality*—can ensure continued progress.

This publication describes some of China's achievements, its continuing challenges, and proposed solutions to reduced PM concentrations, including an expanded focus on fine particles. Reflecting the current important progress in Air Quality Management in China, the Ministry of Environmental Protection promulgated new ambient air quality standards (GB 3095-2012) by the end of February 2012 that, among others, established new standards for $PM_{2.5}$ (e.g. annual average grade II value of 35 $\mu g/m^3$), tightened the annual average standard for PM_{10} grade II from

100 to 70 μg/m^3 and abolished the former Grade III classification. These are great achievements, which also is in line with the recommendations made through this cooperation program and have important impact on the compliance plans being discussed in this report. The report was drafted when the ambient air quality standards (GB 3095–1996) was in place, which is reflected in the analytical presentations in the report. However, a brief introduction to the new GB 3095–2012 and part of its impact on the compliance plan is briefly presented in a new annex 6.

We hope the report is a valuable contribution in our joint efforts to further improve air quality in China.

Acknowledgements

The initial version of this report was prepared by a Chinese expert team under the World Bank—Ministry of Environmental Protection (MEP) of P. R. China *China APC—Particulate Matter Control Project.* With the support from the Ministry of Finance (MoF) of P.R. China, the project has been implemented in China by the Foreign Economic Cooperation Office (FECO) of MEP under the supervision of the Division of Air and Noise Pollution Control, Department of Pollution Control of MEP. The team included: Mr. Chai Fahe (Team Leader of the Chinese team), Vice President, China Research Academy of Environmental Sciences (CRAES); Ms. Wang Shulan, Research Professor, CRAES and Team Leader Assistant; Mr. Chen Zhenxing, PhD, CRAES; Ms. Hu Min, Professor, College of Environment and Engineering, Beijing University; Mr. Yan Gang, Associate Research Professor, Chinese Academy of Environmental Planning (CAEP); Ms. Ning Miao, Research Associate, CAEP; Ms. Yan Li, Associate Research Professor, CAEP; Ms. Wu Yuping, Research Professor, Policy Research Center for Environment and Economy; and Mr. Wang Ruibin, Professor and Divison Chief, China National Environmental Monitoring Center. The project received valuable support from staff in various departments of MEP: Mr. Li Xinming, and Mr. Wang Jian, deputy director generals of MEPs pollution control department, Mr. Ren Hongyan, (former) and Mr. Lu Shize (present) division chiefs of the Air and Noise Pollution Control and Mr. Wang Eyi, deputy division chief in the same division, and Mr. Xiao Xuezhi and Mme Li Pei, deputy director generals of FECO. Mr. Wang Xin, Divison Chief, Division I, FECO/MEP and Mr. Xie Yongming, Research Professor in the same division, implemented the project and coordinated the work between WB and MEP as well as supervised the Chinese national expert team

The initial version provided by the Chinese team was complemented, reorganized and finalized by World Bank staff members Jostein Nygard, Task Team Leader (TTL) and Tijen Arin, Senior Environmental Economist, and Consultants, Haakon Vennemo and Steinar Larssen. Neelesh Shrestha, Junior Professional Associate, and Stefan Csordas, Junior Professional Officer at the World Bank also contributed to the report. Robert Livernash provided editorial support, and the report was designed and typeset by Shepherd Inc. Report translations were provided by Wang Zhujun and Li Li from FECO, while Niu Zijing, Minhnguyet Le Khorami and Lourdes L. Anducta from the World Bank provided administrative assistance. Dick van den Hout, TNO, the Netherland; Dale M. Evarts, Neil H. Frank, and Scott Voorhees of the United States Environmental Protection Agency; and M. Khaliquzzaman, Consultant, and Sameer Akbar, Senior Environmental Specialist at the World Bank provided valuable peer reviewer comments. The team is grateful for the guidance provided by Ede Jorge Ijjasz-Vasquez, Sustainable Development Sector Manager for China and Mongolia; Magda Lovei, Sustainable Development Sector Manager; Carter Brandon, Agriculture, Forestry and Environment Sector Coordinator for China and Mongolia: and Paul Procee, Senior Urban Environment Specialist at the World Bank Beijing Office for their guidance in the preparation and finalization of this study.

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Executive Summary

Particulate matter (PM) pollution is linked with cardiopulmonary disease and lung cancer and constitutes an important public health risk in China. PM is made up of a number of components, including acids (such as nitrates and sulfates), organic chemicals, metals, and soil or dust particles. The size of particles is directly linked to their potential for causing health problems. Particles with a diameter of 10 micrometers (μm) or smaller (PM_{10}) are of major concern because they generally pass through the throat and nose and enter the lungs. Once inhaled, these particles can affect the heart and lungs and cause serious health effects. PM_{10} is normally divided into two categories:[1]

i. "Inhalable coarse particles"—such as those found near roadways and dusty industries—that are larger than 2.5μm and smaller than 10μm in diameter ($PM_{10\text{-}2.5}$).
ii. "Fine particles"—such as those found in smoke and haze—are 2.5μm in diameter and smaller ($PM_{2.5}$). These particles can be directly emitted or formed when other pollutants—such as sulfur dioxide (SO_2), nitrogen oxides (NO_X), and ammonia—emitted from power plants, industries, and automobiles react in the air.

The World Health Organization (WHO) contends that "the risk for various [health] outcomes has been shown to increase with exposure and there is little evidence to suggest a threshold below which no adverse health effects would be anticipated."[2] WHO guidelines for annual mean concentrations are 20 micrograms per cubic meter (μg/m^3) for $PM_{10,}$ which includes both coarse and fine particles, and 10μg/m^3 for $PM_{2.5}$.

In 2009, just a few of the 612 cities where PM_{10} is monitored met China's urban grade I PM_{10} standard (40μg/m^3), while 63 exceeded the grade II range (100–40μg/m^3).[3] Fifty-one of these non-compliant cities are prefecture-level or higher (blue and green dots in Figure 1); of these, 30 are key cities for air pollution control ("key cities"), so designated by the State Council.

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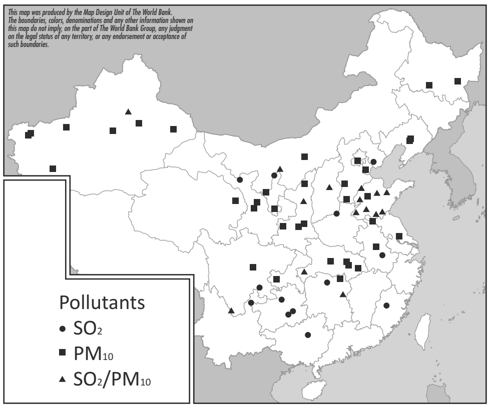
[1] Source: The U.S. EPA particulate matter website: <http://www.epa.gov/air/particlepollution/index.html>.

[2] WHO. 2006. "WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide." Global update 2005. Summary of risk assessment.

[3] The European Union standard for annual average PM_{10} concentrations is 40 μg/m^3, while the United States since 2006 applies standards only for 24-hour concentrations of PM_{10}. According to the U.S. Environmental Protection Agency, available evidence does not suggest a link between long-term exposure to PM_{10} and health problems (U.S. EPA 2011).

FIGURE 1 Non-compliant Prefecture and Higher-level Cities (2009)



OBJECTIVE

This study is a joint effort of the Ministry of Environmental Protection (MEP), Chinese experts, and the World Bank to inform the policy-making process in line with the government of China's medium- and long-term objectives. Specifically the study aims to assist MEP, provincial governments, and municipalities by:

1. Proposing a national PM_{10} compliance plan to help non-compliant cities attain grade II—preferably by 2015 or in certain cases by 2020 at the latest—and already compliant cities to further reduce PM concentrations. The plan would include (a) policies and regulations and associated physical interventions/measures; (b) geographical scope; (c) sequencing of interventions; and (d) feasible environmental investments likely to have high benefit/cost ratios.
2. Recommending a $PM_{2.5}$ monitoring system and related data applications.

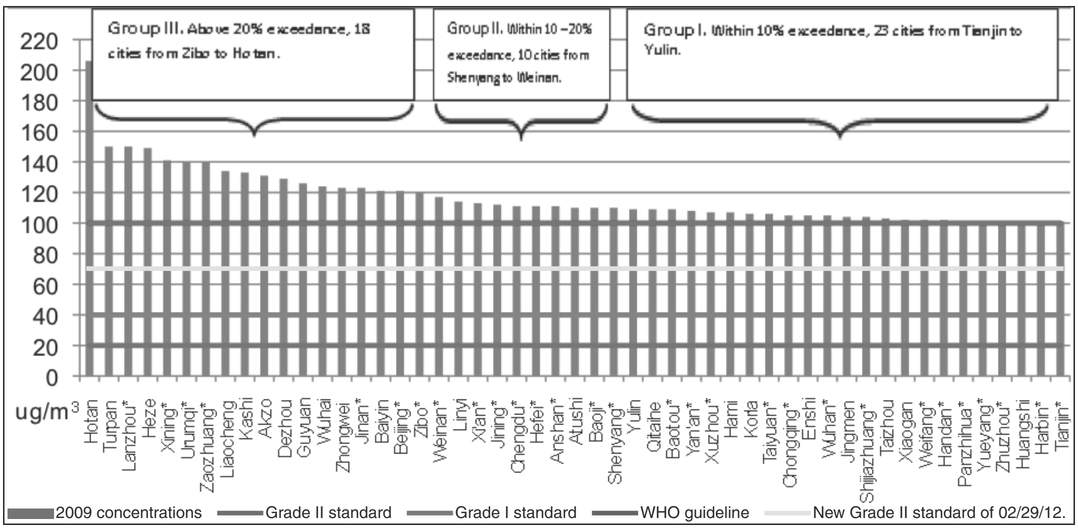
BACKGROUND

Over the past decade, China made significant strides in reducing average urban ambient air pollutant concentrations, including PM_{10}. From 2001 to 2009, the number of Chinese cities reaching the grade II PM_{10} standard or better increased from 36 percent to 84 percent. From 2003 to 2009, the average annual concentration in 113 key cities decreased from 126 to 87μg /m^3. In industrialized North China, where air pollution is particularly severe, the average in key cities dropped from 149 to 98μg/m^3. However, PM pollution remains a significant challenge. These averages are still substantially higher than the above-mentioned WHO guideline or China's own grade I limit value. In some cities recently attaining grade II, concentrations show signs of not being stable within the grade threshold, meaning that they are fluctuating between grade II and grade III. In some cases, reductions in urban air pollution may have been achieved at the expense of higher concentrations in rural areas, where the industries were relocated. In other cases, due to air movements, regional pollution contributes to high urban PM concentrations, including fine particles. Regional PM originates from non-urban sources such as power and industrial plants, agriculture, arid landscapes, or secondary generation.

Recent research indicates serious $PM_{2.5}$ pollution in urban areas. Annual average $PM_{2.5}$ concentrations are 80–100 μg/m^3 in some northern cities, such as Beijing and surrounding provinces, which is 5–6 times higher than the corresponding U.S. standard of 15μg/m^3. Concentration levels reach 40–70μg/m^3 in southern regions, which is 2–4 times higher than the U.S. standard. This situation is of significant concern because $PM_{2.5}$ is one of the most damaging pollutants to the human body. It can enter the upper and lower respiratory tract and be deposited in the lungs. It can even enter the bloodstream through the alveolus. Fine particles, including black carbon, easily accumulate heavy metals, acid oxides, and organic pollutants. In addition, they are carriers of bacteria, viruses, and fungi. Black carbon also plays an important role in radiative forcing and hence climate change. However, although substantial $PM_{2.5}$ research has been carried out in about 20 cities, and 14 background monitoring and 31 rural monitoring stations were established during the 11th FYP to measure regional PM_{10} *and* $PM_{2.5}$ concentrations, China has neither a $PM_{2.5}$ monitoring system or standards nor any $PM_{2.5}$ abatement guidelines or policies.

The degree to which the 51 prefecture or higher-level cities exceed the grade II PM_{10} limit value varies (Figure 2). In 23 of these cities (Group I), including 14 key cities, the annual average PM_{10} concentration is up to 9 $\mu g/m^3$ higher than the grade II limit value of 100 $\mu g/m^3$.[4] This group includes six cities that exceed the limit value by 1 percent and three by 2 percent. Thirteen of the key cities in this group—namely Baotou, Chongqing, Handan, Harbin, Panzhihua, Shijiazhuang, Taiyuan, Tianjin, Xuzhou, Yan'an, Wuhan, Yueyang, and Zhuzhou—recorded remarkable reductions of 140–20ug/m^3 in average annual concentrations from 2003–09. Weifang, which was compliant in 2003–07, but exceeded the grade II limit in 2008 and 2009, illustrates the volatility of PM_{10} compliance. Ten cities, including eight key cities, exceed the limit by 10–19 percent (Group II). Among these cities, Shenyang, Weinan, and Xi'an achieved significant reductions of 64 to 23 ug/m^3 between 2003 and 2009; on the other hand, in Hefei and Jining the annual average concentrations actually increased. Eighteen cities, including seven key cities, exceed the limit value by more than 20 percent (Group III). This group includes Beijing. The situation is particularly dire in Hotan where the annual average concentration was 206 ug/m^3 in 2009. In Beijing, Jinan, and Lanzhou, from 2003–09 the average annual concentrations decreased substantially, albeit with significant fluctuations. In Urumqi, Xining, Zaozhuang, and Zibo, the 2009 values exceeded the 2003 values, although

FIGURE 2 Grade II Non-compliant Prefecture or Higher-level Cities by Level of Non-compliance



* indicates key cities

[4] 70 $\mu g/m^3$ in the new GB 3095–2012 of 02/29/12.

grade II-compliant concentrations were observed intermittently during the period.[5]

PM_{10} pollution sources vary significantly among non-compliant cities, as illustrated by Group III cities. In Beijing, important sources are secondary PM formation, biomass burning, and motor vehicles, in addition to PM from coal combustion, which is still the most important primary PM sector. In Heze, Dezhou, Zibo, Jinan, and Liaocheng in Shandong Province, a coal-based heavy industry leads to elevated levels of both PM_{10} and SO_2. Suspended natural background soil dust contributes significantly to the coarse fraction of PM_{10} in the dry western China cities, namely Urumqi, Turpan, Akzu, Kashi, and Hotan (Xinjiang Autonomous Region); Baiyin and Lanzhou (Gansu Province); Zhongwei (Ningxia Autonomous Region); and Wuhai (Inner Mongolia).

In general, coal combustion for heating is a common PM source in northern and western cities. Construction and road dust is a problem in most of the non-compliant cities. Industrial sources contribute significantly to PM in all the non-compliant cities, and are among the most prominent sources in Shandong Province. The industrial sector contributes both through coal combustion for process heat and power, as well as through PM emissions from production processes, which can be rich in harmful heavy metals. Regional PM pollution makes up a significant part of the PM concentration in urban areas, and consists to a large extent of secondary $PM_{2.5}$ resulting from emissions of SO_2, NO_X, and ammonia.

KEY ELEMENTS OF THE PROPOSED COMPLIANCE PLAN

The policy and legal framework. *The 12th Five Year Plan* (2011–15) (FYP) targets compliance with grade II standards by 80 percent of prefecture and higher-level cities. The FYP also stipulates that a sound regional atmospheric pollution prevention and control mechanism would be put in place and control of regional pollution would be approached. The FYP also emphasizes that prevention and management of air pollution by particulates would be deepened. The *State Council Announcement No.33 regarding the promotion of joint prevention and control of air pollution to improve regional air quality* (May 2010) ("*The State Council Announcement*") requires that nine key regions—namely the Beijing Hebei Tianjin region, the Tangtze River Delta, the Pearl River Delta, Central Liaoning, Shandong Peninsula, Greater Wuhan, the Changsha, ZhuZhou and Xiangtan region, the Chengdu and Chongqing region, and areas around the Taiwan Strait—meet or exceed grade II standards. Cities that have reached grade II are to develop plans to continouosly improve within and beyond the grade II range or prevent deterioration. MEP's recent draft—*Administrative Measures on Urban Air Quality Management ("The Administrative Measures")*—stipulates that by 2015, 90 percent of the county-level cities and 80 percent of the key cities will comply with grade II (Table 1).[6] By 2020, all these cities should be compliant.

Two regulatory documents drafted by MEP with support from this study—*The Administrative Measures* and *Technical Guidelines for Compilation of Urban Ambient Air Quality Control Plans ("The Technical Guidelines")*—aim to guide city leaders in preparing city air quality management plans to reach both the above-mentioned compliance targets and already compliant cities to further reduce PM concentrations (attached as annexes to the Component 1 report). The authors of this study propose improvements in these two key compliance aids. Notably, *The Administrative Measures* should emphasize proper sequencing of the complete air quality management (AQM) process (explained below), regulating testing and evaluation of air

[5] Less information is available about the 12 county-level cities that do not comply with grade II PM_{10} standards, therefore the study focuses on the prefecture and higher-level cities.
[6] Note this may be revised after GB 3095–2012 is adopted.

TABLE 1 Grade II (and higher) Compliance in 2009 and Targets for 2015 and 2020†

		Grade II PM_{10} compliance (2009)	Grade II overall compliance+ (2009)	12th FYP grade II overall compliance target		Administrative Measures compliance target
Monitored cities	612	549 (89.7%)	504 (82.4%)*		9 key regions to meet or exceed grade II standards; grade II compliant cities to continuously improve within grade II and then meet grade I	
Prefecture and higher level	320	269 (84.0%)	255 (79.6%)**	80% by 2015		
County level	292	280 (95.9%)	250 (85.6%)			263 (90%) by 2015 292 (100%) by 2020
Key cities*	113	83 (73.5%)	76 (67.3%)***			90 (80%) by 2015 113 (100%) by 2020

+ Grade II includes annual average standards for PM_{10}, SO_2, and NO_2. * Incl. 4.2% grade I. ** Incl. 3.7% grade I. *** Incl. 0.9% grade I.
† Note that this table is based upon GB 3095–1996 and not on the new GB 3095–2012, see Annex 6.

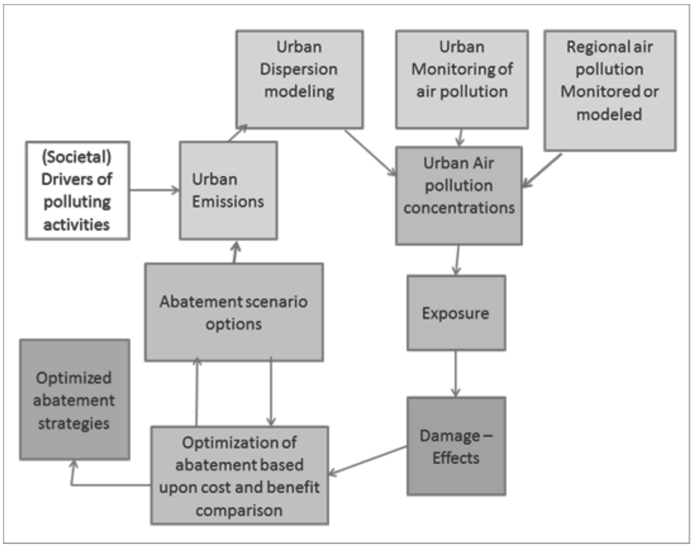
pollution models, and clarifying the relationship between AQM and the total load control process. *The Technical Guidelines* could be strengthened by recommending the use of benefit/cost or cost effectiveness analysis for evaluating abatement options; providing monitoring network design recommendations; prescribing a comprehensive emission inventory; emphasizing the need for testing and evaluating air pollution models; and clarifying the steps of the AQM process.

Institutional coordination. *The Technical Guidelines* require that each city establish a "leading group on air pollution control" to coordinate sector policies, including notably energy, industry, agriculture, transportation, and urban development. It is recommended that the leading group be led by a deputy mayor (or a mayor, as in the case of Urumqi) and be composed of representatives of local government bodies responsible for air-pollution-related sectors, notably industry, power, construction, and transport, as well as public health. Initiatives that the leading group could coordinate include district heating; public transport; cogeneration, SO_2 abatement, energy efficiency and clean coal in the power sector; energy efficiency in buildings; road dust and construction site management; public awareness of preventive measures against air-pollution-related illnesses; and $PM_{2.5}$ monitoring.

Differing compliance timetables. Overall, Group I cities have a good chance to attain grade II compliance for PM_{10} by 2015 by adopting the most technically and economically feasible abatement option(s) (below). For some Group II cities, it may be a challenge to reach grade II by 2015. In such cases, they may need additional time up to 2020 to comply and will need technical assistance in preparing economically efficient air quality management plans. In Group III cities, the severity of the situation requires immediate application of abatement measures with proven effectiveness in China (see below). Additional abatement measures may also need to be considered and should be prioritized based on cost-benefit analysis and the different sources. The severity of the situation and setbacks experienced suggest that compliance by 2015 is unlikely, and a target date of 2020 would also require significant technical assistance.

The guiding principle: complete air quality management (AQM). Within the compliance plan, air pollution reduction measures must be tailored to each city's specific air pollution characteristics, economic and capacity constraints,

FIGURE 3 Graphical Presentation of the AQM Approach



and population conditions. The study recommends the AQM approach to identify the most cost-effective abatement options for each city (Figure 3).

The AQM process begins with an inventory and analysis of emission sources. Next, a dispersion model incorporating the inventory and climatic data is developed and calibrated to estimate the impact on pollutant concentrations of technically feasible abatement options. The population-weighted exposure related to each measure is determined by overlaying a map of concentration impacts on a map of population density. Such exposure data are used to estimate improvements in public health and other environmental benefits resulting from each abatement option. The benefits are then quantified in monetary terms and compared with the corresponding costs. The measure(s) with the highest net benefits is (are) selected for implementation.

Holistic approach to air quality management. While this report focuses on PM pollution abatement, air quality management should be carried out in a multi-pollutant fashion, applying controls that address multiple pollutants and effects simultaneously. Experiences in the United States, Europe, and elsewhere have shown that single-pollutant-abatement is arduous and inefficient.

Emphasis on health benefits and co-benefits. Multiple co-benefits accrue from primary and secondary PM abatement. Notably, PM abating measures also reduce NO_X, SO_2, organic aerosols, and black carbon, which contribute to a variety of effects in addition to health, including acid rain, ozone pollution, waterway eutrophication, haze and visibility problems, and climate change. In addition to environmental co-benefits, economic co-benefits—notably from decreased production costs due to more efficient production processes or energy usage—are also possible. The benefit assessment, which is part of the AQM approach, should include all of these benefits. The study team also recommends that both *The Administrative Measures* and *The Technical Guidelines* incorporate the concept of co-benefits.

Menu of possible PM abatement options. The proposed plan provides a menu of possible pollution reduction measures covering demand-side management and structural measures, cleaner technologies and fuels, end-of-pipe control, and measures to reduce suspended dust from natural areas, construction sites, and roads (Box 1).

Options for high-priority cities. Among the abatement options—phasing out of inefficient plants, boilers, and small-scale coal combustion; moving point-source industry and power plants away from urban centers; enhancing district heating; increasing natural gas use; use of low-sulfur and low-PM coal, clean coal, or briquettes where possible; and construction and traffic dust control—are options that have proven effective in China in significantly reducing PM concentrations. In particular, widespread switching to natural gas is a short-term measure, provided that the necessary infrastructure is in place. The feasibility of the options should be investigated immediately for short-term implementation in the eighteen Group III cities.

Box 1 Summary of PM Reduction Options

Demand-side management and structural measures	Cleaner technology and fuel	End-of-pipe control	Other
Phasing out inefficient plants, inefficient industrial boilers, and small-scale coal combustion	Increasing use of natural gas for energy and heat generation	Increasing use of technologies such as FDG, SCR, and ESP in industrial and power plants	Measures to reduce dust from natural areas, such as increasing vegetative cover
Moving heavy industry and power generation plants away from city centers*	Increasing use of low-sulfur and low-PM coal, and, where possible, of clean coal and briquettes	End-of-pipe controls for motor vehicles	Construction site management for dust abatement
Expanding coverage of district heating	Increasing energy and process efficiency in industry		Reducing dust from roads
Greater use of public transportation	Improving engine technology for motor vehicles		
	Improved energy efficiency in buildings		
	Improving stoves for biomass burning		

*This measure will redistribute regional PM pollution, and increase it in some places.

Policy options. Policy options to improve compliance with PM_{10} standards include (a) strengthening prevention and control of regional PM pollution in the key regions defined in the *State Council Announcement*; (b) coordinated city and central government attention to promote continuous reduction of PM concentrations in cities after they reach urban grade II limits, with the goal of achieving grade I status and ultimately WHO guidelines; (c) reducing energy price subsidies that prevent energy efficiency investments by industry; (d) increasing pollution charges so they truly provide incentives for reducing emissions; and (e) initiating total NO_X management as indicated by the 12th FYP, as NO_X emission reduction reduces secondary PM formation.

Regional PM pollution abatement. AQM analytical work in Shanxi cities indicated that regional PM_{10} makes up about half of the urban concentrations. Thus, local abatement efforts can impact only about half of the concentrations; regional measures are needed to control the rest. Furthermore, separate measurement of coarse particles and $PM_{2.5}$ would be useful for source identification and targeting abatement measures according to effectiveness and economic efficiency, especially in dry areas (also see section on $PM_{2.5}$ monitoring below).

PROPOSED $PM_{2.5}$ MONITORING FRAMEWORK

The objective of $PM_{2.5}$ monitoring would be to assess fine particles, their impact on public health, and to inform medium- and long-term plans that would be developed to abate them.

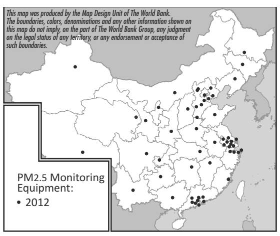
The monitoring framework would build on the $PM_{2.5}$ standards that MEP is expected to publish in 2011. Adoption of the WHO interim targets (IT) for average annual concentrations (IT-1: 35 μg/m^3, IT-2: 25 μg/m^3, and IT-3: 15 μg/m^3) is recommended. In view of the existing high concentration levels, a transition period should be granted for compliance with IT-1.

Monitoring networks and compliance plans would be developed in three phases and completed in 320 prefecture and higher-level cities by the end of the 12th FYP period (Box 2). This phased approach would allow gradual development of necessary administrative structures and technical expertise, including the important task of data quality assurance. Each city would have at least two $PM_{2.5}$ monitoring stations. The final number of monitoring stations in a city would be a function of the diversity of urban pollution sources and known spatial patterns, and determined based on the $PM_{2.5}$ levels measured at the first two stations and background monitors. The $PM_{2.5}$ monitoring roll-out would be synchronized with the ozone and carbon monoxide monitoring network development.

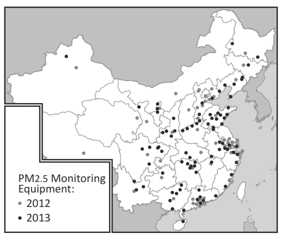
Additional key recommendations are:

- *Site selection for $PM_{2.5}$ monitors.* To the extent possible, new $PM_{2.5}$ monitors should be integrated into existing monitoring networks to ensure compatibility of data; however, existing PM_{10} monitoring locations may not always be the best sites for $PM_{2.5}$ monitoring. The monitoring program should include a significant number of rural monitoring stations to assess the significant regional component of $PM_{2.5}$ pollution. Ideally, regional concentrations should be measured using monitors located 50–150km away from the city center to identify the urban, suburban, and regional $PM_{2.5}$ components. It is also important that monitoring station sites are selected in a consistent manner across the cities of the network. In each city, one of the two monitors should be placed in a high-concentration area, and the other in an average concentration location.
- *Monitor types*. A variety of monitoring technologies—ranging from simple filter-based

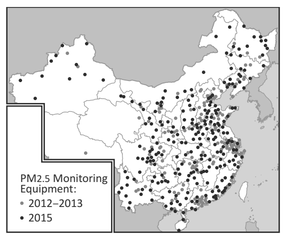
BOX 2 Proposed Three-phase Plan for Installing $PM_{2.5}$ Monitoring Equipment in Chinese Cities



Phase 1: By the end of 2012, over 100 stations would be introduced in about 60 cities, including all provincial capitals, 5–6 cities in the Beijing-Tianjin-Hebei area, 10–11 cities in the Yangtze River Delta, 8 cities in the Pearl River Delta, and certain developed cities. Inclusion of some prefecture-level or smaller cities with particularly large $PM_{2.5}$ levels would be useful.



Phase 2: By the end of 2013 about 260 stations would be established in about 130 cities. This includes 60 cities from phase 1 and those of the 113 "air pollution focus cities" that were not covered in phase 1.



Phase 3: By the end of 2015, more than 650 stations would be installed in 320 prefecture-level and larger cities.

systems to sophisticated continuous recording information systems—are available responding to diverse objectives. The objectives of $PM_{2.5}$ monitoring may include comparing with standards, reporting to the public, developing abatement strategies, assessing progress and trends, assessing exposure and health impact, and assessing visibility. As most of these objectives are relevant for China, it is recommended that a multi-technology, multi-functional monitoring system be assembled. Among the available technologies, chemical speciation (CS) may warrant particular interest because it can assist in assessing the contributions from main source sectors to PM pollution and thus assist in developing effective abatement strategies.

- Global experience shows that $PM_{2.5}$ monitoring can be challenging. Typical state-of-the-art monitors tend to underestimate the $PM_{2.5}$ concentration due to the semi-volatile nature of part of the $PM_{2.5}$ mass. Such underestimation can be substantial, depending on the chemical composition of the $PM_{2.5}$ mass and local climatic conditions (especially in warm climates). More expensive top-of-the-line monitors, such as the TEOM 1405-DF instrument, can correct the problem. It is strongly recommended that designers of the monitoring program and data quality assurance procedures consult the U.S. and European experiences in implementing similar programs.
- *Black carbon (BC)*. BC from coal combustion, biomass burning, brick kilns and coking processes is a significant contributor to ambient fine particulates. Monitoring and control of BC should be considered because of BC's important role in $PM_{2.5}$ health and climate change impact. BC can be measured by reflectance from the filter-based $PM_{2.5}$ samples.

1

Policy, Institutional and Regulatory Framework for Particulate Matter Control in China

1.1 HISTORY OF PM CONTROL POLICIES IN CHINA

Particulate matter (PM) has been a key aspect in China's efforts to prevent and control atmospheric pollution and focus on PM has intensified over time. Prevention and control policies, which have led to significant improvements in urban PM concentrations during the past decade (see chapter 3), can be divided into three stages (Table 1.1). The first stage is marked by

TABLE 1.1 Development of Air Pollution Control Policies in China

	1980–1990	1990–2000	2001–2010	2011–future
Source: APC policies focused on	Coal, industry	Coal, industry, dust	Coal, industry, motor vehicles, dust Special focus on 113 cities	All sectors All cities
Pollutants: APC policy focused on	Mainly SO_2, TSP	SO_2, NOx, TSP, some PM_{10}	SO_2, PM_{10}, NOx Certain cities (Pilot) research : $PM_{2.5}$, VOC, NH_3	SO_2, NOx, PM_{10} Gradually: $PM_{2.5}$ VOC, NH_3
Control measures	Eliminating smoke and dust	Eliminating smoke and dust, move or close polluting enterprises, integrated treatment	Desulphurization and dust removal, industrial pollution abatement, vehicle control, total load control	Further strengthened through administrative measures and technical guidelines to get all cities in compliance; new standards and policies for $PM_{2.5}$ control from 2011
Air pollution	Smoke	Smoke, acid rain, some PM_{10}	Smoke, acid rain, photochemical smog, haze/fine particle, toxic substances	Same
Scale	Local	Local + regional	Regional + hemisphere	Increased focus on regional pollution. State Council Notification No 33 (2010)

the National Environmental Protection Conference held by the State Council in 1973, when China began to control industrial point sources of air pollution. During this period, China's air pollution abatement efforts included transforming boilers, eliminating smoke and dust, and controlling point-source pollution.

The second stage spans the 1980s. The Law of the People's Republic of China on the Prevention and Control of Atmospheric Pollution (hereinafter referred to as "the Air Law") was formally promulgated in 1987. The Air Law focused on lowering smoke pollution, especially the prevention and control of coal emissions. The emphasis on the control of atmospheric pollution changed from point sources to integrated control. Activities included combining the control strategy with national economic adjustment; changing the urban structure and layout; planning for pollution prevention; technological transformation of enterprises and comprehensive utilization of resources; controlling and preventing industrial pollution; saving energy and changing the urban energy structure; expanding integrated controls on coal smoke pollution; and adjustments to industry, including the closing, suspension, merging, or moving of heavily polluting enterprises. These measures played an important role in controlling the rapid deterioration of the atmospheric environment.

The third stage occurred in the 1990s. Prevention and control of atmospheric pollution shifted from lowering ambient concentrations of pollutants to "total load control," and from comprehensive urban environment pollution control to regional pollution control. The control strategy entered a new historical stage. Much has been done in enacting laws and regulations, establishing supervision and management systems, strengthening air pollution control measures, and developing and promoting control technologies. This has promoted atmospheric pollution prevention and control of atmospheric PM. At the same time, the State Council approved the "two control zones" classified program, which controlled SO_2 and acid rain, and made corresponding support policies. This promotes the integrated prevention and control of acid rain and sulfur dioxide in China, while also affecting particulate pollution.

At the beginning of the 21st century, China began a new stage in total emission control of major air pollutants. In April 2000, the Air Law was revised.[8] The new version stipulated that total load control and a discharge permit system would be implemented in key areas. The new strategy also prohibited the emission of pollutants; charged pollutant discharge fees according to the type and quantity of pollutant; reinforced pollution control measures on motor vehicles; regulated compliance deadlines in the key cities; and controlled urban dust pollution. Moreover, the law mandated that the State Council designate key cities for prevention and control of atmospheric pollution ("key cities") that were to meet ambient air quality standards on the basis of a time-bound plan approved by the State Council or the administrative department for environmental protection under the State Council. Key cities include municipalities directly under the central government, provincial capitals, open coastal cities, and key tourist cities (Article 17). A total of 113 key cities were designated (see Annex 1 for a list of the key cities and Map 1.1 for their locations).

In May 2000, the State Council sent to the Ministry of Environmental Protection (MEP) a *Notification on Improving Regional Air Quality through Joint Prevention and Control Measures* ("State Council Notification*"*). The State Council Notification stipulates that by 2015 the urban air quality of all nine key regions meet or exceed urban grade II limit (see Section 1.4) values (Article 3). The nine key regions include (1) the Beijing Hebei Tianjin region; (2) the Tangtze River Delta; (3) the Pearl River Delta; (4) Central Liaoning

[8] Law of the People's Republic of China on the Prevention and Control of Atmospheric Pollution (Order of the President No.32)

[Province], including Shenyang; (5) Shandong Peninsula, including Qingdao; (6) Greater Wuhan; (7) Changsha, Zhuzhou, and Xiangtan region; (8) Chengdu and Chongqing region; and (9) areas around the Taiwan Strait, including Xiamen (Article 4). Each of these nine regions includes several key cities (Map 1.1). The notification also requires that cities not meeting grade II standards develop compliance programs to ensure that air quality improvement goals are met on schedule. Cities that have already achieved grade II standards should develop plans to continuously improve air quality within and beyond grade II or prevent deterioration (Article 22).

The *12th Five Year Plan of the People Republic of China (2011–15)*("12th FYP") targets compliance with grade II standards by 80 percent of prefecture and higher-level cities. The FYP also stipulates that a sound regional atmospheric pollution prevention and control mechanism would be put in place and control of regional pollution would be approached. The FYP also emphasizes that prevention and management of air pollution by particulates would be deepened.

1.2 INSTITUTIONAL FRAMEWORK FOR AIR QUALITY MANAGEMENT

This section summarizes the key provisions of the 2000 Air Law and the 2010 State Council Notification regarding the division of institutional responsibilities in air quality management.

Planning and implementing measures for air quality management. Article 3 of the Air Law states that "the State takes measures to control or gradually reduce, in a planned way, the total amount of the major atmospheric pollutants discharged in different areas." Furthermore "the local people's governments at various levels shall be responsible for the quality of the atmospheric environment within the areas under their jurisdiction, making plans and taking measures to ensure that the quality of the atmospheric environment within the said areas meet the standards." Article 27 of the State Council Notification, which aims to promote joint prevention and control of air pollution to improve regional air quality in nine key regions, requires that a mechanism be established to coordinate regional joint air pollution. Work plans are to be completed and approved by the end of 2011. Article 28 of the State Council Notification states that "local governments are the lead responsible party for implementing regional air pollution prevention and control, and they shall strengthen organization and leadership, develop workplans and programs for joint air pollution prevention and control, designate tasks under the workplans to responsible units and enterprises, strengthen supervision and examination." The State Council Notification also stipulates that "all regions must submit implementation plans for attaining these goals and the recommendations listed in this notice to MEP by the end of June 2010." The draft *Technical Guidelines* stipulates formation of "leading groups for air quality control" composed of city authorities for various relevant sectors. to coordinate regional air quality measures.

Monitoring, inspection, and enforcement. Administrative departments for environmental protection under the people's governments at or above the county level are tasked with the "unified supervision over the prevention and control" of air pollution. Administrative departments for public security, transportation, and fisheries at various levels will be responsible for "supervision over atmospheric pollution caused by motor vehicles and vessels" (Air Law Article 4). Besides, "All units and individuals shall have the obligation to protect the atmospheric environment and shall have the right to inform or lodge charges against units or individuals that cause pollution to the atmospheric environment" (Air Law Article 5).

Setting standards for ambient air quality. Air Law Article 6 mandates that "the administrative department for environmental protection under the State Council shall establish the national standards for atmospheric environment quality." Furthermore, "The people's governments of provinces, autonomous regions, and municipalities directly under the Central Government may establish their local standards for items not specified in the national standards for atmospheric environment quality and report the same to the administrative department for environmental protection under the State Council for the record."

Setting emission standards. Article 7 of the Air Law stipulates that: "The administrative department for environmental protection under the State Council shall, on the basis of the national standards for atmospheric environment quality and the country's economic and technological conditions, establish the national norm for the discharge of atmospheric pollutants." In addition, "The people's governments of provinces, autonomous regions, and municipalities directly under the Central Government may establish their local discharge norms for items not specified in the national norm for the discharge of atmospheric pollutants; with regard to items already specified in the national norms for the discharge of atmospheric pollutants, they may set local discharge norms which are more stringent than the national norm and report the same to the administrative department for environmental protection under the State Council for the record."

1.3 THE DRAFT ADMINISTRATIVE MEASURES AND TECHNICAL GUIDELINES

In the Spring of 2011, with support from this project, MEP drafted *Administrative Measures on Urban Air Quality Management* ("*The Administrative Measures*") and *Technical Guidelines for Compilation of Urban Ambient Air Quality Control Plans ("The Technical Guidelines")*, which aim to operationalize the State Council Notification, notably by means of "city air quality management plans." (These draft documents are reproduced in Annexes 2 and 3; comments are provided in Chapter 4.) These two regulatory documents aim to guide city leaders in preparing the city air quality management plans.

The Administrative Measures prescribes a system and procedures for administration of air quality at different levels, describes reporting and evaluation requirements, and outlines a reward and punishment system. The document makes clear that "municipal government at different levels shall be responsible for the air quality in its jurisdiction." Cities that are not compliant with grade II (section 1.4) standards normally have five years to reach compliance, although the deadline can be stretched to ten years. Municipal governments should draw up a program or plan consisting of i) baseline/status analysis, ii) guiding principles, iii) deadline and intermediate goals, iv) key tasks and measures, v) key engineering projects, vi) safeguard measures, and vii) estimates of emission reductions and effects. In the 113 key cities the program shall be submitted to MEP for approval. In other cities the plans shall be approved by provincial governments. Reviews of the management plans shall be conducted by the cities themselves and by MEP. The MEP examination indicators consist of a maximum of 100 points, in which quality indicators account for 37%, management indicators account for 23% and engineering indicators account for 40%. A plan scoring less than 60 points is a failure and must be revised. In addition, "related funding" will be reduced and projects that may increase emissions will be limited until an acceptable plan is devised. Leaders will also be "publicized for criticism." The examination takes place at the deadline for complying with the standard. Before that the actual air quality will be considered an evaluation indicator, not an examination indicator.

The Technical Guidelines provides detailed advice on the content of the municipal air pollution control programs/plans. It suggests that "major pollutants that cause urban air pollution should be managed first" and that "coordinated control" of particles, SO_2, NO_x and VOC shall be emphasized." The document provides detailed guidance on the tasks listed in Article 18 of *The Administrative Measures*, such as how to forecast the baseline trend in emissions. *The Technical Guidelines* also suggests a menu of possible abatement measures, including (a) improving urban industrial structure and layout; (b) reinforcing the use of clean energy; (c) strengthening end-of-pipe prevention and control of major pollutants; (d) preventing and controlling transport pollution; and (e) monitoring key enterprises (point sources) for emission reductions. Furthermore, *The Technical Guidelines* recommends that a "detailed list of projects be worked out in line with the major tasks of the urban air pollution control plan" and that cost estimates be made. But, it does not recommend cost-benefit or cost-effect analysis to evaluate abatement measures and projects. As discussed in Chapter 4, such analysis is critical to selecting the most appropriate measures in a budget-constrained environment. Finally, *The Technical Guidelines* also suggests capacity building efforts and establishment of a "leading group for air quality control" to coordinate sector policies, notably agriculture, industry, agriculture, transportation, and urban development.

1.4 AMBIENT AIR QUALITY STANDARDS AND MONITORING[9]

China has ambient concentrations standards for all major pollutants, including NO_2, NO_x, lead (Pb), PM_{10}, SO_2, and TSP. These standards are grouped in three levels. They are differentiated by urban vs. rural areas, as well as by annual versus 24-hour average concentrations. The three urban grades for average annual PM_{10} concentrations are presented in Table 1.2. For comparison, various international guidelines, standards and limit values for ambient PM_{10} and $PM_{2.5}$ concentrations are provided in Table 1.3.

TABLE 1.2 PM_{10} Annual Average Concentration Limits by Grade

Grade	Limits
I	<40 μg/m³
II	40 - 100 μg/m³
III	100-150 μg/m³

TABLE 1.3 International Air Quality Guidelines, Standards and Limit values for $PM_{2.5}$ and PM_{10} (μg/m³)

	PM_{10}		$PM_{2.5}$	
	Annual average	24 hour average (daily)	Annual average	24 hour average (daily)
WHO Guidelines, 2005	20	50	10	25
WHO Interim Targets (IT)				
IT-1	70	150	35	75
IT-2	50	100	25	50
IT-3	30	75	15	37.5
USEPA AQ Standards, 2006	-*	150	15	35 [1]
EU Limit Values	40	50 [2]	25 [3] 20 [4]	-

* Since 2006, the United States applies standards for 24-hour concentrations of PM_{10}. According to the USEPA, available evidence does not suggest a link between long-term exposure to PM_{10} and health problems (US EPA 2011).
1) 7 days above 35 per year is allowed (98th percentile); 2) 35 days above 50 per year is allowed (90th percentile); 3) To be met by 2010; 4) To be met by 2020

[9] This section aims to aid the reader of the report by providing basic information about air quality standards and monitoring related to the issues covered in the report. A full review of these topics is outside the scope of the section.

Compliance with standards is often set or reported in terms of composite grades, comprising NO_2, NO_x, Pb, PM_{10}, SO_2, and TSP, or a subset depending on the purpose of the classification. Targets set in policy and planning documents generally use composite grades. Given the importance of NO_2, PM_{10}, and SO_2 for air quality in China, the classification of cities is often based only on these pollutants and their annual average concentrations are published in environmental yearbooks. When composite grades are used, a city is classified in the lowest grade that individual pollutants achieve. In other words, a city is classified as grade III if one pollutant's annual average concentration is at grade III level even if all other pollutants are below grade II or I limits.

In China, the officially reported air pollution concentrations in a city always represent the average of the concentrations measured at all the monitoring stations in a city. All the concentration data presented in this report are such city-averaged concentrations. This means that there are locations in the city where the concentrations are higher than the reported average. Compliance with standards in China is always based on this averaged concentration. This means that even if a city is reported as being in compliance, there are areas in the city where the standards are exceeded.

Ambient particulate matter concentrations are monitored in 612 cities. Of these, 592 cities monitor PM_{10} and TSP, while 20 continue to measure TSP only. Of these 612 cities, 320 are prefecture and higher-level cities, and 292 are country-level cities. The 113 key cities are included in the 320 prefecture and higher-level cities.

PM_{10} monitoring was first introduced in 2000 in the 113 key cities. In the remaining In the remaining prefecture and higher-level cities, transition to PM_{10} monitoring was complete in the mid-2000s. Finally with regards to county-level cities, all but 20 have PM_{10} monitoring.

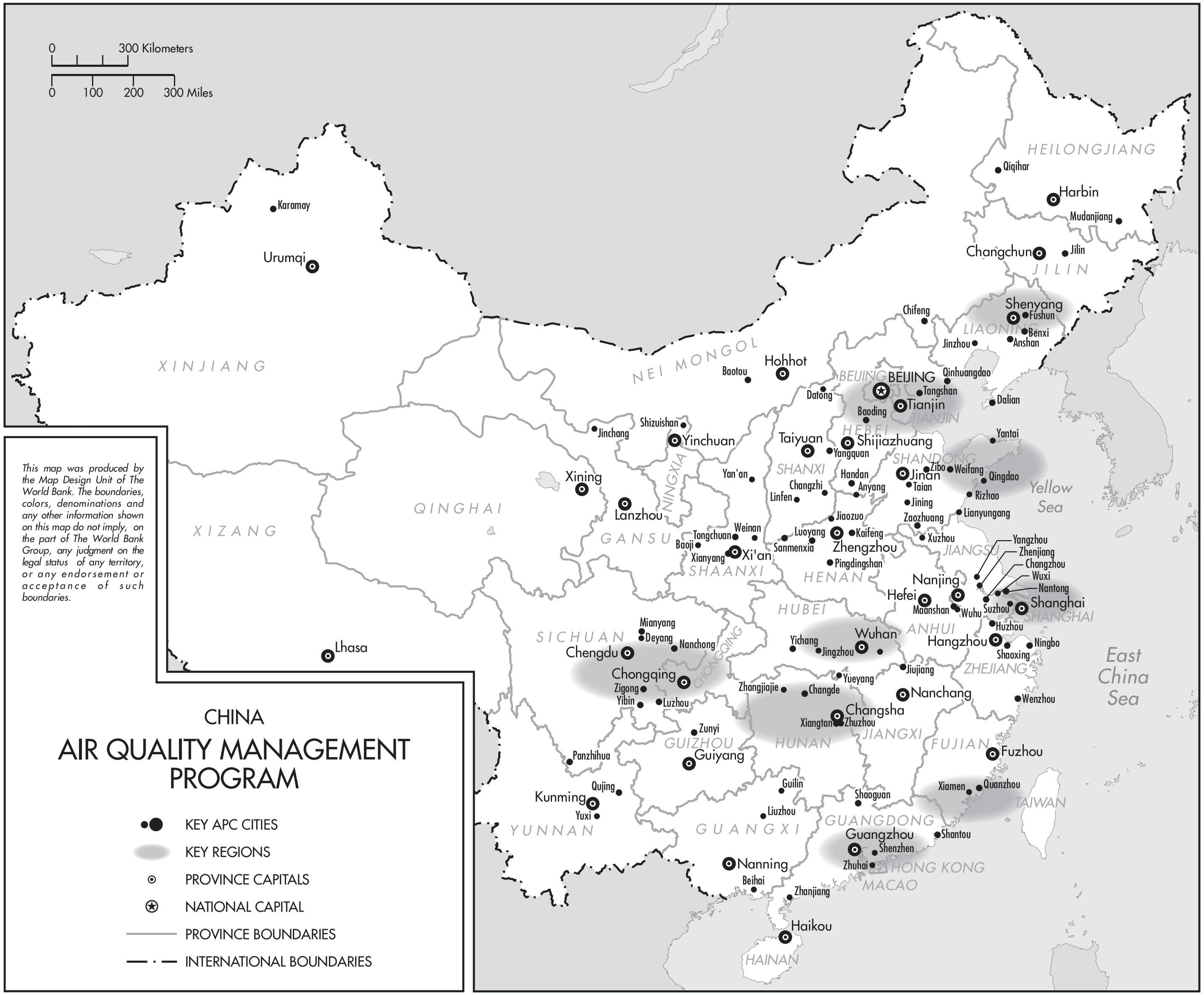
Presently, ambient concentration standards do not exist for $PM_{2.5}$. However, substantial $PM_{2.5}$ research has been carried out in about 20 cities, and 14 background monitoring and 31 rural monitoring stations were established during the 11th FYP to measure regional PM_{10} *and* $PM_{2.5}$ concentrations. $PM_{2.5}$ abatement guidelines or policies have also not been elaborated.

China's latest air pollutant emission standard for thermal power plants (GB13223-2003) was promulgated and implemented in 2004. Compared with its previous version (GB13223-1996), the dust concentration standard changed from 200–600mg/Nm^3 to 50–600mg/Nm^3. Power plant dust emission standards in some countries and regions are shown in Table 1.4. The Chinese standards are still higher than those of other countries and regions.

TABLE 1.4 Chinese and International Standards for Discharge of Smoke and Dust from Thermal Plants

Country or region	Australia	Japan	U.S.	Germany	China	Korea
Standard (mg/Nm^3)	80	50–150	40	50	50–600	50

Map 1.1 Map of China Indicating "Key Regions" and "Key Cities" for Air Quality Management



2

Sources of PM Pollution in Urban China

Information about the relative contributions and key sources of ambient air pollution in a city allows the formulation of well-targeted abatement policies and measures. This chapter first presents the main ambient PM source apportionment methods, followed by a review of existing source apportionment studies. The key sources of PM pollution are then discussed by region.

2.1 AMBIENT PM SOURCE APPORTIONMENT METHODS

The chemical composition of PM often allows it to be traced to its source. With the recent improvement of PM monitoring technology, detailed information can be collected on emission sources and ambient PM, including concentrations and chemical composition—such as ionic matters, crustal elements, organics, and black carbon. This chemical information—combined with information on meteorological conditions, economic structure, and emission inventories—allows integrated judgments of the characteristics and contribution of each source by using mathematical methods of multivariate statistical analysis.

Source apportionment of PM with the chemical (so-called "receptor model") method is one method to identify the sources of PM. It estimates the contribution of each type of source using data on atmospheric PM chemical composition and physical characteristics. Since 2000, receptor models have been used in nearly 30 Chinese cities to study sources of ambient PM. Specific models used include the chemical mass balance (CMB) model, the positive matrix factorization (PMF) model, and the principal factor analysis (PFA).

The CMB model is the most widely used receptor model in China. With prior knowledge of major sources and their emission characteristics in the study area, the CMB model can conveniently calculate the contribution of each source to a certain receptor point. The principle of this model is clear, though it needs source profiles that should be updated regularly.

The PMF model makes source apportionment without prior knowledge of the source profiles by analyzing a large data sample. Both the source profiles and the contributions of each source are outputs of this model. These outputs make PMF increasingly popular, though it is more difficult to use than CMB.

PFA targets a small number of variables and is useful when source profiles are unavailable and the sample size is small. However, it needs to be combined with other methods in order to estimate the total contribution from various sources.

These methods are limited to the analysis of the situation at the locations where PM is measured. This chemical method of source apportionment should be accompanied by air pollution modeling methods based on emission inventories, and meteorological and population distribution data, which can enable the apportionment of source contributions to the exposure of the entire population to PM pollution, a necessary basis for cost-effectiveness and cost-benefit ranking of control options.

2.2 CHARACTERISTICS AND CONTRIBUTIONS OF URBAN PM SOURCES IN CHINA

The receptor model applications in China have provided information on the main features of urban PM pollution in China that are summarized below. Note that the assessment is always limited to the locations of the PM measuring stations. When the measurement station locations can be said to represent the city as a whole, the results can be said to be representative.

Suspended dust

Suspended dust particles are induced into the air by natural and artificial forces. Its main components are soil dust, road dust, cement, and construction dust. Soil dust comes directly from bare soil surfaces, including local and distant sources. For example, a dust storm, which normally occurs in the spring in northern parts of China, is an extreme event involving the creation and transportation of soil dust.

Road dust originates from road surfaces and is suspended into the atmosphere by the air turbulence created by vehicles, especially large (heavy duty) vehicles. Cement and construction dust come from municipal construction, building construction, and demolition.

The chemical composition of dust varies greatly in different geographic regions. In general, all dust sources are abundant in crustal elements such as silicon (Si), aluminum (Al), and calcium (Ca). The Ca concentration is higher in construction and cement dust than in soil or road dust. Road dust is significantly richer in organics. As the largest part of road dust is resuspended soil dust, a collinearity problem exists with these two sources (Rui et al. 2008; Xu 2007). Sometimes these two sources cannot be distinguished and are identified as one source.

Studies show that soil dust and road dust contribute the most to urban atmospheric PM. In northern cities—such as Beijing, Shenyang, Taiyuan, Tianjin, and Jinan —soil dust and road dust account for 30–60 percent of PM_{10} concentration (Bi et al. 2007; Feng et al. 2004; Liu et al. 2007; Xie et al. 2008; Xu 2007), with the highest level being 60 percent in Yinchuan (Bi et al. 2007). In southern cities—such as Nanjing, Guangzhou, and Hangzhou—the percentage is lower. The contribution of soil dust and road dust to PM_{10} concentration ranges from 5 percent to 30 percent (Cui et al. 2008; Rui et al. 2008; Song et al. 2008; Wang et al. 2003; Wang et al. 2006).

China is characterized by intensive urbanization. Building demolition and construction, road construction, and general construction generate cement and construction dust that contribute 3 percent to 20 percent of PM_{10} concentration and is becoming an important source of urban atmospheric PM (Bi et al. 2007; Rui et al. 2008; Song et al. 2008; Wang et al. 2003; Wang et al. 2006; Xu 2007).

Suspended dust tends to occur seasonally, as it is much more abundant during winter and spring.

Results from about 20 source apportionment studies in China are summarized in Table 2.1

Coal combustion

Coal is the dominant industrial and residential fossil fuel in China. In 2008, coal accounted for 68.7 percent of energy consumption (Li 2010). Power plants, large-scale boilers for steel mills,

TABLE 2.1 Summary of source apportionment using studies from nearly 30 cities of China

Source	Percentage
1. Suspended dust	
- Soil & road	30–60%
-	
2. Coal combustion	15–30%
- Winter	20–60%
- Summer	5–20%
3. Industrial dust process (iron & steel, cement)	Up to 20%
4. Vehicle emissions	5–20%
5. Biomass burning	Up to 10%
6. SO_2 & NO_x forming sec. PM	
- Beijing, Yangze, Pearl River	20–40%
- Jinan, Chengdu, Nanjing	Up to 20%

Source: Based on sources reviewed in this report.

central heating boilers, and domestic small stoves are the major coal users. Combustion by products include particles and incomplete oxidation products such as CO and hydrocarbons. The particles from coal combustion contain organic matter and black carbon as well as Si, Ca, iron (Fe), and other crustal elements, notably arsenic (As) and vanadium (V). If the coal contains sulfur and nitrogen, the compounds will also include SO_2 and NO_x. Furthermore, high combustion temperatures will oxidize atmospheric nitrogen and create NO_x, which is the dominant source of NO_x from the combustion.

Because of the energy structure, coal dust has a large impact in nearly all cities. Coal combustion has an average annual contribution of 15 to 30 percent of PM_{10} concentration (Bi et al. 2007; Feng et al. 2004; Liu et al. 2007; Rui et al. 2008; Wang et al. 2003; Wang et al. 2006; Xie et al. 2008; Xu et al. 2007). In small and medium cities, the contribution may be larger. Coal combustion pollution also exhibits seasonal variation, being high in winter (20–60 percent of PM_{10} concentration) and low in summer (5–20 percent of PM_{10} concentration) (Feng et al. 2004; Bi et al. 2007; Liu 2007; Wang et al. 2006; Xu 2007; Xie et al. 2008). Domestic heating greatly impacts PM pollution.

Industrial dust

Many industrial processes discharge atmospheric particles. The characteristics and chemical composition of this particulate matter varies among industries. For example, particles from the steel industry are rich in Fe, Ca, and Si, while particles from the nonferrous metallurgical industry contain corresponding elements such as zinc (Zn), copper (Cu), and Al.

Industrial dust greatly impacts urban and industrial cities. In some well-known iron and steel cities such as Anshan and Panzhihua, steel dust can contribute 20 percent of the PM_{10} concentration (Liu et al. 2007; Xue et al. 2010). Cities containing specific heavy industries also are influenced. For example, the zinc industry in Huludao (Xu 2007) and the petrochemical industries in Harbin (Huang et al. 2010) substantially contribute to the PM concentration of those cities.

Vehicle emissions

From 1990 to 2009, the vehicle population in China increased from 5 million to 186 million. As a result, vehicle emissions have also become an increasing source of PM pollution. Vehicle emissions mainly come from incomplete fuel combustion, resulting in exhaust components such as organic matter, soot, CO, and NO_x. Vehicle emissions may have a similar source profile to coal combustion. However, compared with coal dust, particles from vehicle emissions have larger amounts of black carbon.

Between 5 percent and 20 percent of the PM_{10} concentration comes from motor vehicle emissions (Bi et al. 2007; Feng et al. 2004; Liu et al. 2007; Rui et al. 2008; Wang et al. 2003; Wang et al. 2006; Xie et al. 2008; Xu 2007), which is large enough to cause concern. Furthermore, since these published studies are based on PM concentration data prior to 2006 and the vehicle population has substantially grown since then, the contribution of vehicle emissions to PM concentrations could be higher. NO_x emitted by motor vehicles not only is an important atmospheric photochemical reaction precursor, but also is a precursor of particulate nitrate.

Biomass burning

Agricultural production results in straw and other crop residues. Crop residues are partly burned by rural residents for heating and cooking and are also burned after harvesting. The incineration of leaves and municipal solid waste and forest fires are other important examples of biomass burning. Such burning produces substantial particulate and gaseous pollutants. The particles mainly contain organic matter, black carbon and potassium, while potassium and L-glucan are mainly regarded as tracers of biomass burning.

The chemical composition of particles depends on the type of biomass and the burning conditions, so it is difficult to obtain an integrated profile of biomass burning. The CMB model cannot estimate this source. However, studies using the PMF model in Beijing, Guangzhou, and other cities have concluded that 10 percent of PM_{10} concentrations is due to biomass burning (Song et al. 2008; Xie et al. 2008) and thus is an important source of atmospheric particles. Biomass particles are, like particles from motor vehicles, comparatively small, making them an even more important source of $PM_{2.5}$ emissions.

Secondary particulate matter

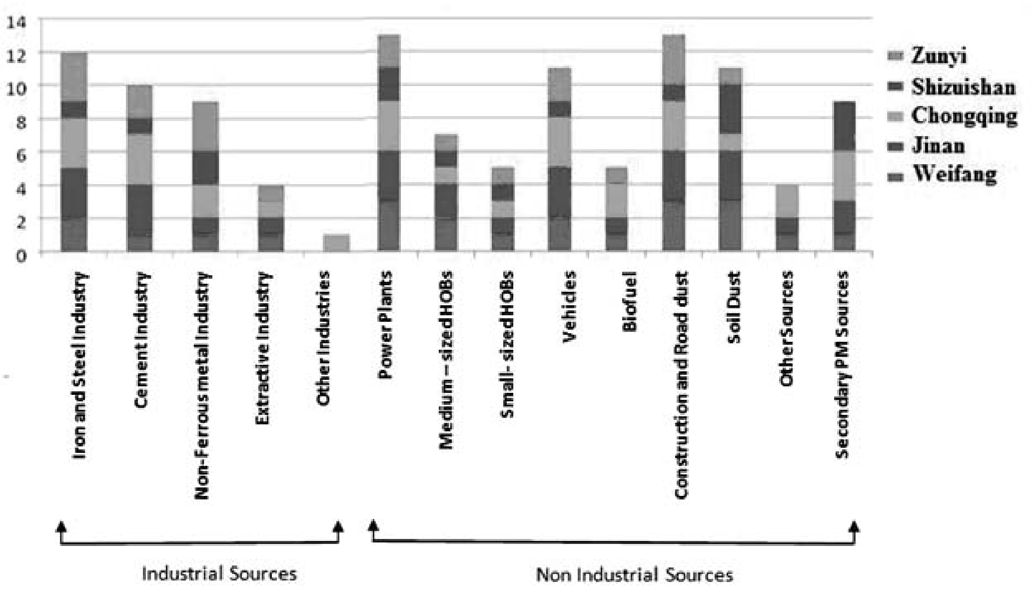
Industrial processes, coal combustion, vehicles, and biomass burning discharge large amounts of gaseous pollutants such as SO_2, NO_x, and volatile organic compounds (VOCs). During the daytime, photochemical reactions occur between atmospheric NO_x and VOCs, leading to elevated concentrations of ozone and other atmospheric oxidizing substances. This significantly enhances atmospheric oxidation.

Based on the high atmospheric oxidation, gaseous precursors (SO_2, NOx) are oxidized through gas phase oxidation, heterogeneous oxidation, and liquid-phase oxidation into gaseous sulfuric acid and nitric acid, which are then neutralized by atmospheric ammonia and form the particulates ammonium sulfate and ammonium nitrate. Some volatile organic compounds can also be oxidized to low volatile substances and transform into particulates by coagulation and condensation (Tang et al. 2006). Therefore, the chemical composition of inorganic secondary particles is basically sulphate, nitrate, and ammonium. Some organic secondary particulate matter also exists. The particle size is predominantly within 2.5 mm.

BOX 2.1 City-level information about PM pollution source contributions

As part of this project, selected cities were surveyed for details about PM pollution problems (see Annex 4). Responses from five cities drawn from different parts of the country confirm the general picture among the Chinese regions, but also indicate significant differences between cities depending on their location and regional characteristics (figure below). For example, compare Jinan, a city of Shandong Province, with Shizuishan, a city of Ningxia Autonomous Region, and the city-province of Chongqing. Jinan, the red element of the columns, obtains concentrations of PM from iron and steel, cement, vehicles, construction and road suspended dust, coal, and soil dust, all in similar proportions. In other words, there are many sources. Jinan is currently 23 percent away from class II compliance (Table 3.5). It is representative of northeastern conditions. Shizuishan is the purple element of the columns. It is representative of northwestern conditions. Soil dust and secondary PM, as well as industry (all sectors together), are important. Finally, in Chongqing the situation in terms of sources is similar to Jinan, but secondary PM and biomass burning are also important. In other words, there are even a larger number of significant sources than in Jinan. Chongqing is representative of central to southern conditions and is only 5 percent away from compliance (Table 3.3). In all three cities, there are a multitude of sources, with relative weights a bit different, but with a low weight for soil dust in Chongqing in the central/southern region. In all these cities, the control of PM has to address many sources in order to move toward compliance, using cost-effect considerations to develop a detailed control plans.

Sources of PM Concentrations in Five Selected Cities



Note: The main sources of population-weighted PM concentrations according to city and province environmental protection bureaus. Cities have ranked sources on a qualitative scale 1–3. The longest sections of columns correspond to a "3" and so on. HOB means heat-only boiler.

Due to the time scales involved in the chemical transformations (from several hours to days), the secondary PM formation takes place mostly on the regional scale (several tens to hundreds of km). Emissions in the cities as well as outside cities (such as from rurally located sources, e.g. power plants, domestic, agricultural sources) combine in the chemical transformation processes. Therefore, control of secondary PM requires a regional outlook, where the control efforts involve rural as well as urban sources.

Secondary PM is not yet a very important source of PM_{10} pollution in China, in contrast to the European Union and OECD countries, where it constitutes up to 90 percent of regional PM_{10} concentrations. For example, in most northern cities, secondary PM has not become a predominate source of PM_{10} concentration (Bi et al. 2007; Liu 2007; Xu 2007) but it is probably a larger source of $PM_{2.5}$ concentrations. With the enhancement of atmospheric oxidation, secondary particulate pollution is becoming more significant in megacities and city clusters such as Beijing, the Yangtze River Delta, and the Pearl River Delta. In these areas, secondary PM can account for 20–40 percent of PM_{10} concentrations during some seasons (Rui et al. 2008; Xie et al. 2008). In other large cities such as Jinan, Chengdu, and Nanjing, secondary PM can account for up to 20 percent of PM_{10} concentrations (Feng et al. 2004; Wang et al. 2006).

3

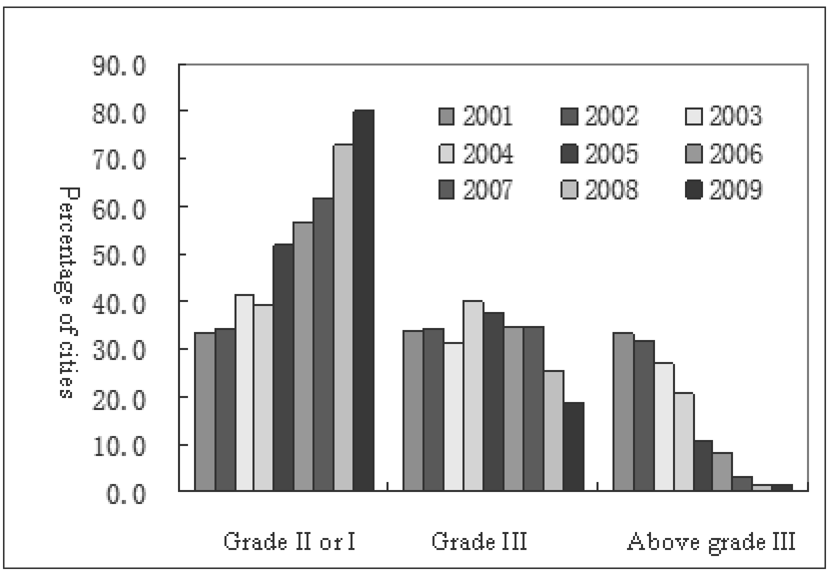
Recent Trends, Current Status, and Sources of Urban PM_{10} Pollution in China

This chapter reviews air quality improvements in Chinese cities since 2000 and its current status. The chapter then discusses sources of air pollution and levels of exceedance in cases of non-compliance. The chapter closes with a review of the characteristics of the $PM_{2.5}$ pollution situation in cities.

3.1 TRENDS IN CHINA THE 2000s[10] AND INTERNATIONAL COMPARISON

China made impressive progress in air quality management—including of SO_2, NO_2, and PM_{10}—during the period from 2001 to 2009.[11] In 2001, about one-third of China's air quality

FIGURE 3.1 Urban Air Quality Comparisons 2001–09 (based on SO_2, NO_2, and PM_{10})



[10] All PM data included in this report are annual average concentrations; 24-hour concentrations were not analyzed due to limited data availability and time constraints.

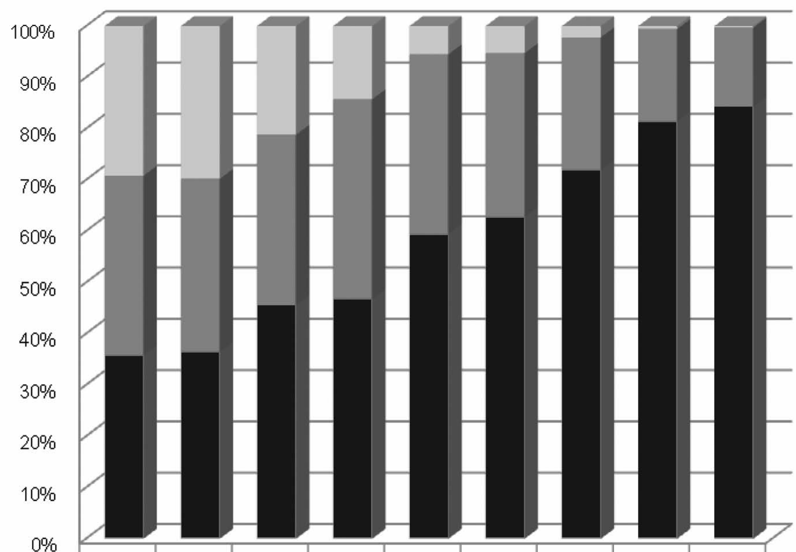
[11] As discussed in section 1.4, PM_{10} monitoring was phased in gradually during the 2000s. For the earlier years in this period, PM_{10} concentrations in non-key cities were estimated from measured TSP concentrations.

monitored cities attained the composite grades II or I covering these pollutants (Section 1.4); about one-third were within grade III, and about one-third exceeded grade III. In 2009, there were very few cities left above grade III, about 20 percent left in grade III, and almost 80 percent were in grades II or I (Figure 3.1). The improvement in ambient PM_{10} concentrations followed a similar pattern (Figure 3.2). In 2001, of the 612 cities, about 29 percent were above the grade III limit for PM_{10}, 35 percent were in grade III, and 36 percent were in grades II or I. In comparison, in 2009, less than 1 percent of the cities exceeded the PM_{10} grade III limit, about 15 percent were in grade III, while almost 84 percent were in grades II or I. The number of grade I cities increased from zero to seven during this period.

China's achievements in controlling air quality concentrations are all the more remarkable since emissions did not follow a similar downward trend during the same period. Emissions of industrial soot and dust, the PM emission indicators, were decreasing in the previous decade, but soot, the better indicator of PM, showed only a small decrease. Emissions of SO_2 rose, then fell, and were about the same at the end of the decade as they were at the beginning. Emissions of NO_x rose during the entire decade.

The improved air quality in urban areas is attributable both to lower emissions of soot and dust, as well as measures to relocate emission sources outside urban areas. The previous decade saw increased efforts to limit PM emissions from industrial as well as mobile and natural sources. Further, there was a reduction in small coal boilers that emit pollutants at low height; in addition, large industrial sources—such as iron and steel works—were relocated

FIGURE 3.2 Distribution of Monitored Cities by PM_{10} Grade During 2001–09



	2001	2002	2003	2004	2005	2006	2007	2008	2009
Above class 3 (>150 μg/m³)	29.2	29.8	21.2	14.3	5.5	5.3	2.2	0.6	0.3
Class 3 (100-150μg/m³)	34.9	33.7	33.2	38.9	35	31.9	25.8	17.9	15.4
Class 1-2 (< 100 μg/m³)	35.9	36.5	45.6	46.8	59.5	62.8	72	81.5	84.3

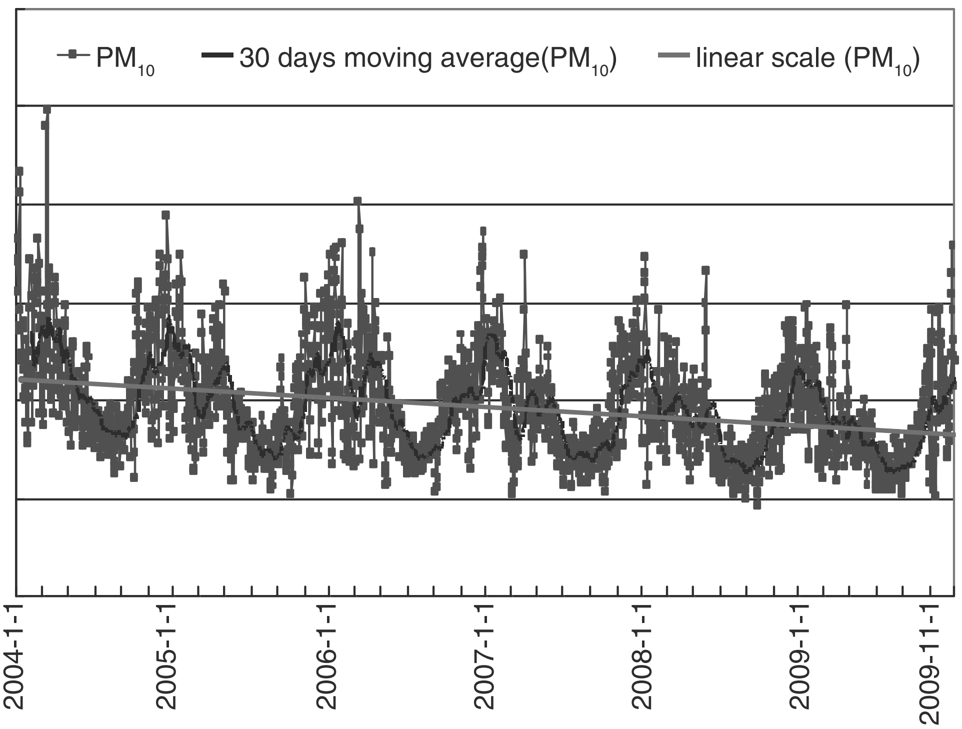
away from downtown areas. These measures contributed to improved city-level air quality for a given level of emissions. An unintended effect of this can be that pollution levels increase in the surrounding areas where the sources were moved. Regional air pollution levels also will be affected by moving these large industrial and power sources.

Figure 3.3 illustrates the behavior of PM_{10} concentrations in the 113 key cities from 2004–09. The trend was downward sloping and passed through the grade II limit of 100µg/m^3 in the middle of the period. However, this figure also shows the strong seasonal variation in concentrations, with significantly higher concentrations occurring in the winter. In addition, occasional spikes occurred in select individual cities. (See Annex 1A for annual average PM_{10} concentrations in all 113 key cities during 2003–09.)

Figure 3.4 examines the difference in trends between South China and North China cities during 2003–09. Concentrations declined both in North China and South China, and the difference between the two regions became smaller. The average in North China cities recorded a slight increase between 2008 and 2009, but remained just below the grade II limit in 2009. South China cities were on average robustly below the grade II limit and continuously reduced average concentrations during this period.

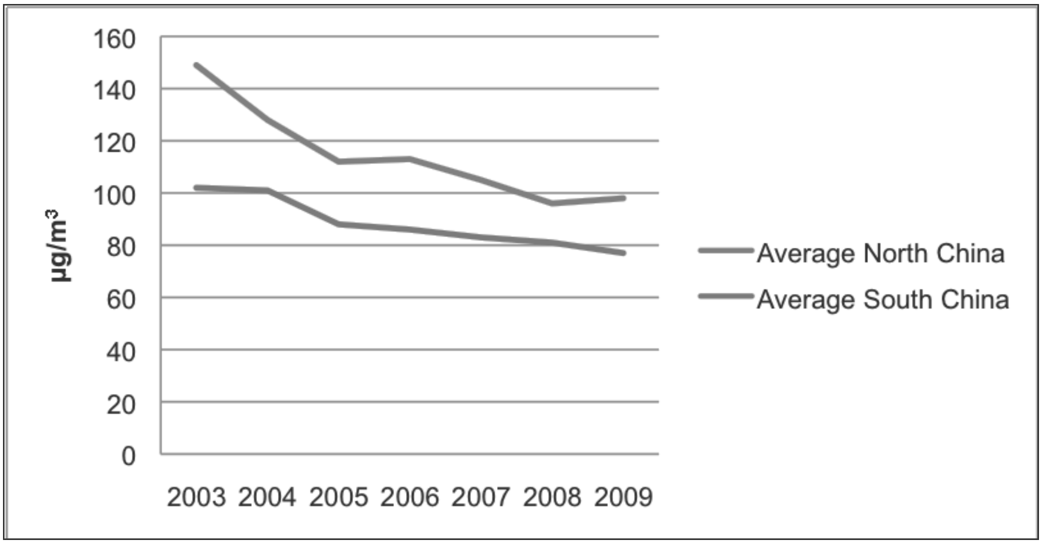
Figure 3.5 provides a picture of where China stands with regard to its annual average PM_{10} concentrations compared to USA, Europe, and Eastern Europe. China has shown a steady progress in reducing its PM_{10} concentration. For instance, the average value decreased from 118 µg/m^3 in 2003 to 87 µg/m^3 in 2009[12], and is thus within the national Grade II standard of

FIGURE 3.3 Trends in PM_{10} Concentrations in 113 Key Cities, 2004–09



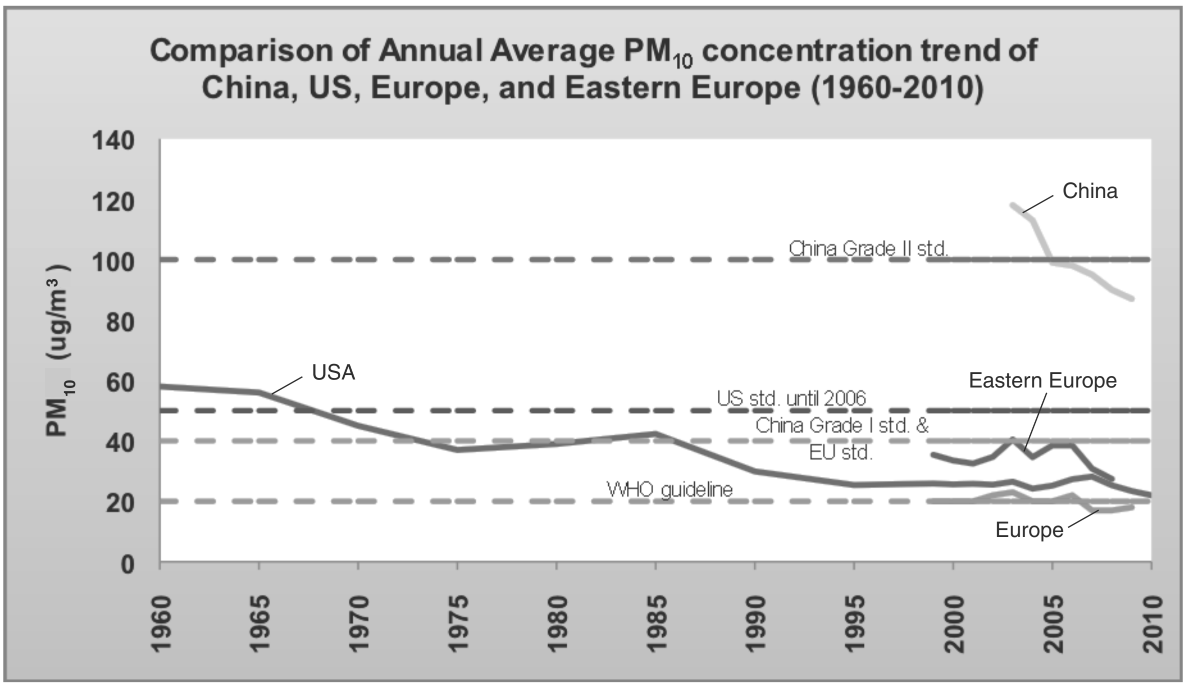
[12] Based on 113 key cities data.

FIGURE 3.4 Development in Annual PM_{10} Concentrations in Northern vs. Southern Key Cities*



* Simple averages of concentrations of cities in North and South China

FIGURE 3.5 Comparison of Annual Average PM_{10} concentration trend of China, US, Europe, and Eastern Europe (1960–2010)



100μg/m³. However, the 2009 value is still more than 2 times the national Grade I & EU standard of 40μg/m³ or more than 4 times the WHO standard of 20μg/m³. On the other hand, USA[12], Europe[13], and Eastern Europe[14] have already or almost achieved the WHO standard. It is worth to note that even in the 1960s, the average PM_{10} concentrations in USA was lower than that of China's present.

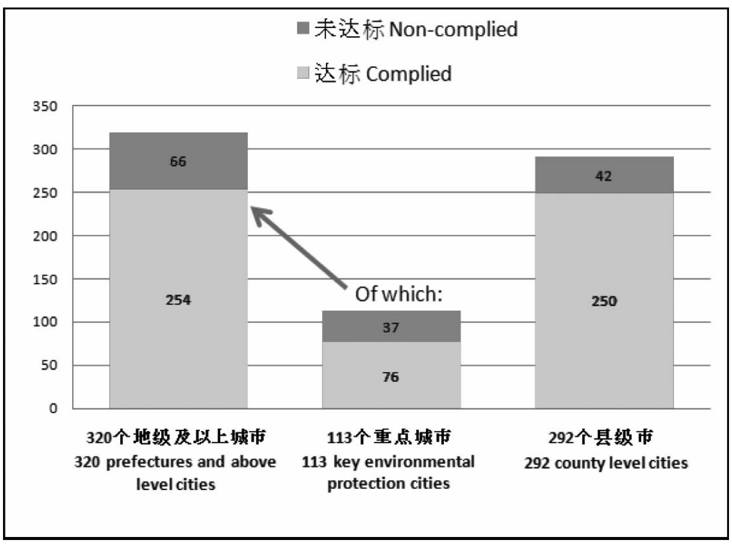
3.2 THE PRESENT STATUS

This section reviews the present status of air pollution on the basis of average annual concentration data from 2009, the latest year in which comprehensive data are available.

Of the 612 cities monitored in 2009, 108 did not comply with the composite grade II for NO_2, SO_2, and PM_{10}. Of these, forty-two were county-level cities and sixty-six were prefecture or higher-level cities, including thirty-seven key cities (Figure 3.6). Table 3.1 provides a more detailed distribution of cities by grade and administrative level. It is interesting to note that prefecture and higher-level cities exhibit a slightly lower compliance rate with grade II or I —79 percent compared to the county-level city rate of 85 percent.

With regard to PM_{10}, in 2009 average annual concentrations in most of the 612 monitored cities clustered in the 60–120μg/m³ range with a mean of about 80μg/m³, which is below the 100μg/m³ grade II limit. A long but thin right tail of the distribution indicates that only a few cities experience highly elevated PM_{10} levels (Figure 3.7). In terms of grades, almost 90 percent of

FIGURE 3.6 Characteristics of 108 Cities in Non-compliance with the Composite Grade II for NO_2, SO_2, and PM_{10}



[13] Data from 1960-1980 was an approximation from Pace et.al (1986), EPA (1988), Bachmann (2007); Data from 1985-2010 is from US EPA, from which an average was taken from all monitoring stations for respective years.

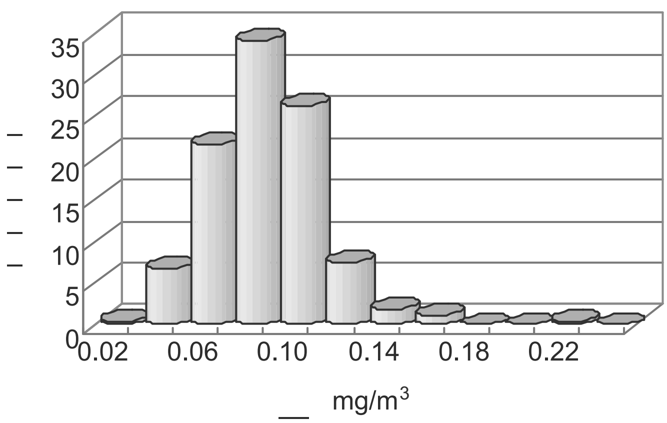
[14] Suburban background station data from Mol, W., van Hooydonk, P. and de Leeuw, F. (2011). Countries included: Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, United Kingdom, Greece, Ireland, Italy, Netherlands, Poland, Portugal, Slovakia, Slovenia, Sweden.

[15] Suburban background station data from Mol, W., van Hooydonk, P. and de Leeuw, F. (2011). Countries included: Czech Rep., Poland, Slovenia, and Slovakia.

TABLE 3.1 Distribution of 612 Monitored Cities by Composite Grade Attainment, 2009 (%)

Grade	All cities	Prefecture-level cities	County-level cities
Grade I	4.2	3.7	4.8
Grade II	78.3	75.8	80.8
Grade III	16.2	18.9	13.4
> Grade III	1.3	1.6	1.0

FIGURE 3.7 Distribution of PM_{10} Concentrations Among All 612 Monitored Cities, 2009



the 612 cities attained grade II or I. Seven percent of all cities now attain grade I status. As in the case of composite grades, county-level cities exhibited lower average PM_{10} concentrations. Ninety-six percent of the county-level cities—compared to 84.3 percent of the prefecture and higher-level cities—attained grade II or I (Table 3.2).

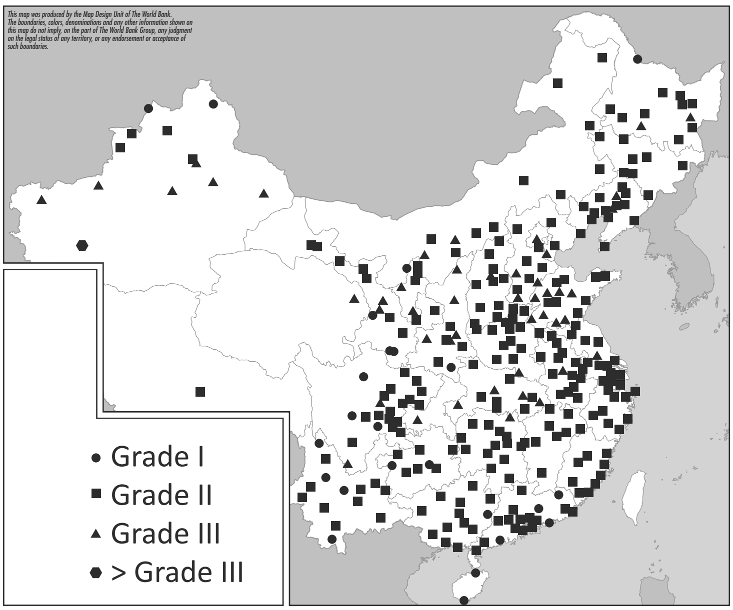
Tables 3.1 and 3.2 also show that cities have performed better in complying with grade II or I with respect to PM_{10} alone than with SO_2, NO_2, and PM_{10} together. Of the 612 cities, 89.7 percent complied with PM_{10} grade II or I, compared with 82.5 percent attaining the composite grade II or I. Non-compliance with SO_2 limits was the main cause for this discrepancy, while NO_2 concentrations were below the grade II limit in the majority of cities. Separate data on SO_2 and NO_2 are not available for the 612 cities. However, Annex 1B data show that all key cities are either grade II or grade I compliant with respect to NO_2.

At the county level, twelve cities did not comply with PM_{10} grade II standards in 2009. Eleven cities were within the class III category, while one county-level city was above the grade III limit with a concentration level of about 200μg/m^3. Most of the county-level cities that do not comply with China's class II or better are due to high SO_2 concentrations (thirty cities) rather than PM_{10} concentrations (twelve cities). High PM_{10} concentrations seem to be less of a problem

TABLE 3.2 Distribution of 612 Monitored Cities by PM_{10} Grade Attainment, 2009 (%)

Grade	All cities	Prefecture and higher-level cities	County-level cities
Grade I	7.1	6.6	7.7
Grade II	82.6	77.7	88.3
Grade III	10.0	15.4	3.6
> Grade III	0.3	0.3	0.4

FIGURE 3.8 Distribution of Annual PM_{10} Concentrations at All 320 Prefecture and Higher-level Cities, 2009



among smaller county-level cities compared to larger prefecture-level and above cities.[16]

Figure 3.8 illustrates the geographical distribution of the 320 prefecture and higher-level cities and their PM_{10} grade status as of 2009. Most cities are blue, indicating that they attained grade II, and some cities in the South and up through Sichuan and Gansu provinces are green, indicating grade I compliance. The non-compliant yellow and red cities are mostly found in the North and West, with one red city in Xinjiang being above the grade III limit.

[16] Nevertheless, all county-level cities, regardless of whether they struggle with SO_2 or PM_{10}, are included in China's efforts to have all their cities comply with class II (or better) category. There is an ongoing dialogue with MEP and the China National Monitoring Center (CNMC) to clarify the specific PM_{10} concentration levels of these cities in order to get them integrated into the classifications of the compliance plans.

3.3 GEOGRAPHICAL DISTRIBUTION AND SOURCES OF NON-COMPLIANCE

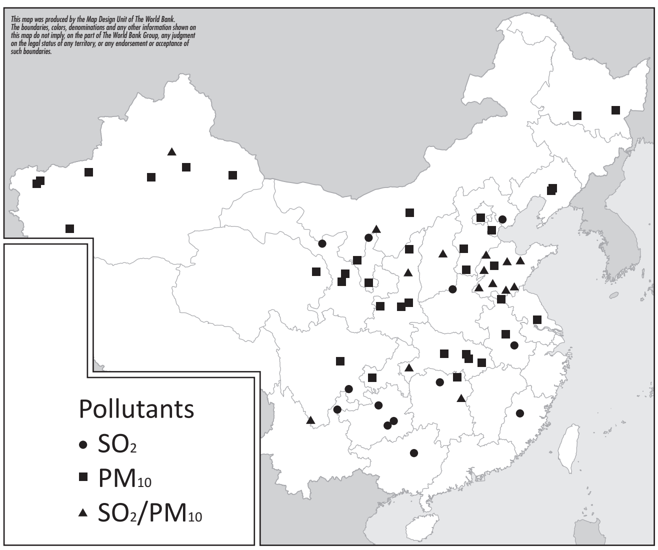
This section focuses on the causes of non-compliance with the composite grade II in sixty-five prefecture or higher-level cities. Cities that are non-compliant with composite grade II have excessive concentrations of SO_2, PM_{10}, or SO_2 and PM_{10} together. The geographical distribution of non-compliant prefecture or higher-level cities is illustrated in Figure 3.9 by red, blue, and green dots. PM_{10} was the primary pollutant in the majority of the non-compliant cities at this level in 2009.[17]

Of the 320 cities, 13 (4.1 percent) had SO_2 concentrations that exceeded the grade II limit. These cities include Tongling, Zunyi, Kaili, Dujun, Shizuishan. and Zhaotong, and are mainly located in the in Guizhou, Guangxi, Yunnan, Sichuan, Gansu, Ningxia, Henan, Hebei, and Anhui provinces. The predominant industries in these cities are coal mining, metal smelting, chemicals, and thermal energy generation.

Thirty-eight cities (12 percent) had excessive PM_{10} concentrations and can be divided into three groups according to PM_{10} sources: (1) cities with a large number of motor vehicles and substantial secondary pollution in addition to industrial and other combustion sources, such as Beijing, Tianjin, Chongqing, Chengdu, and Xi'an; (2) industrial cities such as Xuzhou, Anshan, Handan, Yushu, Baoji, and Yueyang, where the coal, metallurgy, and petrochemical industries are the main source of pollution; and (3) cities that are rich in mineral resources and vulnerable to dust effects, such as Turufan, Kuerle, Atushi, and Guyuan.

In fifteen cities (4.7 percent), both SO_2 and PM_{10} concentrations exceeded the grade II limit. Cities in this category included Panzhihua, Zaozhuang, Zibo, Linyi, Liaocheng, Wuhai, Zhuzhou, Taiyuan, and Urumqi. They are located

FIGURE 3.9 Distribution of Non-compliant Cities at Prefecture and Above, by Source of Non-compliance



[17] In contrast to the county-level cities where excessive SO_2 pollution was the main cause for non-compliance with the composite grade II.

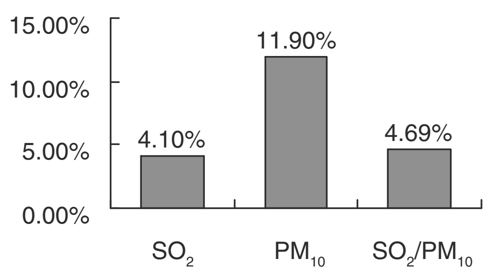
mainly in Shandong (8 cities), Xinjiang, Inner Mongolia, Hunan, Hubei, Sichuan, and Shanxi provinces. These cities are characterized by heavy coal mining and coal consumption (Figure 3.10).

In terms of regional distribution, twelve of the non-compliant prefecture level or above cities (18 percent) are located in the South. Cities in the North and West make up 41 percent (twenty-seven cities each) (Figure 3.11).

Pollution types of northern cities

Eighty-five percent of northern non-compliant cities failed to meet urban grade II for PM_{10}. Shijiazhuang, Handan, Shenyang, and Anshan are typical. Fifty-two percent of the cities failed because of SO_2. In total, 37 percent of the Northern non-compliant cities exceed both SO_2 and PM_{10} standards. Cities in Shandong Province—such as Zaozhuang, Liaocheng, and Jining—are examples.

FIGURE 3.10 Non-compliant Cities at Prefecture Level and Above, by Pollutant Source of Non-compliance



Typically, northern cities in China are always dry and have much bare surface, which often causes dust particle pollution. Coal is the main energy source in the heating period, and extensive coal-burning leads to SO_2 and dust emissions, which combined with industrial and vehicle emissions result in both PM_{10} and SO_2 non-compliance in cities. In general, cities in the North China Plain are polluted with dust emitted from industry, roads, and construction. Northeastern and northwestern cities have better diffusion conditions and are mainly polluted with dust.

Pollution types of western cities

In the western non-compliant cities, PM_{10} mainly comes from natural sources such as dust from the desert. Eighty-five percent of western non-attainment cities exceeded the urban grade II standard for PM_{10}. These cities are located mainly in Gansu, Ningxia, Inner Mongolia, and Xinjiang. Fifty-two percent of them failed to meet the SO_2 standard.

Fifteen percent of western cities failed to meet the urban grade II standards for both SO_2 and PM_{10}. These cities are development cities with high populations densities—such as Urumqi, Yan'an, and Wuhai—that depend on coal utilization.

Pollution types of southern cities

The pollution situation in southern cities is complex. The southern cities can be divided into

FIGURE 3.11 Non-compliant Prefecture and Above Cities by Geographical Region

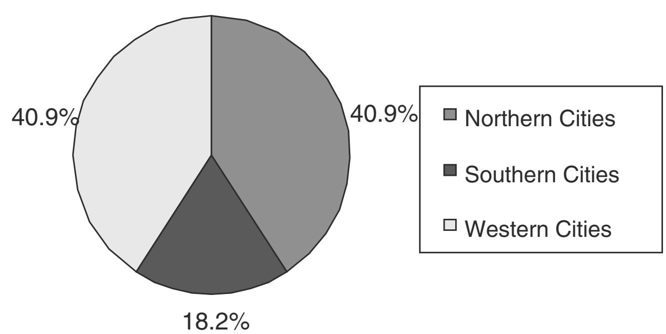
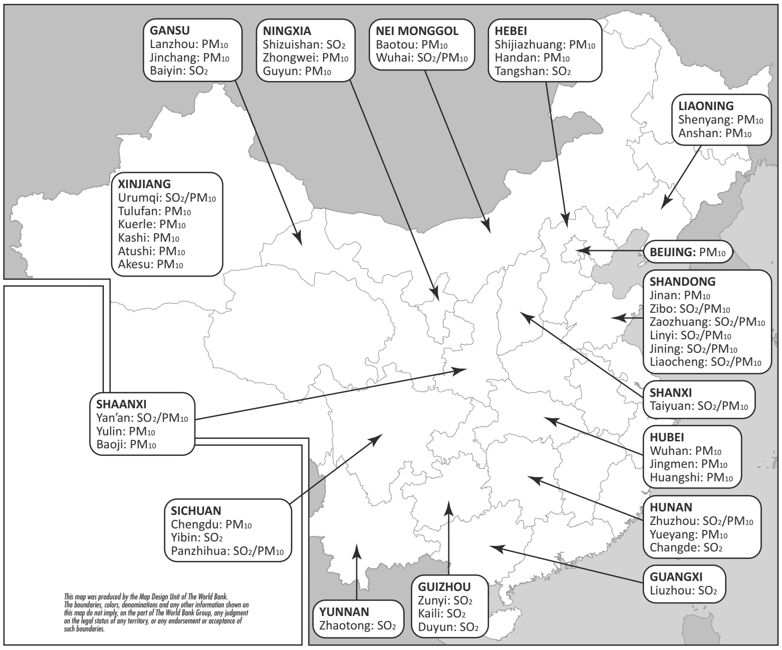


FIGURE 3.12 Spatial Distribution of Non-attainment Cities in 16 Provinces in China



Note: This figure includes the names of non-compliant cities in 16 of the 22 provinces with non-compliant cities at the prefecture level and above. Figure 3.9 includes all non-attained cities in dots.

two parts, southeast and southwest cities. Southeast cities, located in the Pan-Yangtze River Delta region, have developed industrial economies. Their PM_{10} pollution is caused by a combination of industrial and motor vehicle emissions. For example, Wuhan in Hubei Province and Yueyang in Hunan Province both failed to meet the urban grade II standard for PM_{10}. In 2009, cities of this type accounted for 34 percent of southern cities.

Cities in Guizhou, Yunnan, and Guangxi provinces—such as Zunyi, Zhaotong, and Liuzhou—and other southwestern provinces possess abundant energy and other resources, and rely mainly on energy extraction and resource processing as their pillar industries. This results in excessive SO_2. These cities account for 34 percent of non-compliant southern cities.

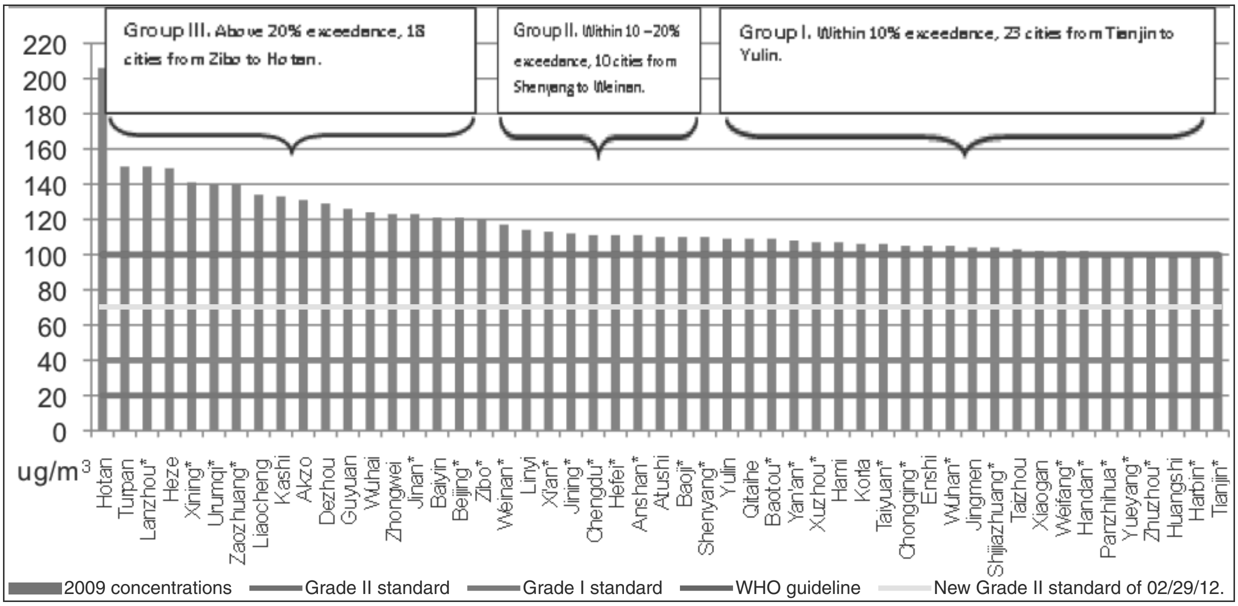
Figure 3.12 summarizes the above information.

3.4 DEGREE OF PM_{10} NON-COMPLIANCE[18]

The degree to which PM_{10} non-compliant cities—sixty-three of the 612 monitored

[18] Throughout this document, non-compliance is defined as having annual average concentrations above the grade II limit of 100μg/m³. Furthermore, in China, the officially reported air pollution concentration in a city always represents the average of the concentrations measured at all the monitoring stations in a city. All the concentration data presented in this report are such city-averaged concentrations. This means that there most likely are locations in the city where concentrations are higher or lower than the reported average. Compliance with standards in China is always based on this averaged concentration. This means that even if a city is reported as being in compliance, there are most likely areas in the city where the standards are exceeded.

FIGURE 3.13 Grade II Non-compliant Prefecture or Higher-level Cities, by Level of Non-compliance



* Indicates key city

cities—exceed the grade II limit varies significantly. This variation is examined for the fifty-one prefecture and higher-level cities where detailed data are available. Cities are categorized into three groups according to the percentage by which their 2009 annual average concentration measured exceed the grade II limit (Figure 3.13). This categorization informs the proposed PM_{10} compliance plan presented in Chapter 4.

Group 1 consists of twenty-three cities, including fourteen key cities, whose exceedance was less than 10 percent (Table 3.3) This group includes six cities that exceed the limit value by 1 percent and three by 2 percent. Thirteen of the key cities in this group—namely Baotou, Chongqing, Handan, Harbin, Panzhihua, Shijiazhuang, Taiyuan, Tianjin, Xuzhou, Yan'an, Wuhan, Yueyang, and Zhuzhou—recorded remarkable reductions of 20–140 μg/m^3 in average annual concentrations from 2003–09. Weifang, which was compliant in 2003–07, but exceeded the grade II limit in 2008 and 2009, illustrates the volatility of PM_{10} compliance.[19]

Group 2 consists of ten cities, including eight key cities that exceed the limit by 10-19 percent (Table 3.4). This category includes provincial capitals like Shenyang, Chengdu, and Xian that have resources and a demonstrated will to reduce PM_{10} pollution levels further. Among these cities, Shenyang, Weinan, and Xi'an achieved significant reductions of 23-64 μg/m^3 between 2003 and 2009; on the other hand, in Hefei and Jining the annual average concentrations actually increased.

Group 3 is made up of eighteen cities, including seven key cities, which exceed the limit by 20 percent or more (Table 3.5). This group

[19] See Annex 1 for annual average concentrations for all key cities for 2003–09.

TABLE 3.3 Prefecture-level and Above Cities That Are Less than 10 Percent Above the Class II Limit for PM_{10}

No.	City	Exceedance (%)	No.	City	Exceedance (%)
1	Tianjin*	1	13	Wuhan*	5
2	Harbin*	1	14	Enshi	5
3	Huangshi	1	15	Chongqing*	5
4	Zhuzhou*	1	16	Taiyuan*	6
5	Yueyang*	1	17	Korla	6
6	Panzhihua*	1	18	Hami	7
7	Handan*	2	19	Xuzhou*	7
8	Weifang*	2	20	Yan'an*	8
9	Xiaogan	2	21	Baotou*	9
10	Taizhou	3	22	Qitaihe	9
11	Shijiazhuang*	4	23	Yulin	9
12	Jingmen	4			

* Indicates key city

TABLE 3.4 Prefecture-level and Above Cities That Exceed the Grade II PM_{10} Limit by 10–19 Percent

No.	City	Exceedance (%)	No.	City	Exceedance (%)
1	Shenyang*	10	6	Chengdu*	11
2	Baoji*	10	7	Jining*	12
3	Atushi	10	8	Xi'an*	13
4	Anshan*	11	9	Linyi	14
5	Hefei*	11	10	Weinan*	17

* Indicates key city

includes provincial capitals such as Beijing, Urumqi, and Lanzhou. Many are located in Shandong Province, such as Zibo, Jinan, Dezhou, Liaocheng, Zaozhuang, and Heze. Some of the cities with the highest non-compliance rates—including Akzo, Kashi, Urumqi, Turpan, and Hotan—are located in the Xinjiang Autonomous Region. The situation is particularly dire in Hotan, where the annual average concentration was 206 ug/m^3 in 2009. In Beijing, Jinan, and Lazhou, from 2003–2009 the average annual concentrations decreased substantially, albeit with significant fluctuations. In Urumqi, Xining, Zaozhuang, and Zibo, the 2009 values exceeded the 2003 values, although grade II-compliant concentrations were observed intermittently during the period.[20]

[20] Less information is available about the twelve county-level cities that do not comply with grade II PM10 standards, therefore the study focuses on the prefecture and higher level cities.

TABLE 3.5 Prefecture-level and Above Cities That Exceed the Grade II PM_{10} Limit by 20 Percent or More

No.	City	Exceedance (%)	No.	City	Excedance (%)
1	Zibo*	20	10	Kashi	33
2	Beijing*	21	11	Liaocheng	34
3	Baiyin	21	12	Zaozhuang*	40
4	Jinan*	23	13	Urumqi*	40
5	Zhongwei	23	14	Xining*	41
6	Wuhai	24	15	Heze	49
7	Guyuan	26	16	Lanzhou*	50
8	Dezhou	29	17	Turpan	50
9	Akzo	31	18	Hotan	106

* Indicates key city

FIGURE 3.14 PM_{10} Annual Concentrations in 30 Provincial Capitals, 2009

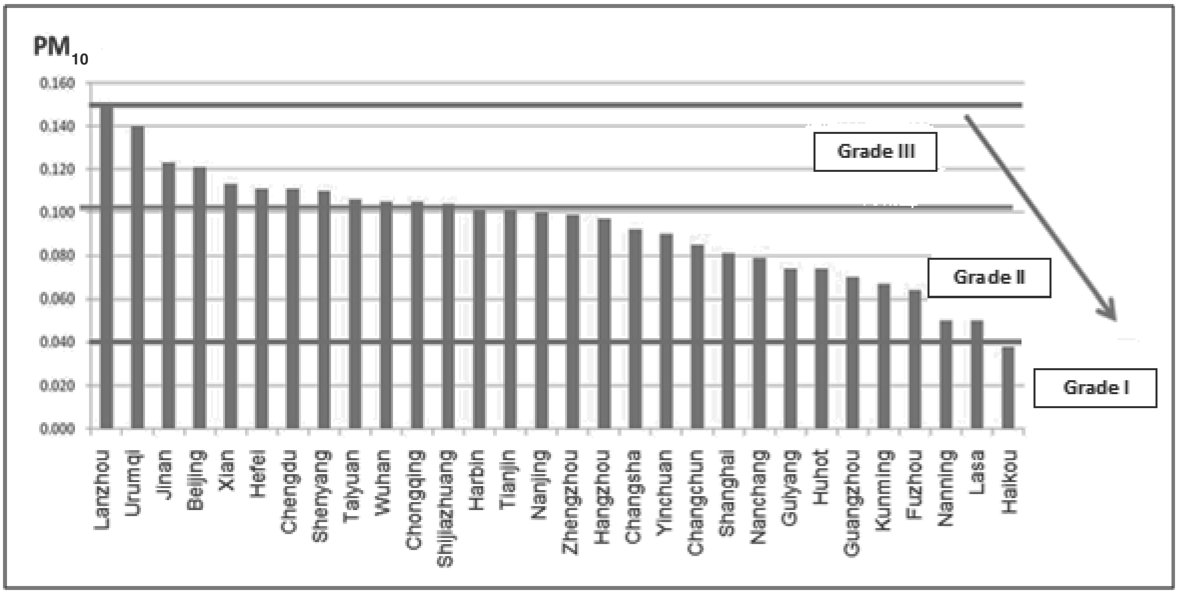
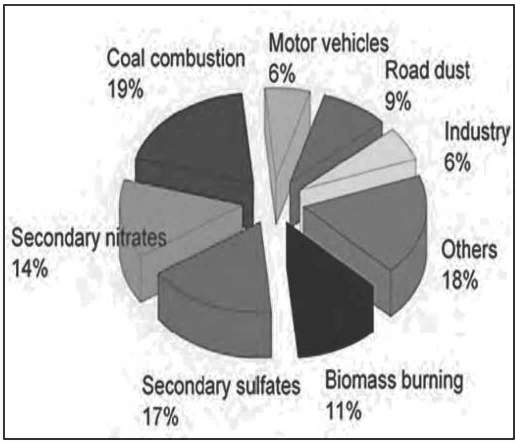


Figure 3.14 examines the thirty provincial capitals, which are a subset of the cities reviewed above. The ten cities having the highest concentration levels are located in the North and West. The ten cities with the lowest levels are with one exception located in the South. The exception is Huhot, the capital of Inner Mongolia. Cities of Inner Mongolia face adverse air pollution conditions, including high levels of dry dust, but data reported from monitoring stations in Huhot show that it is possible to make progress despite adverse conditions.

Sources of PM_{10} pollution in the eighteen Group 3 cities of high non-compliance

Even when the scope is narrowed down to the eighteen cities of high non-compliance, the air pollution situation in terms of PM is quite diverse. Beijing is seeing more and more vehicle pollution and secondary PM formation, although there is a multitude of source categories there, such as biomass burning (Figure 3.15). The cities of Shandong Province are facing problems of combined PM_{10} and SO_2 non-compliance. This is a province of heavy coal mining, as well as heavy industry based on coal mining. The cities of the Western region—such as the cities of Xinjiang Autonomous Region mentioned above, Gansu Province (Baiyin, Lanzhou), Ningxia Autonomous Region (Zhongwei), and Inner Mongolia (Wuhai)—are facing the issue of suspended dry dust from natural causes, which adds to the man-made pollution problem.

FIGURE 3.15 Source Apportionment of $PM_{2.5}$ in Beijing



Source: Song et al. (2006). The data used are prior to 2006. Since then, motor vehicle pollution has increased dramatically in Beijing. Note also that the study is on $PM_{2.5}$. Still, it has relevance for PM_{10} as well as being relevant in its own right.

Despite differences, there are also similarities. From the source apportionment material above, it is clear that coal combustion is a common source of PM in northern and western cities, most probably including all the eighteen in serious non-compliance. Moreover, secondary PM particles are important to control, both because they are an emerging source and because they constitute a disproportionate share of the smallest particles (Figure 3.15).

Although suspended dust from natural causes is a problem mainly for the West, the issue of construction dust and road dust is a problem in most of the non-compliant cities. However, suspended dust is high in coarse PM fractions. This gives measures to reduce suspended dust a handicap in terms of effect, since coarse PM has a smaller health effect than $PM_{2.5}$. This has a bearing on cost-benefit assessments of measures (see Chapter 4).

Finally while industrial sources are perhaps most prominent in Shandong Province, they are found in all the non-compliant cities. While coal combustion in heavy industry is part of the coal combustion category, the production processes of heavy industry are an independent source of particle emissions that must be taken seriously. As we have seen earlier in Chapter 3, industrial particles are rich in metallic particles, many of which are considered harmful.

3.5 THE STATUS OF URBAN $PM_{2.5}$ POLLUTION

Research on fine particles in about twenty cities indicates serious $PM_{2.5}$ pollution in urban areas. Annual average $PM_{2.5}$ concentrations are 80–100 μg/m³ in cities such as Beijing and surrounding provinces, which is 5–6 times higher than the corresponding U.S. standard of 15 μg/m³. Concentration levels reach 40–70 μg/m³ in southern regions, which is 2–4 times higher than the U.S. standard. In cities that are not part of the fine particle research program, applying the average $PM_{2.5}/PM_{10}$ ratio (0.70) to measured PM_{10} concentrations suggests that in almost all cities the estimated $PM_{2.5}$ concentration would be much higher than the U.S. standard of 15 µg/m. In thirty-seven major cities, it would exceed 70 µg/m^3.[21] Simulation results from an air quality model showed that the $PM_{2.5}$ concentration is relatively high on a large geographical scale, which is typical of regional pollution.

These estimates provide a rationale for the need to develop a $PM_{2.5}$ monitoring and control program, and to not limit the $PM_{2.5}$ control program to the local (city or metropolitan) scale, but to expand the control efforts to the regional scale.

The development of the concentrations of $PM_{2.5}$, which is the PM fraction of PM_{10} that has the largest impact on health, is not known, since long term monitoring data are lacking. Still, most of the PM_{10} control options used in China should also bring $PM_{2.5}$ down in most places.

[21] Measurements have shown that in Chinese cities the $PM_{2.5}/PM_{10}$ ratio varies considerably between 0.28 and 0.89, with an average of 0.70 (see Section 5.2).

4

The Proposed PM_{10} Compliance Plan

4.1 OBJECTIVE, SCOPE, AND TIMEFRAME

The proposed compliance plan aims to guide PM_{10} non-compliant cities in preparing plans to reach the air quality targets specified in the 12th FYP, the State Council Notification and draft Administrative Measures, which are discussed in chapter 1 and summarized in Table 4.1. Specifically, the 12th FYP stipulates that by 2015, 80 percent of all prefecture and high-level cities will comply with overall grade II. While this target was already met in 2009 with regard to PM_{10}, it is important that even compliant cities maintain their status. In fact, the 2010 State Council Notification requires that cities continuously improve their ambient air quality. In other words, cities that have already met grade II standards are to continue to reduce their concentrations within the grade II range and strive to meet grade I standards. Reaching grade I would bring such cities on a par with EU cities (Table 1.3 in Chapter 1). The State Council Notification also requires that the nine key regions it defines meet or exceed grade II standards. The draft Administrative Measures of 2011 specifies timed targets for the key cities—80 percent are to comply with grade II by 2015 and 100 percent by 2020.

TABLE 4.1 Grade II (and higher) Compliance in 2009 and Targets for 2015 and 2020†

		Grade II compliance status (2009)		*Composite* grade II compliance targets		
		PM_{10}	Composite*	12th FYP	State Council Notification (2010)	Administrative Measures (Draft, 2011)
Monitored cities	612	549 (89.7%)	504 (82.4%)*			
Prefecture and higher level	320	269 (84.0%)	255 (79.6%)**	80% by 2015	9 key regions to meet or exceed grade II standards; grade II compliant cities to continuously improve within grade II and then meet grade I	
County level	292	280 (95.9%)	250 (85.6%)			263 (90%) by 2015 292 (100%) by 2020
Key cities*	113	83 (73.5%)	76 (67.3%)***			90 (80%) by 2015 113 (100%) by 2020

* Composite grade II includes annual average standards for PM_{10}, SO_2, and NO_2. * Incl. 4.2% grade I. ** Incl. 3.7% grade I. *** Incl. 0.9% grade I.

† Note that this table is based upon GB 3095–1996 and not on the new GB 3095–2012, see Annex 6.

While the proposed compliance plan focuses on PM pollution abatement, air quality management should be carried out in a multi-pollutant fashion, applying controls that address multiple pollutants and effects simultaneously. Experiences in the United States, Europe, and other parts of the world have shown that single-pollutant abatement is arduous and inefficient. Furthermore, even though the proposed plan's focus is on urban PM pollution, it also recognizes and provides advice about the growing importance of regional pollution both as a result of some urban air quality measures and as a factor influencing urban air quality.

The non-compliant key cities' levels of present exceedance over the grade II limit—coupled with their trend in the 2000s (chapter 3)—suggests the likelihood of their attaining compliance with grade II during the 12th FYP period. This information also helps city authorities in selecting abatement measures. In general, Group I cities appear to have a good chance to attain grade II compliance for PM_{10} by 2015 by adopting the most technically and economically feasible abatement option(s) (below).

For some of the Group II cities, it may be a challenge to reach grade II by 2015. In such cases, they may need additional time up to 2020 to comply and will need technical assistance in preparing economically efficient air quality management plans. Substantial regional-level measures may also be needed for achieving compliance. In Group III cities, the severity of the situation requires immediate application of abatement measures with proven effectiveness in China. Additional abatement measures may also need to be considered and should be prioritized based on cost-benefit analysis and the different sources. Furthermore, measures that reduce regional PM pollution—involving joint action with neighboring jurisdictions—would likely help reduce urban PM concentrations. The severity of the situation and set-backs experienced suggest that compliance by 2015 is unlikely, and a target date of 2020 would also require significant technical assistance.[22]

Given time and resource limitations, it is advisable to focus assistance on cities that are furthest away from compliance and perhaps have insufficient resources. However, the suggestions on cost-effective measures and policies provided in this plan are general in nature. Relevant measures and policies may be adopted by any city, including those that have achieved grade II compliance and seek to further reduce PM concentrations, as mandated by the State Council Notification.

4.2 THE ANALYTICAL AIR QUALITY MANAGEMENT APPROACH

Air pollution reduction measures must be tailored to each city's specific source structure and air pollution characteristics, economic and capacity constraints, and population conditions. This study recommends the air quality management (AQM) approach to identify the technically, financially, economically, and socially most feasible control options for a particular city within the compliance program. Urban air pollution control plans mandated by the 2000 Air Law and the 2010 State Council Notification (chapter 1) are best developed on the basis of AQM analysis.[23]

AQM is a structured approach to (a) continuous assessment of air pollution levels; (b) the

[22] Even when overall compliance in a city reaches compliance according to city-wide concentration averages, some areas may continue to experience concentrations that exceed the compliance limit.

[23] Useful references with details and examples of AQM analysis include:
1) The integrated air quality management concept is described in detail in the Urban Air Quality Management Strategy in Asia Guidebook (World Bank, 1997): http://books.google.com/books?id=9G0c7d_nQcEC&pg=PA8&lpg=PA8&dq=urbair+guidebook&source=bl&ots=9pUtYHlKot&sig=ZlwtkH1m3KqY2OfO3AByz6Zatb0&hl=en&ei=B34SSu2SEI-ysgaus5mFDg&sa=X&oi=book_result&ct=result&resnum=1#PPP1,M1 and 2) World Bank, 2011. "Mongolia – Quality Analysis of Ulaanbaatar. Improving Air Quality to Reduce Health Impacts," Sustainable Development – East Asia and Pacific Region Discussion Papers Series.

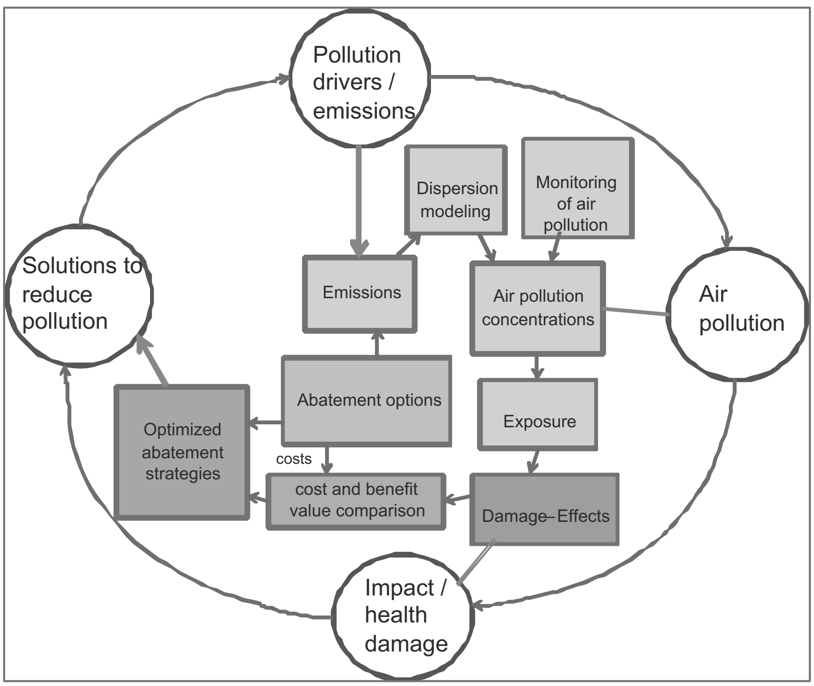
contributions from various sources to ground-level concentrations; (c) their effects on the population from exposure to damaging air pollution; (d) scenarios of the future development of the city, its activities, and impact on the air pollution situation; (e) identification and prioritization of feasible, cost-effective mitigation strategies; (f) implementation; and (g) monitoring and evaluation for continuous readjustment and improvement (Figure 4.1).

In the context of AQM in an urban area, it is important to account for air pollution concentrations in the air entering the city. This can be done either by measuring the concentrations at one of more monitoring stations outside the urban area in locations that are not affected significantly by the city's own emissions. Air pollution modeling for a larger region surrounding the city can also be used to assess the regional air pollution component. The regional concentrations are entered into the urban model as "background concentrations." The concentrations resulting from the city's own emissions are added to this background level.

Elements of the analytical AQM approach include:

- Assessment of air quality and its distribution and variations
- Assessment of the environmental and health damage caused by air pollution
- Development of scenarios for future development of activities and subsequent impact on the air pollution situation
- Assessment of technically feasible pollution abatement options
- Using economic analysis, comparing costs of the abatement options with the resulting reduction in damage costs
- Selection of the best abatement options
- Strategy development for optimal control of pollution
- Follow-up of the pollution control plan to ensure compliance and success

FIGURE 4.1 General Concept for Development of Cost-effective Air Quality Management Strategies



The AQM process begins with an inventory and analysis of emission sources, including scenarios for their future development. Next, a dispersion model incorporating the inventory and climatic data is applied and calibrated against monitored air pollution data to assess the present air pollution state and distribution and to estimate the impact on pollutant concentrations and population exposure of technically feasible air pollution control options. The modeling should take account of the regional pollution level caused by sources outside the modeled area. The population-weighted exposure related to each intervention is determined by overlaying a map of concentration impacts on a map of population density. Such exposure data are used to estimate improvements in public health and other environmental benefits due to each intervention, such as improved visibility, reduced corrosion, higher crop yields, reduced cleaning needs, reduced water body eutrophication, and climate change mitigation. Benefits may also include savings due to higher efficiency in energy and raw material use in industrial processes. The benefits are then quantified in monetary terms and compared with the costs of each intervention. Both benefits and costs should be assessed over the operational life time of the control option.[24] A simpler form of ranking of control options can be carried out when benefit analysis (e.g. health effects estimates) is not available. This approach is based on cost-effectiveness: The costs of the available control options are compared to the reduction they provide in the pollution concentrations, best determined as a reduction in population-weighted average concentration. The best options are those giving the largest decrease in exposure per unit of control cost.

The interventions with the highest net benefits—benefits minus costs—or highest cost effectiveness are selected as the best options, and then analyzed in terms of their technical, financial, and social feasibility.

The follow-up to the air pollution control plan—conducted at regular intervals—can ensure that it produces the expected results and must be an integrated component of the control plan.

4.3 MENU OF POSSIBLE PM ABATEMENT OPTIONS

This study reviews possible PM abatement options in the light of key sources of PM_{10} pollution in Chinese cities. The options can be grouped in four categories: (1) demand-side management measures and industrial restructuring; (2) cleaner technologies, including cleaner fuels, where the industrial production, energy generation or heating process creates less emissions; (3) end-of-pipe measures that abate emissions generated in an industrial, power, or heat generation process; and (4) other options that address mainly suspended dust from non-point sources (Table 4.1).

These options can be applied on a city as well as regional basis. In cases where regional pollution is of significant concern, enlarging the scope of planning from the city level to the regional level may be more effective and efficient than focusing on the sources in a city to reduce urban pollution concentrations.

The following sections discuss these options with a focus on efficiency and effectiveness in the light of available international and Chinese evidence. However, the effects and benefits of any particular control measure will differ among cities. What counts as an effective measure in one city may not be the best in another city. Therefore, a benefit-cost or cost-effectiveness analysis based on AQM is indispensible prior to

[24] It is important to distinguish between economic analysis and financial analysis. The analysis outlined is an economic analysis, in that all costs and benefits accrue to the society as a whole. Costs and benefits accruing specifically to the owner or operator of a plant are part of a financial analysis. Treating economic benefits or costs as financial items and vice versa can lead to misleading results and should be avoided.

TABLE 4.2 Summary of Some PM Reduction Options

Demand-side management and structural measures	Cleaner technology and fuel	End-of-pipe control	Other
Phasing out inefficient plants, inefficient industrial boilers, and small-scale coal combustion	Increased use of natural gas for energy and heat generation	Increased use of technologies such as FDG, SCR, and ESP in industrial and power plants	Measures to reduce dust from natural areas, such as increasing vegetative cover
Moving heavy industry and power generation plants away from city centers*	Increased use of low-sulfur and low-PM coal, and, where possible, of clean coal and briquettes	End-of-pipe controls for motor vehicles	Construction site management for dust abatement
Expanding coverage of district heating	Increased energy and process efficiency in industry		Reducing dust from roads
Greater use of public transportation	Improved engine technology for motor vehicles		
	Improved stoves for biomass burning		
	Improved energy efficiency in buildings		

* This measure will redistribute regional PM pollution and increase it in some places.

determining local regulations and investment programs.

Recommendations on policy instruments—including command-and-control, economic, and awareness raising and voluntary instruments—that support the adoption of these abatement options are provided in Section 4.5.3.

4.3.1. Demand-side management and structural measures

Demand-side and structural measures refer to interventions that aim to change the demand for processes that lead to pollution. Such processes include inefficient power and industrial production; large point-source power generation and industrial production in urban centers; popular reliance on individual modes of transportation, generating a plethora of non-point pollution sources; and heat and energy generation on residential and industrial units, leading to an "urban forest of smokestacks." The proposed measures reduce the prevalence of these processes in the industrial and energy generation structure of the economy.

Phasing out inefficient power generation and industrial plants. Phasing out inefficient plants in the power generation, iron and steel, nonferrous metals, petrochemical, and chemical sectors is a priority and could help lower PM concentrations during the 12th FYP period if carried out early and on a large scale.

Small plants are often the worst offenders in terms of air pollution and therefore are a high priority for phaseout. Small thermal power units with an installed capacity of 200 MW or less still constitute a very important part of China's thermal power industry. Due to their high coal consumption, high levels of pollutant emissions, and since they are nearing the end of their service life, these small units should be the focus of a sectoral restructuring. Small industrial boilers should be encouraged to close down in order to achieve emission reductions or switch to natural gas (below). At the end of 2008, there were 568,000 in-service industrial boilers in China that consumed 670 million tons of coal per year and accounted for 24.8 percent of national coal consumption, second only to the thermal power industry. Most of these boilers have low steam capacity and no up-to-date pollution control equipment.

Research indicates that the financial costs of operating an inefficient plant may be higher than the sum of the operating and capital costs of a replacement plant. Under such circumstances, it is more profitable for the owner to replace the old unit with a more efficient new unit. Profitable possibilities have been found within China's population of industrial boilers (Fang et al. 1999; Aunan et al. 2004) and power plants (Cao et al. 2009a).

Moving heavy industry and power generation plants away from city centers would also reduce PM concentrations in cities by the end of the 12th FYP period if initiated early during this period. Li et al. (2004) estimate that the health benefits from banning industrial coal use from the urban area of Shanghai and partial relocation to neighboring counties are larger than the costs of this measure. However, relocation would redistribute regional PM pollution and increase it in some areas close to the relocated plants, unless the plants meet emission standards by adopting cleaner technologies or end-of-pipe control methods (see below).

Expanding the coverage of district heating. District heating, including heating for residential use as well as industrial use, should be strengthened. Mestl et al. (2005) show for the case of Taiyuan that coal-based, but more efficient district heating is highly cost effective.

Promoting greater use of public transportation. Greater availability of affordable and convenient public transportation, such as subway and bus rapid transit, would encourage more people to use these means as opposed to private transportation. In the long term, cities with a population of more than 1 million should consider building a subway system. Subways are capital intensive to build, but extremely effective in transporting large numbers of people in densely populated cities.

4.3.2 Cleaner technology

Measures listed under this heading aim to reduce pollutant emissions through the use of cleaner energy sources or more efficient processes for energy generation, industrial production, and in motor vehicles. Energy-efficient heating in buildings is also listed under this heading. Measures promoting energy efficiency in different sectors of the economy also reduce demand for energy which in turn will reduce pollution caused by energy generation.

Increasing the use of natural gas for energy and heat generation. Mao et al. (2005) show for the case of Chongqing that promoting natural gas as a substitute for coal in densely populated urban areas can entail environmental benefits that outweigh the investment costs. There is also a case for switching from inefficient industrial boilers to natural gas boilers. However, the cost-benefit ratio of this type of intervention strongly depends on local conditions, including whether the city in question has the infrastructure in place to supply natural gas. In case long-distance gas pipeline systems have to be constructed—as is the case for Beijing (Mao et al. 2005)—the cost-benefit ratio tends to be less favorable.

Cao et al. (2009b) estimate the environmental benefits inherent in lower coal consumption, and similarly for consumption of oil and gas. They make use of a large data set of power plants and industrial sources in different locations, in combination with epidemiological research and environmental economic data. They conclude with an "enormous" 53.5 cents of damage per yuan of coal burned, which amounts to 3–4 yuan in damage per yuan of coal burned. The price of coal may have increased since the base year 2002 of this research, but the benefit of reducing emissions from coal still seem quite extraordinary. Primary and secondary PM are the main sources of benefit. Regarding oil and gas, Cao et al. (2009b) find that damages from oil are 0.2 yuan per yuan of oil burned, and damages from natural gas are negligible. These results are like a measuring rod by which to compare costs of suggested measures to reduce emissions from coal and also oil. The extension of a natural gas grid, for instance, involves a substitution of gas for coal that may have environmental benefits of 3–4 yuan per yuan in volume.

Measures that utilize waste gas for electricity production also tend to be financially profitable. The condition here is that the value of electricity production exceeds, in discounted terms, the investment cost and any operations and maintenance costs associated with the measures. Mestl et al. (2005) identify financially profitable measures utilizing waste gas in a huge iron and steel plant in Taiyuan. London et al. (1998) and Aarhus et al. (1999) identify possibilities within the textile and paper industries.

Increasing the use of clean coal. Clean coal is a broad category that covers everything from simple measures like cleaning and briquetting of coal to capital-intensive investment such as in district heating systems and integrated gasification combined cycle technology. There are variations in cost-benefit ratios among the measures, but the general message is that they pass the cost-benefit test in almost any city. Cleaning and briquetting of coal can reduce PM and SO_2 by as much as 35–40 percent and have a positive net benefit (Aunan et al. 2004; Mestl et al. 2005; Li et al. 2004). Their effect will be felt immediately. Other means of enhanced steam coal preparation that reduce boiler pollution, particle emissions, and smoke pollution should also be considered.

Increasing energy and process efficiency in industry. This includes improving whole-process management of a recycling economy, recycling and reusing waste heat from new dry process kilns, and using waste heat for power generation. Measures that utilize waste gas for electricity production also have a tendency to be financially profitable. The condition here is that the value of electricity production exceeds, in discounted terms, the investment cost and any operations and maintenance costs associated with the measures. Mestl et al. (2005) identify financially profitable measures utilizing waste gas in a huge iron and steel plant in Taiyuan. London et al. (1998) and Aarhus et al. (1999) identify possibilities in the textile and paper industries. Measures to improve insulation and improve building standards have also been shown to be financially profitable (McKinsey & Associates 2007). Such measures help improve the energy efficiency of buildings and reduce energy demand.

Improving stoves for biomass burning. Biomass burning in inefficient stoves is a significant source of PM_{10}, and probably a larger source of $PM_{2.5}$. Improving stoves entails huge health gains for the rural population and is highly beneficial in a cost-benefit sense (Sinton 2004; World Bank 2007).

4.3.3 End-of-pipe technologies

End-of pipe technologies are "conventional" pollution control methods that aim to reduce emissions at the end of a production process rather than modifying the process itself or the inputs. They include (a) dust removing technologies in power generation and industry; and (b) end-of-pipe controls for motor vehicles.

Dust removing technologies in power generation and industry. Dust control is a priority for cement, iron and steel, power plants, and industrial boilers. End-of-pipe dust control technologies have high benefit/cost ratios and an immediate effect on emissions. Electrostatic precipitators (ESPs), along with flue gas desulfurization (FDG), which prevents secondary PM formation, were aggressively implemented and significantly contributed to the general PM concentration reduction across China during the 2000s (Box 4.1). Research suggests that most conventional measures in China have higher environmental benefits than costs (below).

Ninety-five percent of the thermal power plants in China now employ ESPs, which are at least 98 percent efficient and limit the concentration of particulate emissions to below 50 mg/m^3. Vennemo and Yan (2008) found that ESPs have benefits 60 times higher than costs.

There is scope for introducing ESPs on industrial boilers that presently use cyclones for PM abatement. Industrial boilers with an output of less than 10 t/h are usually equipped with single and multi-cylinder cyclones; those with an output of more than 10 t/h are partially equipped with multi-cylinder cyclones or wet dust collectors. With a dust removing efficiency of less than 80 percent, these cyclones and collectors cannot satisfy the requirements of environmental management and must be upgraded for the purpose of enhancing efficiency.

At present, only some of the coal-fired plants use bag filters and electro-bag combined dust collectors. As the dust emission standards of the thermal power industry become more stringent, the dust removing devices of many power plants fail to meet the requirements of a new standard (30 mg/m^3) and need to be upgraded for the purpose of enhancing efficiency.

New Suspension Preheater (NSP) dry process cement production lines are mainly provided with bag filters, and only a few continue to use electrostatic dust collectors. Seventy-eight percent of the sintering (pelletizing) equipment used in the steel industry employs electrostatic dust collectors, and 10 percent of them are equipped with bag filters. To comply with the new emission standards, the steel industry is now facing the challenge of upgrading dust collectors.

Flue gas desulfurization (FDG). SO_2 is a precursor to secondary PM, therefore its abatement will contribute to PM_{10} reductions. FDG is now established on a large number of power plants, but further expansion is possible in power generation and industrial plants. Cao et al. (2009) found that the environmental benefits associated with FDG are about ten times larger than the costs. However, use of extremely low-sulfur coal (a cleaner fuel) is another option where such coal is available (above). The decision on which option to adopt should be based on the ratio of environmental and other benefits over costs.

Selective Catalytic Reduction (SCR). Being a precursor to secondary PM, NOx is important for the PM compliance plan. SCR and other NOx control technologies are commercially available. While SCR was previously considered too expensive for Chinese conditions (Xu et al. 2007), its combined impact on NOx and PM reduction may make its application economically feasible in power generation and industrial plants.

An additional benefit of ESP, FGD, and SCR is the reduced emission of other compounds, notably mercury and black carbon.

Annex 5 analyzes the investment costs of various dust collectors.

4.3.4 Other measures

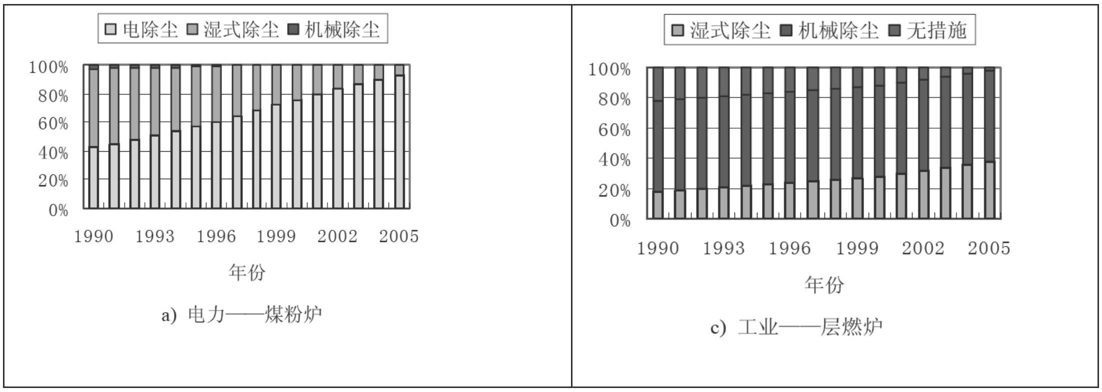
This category includes measures that do not fit under the previous three groups but are of significant relevance for combating PM pollution from natural sources, construction sites, and roads.

Control of suspended dust from natural sources. Low-cost measures with potentially noticeable effects over a five-year period include planting and increasing vegetation cover in rural and bare urban areas. The effects of vegetation improve over time. Agricultural practices that lead to higher dust levels—including overgrazing on

BOX 4.1 Application of end-of-pipe technologies in power plans and industry since the 1990s

End-of-pipe technologies for power plants and industry have been important in China's air quality management over the last decade. Since 2003, the control of pollutants emitted from power plants has been strengthened. Over 99 percent of new coal-burning power plants are equipped with a dust collection system. Many coal-burning power plants were equipped with electrostatic precipitators (ESP) or fabric filter systems.

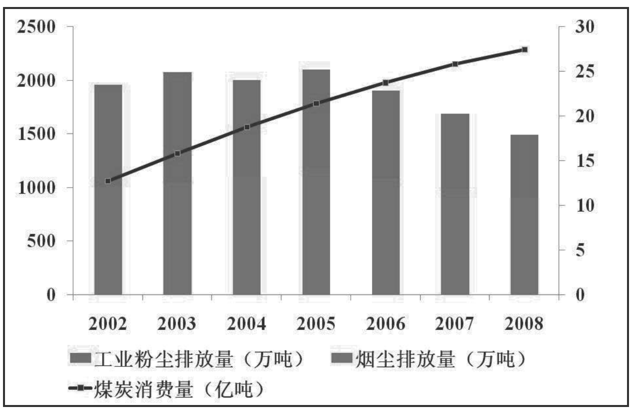
Increased Coverage of PM Removal Technologies in a) Coal-fired Power Plants and b) Industries



Note: For power plants: Electric, wet air, and mechanical dust removal. For industry: wet air, mechanical, and no measure of dust removal

Compared with 2003, the installed capacity of thermal power plants increased by 67.1 percent and electricity generation increased by 49.3 percent by the end of 2006, while dust emissions increased by only 12.1 percent. Dust emissions dropped from 2.1 g/kWh in 2003 to 1.6 g/kWh in 2006. The 2003 and 2005 levels represented a peak. Since then, although coal consumption has sharply increased, emissions of industrial dust and soot were constantly reduced.

Trends in Dust (red), Smoke (blue), and Coal Consumption (black line)



the western plains, plowing on hilly terrain and during high winds, tillage, and open burning of straw, hay, and other foliage—should be avoided.

Control of suspended dust from roads and construction sites. Simple, low-cost measures with an immediate effect include cleaning of roads with effective machinery (should be better than regular sweeping machines) and covering of construction areas.

4.3.5 Options for high-priority cities

Among the abatement options—phasing out of inefficient plants, boilers, and small-scale coal combustion; moving point-source industry and power plants away from urban centers; enhancing district heating; increasing natural gas use; use of low-sulfur and low-PM coal, clean coal, or briquettes where possible; and construction and traffic dust control—are options that have proven effective in China in significantly reducing PM concentrations. In particular, widespread switching to natural gas is a short-term measure, provided that the necessary infrastructure is in place. The feasibility of the options should be investigated immediately for short-term implementation in the eighteen Group III cities.

4.4 POLICY AND REGULATORY FRAMEWORK

4.4.1. Recommendations for policies and regulations

The following general polices are recommended to support the proposed PM_{10} Compliance Plan.

Continuous PM Reduction. As prescribed by Article 22 of the *State Council Announcement No. 33 on Improving Regional Air Quality through Joint Prevention and Control Measures* (2010) ("The State Council Announcement"), coordinated city and central government management to promote continuous reduction of PM concentrations in cities is essential. This applies not only to cities that do not yet comply with urban grade II standards and must prepare compliance programs to reach this grade, but also to cities that are already in compliance with urban grade II. The latter cities should strive to reduce their PM concentrations and reach grade I status. Administrative and technical guidelines should be promulgated as soon as possible to guide cities in this process. Forming city-level "leading groups on air pollution control" (see subsection on institutional coordination) will contribute to this effort.

Regional PM Reduction. As prescribed by Article 4 of the *State Council Announcement,* launch regional air pollution prevention and control efforts in key areas—including Beijing Hebei Tianjin region, the Yangtze Delta, Pearl River Delta, Central Liaoning, Shandong Peninsula, Wuhan and surrounding regions, Changsha, Zhuzhou and Xiangtan region, Chengdu, Chongqing and surrounding areas, as well as areas around the Taiwan Strait (including Xiamen). As suggested in the *State Council Announcement*, this will require review by local governments of nonlocal sources of PM pollution and collaboration among local governments to prepare joint prevention and control programs.

Economic Instruments. Abolish fuel subsidies, especially on dirty coal, and increase air pollution charges or tradable quotas so industrial thermal power plants have incentives to invest in cleaner technologies and fuels, energy efficiency, or end-of-pipe control measures. Consider a fuel tax and offer affordable and convenient public transportation to discourage increased use of private transportation.

NO_x Management. Initiate comprehensive NO_x management, as lower NO_x emissions decrease secondary PM formation.

Co-control of Greenhouse Gases (GHG) and Conventional Air Pollutants. Air pollutants and GHGs mainly derive from fossil fuel combustion. For instance, air pollution and GHGs share the same source in motor vehicles, power plants, and other industrial activities. Therefore, the control measures targeting air pollutants can be the same as those targeting GHGs, such as energy structure adjustment, sector structure adjustment, and clean-coal technology. Controlling fine PM also reduces soot and its related climate forcing capabilities (decreased deposition on Himalayan glaciers).

In capital investment decisions or for production or emission abatement, power plants and industrial enterprises should consider the impact on both GHG and conventional pollutants. As research in China has shown (Aunan et al. 2004; Mestl et al. 2005), public health benefits associated with the reduction of conventional pollutants—such as PM, NO_x, and SO_2—may exceed the cost of a highly expensive GHG control technology. In such instances, plants would benefit from reduced pollution charges. Conversely, plants that wish to invest in reducing conventional air pollutant emissions may opt for a technology that also reduces GHG emissions, which could earn them carbon credits.

Specific policy options for co-control include:

- Prepare a co-control strategy during the 12th FYP period. Special attention should be paid to coordinating efforts to control black carbon, NO_2, CO_2, and conventional air pollutants. The strategy should include GHG density monitoring, emission statistics, coordination domains, control policy formulation, and technical research and development.
- Demonstrate co-control measures in low-carbon city initiatives.

Strengthen the Strategy Research of Regional Composite Air Pollution Control. Systematically develop pollution monitoring, damage evaluation, forecast and alarm measures, and research into regional control systems and pollution mechanisms in order to provide a technical foundation for the future healthy development of China's cities. Build scientific air quality standards and target systems to shift the emphasis from single pollutant control to the control of multiple pollutants, especially ozone and fine particles. Under the specifically defined air quality targets, establish co-control technical options for multiple pollutants. Gradually establish regional coordination mechanisms and management practices. Carry out experiments in Beijing and surrounding provinces and cities, the Yangtze River Delta, and the Pearl River Delta in order to study how to effectively organize regional coordination and policy making of air pollution control among different administration units. These areas are also identified in the State Council Announcement No. 33.

4.4.2 Comments on the draft *Administrative Measures and Technical Guidelines*

This section presents the study team's recommendations to improve the draft Administrative Measures and Technical Guidelines. Introductions to these draft documents are to be found in Annexes 2 and 3 of this report.

Comments on the draft *Administrative Measures:*

1. Incorporate the concept of integrated management of local/regional pollution and greenhouse gas emissions (Articles 9 and 17).
2. Consider banning practices, notably open biomass burning, that generate health damaging fine PM particles (Article 10).
3. Emphasize the correct sequence and complete application of the AQM approach. Importantly, analysis of the costs, pollutant reduction impacts of abatement options in terms of reduced health and environmental damage, and monetary benefits of available technical options are an integral part of the AQM process that help determine the most economically feasible intervention (Article 18).
4. Incorporate testing and evaluation of air pollution models (Article 32).
5. Clearly state the link between the analytical AQM process and the total load control process (Articles 37 and 18).
6. Include provisions for making monitoring data available to the public in near-real time, to enable the public to evaluate their individual needs to protect themselves against high air pollution, including PM.

Comments on the draft *Technical Guidelines (see introduction in Annex 3):*

1. Mention the concept of co-control (chapter II).
2. Regarding design of the monitoring system, develop monitoring network design recommendations and review the monitoring network (chapter V).
3. Regarding the emission inventory, include all sources such as domestic/small enterprises. PM, "smoke," and "dust" should be measured in terms of particle fractions, such as $PM_{2.5}$ and PM_{10} (Chapter V).
4. Regarding air pollution modeling, state the need for model testing and evaluation. While the choice of models should not be restricted, the chosen models must be evaluated and tested. Consider using population-weighted exposure methodology by combining the modeled air pollution distribution with the population distribution (Chapter V). Incorporate the concept of regional scale in the modeling efforts.
5. Clarify the steps of the analytical AQM process and include at the beginning of Chapter V ("Tasks and Technical Method") a list of the following steps of the AQM analysis:
   i. Assessment of the present situation, the "base case"
   ii. Analysis of the forecasted development, which includes present policies and regulations and the "base line"
   iii. Selection of feasible control options and scenarios
   iv. Cost effectiveness analysis of the selected options and scenarios
6. Incorporate the notion of ongoing evaluation of progress toward goals and adjustments as needed.
7. Consider including "energy efficiency" in the menu of possible abatement options.

4.4.3 Institutional coordination

The Technical Guidelines (see introduction in Annex 3) require the establishment of a cross-institutional leading group on air pollution control that assembles relevant departments, bureaus, enterprises, and other stakeholders into one unit. The government may consider the following suggestions regarding the leading group:

A deputy mayor should head the leading group.[25]

The leading group should be composed of representatives from all departments and sectors under the municipal government that are responsible for sectors linked to PM pollution, including construction, transport, industry, and power. This composition would improve horizontal coordination and cooperation in the municipal government.

An office should be established in the city environmental protection bureau to act as the secretariat of the leading group.

Some Initiatives that the leading group could coordinate include district heating; public transport; co-generation, SO_2 abatement, energy efficiency, and clean coal in the power sector; energy efficiency in buildings; road dust and construction site management; public awareness of preventive measures against air-pollution related illnesses; efforts to address regional pollution; and monitoring of fine particles.

4.4.4 Recommendations on policy instruments to support priority PM abatement options

This section presents a summary of policy instruments, including command-and-control, economic, and voluntary instruments that may be used in support of PM abatement measures discussed in Section 4.3.

[25] In the case of the eighteen cities that are more than 20 percent above the class II mark for PM_{10}, consider having a mayor heading the leading group.

	PM Abatement Option	Command and Control Instruments	Economic Instruments	Awareness Raising, Voluntary and Other Instruments
Demand Side and Structural Measures	Phase out inefficient industrial and thermal power plants and inefficient small industrial boilers	• Government decision to close inefficient plants that do not meet emission standards • Energy sector restructuring plans to focus on thermal power plants of 200 MW or less • Enhance inspection of boilers	• Abolish state support for inefficient industrial plants, notably subsidized energy prices, preferential credit and other subsidies that artificially make such plants competitive • Provide fiscal incentives for large thermal power plants and large efficient industrial boilers	
	Phase out small-scale coal combustion		• Abolish price subsidies for coal	
	Move heavy industry and power generation plants away from city centers	• Government decision		
	Greater use of public transportation (increased capacity, subway systems, bus rapid transit)	• Develop a plan for expanding public transportation • Consider parking regulations and zoning restrictions for private cars	• Continue supporting public transportation development in large cities • Consider a gasoline tax that internalizes the environmental and health impact of air pollution from motor vehicles • Consider competitive fares for public transportation while ensuring financial sustainability of the public transportation enterprises	• Raise public awareness of the environmental benefits of public transportation
	Expand district heating	• Prepare development plans	• Support demonstration projects	
Cleaner Technology and Fuel	Increase use of natural gas for energy and heat generation	• Prepare natural gas development plan.	• Support demonstration projects • Abolish any subsidies for dirty coal	
	Increase use of low-sulfur and low-PM coal, and, where possible, of clean coal and briquettes		• Support demonstration projects • Abolish any subsidies for dirty coal	
	Increase use of energy-efficiency in industry	• Prepare energy efficiency development plan	• Support demonstration projects • Abolish subsidies on fuel sources to encourage efficiency investments	• Carry out targeted awareness raising activities on measures to raise energy efficiency in different industrial sectors
	Improve engine technology for motor vehicles	• Upgrade and implement emission standards following the EU Euro Standards	• Consider a gasoline tax internalizing the environmental impact of air pollution from motor vehicles	• Strengthen environmental labeling

(continues)

	PM Abatement Option	Command and Control Instruments	Economic Instruments	Awareness Raising, Voluntary and Other Instruments
End-of-Pipe	End-of-pipe abatement technologies, including FDG, SCR, and ESP	• Strengthen enforcement of emission standards	• Increase air pollution charges to levels that provide real incentives for plants to invest in abatement control technologies	
	End-of pipe controls for motor vehicles	• Upgrade and implement emission standards following the European Union Euro Standards • Strengthen vehicle emission inspections	• Consider a gasoline tax internalizing the environmental impact of air pollution from motor vehicles	• Strengthen environmental labeling
Other	Measures to reduce dust from natural areas, such as increasing vegetative cover, alternative biomass utilization technologies to replace open burning, plowing during low wind, reduced or no-tillage	• Ban open burning of biomass • Incorporate dust control in gardening and landscaping technical regulations	• Consider incentives, such as cost sharing grants for pilot investments in dust reducing agricultural practices and biomass utilization • Support reforestation/ forestation and other revegetation initiatives	• Carry out awareness raising campaigns on the health impact of increased dust levels and on measures to avoid dust from natural areas • Support research and demonstration of cleaner biomass utilization technologies
	Construction site management for dust control	• Legislate compulsory construction site dust management; enforce regulations through close inspection and penalties for noncompliance.		• Carry out public awareness raising campaigns on the benefits of construction site dust management
	Measures to reduce dust from roads, such as sweeping	• Legislate regular road sweeping by local governments		

5

Proposed Plan for Establishing a $PM_{2.5}$ Monitoring System during the 12th Five-Year-Plan Period

THE NECESSITY OF MONITORING $PM_{2.5}$

$PM_{2.5}$ is one of the most damaging pollutants to the human body. It affects human health more directly than PM_{10}. Fine particles can enter the upper and lower respiratory tract of humans and be deposited in the lungs. It can even enter the bloodstream through the alveoli. In addition, $PM_{2.5}$—including black carbon—easily accumulates heavy metals, acid oxides, organic pollutants such as polycyclic aromatic hydrocarbons, and pesticides. It is also the carrier of bacteria, viruses, and fungi. From experiences in Europe and the U.S., there should be no doubt that the health effects from $PM_{2.5}$ are significant in China. In recent years, a number of epidemiologic studies have been conducted within China, showing very similar mortality and morbidity impacts of exposure to air pollutants (HEI 2010).[26]

Since the 1990s the World Health Organization (WHO), the United States (US), the European Union (EU), and some other developed countries have started to pay attention to fine particle pollution. After nearly a decade of research, they developed air quality guidelines, standards, and limit values (Table 5.1), and countries implemented a series of action plans to protect human health. The U.S. has enacted the annual average $PM_{2.5}$ standard of 15 μg/m^3 and 24-hour average standard of 35 μg/m^3. The EU has a limit value of 20–25 μg/m^3, while the WHO guideline for annual average $PM_{2.5}$ concentrations is as low as 10 μg/m^3. WHO also has interim targets (IT) for use in countries with high pollution levels to give time for a phased improvement. China does not at present have a $PM_{2.5}$ quality standard, but may establish standards in 2011.

5.2 EXISTING EVIDENCE ON $PM_{2.5}$ MASS CONCENTRATION AND ITS EFFECTS

China does not have systematic and comprehensive data to evaluate $PM_{2.5}$ pollution, because $PM_{2.5}$ is not an indicator in China's routine monitoring. Until now, the analyses of fine particle pollution and its status have been using research data from monitoring stations in about 20 cities.

Jiangsu Province Monitoring Center's survey in Nanjing during the four seasons of 2001

[26] Health Effects Institute (HEI). 2010. "Outdoor Air Pollution and Health in the Developing Countries of Asia: A Comprehensive Review". HEI International Scientific Oversight Committee HEI Special Report 18, November 2010.

TABLE 5.1 International Air Quality Guidelines, Standards, and Limit Values for $PM_{2.5}$ (μg/m³)

	Annual average	24 hour average (daily)
WHO Guidelines, 2005	10	25
WHO Interim Targets (IT)		
IT-1	35	75
IT-2	25	50
IT-3	15	37.5
U.S. EPA AQ Standards, 2006	15	35*
EU Limit Values		
To be met by 2010	25	-
To be met by 2020	20	-
Bangladesh	15	65
Hong Kong SAR	35	75
India	40	60
Mongolia	25	50
Pakistan		
To be met by 1.1.2009	25	40
To be met by 1.1.2012	15	35
Singapore	15	35
Sri Lanka	25	50

Sources: WHO; U.S. EPA; EU Air Quality Directive; cleanairinitiative.org
* 7 days above 35 per year is allowed (98th percentile)

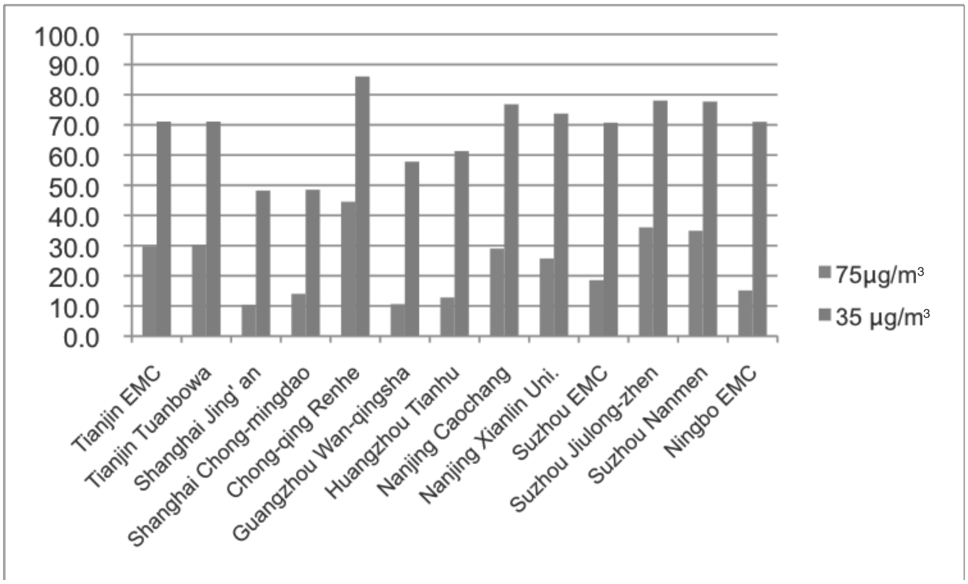
showed the following basic characteristics of the concentration distribution: the proportion of PM_{10} in TSP mass concentration reached 71 percent, while the proportion of $PM_{2.5}$ in PM_{10} accounted for 28 percent to 89 percent, averaging 70 percent. The daily average PM_{10} concentration ranged from 100 to 450 μg/m³ during the survey period, with an average concentration of 317 μg/m³. The daily average $PM_{2.5}$ concentration was 221 μg/m³. If evaluating air quality by comparing it to the U.S. air quality standards, the daily average concentration is more than 3 times higher, and more than 6.5 times on both sides of the highest concentration of traffic routes. This distribution represented the situation in China's southern cities in 2001; however, it is likely they no longer represent the current situation, as overall urban PM concentrations have decreased since then, as discussed in Chapter 2.

Figure 5.1 indicates results from recent experimental $PM_{2.5}$ monitoring stations in selected cities in 2009. The columns show the percentage of time that measured 24-hour concentrations exceeded 35 and 75 μg/m³ respectively. It can be seen that the 35 μg/m³ level was exceeded more than 50 percent of the time. From this, we conclude that the WHO guidelines are exceeded most of the time in China.

5.3 RECOMMENDATIONS FOR $PM_{2.5}$ STANDARDS IN CHINA

Many developed countries like the U.S. and European countries have developed appropriate standards. As mentioned, there are still no standards for evaluating $PM_{2.5}$ in China. The evaluation of $PM_{2.5}$ is different at each experimental

FIGURE 5.1 Percent of Time That 35 and 75μg/m³ Are Exceeded at Experimental $PM_{2.5}$ Monitoring Stations in Selected Chinese Cities, 2009



Source: CNMC database.

monitoring site, and evaluation results of $PM_{2.5}$ are barely comparable.

China should develop its $PM_{2.5}$ standards with a view to the WHO guidelines and interim targets, as well as the U.S. and European standards. On the basis of the high pollution experienced in China's cities, and also regionally, it is clear that China will need a multi-phase process toward a standard that is in line with the need for health protection. Therefore, China should establish $PM_{2.5}$ standards that are in line with the WHO interim targets, starting with the interim target 1 (IT-1). Both the annual average IT-1 of 35 μg/m³ and the 24-hour IT-1 of 75 μg/m³ should be introduced. In view of the high $PM_{2.5}$ levels in China compared to this standard (or most other $PM_{2.5}$ standards available), a "phase-in"-period for IT-1 should be established, which may last through the 12th FYP period. For the future, and beyond the 12th FYP period, the recommended standards are 15 μg/m³ for annual average concentrations and 35 μg/m³ for 24-hour average concentrations.

Given the existing high concentrations, even using the most lax interim standard (IT-1) could result in significant compliance problem. Therefore, it is recommended that plans to reduce $PM_{2.5}$ concentrations be initiated. While it is beyond the scope of this report to offer advice on the elements of a $PM_{2.5}$ compliance plan, a few initial suggestions are provided here. Control efforts should concentrate on the emissions from coal combustion, its primary particles as well as its emissions of precursor gases (SO_2, NH_3 and NO_x), since ammonia emissions (agriculture, waste) and NO_X (also from road traffic) also play a part. Multiple benefits, other than only human health, result when effectively controlling both primary and secondary forms of $PM_{2.5}$. Reducing secondary PM also reduces deposits of sulfur and nitrogen to land and water and helps limit ozone formation, regional haze, and visibility. It lessens black carbon emissions, with resulting climate benefits as well. Dry dust particles, which contribute significantly to PM_{10}, play a relatively smaller part in the $PM_{2.5}$ problem; therefore its control may be considered a secondary priority.

5.4 AVAILABLE $PM_{2.5}$ MONITORING METHODS

At present, monitoring instruments for $PM_{2.5}$ are mature. The automatic monitoring methods mostly used today worldwide are the ,-ray method (in the U.S. known as the Beta attenuation monitor, or BAM) and the tapered element oscillating microbalance (TEOM) method.

Reference methods for $PM_{2.5}$ measurements are based upon sampling of particles in filters. There are many relatively low-cost filter samplers on the market, with various operational features such as automatic sample-changing and two-fraction sampling. These filter-based $PM_{2.5}$ samplers provide good quality measurements of $PM_{2.5}$ that are often of better quality than the automatic samplers, and are appropriate for judging compliance with standards and implementing control programs. An additional advantage of such samplers is that the filters with a PM sample can be subjected to detailed chemical and elemental analysis. Such data can be used as a basis for assessing which types of sources contribute to the PM sample, and to what extent. This is one of the useful bases for developing cost-effective control programs.

The main advantage of the automatic samplers is that they can provide online near-real-time short-term average (e.g. 1-hour averages) data that can be viewed directly, for instance on the Internet, both by policy makers and the public. The public can then have the chance to protect themselves against episodes with high-level pollution.

Global experience also shows that monitoring of $PM_{2.5}$ is not entirely free of problems. Typical state-of-the-art automatic monitors tend to underestimate the $PM_{2.5}$ concentration due to the semi-volatile nature of part of the $PM_{2.5}$ mass. The underestimation can be substantial, depending on the chemical composition of the $PM_{2.5}$ mass, as well as of the local climate conditions (problems tend to be larger in warm climates). Top-of-the-line, but rather expensive monitors such as the TEOM 1405-DF instrument correct that problem. It is very useful to study the experiences that have accumulated in Europe and the U.S. in running similar monitoring programs over several years when designing the program and the data quality assurance procedures. A $PM_{2.5}$ measurement network can preferably be constructed using both these types of measurement equipment (automatic monitors and samplers).

At present there are no monitoring equipment manufacturers for $PM_{2.5}$ located in China. However, there are several mature foreign equipment manufacturers, whose products have been applied to monitor $PM_{2.5}$ in experimental monitoring sites in China. The price of $PM_{2.5}$ monitoring instruments is currently about 200,000–270,000 yuan in the market. This is similar to the price of other conventional monitoring instruments, and it should be within an acceptable level of national and local monitoring capacity and reasonable within capacity building programs.

5.5 SUGGESTED PLAN FOR ESTABLISHING A $PM_{2.5}$ MONITORING NETWORK DURING THE 12^{TH} FYP PERIOD

According to China's characteristics of regional pollution and different levels of economic development in different regions, in the 12^{th} FYP period the country will gradually increase the number of indicators to be monitored to include O_3, $PM_{2.5}$, and CO indicators in addition to the existing SO_2, NO_2, and PM_{10} indicators.

Urban network design

The total number of monitors per city with high levels of pollution depends on factors such as known spatial patterns and diversity of urban pollution sources as well as the population distribution, and may be guided with the aid of temporary portable samplers to perform what is known as "survey sampling." Such surveys can assist in locating proper sites for permanent monitors.

To the extent possible, new $PM_{2.5}$ monitors should be integrated into existing monitoring networks so that the resulting output data will be compatible. The siting of monitors and the choice of type of monitoring devices should consider other potential uses for the resulting data, such as real time air quality reporting to the public. Automatic monitors can also be used for comparison with air quality modeling outputs. This helps validate the modeling results.

MEP has proposed that the cities that will monitor $PM_{2.5}$ must choose at least two existing monitoring sites for $PM_{2.5}$ monitoring. If the monitoring results show that one of the O_3, $PM_{2.5}$, or CO indicators have serious pollution (annual average concentration is 20 percent higher than the national standard, or the number of pollution days is more than 20 percent of a year), the city shall increase the indicator to all monitoring sites in the city.

Rural monitoring network

In view of the regional-level nature of the $PM_{2.5}$ pollution problem in China, it is strongly recommended that the monitoring program include a significant number of MSs in rural locations to assess the significant regional component of $PM_{2.5}$ pollution in China, which largely consists of secondary particles formed from SO_2, NO_x, and ammonia (NH_3). Such monitoring is common in both Europe and the United States and would provide important input to compliance plans that must address both local and regional components of $PM_{2.5}$ pollution. They should be located far enough away from urbanized areas—at least several tens of km and up to 50–150 km—so they can be said to represent the regional component of $PM_{2.5}$ pollution.

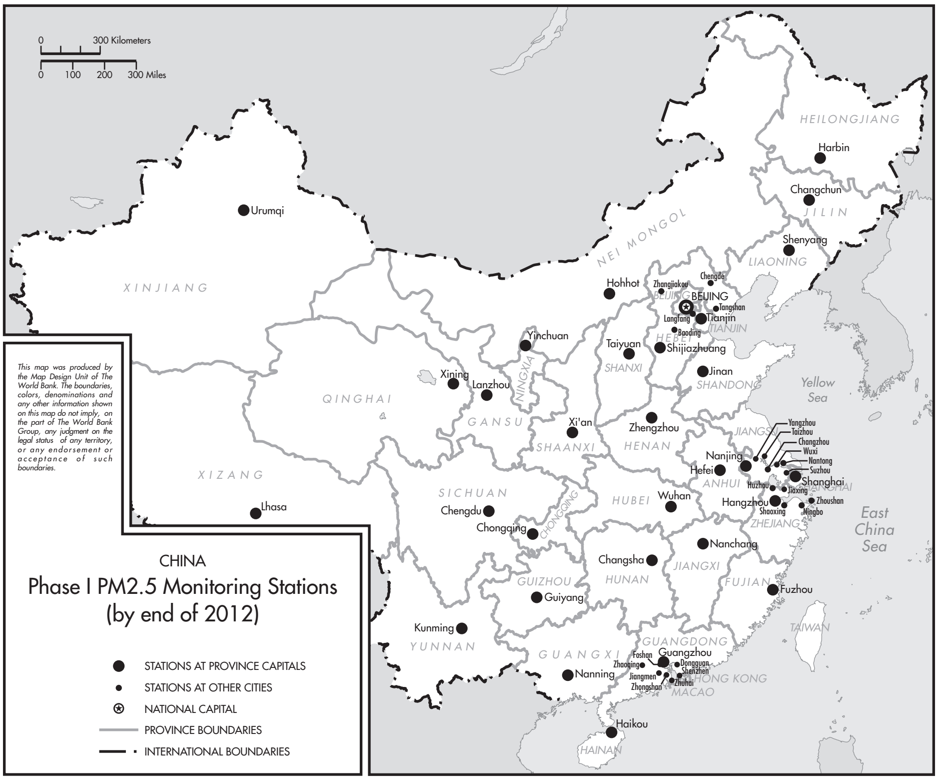
This is a successful practice in both Europe and the United States (see boxes below). It will provide a very important input to the basis for developing compliance plans and tracking program results. There are different strategies needed for tackling the local and regional components the $PM_{2.5}$ pollution. The local component mainly consists of locally emitted primary particles, while the regional component is to a large extent made up of secondary particles formed from precursor gases. For successful compliance, knowledge of both the local and regional components is necessary.

Phased development of the $PM_{2.5}$ monitoring network

The project team proposes the following $PM_{2.5}$ implementation program up to the end of 2015:

1. **Phase I:** $PM_{2.5}$ monitoring stations will be established in about fifty-five cities, which includes all the capital cities in China (thirty-one), in addition to five or six selected cities in the Tienjin-Hebei-Beijing Delta, about ten cities in the Yangze River Delta, and about eight cities in the Pearl River Delta (Figure 5.2 and Box 5.1). The selected locations have strong economic and technical capacity. With a minimum of two $PM_{2.5}$ monitoring stations in each city, the total number of MSs in China by the end of 2012 would be about 110.
2. **Phase II**: Monitor O_3, $PM_{2.5}$, and CO in all "key cities" of environmental protection before the end of 2013. These are all cities that have been subject to air quality monitoring over a number of years with well-established air quality monitoring and reporting procedures (Box 5.1).

FIGURE 5.2 Location of About 55 Cities and Stations for $PM_{2.5}$ Monitoring During Phase I (by end of 2012)



3. **Phase III**: Monitor O_3, $PM_{2.5}$, and CO in all 320 prefecture-level and above cities before the end of 2015 (Box 5.2). If each city established at least two MSs, about 650 $PM_{2.5}$ monitoring stations (MS) would have been established in China before the end of the 12th FYP.

As part of Phase II–Phase III, China should also establish a network of filter-based samplers. In addition to the need for measurements with such reference method samplers as a part of the quality control and assurance (QAQC) program, such a network of samplers will also provide filters for chemical analysis as a basis for source apportionment (as mentioned above).

In Europe, the $PM_{2.5}$ monitoring network established more than 500 MSs over a 7-year period (2001–08) covering all Western European and many Eastern European countries. Today, the network has about 775 MSs, about the same as China may have after the first 4–5 years of implementation. (The network to be established in China would have a substantively larger population to cover.) The network in Europe is balanced among urban background stations, traffic stations, industrial stations, and rural stations, a balance that is also recommended for China. In the United States, the Federal Reference Method (FRM) sampler network has installed about 940 $PM_{2.5}$ MSs covering all 50 states. Following adoption of the national $PM_{2.5}$ standards in 1997, the states established their FRM sampler network from 1998 to 2000. Based upon a division of labor with different monitoring functions, there are today also two additional $PM_{2.5}$ networks and an

IMPROVE and Chemical Specification Network in the United States (Box 5.3).[27]

Taking into account that China largely established its PM_{10} monitoring system in 612 cities from 2001 to 2008 and with the experiences from both Europe and the U.S., it seems realistic that China can establish $PM_{2.5}$ MSs in 320 cities within the 12th FYP period if $PM_{2.5}$ standards are adopted early in the FYP period. It would be important for China to develop a monitoring network that balances the various functions—comparing with standards, public reporting, developing control strategies, assessing trends, assessing human health exposure, and assessing visibility—and is supported by overall AQM.

In addition to the city-based monitors, a minimum of 50 regional/rural background MSs would be needed.

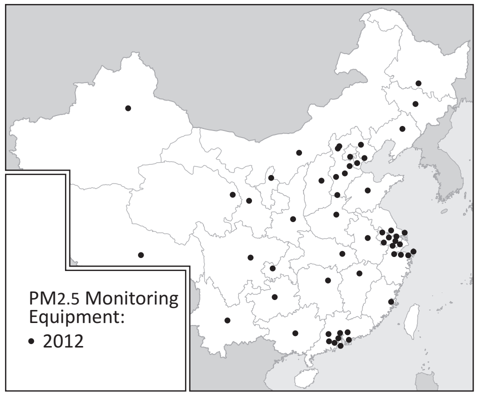
This is a bold plan, in view of the need to build up local technical monitoring expertise, including the need for quality assurance programs to assure the quality of the data, as well as the system for data collection and transfer, and utilization of the data for various purposes, including real-time availability for the public. A robust organization needs to be built up to tackle this challenging task. Still, it is important to consider whether there are prefectural- and lower-level cities with a clearly large $PM_{2.5}$ problem that could be included in the first wave of $PM_{2.5}$ monitoring in 2012.

The question of the quality analysis / quality control (QA/QC) program is extremely important. A state-of-the-art QA/QC program for the $PM_{2.5}$ monitoring network must be established.

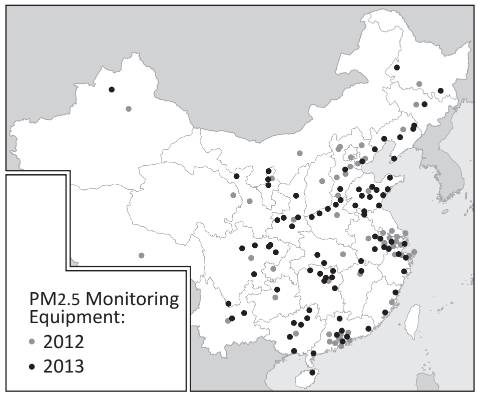
[27] A main feature of the IMPROVE and chemical speciation (CS) networks is to provide the chemical composition of $PM_{2.5}$. IMPROVE provides important information about background concentrations to estimate visibility impairment in national parks and other remote protected scenic areas, and to help establish regional concentrations and their contributing emission sources. CS provides measurements of $PM_{2.5}$ chemical constituents in urban areas, primarily to establish emission sources, support air quality modeling, and track emission trends. An advantage of the filter-based $PM_{2.5}$ monitoring for compliance purposes also provides the opportunity to subsequently perform supplementary chemical analysis for many of the reasons mentioned above and to help understand contributing emission sources on particularly high $PM_{2.5}$ days.

BOX 5.1 Proposed Expansion Plan for Installation of a $PM_{2.5}$ Monitoring Equipment in China During the 12th FYP

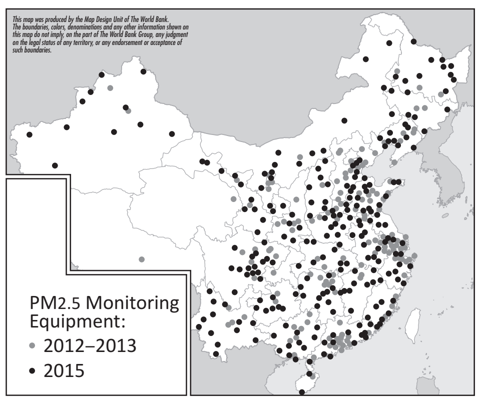
Phase 1 (Before the end of 2012): All capital cities in China and cities in the Beijing-Tianjin-Hebei (BTH) area, in the Yangze River Delta (YRD), in the Pearl River Delta (PRD), and in certain developed cities will install $PM_{2.5}$ monitoring stations (MS). Taking into account about five or six additional cities in the BTH area, about ten or eleven cities in the YRD, and about eight cities in the PRD, the total number of cities having installed $PM_{2.5}$ MSs would be about 50–55, with all together over 100 MSs.



Phase 2 (Before the end of 2013): The plan is expanded to include all the 113 focused cities for Air Pollution Control to have installed $PM_{2.5}$ MSs. Taking into account the already established MSs during phase 1, the total number of cities that would have installed $PM_{2.5}$ MSs would be about 130 cities with more than 260 MSs.



Phase 3 (Before the end of 2015): The plan has expanded to include all the 320 cities at prefecture level-and-above that would have installed $PM_{2.5}$ MSs. Taking into account that each city is installing a minimum of two MSs (some need to install several more), the total number of MSs at the end of the 12th FYP would be above 650 (or substantially more) in addition to recommended background monitors.



BOX 5.2 Monitoring of $PM_{2.5}$ in Europe

The monitoring of $PM_{2.5}$ in Europe is governed by the Air Quality Directive of the European Union. (see link: Directive 2008/50/EC). The directive sets requirements for issues like (a) selection of cities; (b) specification of types of stations; (c) number of stations in each city; (d) location of stations (details); (e) quality control and quality assurance programs; (f) time schedule of reporting of data and additional information to the central (European) data base; and (g) air quality standards (target and limit values) and the time schedule for compliance.

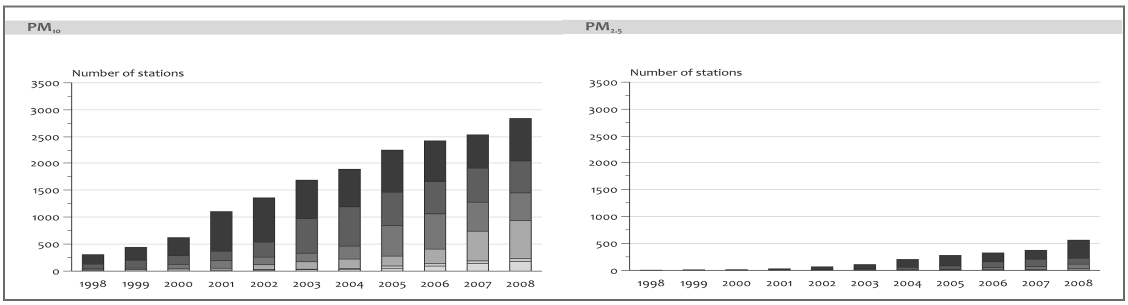
The extent of the European monitoring of PM is as follows, covering 27 countries:

Number of stations	All stations	Urban background stations	Traffic stations	Industrial stations	Rural stations
PM_{10}	2,685	1,174	790	425	296
$PM_{2.5}$	540	240	138	61	101

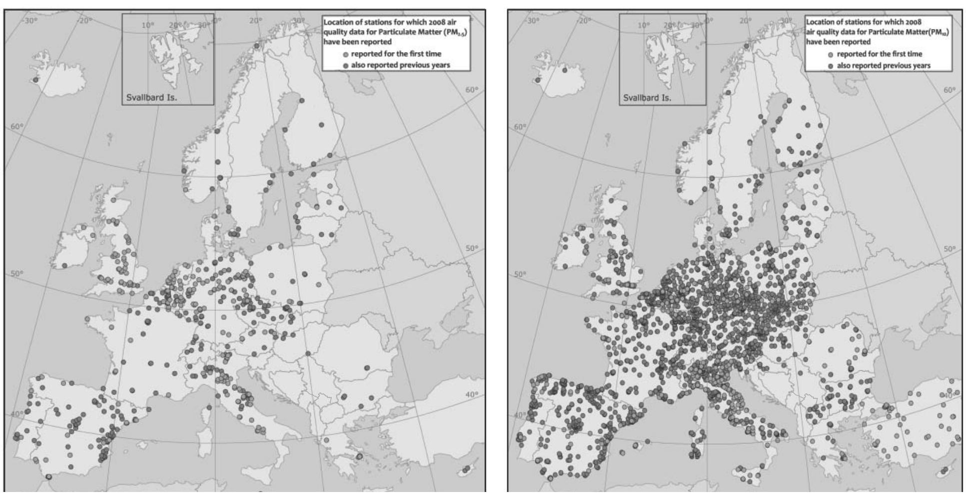
As shown, in Europe the following station types are specified:

- Urban background stations: general urban/suburban stations not dominated by any specific source
- Traffic stations: located in highly trafficked areas, close to streets/roads
- Industrial stations: located to monitor the influence from industrial sources
- Rural stations: located outside cities to monitor the regional components of air pollution

The monitoring network has been built mainly since 1998, although several hundred PM_{10} stations were in operation before then (see the figure below).



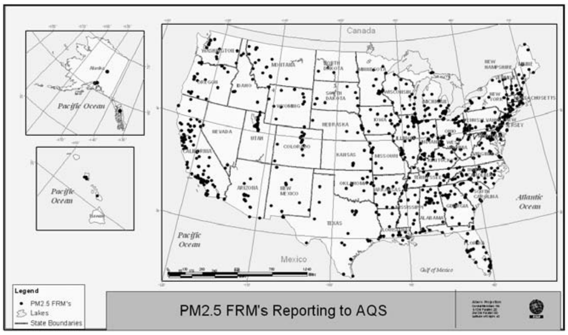
The figures below visualize the location of cities and rural stations (left, $PM_{2.5}$; right, PM_{10}).

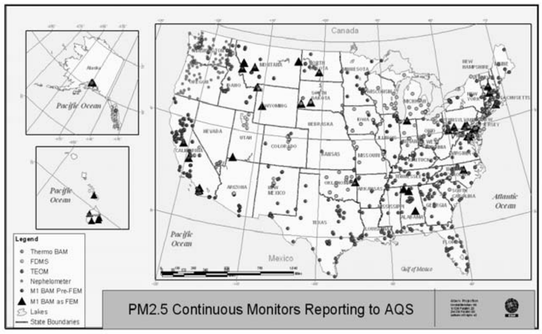


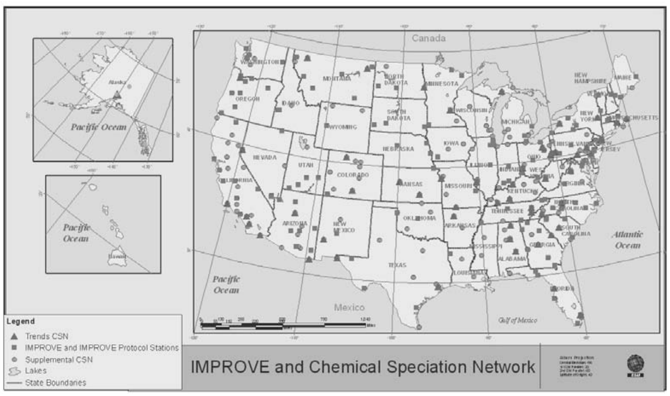
Reference: Mol et. al. 2008. State of AQ (in Europe), 2008. European Topic Centre of AQ and Climate Change (http://acm.eionet.europa.eu/), Technical Paper 2010/1. http://acm.eionet.europa.eu/reports/ETCACC_TP_2010_1_EoI_AQ_meta_info2008

BOX 5 3 Monitoring of $PM_{2.5}$ in the United States

$PM_{2.5}$ monitoring in the United States is governed by the national $PM_{2.5}$ ambient air quality standards with an annual value of 15 μg/m^3 (1997) and an 24-hour value of 65 μg/m^3 (1997), which was modified to 35 μg/m^3 in 2006. In the U.S., there are a number of different $PM_{2.5}$ networks that have different monitors with different functions. Of the roughly 940 MSs in the Federal Reference Method (FRM) sampler network (NW), most were established in the 1998–2000 period (upper left-hand map). The FRM network installed mass monitors, which collect samples on filters that are weighted and analyzed. The main purpose is to compare standards, assess progress/trends, and analyze health exposure. In addition, there are about 700 $PM_{2.5}$ MSs reporting to the AIRNow and/or the AQS that apply continuous monitoring (upper right-hand map), with the main purpose of public reporting, applying air quality indicators, developing control strategies, and also assessing the exposure on human health. Moreover, there is a chemical specification and IMPRONE NW (lower map) that provides background monitoring at state boundaries. It is being used to develop control strategies and assess progress/trends, as well as assessing visibility.







Types of $PM_{2.5}$ Monitoring Networks in the U.S.

Network Element	Compare to Standards	Public Reporting - AQI	Develop control strategies	Assess progress/ trends	Health/ Exposure	Assess Visibility
FRM Mass	V			S	S	
Continous Mass	Now available	V	S		S	
Chemical Speciation NW			V	V	S	
IMPROVE			S	S		V

Source: Tim Hanley et al. 2009. U.S. EPA PM Monitoring Program Update for Environment Canada.

V= Main function, S = Secondary function

6 Conclusions and Recommendations

CONCLUSIONS

The present study documents that over the past decade, China has made significant strides in reducing average urban ambient air pollutant concentrations, including PM_{10}. From 2001 to 2009 the number of Chinese cities reaching the grade II PM_{10} standard or better increased from 36 percent to 84 percent. From 2003 to 2009 the average annual concentration in 113 key cities decreased from 126 to 87 μg /m³. In the industrial northern region, where air pollution was particularly severe, the average in urban areas dropped from 149 to 97 μg/m³. However, PM pollution remains a significant challenge. These averages are still substantially higher than the WHO guideline or China's own grade I limit value. In some cities recently attaining grade II, concentrations show signs of not being stable within the grade threshold meaning that they are fluctuating between grade II and III. In some cases, reductions in urban air pollution may have been achieved at the expense of higher concentrations in rural areas, where the industries were relocated. Regional pollution contributes to high urban PM concentrations, including fine particles. Regional PM originates from non-urban sources such as power and industrial plants, agriculture, arid landscapes, or secondary particles, notably from atmospheric reactions between sulfur dioxide (SO_2), nitrogen oxides (NO_x), and ammonia.

In 2009, just a few of the 612 cities where PM_{10} is monitored met China's urban grade I PM_{10} standard (40 μg/m³), while 63 cities exceeded the grade II range (100–40 μg/m³).[28] Fifty-one of these noncompliant cities are prefecture level or higher; of these, 30 are key cities for air pollution control as designated by the State Council.

In general, coal combustion for heating, particularly from small-scale combustion, is a common PM source in northern and western cities. Construction and road dust is a problem in most of the noncompliant cities. Industrial sources contribute significantly to PM in all the noncompliant cities. The industrial sector contributes both through coal combustion for process heat and power, as well as through PM emissions from production processes, which can be rich in harmful heavy metals. The size of the contributions from these main source types vary considerably between cities. Regional PM pollution makes up a significant part of the PM concentration in urban areas, and consists to a large extent of secondary $PM_{2.5}$, resulting from emissions of SO_2, NO_X and ammonia.

The present study recommends a national PM_{10} compliance plan to help noncompliant

[28] 40–70 μg/m³ according to the new GB 3095-2012 of 02/29/12. See Annex 6.

cities attain grade II—preferably by 2015, or in certain cases by 2020 at the latest—and already compliant cities to further reduce PM concentrations toward grade I. The plan would include (a) policies and regulations and associated physical interventions/measures; (b) geographical scope; (c) sequencing of interventions; and (d) feasible environmental investments likely to have high benefit/cost ratios. When the Chinese government has set standards for $PM_{2.5}$, at present proposed by MEP to be 75 μg/m³ (24 hour average/daily) and 35 μg/m³ (annual average), similar compliance plans should be developed to reach these new standards and to further accelerate toward reaching the interim targets recommended by WHO in the longer-term.

According to targets prepared by MEP and set in the 12th Five-Year Plan, 80 percent of prefecture and higher-level cities have to comply with grade II standards by the end of 2015. MEP's *Administrative Measures* and *Technical Guidelines*, which was supported through this project, will guide local decision makers and stakeholders in preparing urban air quality management (AQM) plans to comply with grade II standards and further reduce PM concentrations. In the process, it is important for activities to be properly sequenced and to apply air pollution and economic analyses, such as cost effectiveness for evaluating air pollution abatement options and strengthen emission inventories and air quality monitoring. When standards are set, new monitoring systems are in place, and compliance plans completed for $PM_{2.5}$, the *Measures* and *Guidelines* should be further refined and applied as a tool to assist in the effective control of these small particles.

SPECIFIC RECOMMENDATIONS:

The *administrative measures should:*

- Incorporate the concept of integrated management of local/regional pollution and greenhouse gas emissions while considering a number of abatement options such as banning small-scale coal burning and open biomass burning.
- Emphasize the correct sequence and complete application of the AQM approach, including an analysis of air pollution, its costs, and impacts of abatement options on health and environmental effects, as well as the monetary benefits of the options.
- Incorporate testing and evaluation of air pollution models and clearly states the link between the analytical AQM process and the total load control process.
- Include provisions for making monitoring data on the critical pollutants available to the public in near-real time.

The *technical guidelines should:*

- Mention the concept of co-control and include monitoring network design recommendations.
- Include all sources in the emissions inventory; "smoke" and "dust" should be measured in the form of particle fractions like $PM_{2.5}$ and PM_{10}.
- State the need for testing and evaluation of the air pollution models and clarify the steps of the analytical AQM process.
- Incorporate the notion of ongoing evaluation of progress toward goals and adjustments as needed, and consider including energy efficiency as a possible abatement option.
- With regard to the leading group, require that (a) a deputy mayor should lead the group (in cities that are furthest from reaching compliance the mayor should lead the group); (b) the group should include representatives from all sectors that are linked to PM pollution in the city; and (a) the group should be supported by a secretariat in the environmental protection bureau.

$PM_{2.5}$ standards monitoring and control:

- $PM_{2.5}$ standards should be developed with a view to the WHO guidelines and interim targets (IT) as well as relevant standards in the

U.S., Europe, and other countries, starting with the IT-1 of 75 μg/m^3 (24 hour/daily) and 35 μg/m^3 (annual average). A "phase-in" period for IT-1 should be established that would last through the 12^{th} FYP period.

- For the future (beyond the 12^{th} FYP period), the recommended standards to be gradually applied should be further tightened through 25 μg/m^3 (annual average) and 50 μg/m^3 (24-hour/daily) to 15 μg/m^3 and 35 μg/m^3 respectively.
- Control options should concentrate on urban emissions from coal combustion, especially from low-level emissions, both its primary particles as well as precursor gases (SO_2, NH_3, and NO_x).
- A three-phased monitoring plan for $PM_{2.5}$ (also including O_3 and CO) should be implemented throughout the 12^{th} FYP period that expands the coverage from all provincial capitals and cities in key regions (1^{st} phase), through all the "key APC cities" (2^{nd} phase) to all the 320 prefecture-level-and-above cities before the end of 2015 (3^{rd} phase).
- While the requirement of two $PM_{2.5}$ monitoring stations per city should be a minimum, the required number of monitors should be substantially larger in certain cities. A significant number of rural background stations also should be included.
- The nationwide $PM_{2.5}$ monitoring system to be established can serve multiple purposes, including measuring progress compared to new standards, reporting to the public, supporting control strategies and assessing progress, and assessing health exposure and visibility.

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ANNEX A1

Annual Average Concentration and Grade Data for 113 Key Cities

Annual Average PM_{10}, SO_2 and NO_2 Concentrations in Northern and Southern Key Cities (2003–2009)

		2003	2004	2005			2006			2007			2008			2009		
NORTHERN KEY CITIES																		
City Name	**Province**	**PM10**	**PM10**	**PM10**	**SO2**	**NO2**	**PM10**	**SO2**	**NO2**	**PM10**	**SO2**	**NO2**	**PM10**	**SO2**	**NO2**	**SO2**	**NO2**	**PM10**
Anshan	Liaoning	0.122	0.132	0.117	0.078	0.038	0.127	0.062	0.043	0.131	0.069	0.037	0.109	0.057	0.039	0.054	0.04	0.111
Anyang	Henan	0.187	0.143	0.115	0.075	0.041	0.102	0.045	0.027	0.112	0.053	0.037	0.093	0.055	0.037	0.051	0.037	0.097
Baoding	Hebei	0.131	0.112	0.108	0.056	0.028	0.109	0.065	0.022	0.106	0.059	0.032	0.085	0.061	0.031	0.046	0.03	0.088
Baoji	Shananxi	0.118	0.139	0.124	0.04	0.046	0.113	0.027	0.029	0.101	0.024	0.026	0.109	0.023	0.026	0.023	0.028	0.11
Baotou	Neimenggu	0.226	0.186	0.143	0.07	0.036	0.147	0.077	0.039	0.135	0.074	0.042	0.124	0.066	0.039	0.059	0.033	0.109
Beijing		0.141	0.149	0.141	0.05	0.066	0.162	0.052	0.066	0.148	0.047	0.066	0.123	0.036	0.049	0.034	0.053	0.121
Benxi	Liaoning		0.133	0.13	0.089	0.041	0.11	0.044	0.028	0.108	0.047	0.031	0.091	0.046	0.034	0.051	0.032	0.09
Changchun	Jilin	0.098	0.085	0.099	0.026	0.035	0.099	0.026	0.039	0.099	0.03	0.038	0.096	0.03	0.038	0.034	0.043	0.085
Changzhi	Shanxi	0.176	0.173	0.122	0.067	0.039	0.128	0.041	0.035	0.106	0.03	0.036	0.09	0.027	0.033	0.028	0.026	0.076
Chifeng	Neimenggu	0.138	0.134	0.115	0.087	0.023	0.134	0.082	0.023	0.11	0.078	0.016	0.094	0.048	0.016	0.044	0.02	0.089
Dalian	Liaoning	0.08	0.085	0.086	0.044	0.032	0.095	0.048	0.041	0.087	0.049	0.043	0.071	0.041	0.041	0.041	0.041	0.067
Datong	Shanxi	0.178	0.18	0.161	0.101	0.038	0.155	0.098	0.036	0.11	0.075	0.034	0.101	0.077	0.034	0.039	0.026	0.077
Fushun	Liaoning		0.162	0.128	0.055	0.035	0.115	0.047	0.037	0.111	0.056	0.031	0.093	0.048	0.034	0.046	0.042	0.1
Handan	Hebei	0.134	0.113	0. Re v 128	0.065	0.039	0.115	0.064	0.038	0.104	0.065	0.035	0.101	0.053	0.033	0.045	0.034	0.102
Harbin	Heilongjian	0.121	0.113	0.104	0.042	0.056	0.104	0.034	0.049	0.102	0.048	0.06	0.102	0.043	0.055	0.046	0.054	0.101
Hohhot	Neimenggu	0.116	0.08	0.097	0.05	0.041	0.102	0.054	0.048	0.084	0.066	0.048	0.07	0.049	0.045	0.049	0.04	0.074
Jiaozuo	Henan	0.148	0.131	0.097	0.076	0.036	0.106	0.055	0.038	0.099	0.068	0.041	0.096	0.07	0.035	0.065	0.035	0.08
Jilin	Jilin		0.141	0.107	0.014	0.034	0.096	0.02	0.02	0.1	0.025	0.019	0.093	0.025	0.025	0.02	0.033	0.095
Jinan	Shandong	0.149	0.149	0.128	0.06	0.024	0.114	0.04	0.021	0.118	0.056	0.023	0.126	0.052	0.022	0.05	0.025	0.123
Jinchang	Gansu	0.132	0.106	0.094	0.12	0.023	0.113	0.108	0.023	0.103	0.084	0.024	0.102	0.079	0.022	0.076	0.028	0.087

		2003	2004	2005			2006			2007			2008			2009		
NORTHERN KEY CITIES																		
Jining	Shandong	0.104	0.109	0.092	0.046	0.037	0.097	0.052	0.033	0.107	0.057	0.033	0.104	0.059	0.033	0.074	0.044	0.112
Jinzhou	Liaoning		0.125	0.113	0.062	0.029	0.104	0.043	0.032	0.098	0.034	0.024	0.085	0.029	0.023	0.023	0.018	0.087
Kaifeng	Henan	0.186	0.198	0.127	0.059	0.045	0.111	0.064	0.039	0.109	0.069	0.043	0.089	0.037	0.038	0.04	0.041	0.095
Karamay	Xinjiang	0.55	0.059	0.05	0.008	0.032	0.059	0.009	0.029	0.066	0.015	0.036	0.072	0.016	0.033			
Lanzhou	Gansu	0.174	0.172	0.158	0.068	0.037	0.192	0.057	0.052	0.129	0.06	0.042	0.132	0.07	0.054	0.059	0.043	0.15
Lianyungang	Jiangsu	0.096	0.091	0.097	0.049	0.024	0.096	0.052	0.026	0.095	0.049	0.026	0.086	0.04	0.025	0.039	0.02	0.091
Linfen	Shanxi	0.233	0.219	0.184	0.177	0.054	0.168	0.112	0.051	0.113	0.072	0.039	0.085	0.05	0.026	0.038	0.019	0.085
Luoyang	Henan	0.217	0.165	0.129	0.065	0.042	0.117	0.049	0.033	0.114	0.052	0.031	0.097	0.043	0.025	0.05	0.032	0.098
Mudanjiang	Heilongjiang	0.152	0.119	0.092	0.034	0.035	0.079	0.035	0.028	0.083	0.032	0.022	0.068	0.023	0.02	0.025	0.027	0.066
Pingdingshan	Henan	0.154	0.174	0.149	0.067	0.043	0.142	0.058	0.045	0.116	0.074	0.05	0.097	0.054	0.051	0.045	0.046	0.096
Qingdao	Shandong	0.097	0.098	0.099	0.057	0.024	0.1	0.056	0.024	0.099	0.054	0.026	0.1	0.055	0.028	0.052	0.043	0.098
Qinhuangdao	Hebei	0.068	0.076	0.077	0.057	0.025	0.083	0.052	0.027	0.08	0.05	0.025	0.071	0.046	0.023	0.043	0.025	0.067
Qiqihar	Heilongjiang		0.098	0.088	0.025	0.025	0.098	0.028	0.032	0.079	0.038	0.036	0.082	0.034	0.031	0.033	0.024	0.075
Rizhao	Shandong	0.055	0.058	0.055	0.021	0.027	0.055	0.015	0.019	0.06	0.023	0.03	0.061	0.026	0.037	0.037	0.039	0.085
Sanmenxia	Henan	0.141	0.126	0.113	0.068	0.029	0.112	0.065	0.021	0.102	0.065	0.023	0.102	0.053	0.024	0.051	0.018	0.094
Shenyang	Liaoning	0.135	0.137	0.118	0.054	0.036	0.117	0.058	0.043	0.119	0.054	0.036	0.118	0.059	0.037	0.059	0.037	0.11
Shijiazhuang	Hebei	0.175	0.123	0.132	0.054	0.041	0.142	0.044	0.039	0.128	0.043	0.035	0.116	0.046	0.031	0.045	0.035	0.104
Shizuishan	Ningxia	0.239	0.119	0.101	0.087	0.036	0.105	0.076	0.027	0.097	0.07	0.026	0.093	0.072	0.03	0.072	0.03	0.087
Taian	Shandong	0.086	0.083	0.073	0.048	0.027	0.077	0.048	0.028	0.08	0.048	0.028	0.081	0.047	0.027	0.048	0.032	0.095
Taiyuan	Shanxi	0.172	0.175	0.139	0.077	0.02	0.142	0.08	0.025	0.124	0.076	0.027	0.094	0.073	0.021	0.075	0.022	0.106
Tangshan	Hebei	0.127	0.112	0.092	0.086	0.04	0.1	0.082	0.043	0.094	0.082	0.042	0.082	0.067	0.031	0.061	0.031	0.077
Tianjin		0.133	0.111	0.106	0.076	0.047	0.114	0.067	0.048	0.094	0.062	0.043	0.088	0.061	0.041	0.056	0.04	0.101
Tongchuan	Shananxi	0.159	0.151	0.127	0.067	0.041	0.116	0.04	0.035	0.107	0.073	0.04	0.083	0.044	0.029	0.035	0.032	0.079
Urumqi	Xinjiang	0.127	0.114	0.114	0.116	0.056	0.152	0.113	0.064	0.136	0.088	0.067	0.145	0.105	0.065	0.093	0.068	0.14
Weifang	Shandong	0.094	0.09	0.089	0.058	0.042	0.097	0.061	0.042	0.087	0.058	0.038	0.116	0.082	0.039	0.068	0.041	0.102
Weinan	Shananxi	0.181	0.175	0.145	0.083	0.046	0.138	0.079	0.048	0.123	0.066	0.046	0.11	0.053	0.045	0.048	0.044	0.117
Xi'an	Shananxi	0.136	0.142	0.129	0.044	0.032	0.133	0.056	0.042	0.135	0.053	0.043	0.113	0.05	0.044	0.048	0.046	0.113

		2003	2004	2005			2006			2007			2008			2009		
NORTHERN KEY CITIES																		
Xianyang	Shananxi	0.207	0.137	0.114	0.033	0.025	0.112	0.038	0.025	0.121	0.035	0.021	0.102	0.033	0.021	0.034	0.019	0.094
Xining	Qinghai	0.139	0.127	0.114	0.029	0.026	0.135	0.024	0.029	0.115	0.028	0.035	0.118	0.029	0.03	0.042	0.032	0.141
Xuzhou	Jiangsu	0.211	0.158	0.111	0.066	0.04	0.114	0.047	0.03	0.115	0.052	0.038	0.103	0.051	0.03	0.051	0.022	0.107
Yan'an	Shananxi	0.131	0.139	0.128	0.06	0.037	0.133	0.039	0.045	0.112	0.059	0.04	0.068	0.074	0.051	0.079	0.049	0.108
Yangquan	Shanxi	0.172	0.162	0.126	0.16	0.053	0.109	0.104	0.035	0.086	0.089	0.041	0.071	0.056	0.03	0.046	0.025	0.072
Yantai	Shandong	0.074	0.068	0.061	0.044	0.029	0.055	0.041	0.033	0.07	0.046	0.04	0.078	0.045	0.038	0.044	0.04	0.082
Yinchuan	Ningxia	0.132	0.122	0.09	0.054	0.025	0.097	0.048	0.027	0.092	0.049	0.025	0.084	0.049	0.021	0.044	0.031	0.09
Zaozhuang	Shandong	0.099	0.101	0.077	0.06	0.025	0.083	0.06	0.024	0.102	0.07	0.043	0.113	0.069	0.032	0.076	0.036	0.14
Zhengzhou	Henan	0.107	0.111	0.109	0.059	0.039	0.111	0.06	0.044	0.105	0.069	0.045	0.094	0.06	0.047	0.053	0.046	0.099
Zibo	Shandong	0.103	0.097	0.097	0.053	0.029	0.097	0.055	0.031	0.093	0.051	0.032	0.102	0.079	0.03	0.099	0.034	0.12
Total (AVG.)		**0.1493**	**0.1278**	**0.112**	**0.0631**	**0.04**	**0.1129**	**0.055**	**0.035**	**0.105**	**0.056**	**0.0357**	**0.096**	**0.051**	**0.0338**	**0.0498**	**0.0345**	**0.0976**

		2003	2004	2005			2006			2007			2008			2009		
SOUTHERN KEY CITIES																		
City Name	**Province**	**PM10**	**PM10**	**PM10**	**SO2**	**NO2**	**PM10**	**SO2**	**NO2**	**PM10**	**SO2**	**NO2**	**PM10**	**SO2**	**NO2**	**SO2**	**NO2**	**PM10**
Beihai	Guangxi	0.05	0.043				0.042	0.009	0.003	0.038	0.013	0.003	0.048	0.014	0.008	0.013	0.014	0.054
Changde	Hunan	0.103	0.118	0.089	0.077	0.015	0.093	0.065	0.022	0.104	0.06	0.022	0.112	0.072	0.026	0.064	0.024	0.094
Changsha	Hunan	0.135	0.14	0.122	0.081	0.036	0.111	0.082	0.039	0.104	0.065	0.041	0.097	0.053	0.043	0.039	0.042	0.092
Changzhou	Jiangsu	0.117	0.118	0.112	0.041	0.033	0.097	0.025	0.022	0.104	0.029	0.027	0.098	0.043	0.03	0.04	0.032	0.091
Chengdu	Sichuan	0.118	0.115	0.125	0.077	0.052	0.123	0.065	0.049	0.111	0.062	0.049	0.111	0.049	0.052	0.038	0.055	0.111
Chongqing		0.147	0.142	0.12	0.073	0.048	0.111	0.074	0.047	0.108	0.065	0.044	0.106	0.063	0.043	0.053	0.037	0.105
Deyang	Sichuan	0.12	0.095	0.085	0.088	0.022	0.088	0.065	0.022	0.072	0.065	0.028	0.058	0.067	0.02	0.049	0.033	0.057
Fuzhou	Fujian	0..08	0.074	0.072	0.016	0.042	0.072	0.02	0.049	0.065	0.027	0.055	0.071	0.023	0.046	0.014	0.04	0.064
Guangzhou	Guangdong	0.099	0.099	0.088	0.053	0.068	0.076	0.054	0.067	0.077	0.051	0.065	0.071	0.046	0.056	0.039	0.056	0.07
Guilin	Guangxi	0.034	0.046	0.029	0.036	0.032	0.03	0.046	0.03	0.035	0.04	0.029	0.034	0.042	0.031	0.038	0.028	0.049

		2003	2004	2005			2006			2007			2008			2009		
SOUTHERN KEY CITIES																		
Guiyang	Guizhou	0.104	0.083	0.076	0.063	0.013	0.083	0.065	0.017	0.085	0.055	0.023	0.082	0.064	0.023	0.058	0.026	0.074
Haikou	Hainan	0.03	0.033				0.041	0.01	0.012	0.043	0.009	0.012	0.043	0.009	0.017	0.007	0.016	0.038
Hangzhou	Zhejiang	0.119	0.11	0.112	0.06	0.058	0.111	0.056	0.057	0.107	0.06	0.057	0.11	0.052	0.053	0.041	0.052	0.097
Hefei	Anhui	0.1	0.11	0.095	0.018	0.025	0.099	0.024	0.032	0.116	0.023	0.026	0.134	0.022	0.025	0.023	0.027	0.111
Huzhou	Zhejiang	0.1	0.097	0.086	0.03	0.042	0.088	0.032	0.038	0.089	0.035	0.044	0.098	0.028	0.033	0.018	0.046	0.085
Jingzhou	Hubei	0.111	0.098	0.08	0.038	0.022	0.077	0.031	0.021	0.079	0.034	0.024	0.089	0.043	0.027	0.038	0.022	0.085
Jiujiang	Jiangxi		0.091	0.092	0.07	0.037	0.088	0.071	0.039	0.079	0.049	0.024	0.078	0.039	0.022	0.03	0.02	0.061
Kunming	Yunan	0.086	0.085	0.082	0.055	0.038	0.091	0.062	0.044	0.075	0.068	0.042	0.067	0.051	0.039	0.041	0.046	0.067
Lhasa	Xizang	0.065	0.052	0.07	0.01	0.025	0.062	0.009	0.026	0.057	0.007	0.027	0.051	0.005	0.024	0.008	0.021	0.05
Liuzhou	Guangxi		0.091	0.064	0.072	0.032	0.055	0.094	0.038	0.039	0.072	0.029	0.037	0.071	0.031	(Ang) 0.063	0.035	0.054
Luzhou	Sichuan	0.153	0.127	0.119	0.076	0.029	0.127	0.069	0.033	0.118	0.068	0.04	0.082	0.074	0.035	0.059	0.04	0.072
Maanshan	Anhui	0.104	0.093	0.092	0.022	0.027	0.092	0.02	0.022	0.092	0.02	0.023	0.086	0.022	0.024	0.021	0.025	0.078
Mianyang	Sichuan	0.078	0.075	0.067	0.061	0.022	0.096	0.053	0.027	0.084	0.046	0.03	0.066	0.03	0.02	0.026	0.02	0.074
Nanchang	Jiangxi	0.1	0.099	0.089	0.05	0.031	0.086	0.056	0.032	0.083	0.054	0.034	0.083	0.05	0.036	0.054	0.037	0.079
Nanchong	Sichuan	0.128	0.101	0.099	0.066	0.027	0.067	0.059	0.032	0.063	0.049	0.029	0.054	0.046	0.027	0.038	0.032	0.052
Nanjing	Jiangsu	0.12	0.121	0.11	0.052	0.054	0.109	0.063	0.052	0.107	0.058	0.051	0.098	0.054	0.053	0.035	0.048	0.1
Nanning	Guangxi	0.072	0.078	0.067	0.058	0.038	0.066	0.059	0.035	0.064	0.059	0.048	0.056	0.04	0.044	0.032	0.028	0.05
Nantong	Jiangsu	0.1	0.097	0.094	0.043	0.041	0.089	0.038	0.039	0.088	0.042	0.035	0.09	0.032	0.03	0.019	0.021	0.077
Ningbo	Zhejiang	0.078	0.079	0.081	0.047	0.066	0.089	0.044	0.055	0.09	0.047	0.054	0.09	0.049	0.047	0.04	0.046	0.086
Panzhihua	Sichuan	0.251	0.256	0.139	0.06	0.045	0.116	0.059	0.04	0.108	0.073	0.04	0.105	0.076	0.044	0.075	0.043	0.101
Quanzhou	Fujian	0.087	0.081	0.081	0.026	0.018	0.066	0.026	0.016	0.067	0.028	0.02	0.064	0.026	0.019	0.023	0.018	0.056
Qujing	Yunan	0.08	0.084	0.085	0.068	0.023	0.094	0.063	0.028	0.089	0.065	0.028	0.086	0.052	0.027	0.047	0.027	0.08
Shanghai		0.097	0.099	0.088	0.061	0.061	0.086	0.051	0.055	0.088	0.055	0.054	0.084	0.051	0.056	0.035	0.053	0.081
Shantou	Guangdong	0.048	0.059	0.053	0.035	0.041	0.065	0.023	0.035	0.067	0.02	0.022	0.064	0.022	0.024	0.023	0.035	0.059
Shaoguan	Guangdong	0.118	0.104	0.077	0.047	0.027	0.077	0.056	0.023	0.067	0.053	0.028	0.053	0.055	0.022	0.051	0.026	0.062
Shaoxing	Zhejiang	0.107	0.072	0.08	0.044	0.04	0.09	0.045	0.05	0.094	0.047	0.043	0.096	0.054	0.037	0.054	0.036	0.1

		2003	2004	2005			2006			2007			2008			2009		
SOUTHERN KEY CITIES																		
Shenzhen	Guangdong	0.07	0.076	0.064	0.021	0.039	0.064	0.03	0.053	0.064	0.023	0.054	0.063	0.016	0.047	0.013	0.042	0.057
Suzhou	Jiangsu	0.118	0.116	0.1	0.04	0.043	0.096	0.038	0.038	0.093	0.046	0.05	0.096	0.042	0.045	0.035	0.049	0.089
Wenzhou	Zhejiang	0.073	0.068	0.072	0.047	0.059	0.077	0.039	0.058	0.08	0.037	0.055	0.082	0.036	0.053	0.028	0.054	0.076
Wuhan	Hubei	0.133	0.13	0.119	0.054	0.05	0.121	0.057	0.049	0.123	0.061	0.055	0.113	0.051	0.054	0.044	0.054	0.105
Wuhu	Anhui	0.063	0.089	0.085	0.023	0.025	0.068	0.028	0.021	0.072	0.022	0.022	0.076	0.02	0.021	0.027	0.025	0.064
Wuxi	Jiangsu	0.118	0.118	0.1	0.069	0.038	0.094	0.059	0.038	0.083	0.065	0.038	0.083	0.059	0.031	0.046	0.037	0.083
Xiamen	Fujian	0.067	0.063	0.064	0.025	0.045	0.07	0.03	0.049	0.074	0.028	0.049	0.073	0.026	0.049	0.021	0.04	0.059
Xiangtan	Hunan	0.14	0.153	0.138	0.088	0.04	0.126	0.093	0.039	0.13	0.09	0.037	0.103	0.071	0.035	0.059	0.033	0.097
Yangzhou	Jiangsu	0.132	0.123	0.099	0.044	0.023	0.101	0.033	0.018	0.1	0.034	0.018	0.102	0.034	0.015	0.029	0.017	0.085
Yibin	Sichuan	0.149	0.136	0.105	0.127	0.042	0.092	0.092	0.035	0.09	0.061	0.035	0.085	0.073	0.029	0.062	0.03	0.072
Yichang	Hubei	0.06	0.129	0.08	0.049	0.039	0.097	0.054	0.035	0.084	0.047	0.027	0.088	0.078	0.042	0.05	0.027	0.086
Yueyang	Hunan	0.133	0.146	0.129	0.073	0.033	0.125	0.064	0.024	0.125	0.065	0.028	0.123	0.055	0.028	0.035	0.029	0.101
Yuxi	Yunan	0.078	0.082	0.071	0.044	0.012	0.067	0.041	0.015	0.065	0.039	0.016	0.071	0.039	0.018	0.059	0.019	0.085
Zhangjiajie	Hunan	0.106	0.112	0.112	0.067	0.025	0.081	0.048	0.021	0.071	0.055	0.022	0.084	0.051	0.025	0.039	0.027	0.071
Zhanjiang	Guangdong	0.058	0.05	0.05	0.013	0.013	0.05	0.017	0.013	0.048	0.013	0.012	0.047	0.013	0.011	0.012	0.011	0.043
Zhenjiang	Jiangsu	0.108	0.123	0.09	0.033	0.02	0.108	0.04	0.034	0.089	0.034	0.038	0.095	0.037	0.035	0.022	0.033	0.092
Zhuhai	Guangdong	0.049	0.046	0.041	0.018	0.033	0.044	0.02	0.036	0.048	0.016	0.035	0.05	0.017	0.039	0.015	0.029	0.048
Zhuzhou	Hunan	0.165	0.171	0.101	0.09	0.027	0.106	0.081	0.03	0.103	0.074	0.03	0.101	0.076	0.036	0.065	0.036	0.101
Zigong	Sichuan	0.154	0.151	0.099	0.037	0.026	0.094	0.06	0.039	0.082	0.066	0.045	0.082	0.057	0.049	0.041	0.032	0.089
Zunyi	Guizhou	0.11	0.115	0.095	0.096	0.022	0.091	0.112	0.035	0.089	0.13	0.028	0.084	0.093	0.029	0.061	0.035	0.078
Total (AVG.)		**0.1027**	**0.1011**	**0.09**	**0.0524**	**0.03**	**0.0862**	**0.05**	**0.034**	**0.083**	**0.048**	**0.0347**	**0.0813**	**0.045**	**0.0337**	**0.037**	**0.033**	**0.0767**

ANNEX A2

The Administrative Measures for Urban Air Quality
A Brief Introduction

Since China started its reform and opening up policy, development in urban areas has been increasing rapidly and the urbanization rate—that is the share of the population living in urban areas—has increased from less than 20 percent to the current rate of 41.7 percent. Urban areas have a major supporting role in China's economic development. They account for about 65.5 percent of China's GDP, 64 percent of the value of secondary industries, and 86 percent of the value of tertiary industries.

The development of urban areas also has created strong pressures on the quality of life; for example, production and transportation have resulted in substantial pollution. The primary pollutant affecting air quality in urban areas is particulate matter, while sulfur dioxide concentrations remain high and the problem of soot pollution has not been completely resolved. With the accelerated urbanization process, pollution from motor vehicles has become an important urban air pollution source. In recent years, various regions have experienced a shift from coal-burning as the main pollution source to a combination of coal-burning and smoke from motor vehicles. Moreover, due to different natural conditions in many cities and different industrial structures and levels of economic development, there is significant variation in air pollution levels and air pollution characteristics among cities.

During the 12th Five Year Plan Period (2011–15), the government of China will strengthen the management of ambient air quality and strive for environmental air quality improvements and reductions in air pollution through both air pollution prevention and control systems. In May 2010, the General Office of the State Council—with the Ministry of Environmental Protection and eight other ministries—developed a notice entitled "*Guiding Opinions on Pushing Forward the Joint Prevention and Control of Air Pollution to Improve Regional Air Quality.*"[29] The notice stresses that (a) urban air quality management should be strengthened; (b) multifaceted pollution prevention and control measures should be promoted; (c) by 2015, the air quality in key regions—such as Beijing, Tianjin, the Yangze River Delta, and the Pearl River Delta—should be at or better than the Grade II National Ambient Air Quality Standard;[30] (d) acid rain, haze, and smog pollution should be significantly reduced, and regional and urban air quality should be substantively improved; and (e) comprehensive and clear

[29] Chinese edition: http://www.gov.cn/zwgk/2010-05/13/content_1605605.htm. English edition: http://www.chinafaqs.org/files/chinainfo/ChinaFAQs_Joint_Prevention_and_Control_of_Atmospheric_Pollution_by_State_Council_translated.pdf.

[30] China's Ambient Air Quality Standard, Chinese edition: http://www.nthb.cn/standard/standard03/20030411161748.html.

requirements for air quality management work in China should be put forward.

PURPOSE AND MEANING

The notice clearly states that by 2015 all cities in key regions should reach an air quality at or better than the Grade II National Ambient Air Quality Standard. Therefore, linked with China's 12th Five Year Plan (2011–15), the preparation and implementation of the *Administrative Measure for Urban Air Quality* will play an important role in safeguarding the progress of improving air quality, eliminating heavy pollution, ensuring that urban air quality work is smoothly carried out, and enhancing public satisfaction.

BASIS FOR PREPARATION

The *Administrative Measure for Urban Air Quality* (draft) uses the following documents as references:

(i) the *Law of the People's Republic of China on the Prevention and Control of Atmospheric Pollution*[31]
(ii) other national and local environmental laws, regulations and standards
(iii) the *Guiding Opinions on Pushing Forward the Joint Prevention and Control of Atmospheric Pollution to Improve the Regional Air Quality,* issued by the General Office of the State Council with the Ministry of Environmental Protection and other eight other ministries (No. 33 [2010] of the General Office of the State Council)
(iv) national and local environmental protection plans for the 12th Five Year Plan period (2011–15)
(v) Implementation of the Scientific Outlook on Development and Strengthening of Environmental Protection (No. 39 [2005] of the General Office of the State Council).[32]

MAIN CONTENT

The draft *Administrative Measure for Urban Air Quality* includes eight chapters with forty-nine paragraphs. With the exception of the chapter entitled "General Principles and requirement," the main content is as follows:

1. Based on national standards, macro strategies, and general principles, guidance is provided to compliant and non-compliant cities in different regions.
2. In line with the 11th Five Year Environmental Protection Plan (2006–10), which divides China's cities into "key cities" and "normal cities" with differentiated management between the two forms, the government is implementing differentiated urban environmental air quality management.
3. Management ideas focus on both pollution emissions and improving air quality.
4. The entire air quality management process has five components: (1) source; (2) policy; (3) action; (4) assessment; and (5) adjustment.
5. Based on the air quality situation in each city, the imposition of different compliance deadlines for different cities.
6. Process and action-orientation as the basis for the assessment.
7. The use of monitoring sites that are representative of the area and the exposed population as the main basis for evaluation.
8. Giving the responsibility to government departments as well as administrative senior officials, so local environmental quality will be promoted through coordination among various departments.
9. Encouraging the public to play an active role in environmental protection work.

[31] Chinese edition: http://www.envir.gov.cn/law/air.htm. English edition: http://english.gov.cn/laws/2005-09/07/content_29877.htm.
[32] Chinese edition: http://www.law-lib.com/law/law_view.asp?id=120425. English Edition: http://english.mep.gov.cn/Policies_Regulations/policies/Frameworkp1/200712/t20071227_115531.htm.

Technical Guidelines for Compilation of Urban Ambient Air Quality Control Plan Summary of the Draft

1. PURPOSE AND SIGNIFICANCE

The current situation in the urban atmospheric environment in China is very serious. Traditional coal burning-based air pollution has not yet been brought under control, while ozone and fine particles—characterized by complex forms of pollution—have become increasingly prominent. The next five to ten years will become a critical period for China to accelerate its urbanization process. At the same time, conflicts between urban areas, population, resources, and the environment will become more challenging. In this context, the preparation of an urban ambient air quality compliance plan (referred to as a "compliance plan") is significant. In order to improve the scientific and demonstrative capacity of the compliance plan, and enhance its operability and relevance, *Technical Guidelines for Compilation of Urban Ambient Air Quality Control Plan* (draft) (referred to as "*technical Guidelines*") have been prepared.

2. GUIDING IDEOLOGY AND PRINCIPLES

The guiding ideology of the compliance plan is: "In order to achieve compliance of urban ambient air quality as the ultimate objective, apply improvement of the industrial layout, adjust industrial structure, strengthen clean energy use, carry out integrated control over multiple pollutants and reinforce atmospheric environmental management as the main methods. Moreover, make clear the main objectives with urban air pollution control, make annual plans, define main tasks and outline construction projects and supporting measures that together will promote a substantial improvement in urban air quality."

The five fundamental principles of the compliance program are: (1) hierarchical management and differentiated guidance for different areas, (2) coordinated development and structural improvement, (3) energy-saving, recycling, and reuse, (4) strengthened control and a focus on key tasks, (5) improved mechanisms to strengthen regulations.

3. GENERAL REQUIREMENTS

The scope of implementation of the compliance program is administrative zones at the city level, with a focus on the urban part of the city.

The time limit for a city reaching compliance is determined by the exceeded level. The time limit for cities reaching Grade 3 and above shall be five years. The time frame can be lengthened to an appropriately longer extent for those reaching lower levels, but in principle should not be longer than 10 years.

For cities where air quality does not comply with the standards set by the city government, they must prepare compliance plans. For cities that comply with the standards, they should prepare continued improvement plans.

Compliance plans for key cities approved by provincial governments should also be submitted to the Ministry of Environmental Protection for further approval before implementation. Compliance plans or improvement plans for other cities should be submitted to provincial governments for approval before implementation.

4. WORK TASKS

There are six main areas in the work tasks of the compliance plan:

(i) Assessment of Status Quo of Atmospheric Environment and Analysis of Problems

Carry out a systematic review of the current urban ambient air quality and the situation of pollution emissions, evaluate historical trends, and apply CALPUFF/CMAQ models to determine the most important pollution sources by including all sectors and all main pollution sources. For cities that have particulate matter (PM) concentrations that cannot reach the national Grade 2 standards for air quality, source apportionment should be carried out where every source contributing to the PM_{10} concentrations is analyzed, as well as the quantity and volume of the PM_{10} sources.

(ii) Estimate Growth of Urban Air Pollution Emission and Analysis of Environmental Pressure

Based on the regional 12th Five Year Plan of the national economy, energy development, and transportation development, and according to pollution emission standards and requirements in environmental sector plans, project the quantity of air pollution loads. On this basis, apply the CALPUFF/CMAQ model to simulate urban air quality and forecast pressures in air pollution control in the target year.

(iii) Determine Objectives and Index Systems for the Compliance Plan

This includes the three aspects of objectives for urban air quality, control objectives for the total amount of major pollutants, and objectives of environment management. Among them, it is required that the ambient air quality index specifies by which year the city will reach the targeted number of clear days and the targeted average values of SO_2, NO_2, and PM_{10}. Cities in key regions should also develop indexes for ozone (O_3) and $PM_{2.5}$ and non-compliant cities should specify by which year they will comply. Control objectives by year for total amount control should be made for SO_2, NO_x, industrial dust, and soot. Cities in key regions should also set objectives for total amount control of volatile organic substances (VOCs). Based on the urban environmental management index, it is also required that the stability rate of major pollution sources—the central heating rate in urban areas, utility rate of clean energy, amount of tail gas of motor vehicles that reach the standard, etc.—are being set for the target year. In order to effectively match the air quality objectives with the total amount indicators, the CALPUFF/CMAQ should be applied to assess the attainability of the ambient air quality indicators. If it is not possible to comply with the quality index, further serious measures for total emissions control should be carried out.

(iv) Determine the Main Tasks in Complying with Urban Air Quality Standards

First, improve the urban industrial structure to ensure a rational division of industries in urban areas. Follow the principles of zone management, delineating key control zones, implementing stringent industrial access control requirements, and ensuring a rational distribution of local industries and a structural optimization.

Second, reinforce the clean use of energy in the city: (a) promote clean energy development plans, (b) scale up the development of urban central heating, (c) plan construction projects for district heating and develop facing-out plans for small coal-fired boilers, and (d) specify clean-coal control requirements, including requirements for spatial distribution of coal consumption. Requirements for sulfur and dust emissions of direct coal-burning in urban areas are to be determined, as well as requirements to control excessive urban coal consumption.

Third, strengthen the prevention and control of major pollutants—including sulfur dioxide (SO_2), nitrogen oxides (NO_x), industrial smoke, dust, and VOCs—and bring forward requirements for pollution control.

Fourth, strengthen motor vehicle emissions controls, apply new emission standards for vehicles, implement plans for complementary oil, phase out the use of "high emission vehicles" (Huang Biao Cars), and accelerate the use of low-speed freight trucks. Specific proposals for motor vehicle environmental protection labeling are to be put forward, while policies on environmental management for vehicles are to be revised.

Fifth, to improve the capabilities of urban air quality management, undertake atmospheric environmental quality monitoring, online monitoring of businesses, environmental inspection and law enforcement, and also base responses to pollution on scientific research. Propose urban air quality compliance and capacity-building tasks.

(v) Prepare a Standard List of Major Construction Projects

According to the main tasks of the compliance plan for urban ambient air quality, consider the attainability of the main emission control targets and the factors of economic and technical feasibility, and develop a standard project list that includes backward production capacities, removal and closing down of seriously polluting enterprises, clean energy use, pollution control, capacity building, and development of other projects. Fix construction projects on an annual basis. According to the standard list of the pollution control projects, make investment projections.

(vi) Determine Supporting Measures for Implementation of the Compliance Plan

According to the leadership of the organization, estimations, capital investment policies and regulations, scientific and technical support, promotion and education, implement the compliance plan.

I. Summary of the Questionnaire Survey

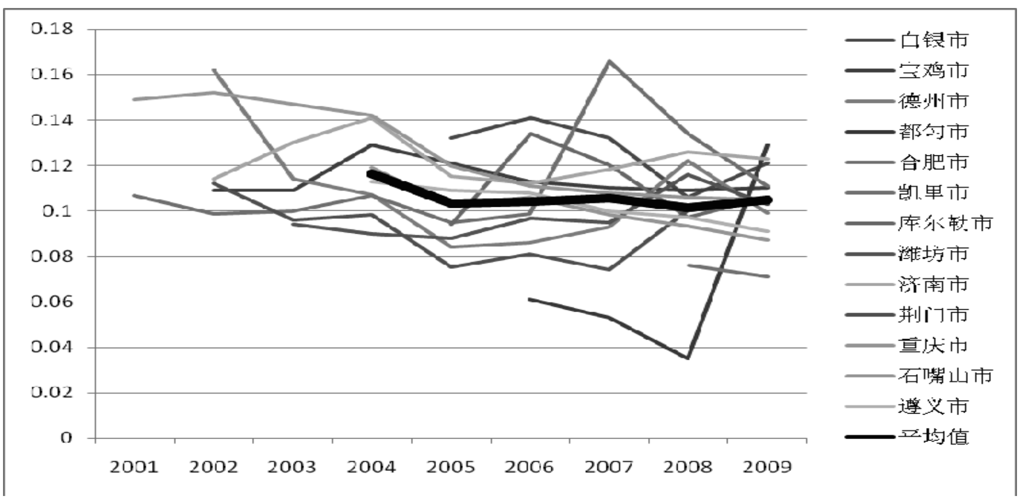
1. SUMMARY/INTRODUCTION

At the China Air Pollution Control (APC) seminar in Beijing on December 6-7, 2010, a questionnaire were circulated to all the participating cities (see part 2 of this Annex 4). The seminar included also a session presenting and discussing the questionnaire. Following the seminar, 6 cities (Zunyi, Chongqing, Jingmen, Jinan, Weifang and Hefei, all cities belonging to the 113 focused cities for APC in China) provided quite complete questionnaires, including information about PM10 sources, reduction measures and 12[th] FYP targets, while 7 cities (Baiyin, Baoji, Dezhou, Erqin, Kaili, Gearmi and Shizuishan) provided the monitoring (PM_{10}) information only (some cities provided TSP information for the first 4 years). Chongqing was the only city providing $PM_{2.5}$ research results.

2. ANALYSES OF THE MATRIX INFORMATION

1. Analyses of $\mathbf{PM_{10}}$ concentrations:

FIGURE 1.1 Development in PM_{10} 2001 to 2009 for the Following Cities*



* Following the order from top to bottom in the fig: Baiyin, Baoji, Dezhou, Erqin, Hefei, Kaili, Gearmi, Weifang, Jinan, Jingmen, Chongqing, Shizuishan, Zunyi and average (black line).

For some cities, the data are for TSP for the first 4 years.

According to Figure 1.1, at present among all the medium and large scale 13 cities that have provided information, about half of the cities have an average PM_{10} concentration level above level 2 (100 μg/m^3) in the recent years. From the black line that illustrates the average PM_{10} concentrations level for all the 13 cities, there is not much change in the average PM_{10} level between 2004 and 2009. However, for some of the individual cities there are large variations from year-to-year. See the following sections for comments on such variations.

The above map shows the trend in average PM_{10} concentrations in 4 cities in North West China. According to Figure 1.2, 3 of the 4 cities were above the national class 2 standards for PM_{10} in 2009. In these cities, there is a considerable contribution to PM_{10} in air from natural sources, such as desert and dust/sand as well as coal-based pollution during the winter.

Baiyin had very high concentrations in 2005–2007, and Gearmi in 2006–2007, being reduced in 2008 and going up again in 2009. Different from that, Shizuishan has had a consistent downward trend over the entire period 2004–2009, while Baoji had a downward trend towards 2006 and a steady level since then.

Figure 1.3 shows how the change in the development trend for PM has been in the four cities. With the exception of Jinan, the cities reached class 2 level of PM_{10} in 2006, but after 2006 the PM concentration has increased again so they became all above the 2nd level of 100 μg/m^3. Jinan City has continuously exceeded class 2 levels. The main causes why the 4 cities are having high PM concentrations are: (i) The climate conditions for these cities are dry with limited rain and more bare ground making them often exposed to pollution. (ii) The cities are mainly coal-based for heating during the winter, which leads to substantive smoke and dust emissions. The cities have had a rather steady level of PM_{10} over the 6–7 years, except Hefei which experienced a substantial increase in 2007 and 2008.

FIGURE 1.2 PM_{10} Concentration Levels in 4 cities (Baiyin, Baoji, Gearmi and Shizuishan) in North West China

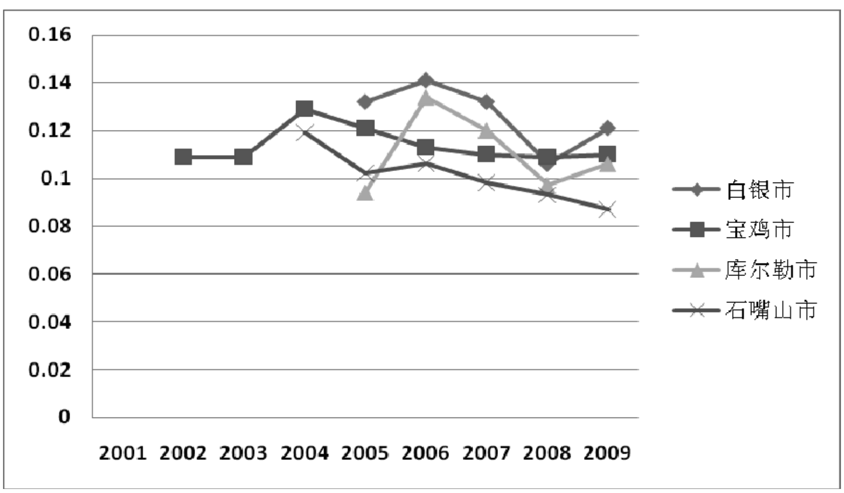


FIGURE 1.3 PM10 Development Trends from 2001 to 2009 for Cities in Eastern China: Dezhou, Hefei, Weifang and Jinan (from top to bottom)

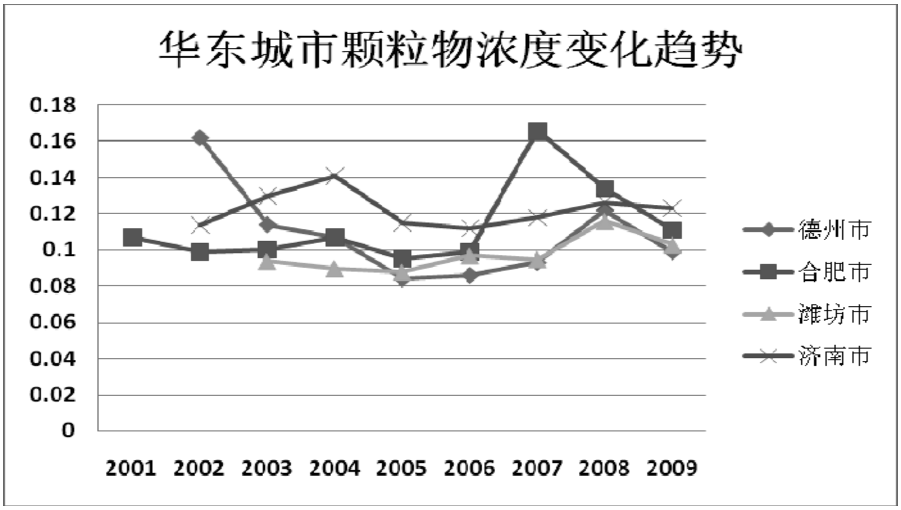


FIGURE 1.4 The Trend for PM Concentrations in Four Cities in the South: Kaili, Jingmen, Chongqing and Zunyi

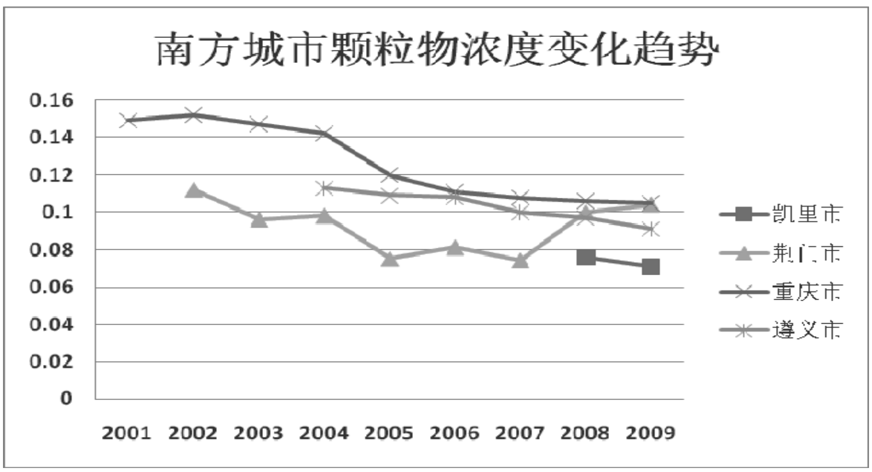


Figure 1.4 shows the trend for PM concentrations in the four cities in the south. The PM concentrations in Chongqing, Zunyi and Kaili went down while the PM concentration levels for Jingmen went down before 2007 and then went up. The sources for the PM concentrations for cities in the South are rather complex, beside emissions from industries and transportation, PM concentrations in some cities are caused by energy extraction, which is an important reason. Chongqing has had a steady downward trend over the entire period

since 2001, which may indicate a successful air pollution control program. Jingmen has also had a downward trend up until 2007 but with a substantial increase since then.

The number of cities in each of the regions (Northwest, South, East) may not be large enough to assess the general difference in PM_{10} levels in these regions. However, among the cities represented here, the average PM_{10} situation in 2009 was similar in the Northwest and East cities, and a bit lower in the South cities.

There are large, and presumably interesting, differences between the cities in terms of the trend over the period as well as in the year-by-year variations. This provides a useful basis for a study of city specific development (industrial, economic, population) and the air pollution control situation in each city, to provide experiences on successful, and not so successful, pollution control efforts.

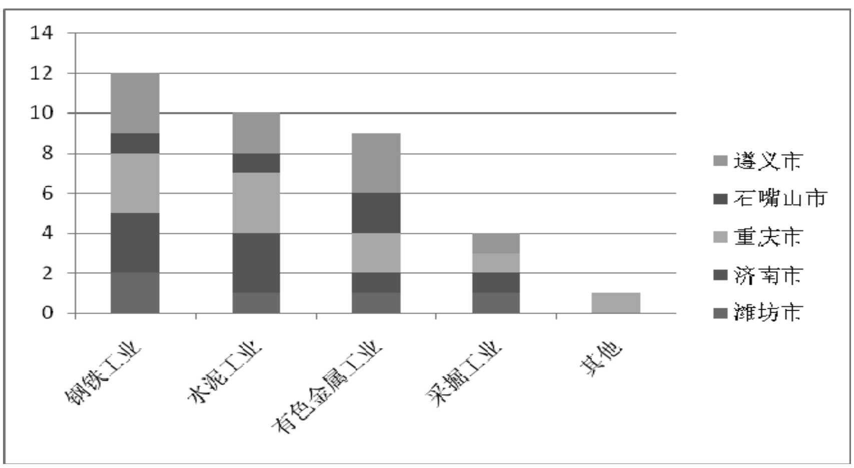
2. Analyses of the sources of Air PM pollution:

In the provided material for PM sources for the cities, iron and steel industry, cement industry and non-ferrous metal industry are the main sources to the atmospheric PM pollution. Among these industries, the iron & steel industry and the cement industry are comparatively large (as main sources) for the population weighted PM concentrations in Jinan and Chongqing and in Zunyi the non-ferrous metal industry is comparatively large (as main source) for the population weighted PM concentrations. Although the number of cities included here is not large enough to say much about regional differences, that is, differences between cities in Northwest, East and South, the findings are in line with general observations about the differences (e.g. about increased soil dust content in North and West China).

In Figure 1.6 we can see power plants, construction and road dust, soil dust and vehicle emissions are the 4 main sources of population weighted PM concentrations.

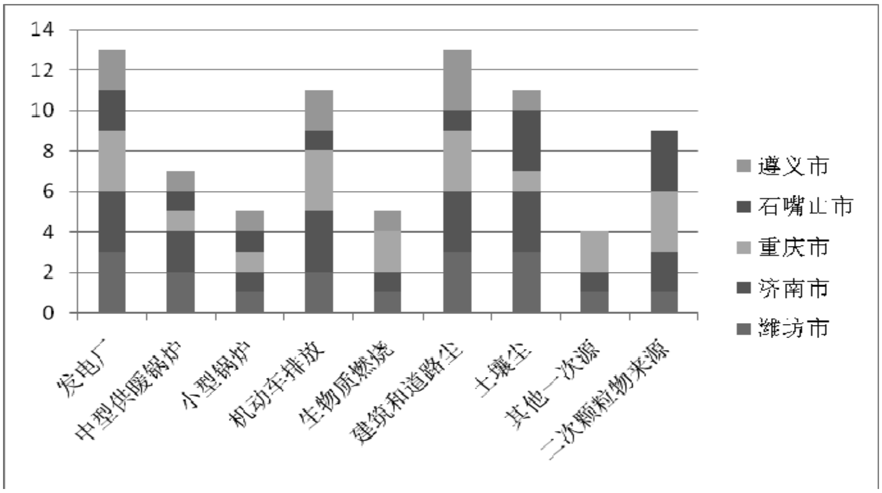
Looking at Figures 1.5 and 1.6 together: In totality, the sources contributing most to the population exposure (PWE) for PM_{10} are power plants, construction and road dust and iron and steel industry, then vehicles and cement industry. In addition, a commonality

FIGURE 1.5 Main Industrial Sources of Population Weighted PM Concentration



Industries along the x axis: Iron and steel industry, cement industry, non-ferrous metal industry, extractive industry and other industries. Cities from top to bottom: Zunyi, Shizuishan, Chongqing, Jinan and Weifang.

FIGURE 1.6 The Main Non-industrial Sources of Population Weighted PM Concentrations



Source along the x axis: Power plants, medium-sized HOBs, small-sized HOBs, vehicles, bio (quality) combustion (material) (I believe it is here meant biofuel), construction and road dust, soil dust, other sources, secondary PM sources. Cities from top to bottom: Zunyi, Shizuishan, Chongqing, Jinan and Weifang.

between most cities is that power plants account for a comparatively large share of population weighted PM concentrations. In the provincial cities (capitals) of Chongqing and Jinan vehicle emissions contributed comparatively much to the population weighted PM concentrations; a different point is that in cities in the North soil dust, construction and road dust contributed comparatively much to the population weighted PM concentrations, and in the southern city of Chonging (as well as in the Northern city of Shizuishan) secondary particles contributed relatively much to the Population weighted PM concentrations. (However, it should be noted that the Northern city of Shizuishan has a high contribution of secondary particles while the Southern city of Zunyi indicates no secondary particle contribution so pattern may be challenging to draw up).

It should also be noted that the estimated contribution from power plants seems to be quite high, and in that context to consider whether the tall chimneys of the power plants have been taken sufficiently into account, in that the tall stacks give very effective dispersion of the emissions and much reduced concentrations at ground level.

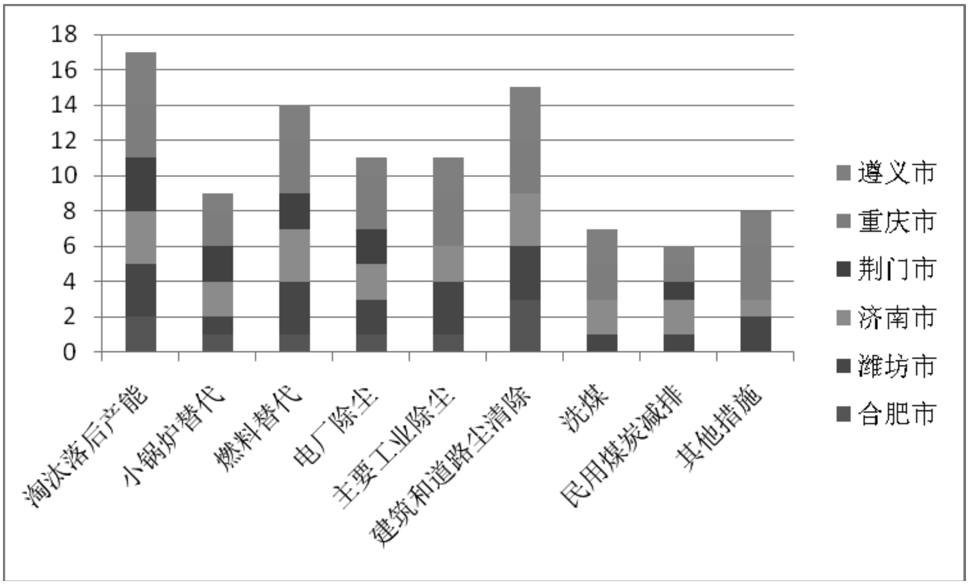
3. PM_{10} reduction measures:

   It is apparent that the cities consider that the most effective PM_{10} reduction options are connected to shutting/moving old industrial plants, reducing dusting from construction and reducing the use of bio-fuels. There is consistency between the cities' assessment of sources' contribution to population exposure (PWE) (shown in Figures 1.5 and 1.6) and their assessment of which sources are most important to control. The use of bio-fuel is an exception. According to Figure 1.6 biofuel is considered a rather minor source for PWE, but in Figure 1.7 it is ranked as an important source to control. This may not be consistent.

4. Summary:

   Although the PM pollution work has made some progress, several cities are still not

Figure 1.7 Reduction Measures



The 9 measures outlined along the x axis are: (i) eliminate outdated (old) energy producers, (ii) replacement of small HOBs, (iii) replacement of biofuel, (iv) reduce dust from power plants, (v) reduce dust from main industries, (vi) clean dust from construction (sites) and roads, (vii) clean coal, (viii) commercial coal with less emissions and (ix) other measures. The cities from top to bottom: Zunyi, Chongqing, Jingmen, Jinan, Weifang and Hefei.

reaching the 2nd PM level and in some cases also facing a rebounding situation. The situation in China's Northern and Southern cities has also differences and also PM sources are different. In the North, PM sources are to a larger extent generated from coal used for heating during the winter, construction and road dust as well as natural PM sources. In the south, the situation is more complex. In addition to construction and road dust, also secondary PM sources and biofuel are important PM sources. In view of this situation, the previous "one size fits all" management model cannot be applied to sufficiently address the present PM pollution control work, but have to address the different PM pollution characteristics of different areas and to come forward with targeted PM pollution control measures.

The statement above is really the main conclusion from this exercise. And it is an important conclusion which can be shown more clearly now, exactly as a result of this exercise.

The other conclusion is that the data from the 5 cities that have provided rather complete information could be used as a study basis for providing good and bad experiences concerning PM control programs, or lack of programs, in Chinese cities.

It is questionable that the contribution from power plants, with very tall stacks, is quite a bit higher than the contribution from Heat Only Boilers (HOB)s. This could mean that small and medium sized HOBs with large emissions have largely been eliminated from the 5 cities.

In any case, the exercise has provided useful material that support conclusions that pollution control programs should be city specific, and that the cities here should be studied to learn from their experiences.

II. Questionnaire Matrix

世行“中国大气污染控制综合管理研究”项目”

“China Comprehensive Air Pollution Control Management Project”

城市颗粒物污染调查表

City PM Classification Scheme

Response example from Chongqing City.

Similar responses were provided by Zunyi, Jingmen, Jinan, Weifang and Hefei cities.

Baiyin, Baoji, Dezhou, Erqin, Kaili, Gearmi and Shizuishan cities responded on PM_{10} concentrations only.

January 5, 2011

2011年1月5日

表（一）：本市大气颗粒物污染情况 Basic PM Pollution Situation

城市：重庆市 City: Chongqing

项目Project			计量单位Measure Unit	浓度值 Concentration	必要的说明 Explanations
PM_{10}监测数据 Monitored values	PM_{10}浓度年平均值 Annual average concentration value	2001年 Year	mg/m^3	0.149	
		2002年 Year	mg/m^3	0.152	
		2003年 Year	mg/m^3	0.147	
		2004年 Year	mg/m^3	0.142	
		2005年 Year	mg/m^3	0.120	
		2006年 Year	mg/m^3	0.111	
		2007年 Year	mg/m^3	0.108	
		2008年 Year	mg/m^3	0.106	
		2009年Year	mg/m^3	0.105	
		近三年最高年均值 Highest average value within last 3 years	mg/m^3	0.108	
		近三年平均值 Average value for last 3 years	mg/m^3	0.106	
		PM_{10}浓度变化趋势[1] Concentration trend.	mg/m^3	−0.043	
	PM_{10}区域背景浓度年平均值 Regional Background Concentration		mg/m^3	0.040	
	监测站点数目No. of monitoring stations.		个 No.	11	

	监测站所在区/县及相应区/县的人口Population of the districts and counties being monitored.		渝中区/71.84万人，Yuzhong District 718,400 people, 九龙坡区/100.82万人，Jiulongpo District 1,008,200 people, 渝北区/97.62万人，Yubei District 976,200 people, 沙坪坝区/91.42万人，Shapoba District, 914,200 people, 江北区/69.62万人，Jiangbei District 696,200 people, 南岸区/71.52万人，Nanan District 715,200 people, 巴南区/90.79万人，Banan District 907,900 people, 北碚区/73.14万人，Beibei District,731,400 people, 大渡口区/27.72万人 Dadukou District, 277,200 people。		
$PM_{2.5}$ 监测与研究数据 monitoring and research figures	$PM_{2.5}$浓度年平均值[2] Average concentration value	2001年 Year	mg/m^3		无 None
		2002年 Year	mg/m^3		无None
		2003年 Year	mg/m^3		无None
		2004年 Year	mg/m^3		无None
		2005年 Year	mg/m^3		无None
		2006年 Year	mg/m^3		无None
		2007年Year	mg/m^3		无None
		2008年 Year	mg/m^3		无None
		2009年 Year	mg/m^3	0.079	科研数据，3—10月份 Research results March – October 2009
		近三年平均值 Average value over last 3 years.	mg/m^3		

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注 Notes：最近三年（2007-2009）PM_{10}平均浓度与最初三年（2001-2003）PM_{10}平均浓度的差值。Most recent average PM10 value（2007-2009 and earliest average PM10 concentration value（2001-2003).

1. 有PM2.5 浓度监测的城市用监测数据，没有监测数据的城市可以用科研中的PM2.5浓度数据。If the city does not have established PM2.5 monitoring stations could use monitored PM2.5 data from research projects.

表（二）：本市大气颗粒物源清单 PM sources in the city.

城市 City：重庆市 Chongqing city

调查项目Surveyed sources			人口权重浓度参数 [3]PWE concentrations	必要的说明 Explanations
本市PM_{10}源清单	主要工业 Main industries	钢铁工业 Iron and steel	3	城市内存在2个大型企业 2 large enterprises remains in the City
		水泥工业 Cement	3	近郊分布水泥企业较多Parts of the suburb have many cement enterprises.
		有色金属工业 Non-ferrous metal	2	
		采掘工业 Extractive	1	
		其他 Others	1	汽车制造 Car manufacturing
	发电厂 Power Plant		3	主城2个电厂，近郊1个 2 plants in the main city, 1 in the suburbs.
	中型供暖锅炉[5]Medium-sized HOBs		1	
	小型锅炉[6]Small-sized HOBs		1	
	机动车排放 Vehicle emissions		3	柴油货车较多，白天晚上可进城 Many diesel vans,can enter the city both day and night time
	生物质燃烧 Biofuel		2	
	建筑和道路尘 Construction and road dust		3	
	土壤尘 Soil dust		1	
	其他一次源[7]Other sources		2	餐饮油烟 soot from food beverage industry,
	二次颗粒物来源 Secondary PM sources		3	

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日 Date:

2. 用人口权重浓度（PWE）的来表示排放源对影响程度。人口权重浓度（PWE）定义如下：

将城市分成几个区域，受当地排放源和周围区域的影响，每个区域有一定的人口数以及一定的PM10平均浓度。PWE的计算是将PM10浓度与当地人口数相乘，将所有区域相加，再除以总人口数。在城市平均PWE中，浓度较高和人口较多的区域拥有更大权重，浓度低和人口少的区域权重教小。如果城市中有多个监测站，且拥有每个区域人口数，就能从监测数据估算PWE。Use the annual average population weighted exposure (PWE)to express the level of effect by the emission sources. PWE is defined as follows: The urban area can be divided into smaller administration districts/areas. Each of the areas will have an average PM_{10} concentration, dependent upon the nearby sources and influence from sources further away. PWE is calculated by multiplying the PM_{10} concentration and the population number for each of the areas, adding this product over all areas, and divide by the total population. Areas with a high pollution level and large population have a small weight in the average. PWE can be estimated from monitoring data, if there are many monitoring stations, and the population distribution is available.

参数1：较小影响 Code 1: Low influence (only small contribution to the PWE in the city)

参数2：中度影响 Code 2: Medium influence.

参数3：显著影响 Code 3: Large influence.

各种源的代码应该具有可比性，同样的代码意味着影响程度相似 The coding should be comparable for all the source categories, so the same code in any column indicate a similar influence on the PWE.

3. 主要工业：主要考虑城市中主要的PM排放源，是否在人口密集的区域，用参数表示它们对PWE的影响。Are some large plants with large PM emissions located within the city? Near densely populated areas? Code their influence.

4. 中型供暖锅炉 (HOB)：城市中是否分散着大量HOBs，用参数表示它们对PWE的影响。Medium-sized HOBs: If there are still a substantial number of HOBs spread around in the city, in populated areas, code

their influence on the average ground level PM10 in the populated areas of the city (on the PWE).

5. 小型锅炉：主要指民用锅炉、小规模工商业、服务业锅炉。在发展比较落后的地区，这样小规模的煤炭燃烧是很普遍的，用参数表示这些活动对PWE的影响。Small-sized HOBs: important individual users, small industrial and commercial users and used in service industries. In less developed areas, coal combustion from such small HOBs are very usual, use a parameter to express how these activities is affecting the PWE.

6. 可能还有其他重要的PM10一次排放源。请列出这些源，像其他源一样用参数表示它们的影响。There may be other important PM10 sources in the city. Code their influence in a similar way as above.

表（三）：本市PM_{10}消减措施及展望 PM_{10} reduction measures and future prospects.

城市 City：

调查项目Surveyed items:		措施有效性[8]Effectiveness of the measure.	必要的说明Explanation
PM_{10}削减措施 reduction measures	落后产能淘汰eliminate outdated energy producers	3	
	小锅炉替代 re- placement of small HOBs	2	
	燃料替代 replacement of biofuel	3	
	电厂除尘 reduce dust from powerplants	3	
	主要工业除尘reduce dust from main industries	3	
	建筑和道路尘清除 clean dust from construction sites and roads	3	
	洗煤 clean coal	2	
	民用煤炭减排commercial coal with less emissions	1	
	其他措施[9] other measures.	3	柴油车排放控制与限行 Control emissions form diesel cars and “control sectors”
“十二五”展望 12th FYP development	PM_{10}削减目标[10]Reduction target	0.075 mg/m^3	

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7. 用参数1-3表示某项措施对降低PM_{10}浓度的有效性 Indicate with a code 1-3 to what extent a policy has been effective to reduce the average ground level PM_{10} concentration in the city:

参数1：较小影响 Code 1: Small influence

参数2：中度影响 Code 2: Medium influence

参数3：显著影响 Code 3: Large influence

8. 可能还有其他重要措施，请列出，并像其他措施一样用参数表示它们的有效性。There may be other important PM_{10} sources in the city. Code their influence in a similar was as above.

9. 在“十二五”末期本城市期望达到的PM_{10}浓度水平 What is the target PM10 concentration the city expects to reach at the end of the 12th FYP?

Analysis Investment Cost of Various Dust Collectors

Research shows that installation of electrostatic precipitators (ESP) and other high efficiency PM collectors in power plants may have 60 times higher benefits than costs, compared to no control (Vennemo and Yan, 2008). The cost for investing in dust collectors includes the cost of dust collecting devices, electric fares, annual operation expenditure and occupied area. For the purpose of this report, a dust collecting devices supporting a 600MW unit is taken as an example, with the amount of flue gas to be disposed set at 3,600,000m^3/h. The electric precipitator has 5 electric fields and bag filter has a filtration speed of 1m/min; for the electro-bag there is a combined dust collector (both one-piece and separated type), 2 fields are used during electric dusting collecting, with an efficiency of 90%, and the filtration rate of bag filter is 1.2m/min. Detailed costs are shown as follows:

Cost of Devices

The filter bags used in the bag filter and the electro-bag combined dust collector are made from PPS/PPS, imported fiber, 550g/m^2, surface finished with PTFE. Their service life is 4 years, while that of the cage frame and the pulse valve is 8 years. Table 1 shows the cost of different types of dust collector.

TABLE 1 Cost of Different Dust-collecting Devices

Item	Bag filter	Electric precipitator	Electro-bag combined dust collector	
			One-piece	Separated
Relative cost of devices	1	1.02	1.1-1.2	1.1-1.2
Expense for changing filter bag and cage frame (RMB 10 thousand/year)	250	0	208	208
Electric fares (RMB 10 thousand/year)	483	447	422	494
Annual operation expenditure (RMB 10 thousand/year)	733	447	630	702

TABLE 2 Electricity Cost of Different Dust-collecting Devices

Item	Electric precipitator	Bag filter	Electro-bag combined dust collector	
			One-piece	Separated
Power dissipation of draft fan caused by resistance (kw)	290	1410	940	1180
Power dissipation of air compressor (kw)	0	180	60	60
Power dissipation of freeze dryer (kw)	0	20	8	8
Power dissipation of electric precipitator during operation (kw)	1,200	0	400	400
Total of power dissipation (kw)	1,490	1,610	1,408	1,648
Total of electric fares (RMB 10 thousand/year)	447	483	422	494

Power Price

The power price is RMB 0.40/kwh and the operating time is 7,500h/year. For the electric precipitator, the draft fan and the high-voltage rectification equipment are the major power consumers; and for the bag filter, the air compressor and the freeze dryer are the leading power users. Detailed electric fares are shown in Table 2.

Occupied Area

The area occupied by dust collecting devices includes the space for inlet and outlet horns, but the side slide excluded. The area occupied respectively by three dust collectors when reaching the same efficiency is shown in Table 3. The price of operating or leasing land is additional to the capital cost. The price varies depending on location specifics.

TABLE 3 Area Required by Different Dust-collecting Devices

Item	Electric precipitator	Bag filter	Electro-bag combined dust collector	
			One-piece	Separated
L×W (m)	38×68	33×58	34×66	39×66
Area (m^2)	2584	1276	2244	2574

Ministry of Environmental Protection of the People's Republic of China Announcement 2012 No. 7[33]

GB 3095-2012 February 29, 2012

To implement *the Environmental Protection Laws of the People's Republic of China* (the PRC) and *the Law on the Prevention and Control of Atmospheric Pollution of the PRC*, the Ministry of Environmental Protection (MEP) hereby endorses the Ambient Air Quality Standards as a national standard on environment quality, with an aim of protecting environment, reducing health risks and controlling air pollution. The standard is jointly published by MEP and the General Administration of Quality Supervision, Inspection and Quarantine.

- The name and code of the standard is as follows: Ambient Air Quality Standards (GB 3095-2012).
- As stipulated in relevant laws, the standard is a legally binding instrument.
- The standard will come into force on January 1, 2016.

Before the above date, the Administrative Agency of Environmental Protection under the State Council may implement the standard in advance in line with *the Guidance on Promoting Joint Prevention and Control of Air Pollution to Improve Regional Air Quality* (Guo Ban Fa [2010] No. 33) and other policies concerned. Specific implementation plans, which include geographic scales and time, will be announced later. Provincial People's Governments may implement the standard in advance according their own state and needs for environmental protection.

The standard is published by the China Environmental Science Press and accessible on the website of MEP (bz.mep.gov.cn).

The Ambient Air Quality Standards (GB 3095-1996), the Revised Version of the Ambient Air Quality Standard (GB 3095-1996) (Huan Fa [2000] No. 1), and the Maximum of Allowable Concentration of Air Pollutants for Crop Conservation (GB 9137-88) will be invalidated once the standards comes into force.

Abstracts from part 4 of the standards:

[33] "The National Standards of the People's Republic of China, GB 3095-2012, Ambient Air Quality Standards," translation of text on p. i and Table 1 on p. 3 of the standards.

TABLE 1 Concentrations Values for Type of Ambient Air Pollutants

No	Type of Pollutant	Average time	Concentration values		Unit
			Grade I	Grade II	
1	SO2	Yearly Average	20	60	µg/m³
		24 hours average	50	150	
		1 hour average	150	500	
2	NO2	Yearly average	40	40	
		24 hours average	80	80	
		1 hour average	200	200	
3	CO	24 hours average	4	4	mg/m³
		1 hour average	10	10	
4	O_3	Daily highest 8 hours	100	160	µg/m³
		1 hour average	160	200	
5	PM_{10}	Yearly average	40	70	
		24 hours average	50	150	
6	$PM_{2.5}$	Yearly average	15	35	
		24 hours average	30	75	

EXAMPLES ON TIGHTENING THE COMPLIANCE TARGETS FOR PM_{10}, GRADE II

FIGURE 1 Implications on tightening compliance target from 100 to 70 µg/m³ for selected cities in North China (PM_{10} levels as of 2009)

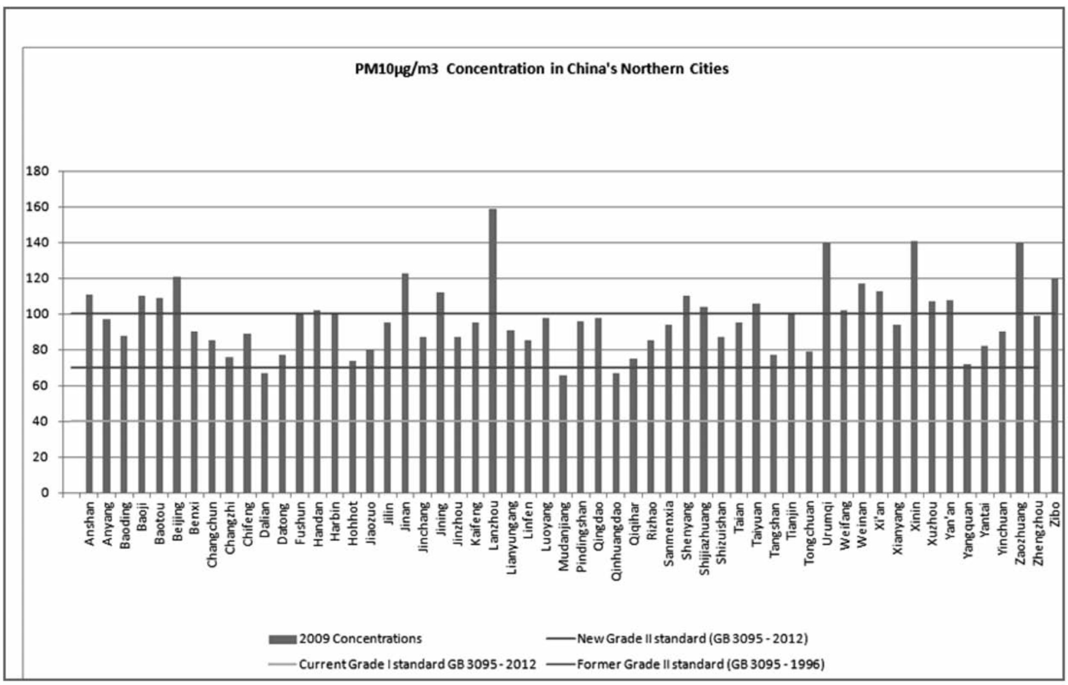
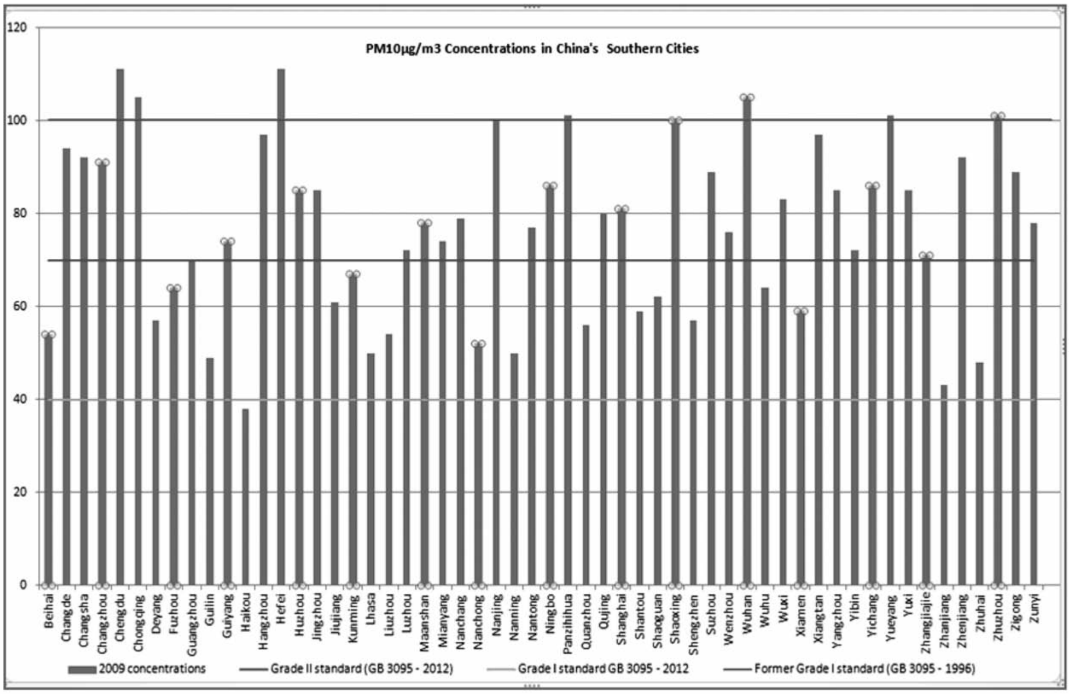


FIGURE 2 Implications on tightening compliance target from 100 to 70 μg/m³ for selected cities in South China (PM_{10} levels as of 2009)



颗粒物污染控制进展

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