



CCICED Special Policy Study
Regional Air Quality
Integrated Control System Research

2012 Annual General Meeting
2012.12.12-14

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Contents

EXECUTIVE SUMMARY	4
1. CHINA IS FACING SEVERE REGIONAL ATMOSPHERIC POLLUTION	4
1.1. High concentration and heavy pollution of PM _{2.5}	4
1.2. Complex PM _{2.5} sources with high percentage of secondary PM	4
1.3. Regional transport	8
1.4. High frequency and elevated levels of heavy pollution days	9
1.5. Single-factor to multi-factors: excessive pollution causes shift	9
2. IMPROVING THE AIR QUALITY IN CHINA IS A LONG AND ARCUOUS TASK.	11
3. CURRENT CONTROL MEASURES ARE NOT EFFECTIVE ENOUGH TO ACCOMPLISH THE SET TARGET IN AIR QUALITY IMPROVEMENT	13
4. POLICY RECOMMENDATIONS FOR REGIONAL AIR QUALITY CONTROL	16
4.1. Accelerate the amendment to the Law on the Prevention and Control of Atmospheric Pollution.	16
4.2. Improve the air quality management mechanism, and enhance air quality management capabilities	18
4.3. Accelerate the transformation of economic development mode and promote the continued reduction of pollutants	20
4.4. Optimize the energy structure to achieve efficient, clean, and sustainable coal utilization	22
4.5. Comprehensively strengthen pollution control in mobile sources	24

EXECUTIVE SUMMARY

1. CHINA IS FACING SEVERE REGIONAL ATMOSPHERIC POLLUTION

China is facing severe air pollution. Though the traditional coal-burning pollution problems have not been solved, a more complex regional air pollution challenge characterized by O_3 (ozone) and $PM_{2.5}$ (Particular Matter having an aerodynamic diameter less than $2.5\ \mu m$ and thus can suspend in the atmosphere for a long time) has emerged. According to the WHO's evaluation of the $PM_{2.5}$ annual average concentration from over 1082 cities around the world, China's best rank is 808 for Haikou and the worst city only ranks 1058, almost at the bottom of the list. $PM_{2.5}$ will become the most important pollutant that influences China's air quality, based on the *Environmental Air Quality Standard* (GB3095-2012) that was revised this year and is about to go into effect.

1.1. High concentration and heavy pollution of $PM_{2.5}$

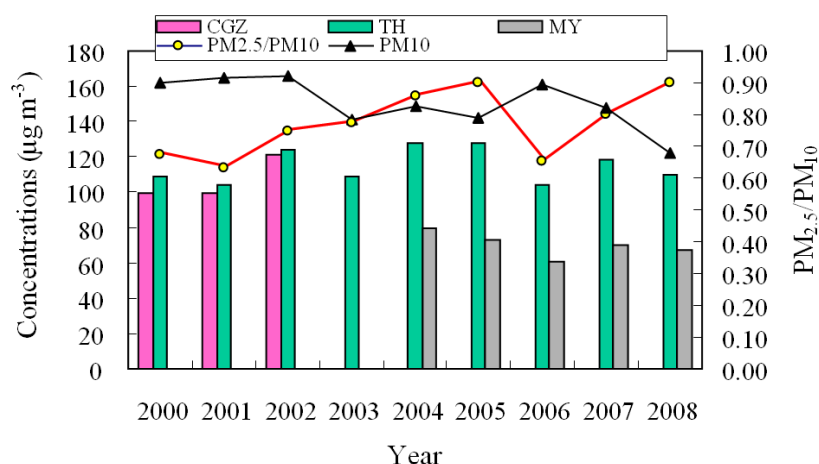
There are three basic characteristics of PM pollution in China. **(1) High $PM_{2.5}$ concentrations.** High $PM_{2.5}$ concentrations are frequently found in Chinese cities. For example, the annual average concentration of $PM_{2.5}$ is as high as $60\text{-}90\ \mu g/m^3$ in Eastern China, whereas $PM_{2.5}$ could exceed $100\ \mu g/m^3$ in industrial areas. These concentrations are significantly higher than the standard recommended by international organizations and other countries (below $10\ \mu g/m^3$). **(2) High contribution of $PM_{2.5}$ to PM_{10} .** Results from long-term measurements conducted in Beijing suggested that the ratio of $PM_{2.5}$ to PM_{10} tended to increase during the last decade, indicating that the contribution of $PM_{2.5}$ to PM_{10} became more important. **(3) Apparent spatial distributions.** $PM_{2.5}$ concentrations varied considerably in different regions. Generally, $PM_{2.5}$ is higher in the northern region compared to the southern region, and is higher in the western region than the eastern region. Moreover, $PM_{2.5}$ is usually higher in winter than the other seasons. Figure 1 presents the annual average $PM_{2.5}/PM_{10}$ concentrations of Beijing, the capital city of China.

1.2. Complex $PM_{2.5}$ sources with high percentage of secondary PM

The mass concentration and chemical speciation of $PM_{2.5}$ is highly dependent on the measurement region. Generally, POM (particulate organic matter, organic species in particles) and SNA (the sum of sulfate, nitrate and ammonium) are the major components in $PM_{2.5}$, and are significantly influenced by emissions (which usually

show spatial and temporal variations) and atmospheric oxidation activity (which control the conversion from the gaseous pollutants to atmospheric particulates). In the eastern region (including urban, rural and forest areas), SNA is the dominant component in $PM_{2.5}$, accounting for 40%~57%; the contribution of POM was 15%~53%, which is lowest at the Changbai Mountain and highest in Urumchi. The sum of POM and SNA constitutes 53% of $PM_{2.5}$ in Beijing, the rest being crustal dust and other un-identified or un-analyzed components.

Figure 1. Annual variations of the $PM_{2.5}$, PM_{10} and the ratio of $PM_{2.5}/PM_{10}$ during 2000 to 2008 in Beijing*

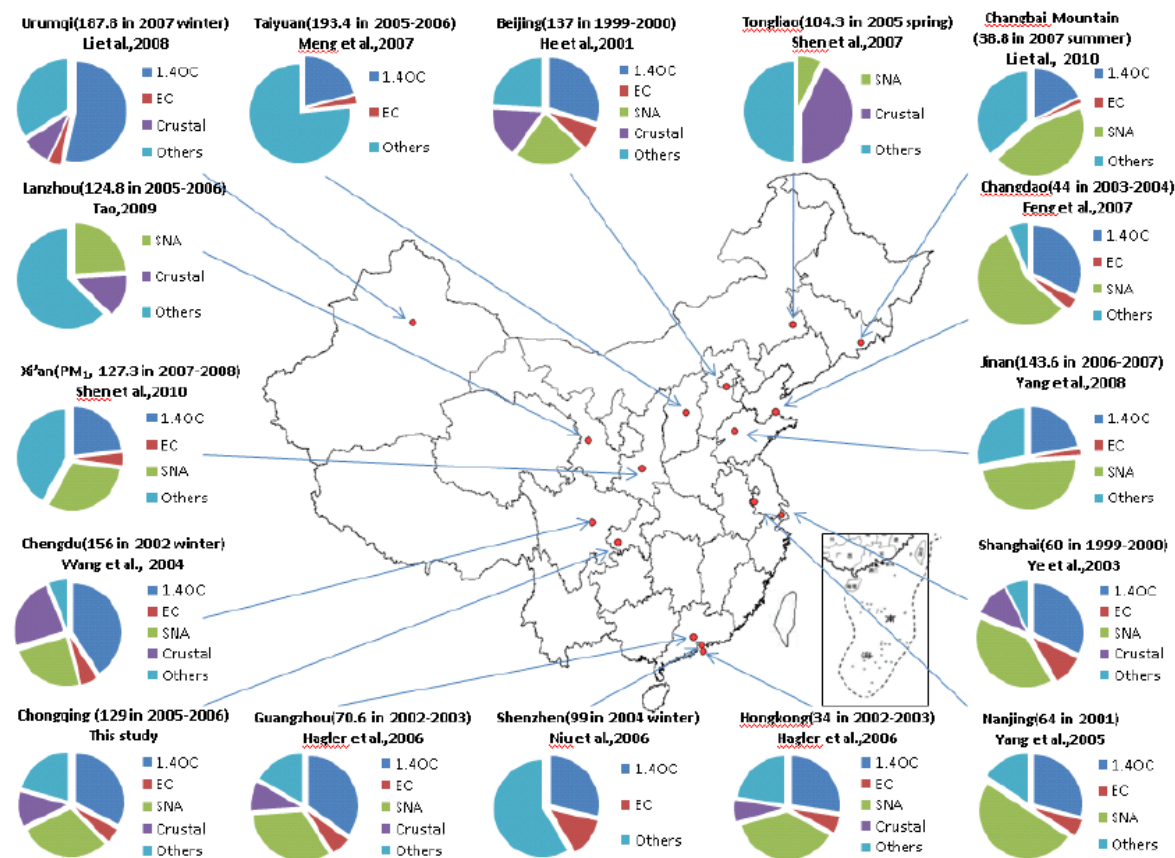


* Sampling was conducted in three sites in Beijing, i.e. ChengGongZhuang(CGZ, an urban-center site), Tsinghua University Campus (TH) and Miyun (MY, a regional background site)

Source: Atmospheric Particular Matter and Regional Complex Air Pollution, He Kebin et. al., Science Press, 2011

When significantly impacted by dust, the contribution of minerals to $PM_{2.5}$ could be considerable. It should be pointed out that in addition to the regions near the source areas of dust (e.g., northern China, which holds a large area of desert, is more inclined to be affected), dust could also be transported to central and southwestern China. Thus, $PM_{2.5}$ in China is also characterized by high contribution of mineral dust relative to the developed countries

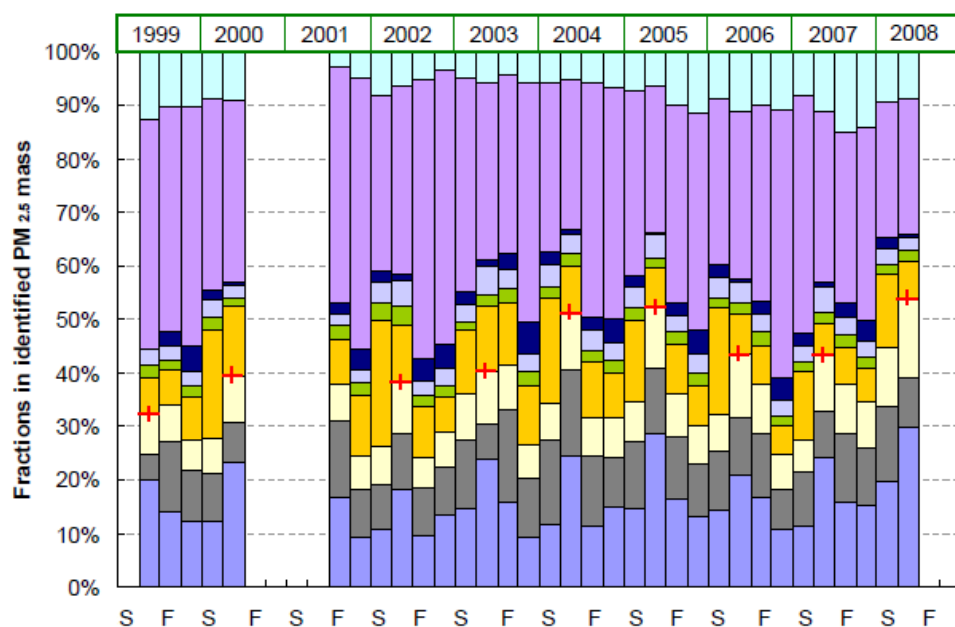
Figure 2. Chemical composition of PM_{2.5} across China



Moreover, total carbon (TC) and SNA in PM_{2.5} were found to be comparable with Chinese cities such as Beijing, Chongqing, Guangzhou, and Shanghai, where SNA was 26% higher than TC in Los Angeles, indicating that the secondary species represent a major source of PM_{2.5} in the mega-cities of the developed countries. The contribution of EC (Elemental Carbon, the aggregate of compounds composed of nearly pure carbon) to PM_{2.5} is much higher in Shanghai and Shenzhen compared with other Chinese cities, but much lower than that of Los Angeles and London. There are large seaports in all of the cities, indicating that emissions from ships might be an important source of EC.

The transportation and evolution of PM are influenced by the meteorological parameters, thus, the composition of PM_{2.5} is expected to exhibit seasonal variation. The contribution of inorganic species among the distinguishable matters in PM_{2.5} tends to be highest in summer, based on the PM_{2.5} samples of Beijing. The **percentage of secondary species continued to grow in PM_{2.5}** from 1999 to 2008. On a yearly basis, the SNA fraction in identified PM_{2.5} mass rose from 29% in 1999 to 36% in 2007 (Figure 3).

Figure 3. Seasonal PM_{2.5} speciation abundances at Tsinghua in Beijing from the summer of 1999 through the summer of 2008

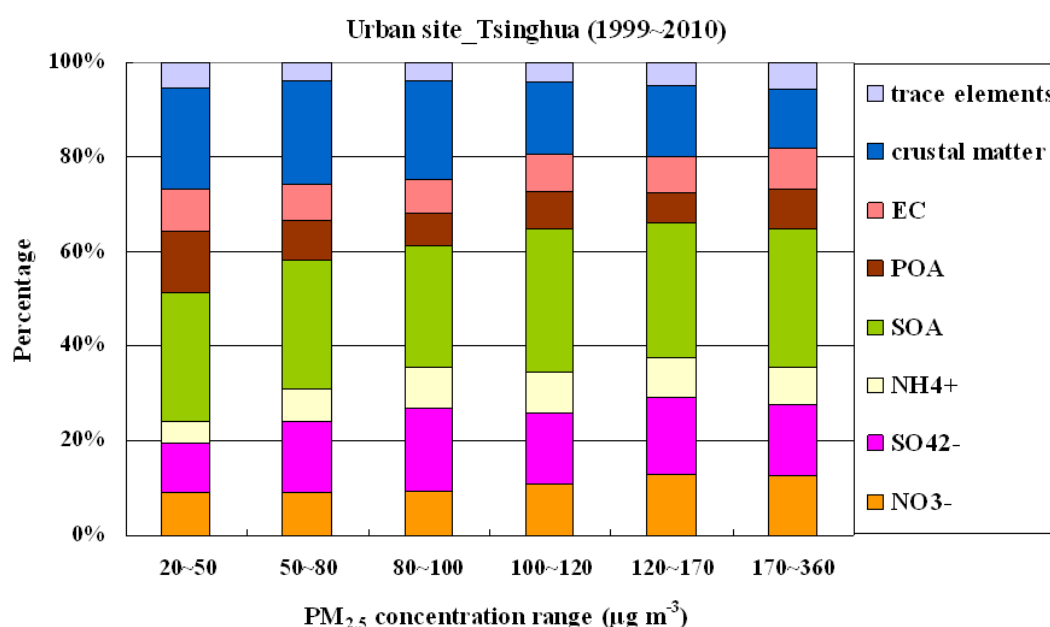


Average percentages of SNA in each summer are marked with cross symbols. S refers to Spring and F refers to Fall.

Source: Atmospheric Particular Matter and Regional Complex Air Pollution, He Kebin et. al., Science

The ratio of secondary species is higher than usual during high PM_{2.5} episodes. Figure 4 presents the relationship between the PM_{2.5} speciation abundances and the PM_{2.5} mass concentration, which was based on a long-term measurement. When the PM_{2.5} concentration was below 120 µg/m³, the contribution of secondary species (including SNA and secondary organic aerosol) was found to increase with the PM_{2.5} concentration; whereas the contribution of secondary species did not increase significantly when the PM_{2.5} concentration was above 120 µg/m³. These results indicate that the secondary species are some of the important factors responsible for the high PM_{2.5} concentrations observed in Beijing.

Figure 4. The relationship between the PM_{2.5} speciation abundances and the PM_{2.5} mass concentration



Source: Atmospheric Particular Matter and Regional Complex Air Pollution, He Kebin et. al., Science Press, 2011

1.3. Regional transport

Rapid development of urbanization and regional economic development aggravate the complex air pollution in the Yangtze River Delta. Cities in the Yangtze River Delta are suffering from regional air pollution beyond local pollution while serious regional pollution is becoming more and more frequent. In winter and spring, influenced by

complex factors like inland pollution, northern sand-dust and adverse local meteorological conditions, the impact of regional fog, haze and floating dust stands out. In early summer and late autumn, stalk-burning contributes atmospheric fine particle pollution to the city and surrounding areas, which triggers large-scale regional haze pollution, resulting in a simultaneous variation trend of air quality in key cities of the Yangtze River Delta.

Table 1 shows that in 2011, there were 28 polluted days altogether in Shanghai. Taking Shanghai, Nanjing, Suzhou, Nantong, Lian Yungang, Hangzhou, Jiaxing and Ningbo as references, over half of these cities were simultaneously polluted on 22 of these days, which amounts to 78.6% of all the air pollution days; the days when all 8 cities exceeded the standard occupied 14.3% of the pollution days, and the situation when only Shanghai exceeded standard occurred on just 2 days.

Table 1. The air quality of 8 cities around Shanghai in the days when Shanghai failed to comply (Year 2011)

	All cities (8) failed to comply	Half cities (4) failed to comply	All the cities meet the air quality standards	Shanghai's API higher than the regional medium
Days	4	22	2	20
Percentage	14.3%	78.6%	7.1%	71.4%

1.4. High frequency and elevated levels of heavy pollution days

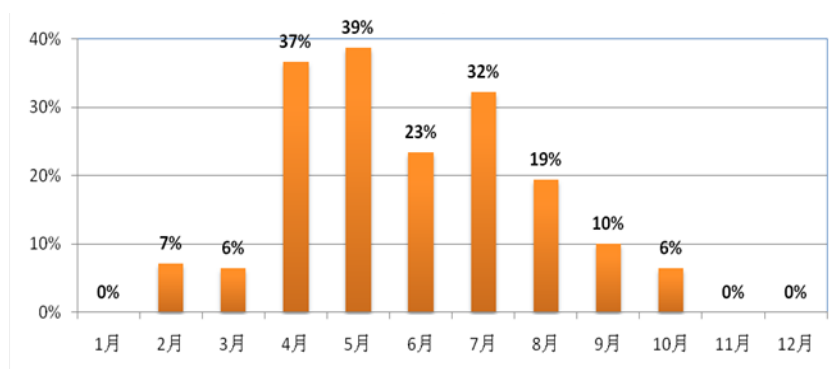
The annual average concentration of atmospheric pollutants including PM_{2.5} is high for Chinese cities. More than that, the heavy pollutant days occur with greater daily average concentrations and higher frequency. Consider Shenzhen, with relatively better air quality, for example. Since 2006, haze days happen much more frequently, the pollution index has grown and the oxidation level of the atmosphere has increased. The highest hourly concentration of PM₁₀ reached up to 428µg/m³, twice the national second-level standard. Some stations have days with the O₃ highest hour concentration over the limit nearly 10% of the time.

1.5. Single-factor to multi-factors: excessive pollution causes shift

With PM_{2.5} and O₃ concentrations increased, the mixed air pollutants promote the chemical and photochemical reactions in the air and result in even more complex air pollution in Eastern China. Especially in summer, the oxidation level of the

atmosphere increases with higher O_3 concentration, and convert more SO_2 and NO_x into secondary particulates such as sulfate and nitrite. Consider Shanghai for example; the pollution levels remain high from April to July and reach the peak in May, as shown in Figure 5. The oxidation level of the atmosphere in summer is enhanced which is one major reason for the high $PM_{2.5}$ pollution.

Figure 5. Monthly distribution of the $PM_{2.5}$ and O_3 simultaneous pollution in Shanghai, 2011



Source: Air quality monitoring data from Shanghai Environmental Monitoring Center

The main reason for China's regional air pollution is abundant emissions and concentrated distributions of many air pollutants. China's coal consumption is growing at the rate of more than 200 million metric tons per year and has accounted for more than 48% of the world total, whereas the population of motor vehicles also grew rapidly from 120 million to 190 million during the 11th Five-Year Plan. These two factors cause China's emissions of primary particulate matter, SO_2 , NO_x and VOCs to be more than 20 million metric tons. The emissions are mostly concentrated in Eastern China and result in deterioration of air quality in some areas such as Beijing-Tianjin-Hebei, Yangtze River Delta, and Pearl River Delta.

The severe air pollution not only did serious harm to the public health, but also caused massive economic loss. The consequences estimated by the WHO and other organizations worldwide: millions of people die of air pollution every year; many respiratory and cardiovascular system problems result in an inability to work or study; grain production shrinks due to the high concentration of O_3 ; acid rain causes damage to the forest and ecological environment, and even to the quality and appearance of buildings. China is experiencing all of these problems. Last year the public alarm induced by the long-time, wide-spread haze days in Beijing very badly impacted the government's credibility.

2. IMPROVING THE AIR QUALITY IN CHINA IS A LONG AND ARDUOUS TASK.

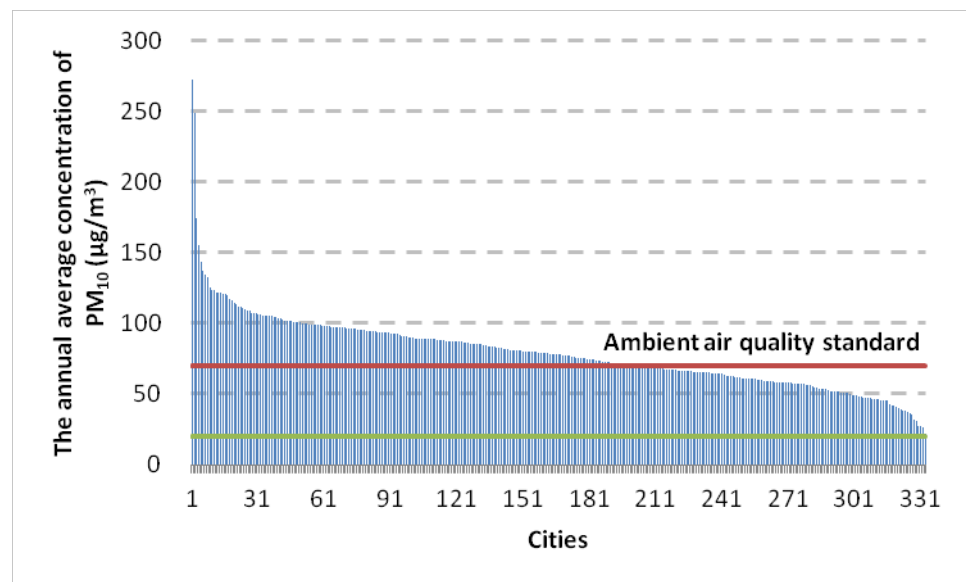
Although PM_{2.5} monitoring has not been introduced in most cities in China, the environmental monitoring data for SO₂, NO₂ and PM₁₀ indicate that the urban air quality remains much worse than the standards for a well-off and modernized society. According to the atmospheric environmental monitoring data in 333 cities at the prefecture level or above in China, the annual mean concentration of SO₂, NO₂ and PM₁₀ in prefecture-level cities was 35μg/m³, 28μg/m³ and 79μg/m³ respectively in 2010. In accordance with the *Ambient Air Quality Standards* (GB3095-2012) which was revised this year and is about to be implemented, cities where the annual average concentration of SO₂, NO₂ and PM₁₀ is higher than the standards number 18, 51 and 201 of the 333 cities respectively. Even with the PM_{2.5} and O₃ pollution not taken into consideration, as many as 216 cities cannot meet the standards, accounting for 2/3 of the total number of cities.

Based on the 2005 World Health Organization (WHO) ambient air quality guidelines, China lags far behind the WHO requirement (20μg/m³) for PM₁₀ in terms of the annual average concentration. Even Haikou, the city with the lowest concentration of PM₁₀ in China, fails to meet the requirement. And the average PM₁₀ concentration national-wide is three times higher than that of Haikou. The results from domestic and international scientific research show that the PM_{2.5} mass concentration is equivalent to about 50%-60% of PM₁₀ mass concentration. In view of this, China's PM_{2.5} mass concentration is at least three times higher than the level specified in the WHO guideline, though PM_{2.5} monitoring data is relatively inadequate in China. **Pollution of atmospheric particulate matters represented by PM₁₀ and PM_{2.5} will remain the primary atmospheric environmental problem facing China for quite a long period of time.**

As China marches on the path to a well-off and modernized society, its people, especially those in cities that are concerned about human health hazards associated with air pollution, are demanding greater attention be given to ambient air quality problems. *Ambient Air Quality Standards* (GB3095-2012), with reference to the WHO air quality standards, has introduced a stricter limit for PM₁₀ and included PM_{2.5} in the index system in the revision this year, so that the PM₁₀ and PM_{2.5} standards are in line with the WHO Phase I target for air quality improvement. To meet people's increasing requirements, the vast majority of cities in China need to achieve the ambient air quality standards in 15 to 20 years. In 2025, 80% of the cities are expected to do so. It means that the compliance rate for PM₁₀ urban mean

concentration should be raised by 40 percentage points during the 12th, 13th and 14th Five-Year Plan period from the current 40% (as shown in Figure 6).

Figure 6. Annual average concentration of PM₁₀ in 333 cities of China, compared to ambient air quality standard for PM₁₀



Source: Air quality monitoring data from China National Environmental Monitoring Centre

Such targets necessitate **a reduction of over 10% in PM₁₀ average concentration in major cities in each FYP period** (as shown in Table 2). According to existing PM_{2.5} monitoring data, PM_{2.5} accounts for more than 50% of PM₁₀ in urban areas, which speaks for much more severe noncompliance with PM_{2.5} standards than PM₁₀ standards. To achieve a compliance rate of 80% for PM_{2.5} in 2025, **PM_{2.5} mean concentration in major cities needs to decrease by at least 13% in each of the coming FYP periods.**

PM_{2.5} resulted from complicated sources, including primary particulate matters directly emitted from pollution sources and secondary particles formed from SO₂, NO_x, VOCs and NH₃ in the atmosphere. For most cities in China, especially more polluted eastern cities, it is more difficult to control the PM_{2.5} pollution than the PM₁₀ pollution. In light of the nonlinear characteristic of the impact of natural sources and the formation process of secondary particulate matter, **precursor emissions must be reduced by more than 15% in each FYP period**, so that a decrease of 13% in PM_{2.5} concentration and a compliance rate of about 80% around 2025 are attainable.

Table 2. Compliance rate of urban annual average PM₁₀ concentration under different scenarios

	2010	2015	2020	2025
PM ₁₀ concentration down by 10% every 5 years	40%	50%	63%	77%
PM _{2.5} concentration down by 13% ¹ every 5 years	27%	44%	60%	79%

Note 1: Results are obtained through the conservative estimation on the premise that PM_{2.5} accounts for 55% of PM₁₀ due to the absence of PM_{2.5} monitoring data in majority cities.

3. CURRENT CONTROL MEASURES ARE NOT EFFECTIVE ENOUGH TO ACCOMPLISH THE SET TARGET IN AIR QUALITY IMPROVEMENT

China has introduced a series of control measures over the years, giving a strong impetus to the prevention and control of atmospheric pollution. In particular, national total SO₂ emissions have declined for the first time owing to the innovative policy measures implemented since the 11th FYP period. It significantly lowers SO₂ and PM₁₀ concentrations in urban ambient air and improves urban air quality. These measures include:

Develop and implement more stringent pollutant emission standards. Air Pollutant Emission Standards are an important legal basis for managing the sources of air pollution. To control the most contributive categories of stationary sources of atmospheric pollutants, China has developed and implemented various emission standards since the 1980s and introduced more stringent standards for improving pollution control requirements (as shown in Table 3). Among them, emission standards for power plant boilers are in line with the international advanced level. Efforts were also made to drive forward the emission standards for mobile sources. National emission standards I was rolled out for light vehicles in 1999 and it has evolved into standards IV for light gasoline vehicles but weaker requirements for heavy vehicles, motorcycles and non-road mobile machinery.

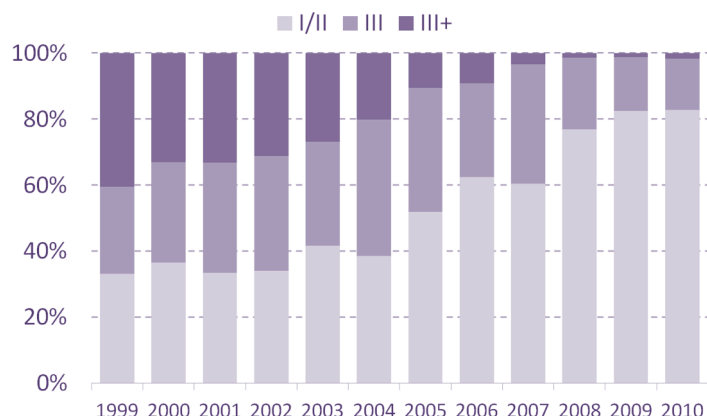
Table 3. Emission standards for stationary sources of major atmospheric pollutants

Control Object	Standard No.	Year of Implementation and Revision
Power plant boilers	GB13223	1991, 1996, 2003, 2011
Industrial boilers	GB13271	1983, 1991, 1999
Coking process	GB16171	1996, 2012
Iron and steel production process	GB28662-GB28666	2012
Cement production process	GB4915	1985, 1996, 2004

Control the total emissions of atmospheric pollutants. On the basis of the *Law of the People's Republic of China on the Prevention and Control of Atmospheric Pollution*, China specifies two control zones and kicks off the control of total SO₂ emissions. A series of policy measures aimed at this binding target was implemented during the 11th FYP period, such as a preferential tariff for desulfurization, replacing small units with large ones, backward capacity elimination, and regional restrictions; remarkable achievements were accomplished in reducing emissions in the engineering, structural and management aspects. During 2005-2010, the desulfurization proportion of thermal power units has increased from 14% to 86%, and small thermal power units with a total installed capacity of 76.83 GW have been shut down. Outdated production capacity equivalent to 120 million tons of iron, to 72 million tons of steel, and to 370 million tons of cement was eliminated. SO₂ total emissions were reduced by 14.29%, which exceeds the emission reduction target in the 11th FYP period. On this basis, a reduction of 8% in SO₂ emissions remains a binding target during the 12th FYP period, and a reduction of 10% in NO_x emissions is included in emissions reduction requirements.

Comprehensively improve the urban atmospheric environment. A national policy to promote service and commerce while restricting industry has been carried out in cities. Specifically, a large number of heavily polluting enterprises were relocated from urban areas to more remote areas. In urban clean energy transformation, cogeneration and central heating were developed and a number of small coal-fired boilers were eliminated. Oil and fuel recovery was introduced in gas stations in the Beijing-Tianjin-Hebei region, Yangtze River Delta, and Pearl River Delta to reduce VOC emissions from oil and gas. Urban atmospheric environmental remediation has achieved positive results. In 2010, the annual average concentration of SO₂ and PM₁₀ in cities at the prefecture level or above were 35μg/m³ and 81μg/m³, down by 24.0% and 14.8% from the 2005 level respectively. In accordance with the then Ambient Air Quality Standards (GB3095-1996), 83% of the cities have meet the Grade II air quality standards, rising from the 52% in 2005 (as shown in Figure 7).

Figure 7. Proportion of cities up to Grade I, II, and III air quality standards and below Grade III standards in China during 1999-2010



Source: State of Environment, Ministry of Environmental Protection

Actively explore the joint prevention and control mechanism for regional atmospheric pollution. To ensure the air quality during Beijing Olympic Games, Shanghai World Expo and Guangzhou Asian Games, North China with six provinces (autonomous regions and municipalities), Yangtze River Delta with three provinces (municipalities) and Pearl River Delta, regardless of the administrative boundaries, have jointly set up the Leading Group, signed the Environmental Protection Cooperation Agreement, and rolled out the air quality assurance program for inter-provincial collaboration and inter-departmental interaction. Concerted efforts with close cooperation were made for the overall control of SO₂, NO_x, PM and VOCs emissions, harmonized environmental law enforcement and supervision, and unified environmental information disclosure. Such a strong joint force for pollution control has produced positive results, guaranteeing good urban ambient air quality in the events. Moreover, useful experience has been accumulated for further regional joint prevention and control of air pollution.

In future years, most of the above measures will continue to play an important role in the prevention and control of air pollution in China. However, this is not enough to cut down the precursor emissions by over 15% in each FYP period, let alone to achieve the target of air quality improvement. There are four types of challenges. First, the legal basis for air pollution control remains very weak, providing inadequate support of air pollution control policies and measures. Second, the capacity building for overall air pollution control lags behind in all aspects, ranging from the national level to the local level, from stationary sources to mobile sources, and from policy making to management and practice. Human input and scientific support are insufficient, hindering the formation of a complete management system and

undermining the response to regional atmospheric pollution with its complex and composite features. Third, with the advance of industrialization, urbanization and mobilization in the future, annual consumption of coal in China will keep increasing and exceed 4 billion tones, and the population of light-duty gasoline vehicles will increase by approximately 15 million every year. China faces tremendous pressure to digest new emissions and to further substantially cut down atmospheric pollutants. Fourth, the pollution control level for coal-fired plants and motor vehicles remains low. Pollution control mainly depends on the end treatment and systematic, comprehensive and efficient control measures are absent.

In accordance with the previous analysis, China needs to make improvements in regulations, management mechanism, capacity building and control measures in order to achieve the goal of air quality improvement. This study summarizes the air quality management experience in the United States and Europe, and comes up with five policy recommendations for regional air quality control based on China's practices.

4. POLICY RECOMMENDATIONS FOR REGIONAL AIR QUALITY CONTROL

4.1. Accelerate the amendment to the Law on the Prevention and Control of Atmospheric Pollution

The Law of the People's Republic of China on the Prevention and Control of Atmospheric Pollution was enacted in 1987. With the process of air pollution control, amendments were made in 1995 and 2000 respectively, on which basis a series of laws and regulations has been rolled out and implemented to promote the prevention and control of air pollution. This law has played an important role over the years in reducing emissions of air pollutants, preventing and controlling air pollution, protecting people's health, and promoting sustainable economic and social development. However, air pollution has undergone a huge change since 2000, shifting from typical coal smoke pollution to combined vehicle and coal pollution. More specifically, the major components of air pollutants changed from SO₂ and PM₁₀ to PM₁₀, PM_{2.5}, O₃ and their precursors as air pollution expands from cities to regions. Mobile sources and industrial process sources joined coal-fired sources in producing air pollution. The existing Law is hardly adapted to the new trend in the prevention and control of regional, combined and complex air pollution shaping in the process of rapid industrialization, urbanization and motorization. To this end, amendments are required in the following aspects to provide legal support for the corresponding policy measures:

First, PM_{2.5} and O₃, having an important impact on human health, should be placed in a core position in the prevention and control of air pollution in China.

Secondary PM formed in the chemical reactions of such pollutants as SO₂, NO_x, VOCs and NH₃ accounts for more than 50% of PM_{2.5} in the air. NO_x and VOCs are also the reactants of O₃. In view of this, the Law shall stress the integrated control of multi-pollutant emissions. In addition to SO₂ and smoke dust, important precursors of PM_{2.5} and O₃ formed from NO_x, VOCs and NH₃ should also be brought under strict control. In terms of sources, as industrial pollution control deepens, prominence should also be given to non-point sources such as small and medium-sized boilers, dust, food and beverage fumes and painting spraying, as well as motor vehicles and other mobile sources.

Second, incorporate air quality improvement as the core content of atmospheric environment management. Government responsibilities and obligations in air quality compliance management within the jurisdiction should be clarified, and more responsibilities and corresponding power should be given to governments at all levels in air quality management. A technical roadmap for urban air quality compliance management should be developed, specifying the compliance deadline based on the status and gap in different cities, as well as the goals and priorities in different phases of the whole process. Consequences for the government of the cities that fail to meet the ambient air quality standards should also be clarified

Third, improve the joint prevention and control mechanism for regional air pollution to address the transmission of atmospheric pollutants across administrative boundaries. Based on the experience of Europe and the United States, the control mechanism for regional total emissions should be improved to address pollutants that travel long distances and affect regional air quality, such as SO₂, NO_x and VOCs. The Ministry of Environmental Protection determines the target of total emission control and assigns it to each administrative region, reducing the impact of upwind atmospheric pollutants on downwind air quality. Joint prevention and control mechanisms for regional atmospheric pollution should be introduced to ensure that the target is achievable.

Fourth, further strengthen the penalties for violations and increase the cost of atmospheric environment illegalities. Punishment and penalties for illegal actions should be raised. Penalty standards provided in the existing Law for excessive emissions, non-compliance with ambient air quality standards and data falsification are too low. As a result, the cost for violations is far less than that for compliance, which is not conducive to the prevention and control of atmospheric pollution.

Moreover, the provisions on treatment and control within specified deadlines should be refined, and the decision-making power clearly allocated to competent administrative departments of environmental protection in governments at all levels. In addition, it is necessary to make law enforcement more cost effective, step-up law enforcement efforts, and refine the legal responsibilities of environmental regulators to ensure that those convicted receive appropriate penalties.

Fifth, put emphasis on the control of emissions from non-road mobile sources.

Emissions from ships, aircrafts, trains, and non-road machineries should also be included under the Law, with clarified management responsibilities of MEP for dealing with non-road mobile sources.

4.2. Improve the air quality management mechanism, and enhance air quality management capabilities

China launched the prevention and control of air pollution in the 1970s. Since then, the emphasis has been put on the emission intensity of key pollution sources and the total emissions of major pollutants, rather than ambient air quality. Targets of atmospheric pollutant emissions reduction are primarily based on emission reduction technologies and economic potential, rather than on the requirement of human health for air quality. Air quality assessment takes into account three “traditional” atmospheric pollutants, SO₂, NO₂ and PM₁₀, instead of PM_{2.5} and O₃, both of which have a more severe impact on human health. To insure a healthy, comfortable and safe atmospheric environment where the masses live, China has to change its thinking about air pollution control—identify compliance with air quality standards as the core and the ultimate management goal, and tackle the emission reduction of PM_{2.5} and related precursors as an important means to improve air quality. Such an air quality management mode needs the support and backup from a sound management mechanism and powerful management capabilities. Compared with Europe and the United States, China is faced with more complex air pollution and a more difficult management task, but has weaker support in terms of the number of managers, institutional facilities, financial inputs and technologies. In order to meet the requirements of air quality standards and pollutant emission reduction for environmental management, it is urgent for China to enhance the mechanisms and capacity building in the following aspects:

First, allocate the appropriate resources with reference to the air management system of Europe and the United States. Atmospheric administration functions are dispersed in several business units of MEP, such as Department of Total Pollutants

Control, Department of Pollution Prevention and Control, Department of Planning and Finance, Department of Environmental Monitoring, and Department of Science, Technology and Standards. Overlapping management responsibilities among business units undermine the efficient coordination in the entire atmospheric management. Meanwhile, human resources for atmospheric administration are limited. There is, at most, one dedicated division taking the responsibilities of air management within each department, and there are only a total of four established persons in the Department of Pollution Prevention and Control directly responsible for air quality management. In contrast, the Office of Air and Radiation (OAR) led by the Assistant Director of U.S. Environmental Protection Agency (EPA) is directly responsible for atmospheric management. It is one of the 11 central bodies of the EPA and has 1,400 managerial persons and four sub-offices, namely air quality planning and standards, atmospheric program, transportation and air quality, radiation and indoor air. Like the U.S, most European countries set up a dedicated coordination organization for atmospheric management and allocate human resources for meticulous management. The U.S. management framework for atmospheric management enables uniform and efficient coordination and refined labor division and duties for specific work. It has laid the institutional and personnel base for raising atmospheric management capabilities. To improve atmospheric management capabilities for quantitative and meticulous management, China needs to comprehensively integrate associated functions and resources, and set up a dedicated atmospheric management department for overall coordination, that is similar to the management mode applied in medicine supervision, water resource and nuclear safety. It also requires substantially increased technical support and human resources to pave the way for quantitative and meticulous air quality management.

Second, improve the joint prevention and control mechanism for regional air pollution to facilitate overall regional management in severely polluted Beijing-Tianjin-Hebei, the Yangtze River Delta and Pearl River Delta. Under the Chinese jurisdiction-based environmental management system, departments of environmental protection account to government at the same level. This is not conducive to the control of regional air pollution. Meanwhile, local management and technical personnel engaged in the prevention and control of air pollution, compared with national atmospheric management, are even more inadequate. In contrast, dedicated representatives in the 10 regional offices under the US EPA cooperate with the state governments. Apart from coordinating regional atmospheric management, they also cultivate leadership talents and skilled specialists with atmospheric management expertise, thus enhancing capabilities to address the issue of regional

atmospheric environment. China needs to set up specialized agencies in areas with serious air pollution, such as the Beijing-Tianjin-Hebei region, the Yangtze River Delta and the Pearl River Delta, to take charge for the overall regional air quality management. Joint meetings should be held to facilitate the unified and coordinated regional joint prevention and control mechanism. A joint law enforcement and regulatory mechanism for regional atmospheric environment should be introduced for enhanced enforcement and supervision. Regional consultations are needed under the environmental impact assessment and consultation mechanism for major projects. In addition, mechanisms should be introduced to facilitate regional exchanges and sharing of environmental information and regional early warning and linkage in atmospheric pollution. All these measures are aimed to increase the capacity in local air quality management under “unified planning, monitoring, supervision, assessment and coordination” in regional air pollution prevention and control by setting up local departments on air quality management and vehicle emission control in some key cities.

Third, increase the funding for air quality management, and advance the implementation of the National Clean Air Action Plan included in the national budget. In the 11th FYP period, the investment in environmental protection accounted for about 1.35% of the GDP, well below the level of developed countries. Also, the inputs for the prevention and control of atmospheric pollution have been insufficient in water environmental protection, heavy metal pollution control, and ecological protection for a long time. It directly leads to inadequate investment in atmospheric management capacity building, and a serious lack of data and research to support quantitative and meticulous management. In terms of funds, the central government should set up special funds for atmospheric pollution prevention and control and increase the introduction of specialized management and technical talents to enhance research capacity and basic management capacity. Meanwhile, it should also develop an investment mechanism for diverse investment subjects and approaches, and lead and encourage local governments and enterprises to put in place financial incentives for air pollution control. In terms of technologies, a number of national special research projects should be carried out in China as soon as possible, in hope of breakthroughs for such major scientific issues as the generation mechanism of air pollution in different regions, source apportionment, and control and prevention paths.

4.3. Accelerate the transformation of economic development mode and promote the continued reduction of pollutants

The U.S. and European experience show that improvement of air quality accompanies

transformation of economic development mode. In the recent three decades, the decreasing proportion of heavy chemical industries in such industrialized regions as Europe and the U.S contributes to the gradual reduction of air pollutant emissions in the industrial process. However, now in the late stage of industrialization, China still depends heavily on energy-consuming and high-polluting industries for economic development. Although the emission intensity of air pollutants per unit of GDP is 40% to 80% lower than the 1990 level, SO₂ and NO_x emissions are still one to three times higher due to the fast growth of heavy chemical industries in the process of rapid economic expansion. In particular, China's crude steel and cement outputs have increased by four and two times respectively since 2000 (as shown in Table 4). In 2010, crude steel output in the Beijing-Tianjin-Hebei region and cement output in the Yangtze River Delta region were 1.9 times and 4.3 times as much as that of the U.S respectively. To substantially cut down emissions of atmospheric pollutants amid stable and rapid economic expansion, it necessitates a faster decline in the emission intensity per unit of GDP than that in last two decades to offset the negative effects of rapid GDP growth on pollution reduction.

Table 4. Steel and cement outputs in 2000 and 2010 (100 million tons)

	1990	2000	2010	Proportion of global output in 2010
Crude steel	0.66	1.29	6.27	44%
Cement	2.10	5.97	18.68	60%

Taking the opportunity of socio-economic transformation, it is pressing for the National Development and Reform Commission (NDRC), Ministry of Industry and Information Technology (MIIT) and MEP to jointly develop proactive policy measures to push ahead industrial restructuring, reduce the massive emissions from heavy chemical industries, as well as adjust industrial output by gradually eliminating the capacity in regions with concentrated heavy chemical industries and severe air pollution. These measures include the following suggested actions:

- **Shape a sustainable investment and consumption pattern that will reduce the dependence of local economic development on heavy chemical industries.** Increase the proportion of the tertiary industry and high value-added industries, and slow down the development of energy-consuming, high-polluting industries. It is forecasted that China will maintain stable and fast economic development in the next 15 to 20 years, the urbanization process will further accelerate, and the feature of heavy chemical industries will remain prominent. China needs to promote the development of strategic emerging industries, and guide the sustainable transformation of investment and consumption patterns via

differentiated economic policies. Meanwhile, total pollutant control and energy consumption should become drivers to achieve peak iron, steel, and cement outputs in the 13th FYP period, followed by decline in their output, with improved air quality.

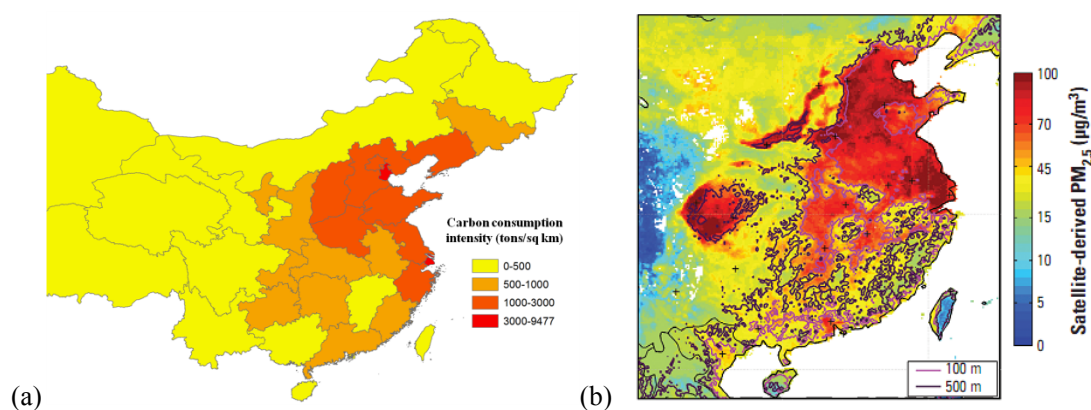
- **Improve the technical level and reduce overall energy consumption and air pollutants while enhancing the industrial output value.** China should raise the industrial access threshold, prioritize such indicators as energy-efficiency, environmental protection and security in the strict implementation of energy efficiency assessment and review, and environmental impact assessment in accordance with the law. Construction land review and loan approval should also be stricter. On the other hand, with the elimination of backward production capacity in such polluting industries as thermal power, iron and steel and building materials, China can improve the overall technical level to drive ahead industrial optimization and reduce air pollutant emissions. Throughout this process, efforts should be made to promote the universal and efficient utilization of best available technologies for cleaner production and pollutant emissions control, for instance, reducing the use of volatile materials in coating and cleaning processes. At the same time, the industrial chain should be extended and the proportion of refined high value-added products increased to reduce pollutant emissions along with the development of heavy chemical enterprises.
- **Progressively reduce the capacity of heavy chemical industries in the Beijing-Tianjin-Hebei region, Yangtze River Delta and Pearl River Delta to reduce severe combined and complex air pollution.** These regions and their cities are experiencing the transition from late industrialization to post-industrialization. In some cities and regions, with the evacuation of heavy chemical industrial production and the substantial adjustment of energy structure, the emissions of multiple atmospheric pollutants are being reduced, thus creating or having created conditions for reducing emission intensities. Strict technical and environmental requirements for access thresholds should be set for transfer of industry from these regions, so as not to affect the realization of air quality improvement goals in other areas such as Central or Western China.

4.4. Optimize the energy structure to achieve efficient, clean, and sustainable coal utilization

Coal is an important basic energy resource for China. China's coal consumption has been on a rapid rise since 2000, up from 1.4 billion tons to 3.1 billion tons in a decade.

In 2010, China accounted for 48.2% of the world's total coal consumption. Compared with clean energy such as natural gas, the coal utilization process generates more air pollutants including SO₂, PM, heavy metals and CO₂. Due to the limitations of resource endowments, coal has been in a dominant position in the energy structure. It has accounted for about 70% of primary energy consumption since the 1980s, far more than the 20% in some other countries. Such coal-dominated energy structure is an important contributor to the massive emissions of atmospheric pollutants. More specifically, it is responsible for 90% of the SO₂ emissions in China, 67% of the NO_x emissions, 40% of the soot emissions, and 70% of human-caused atmospheric mercury emissions. Coal consumption intensity is also significantly consistent with the spatial distribution of regional air pollution, especially PM_{2.5} pollution (as shown in Figure 8). In view of this, a substantial reduction of air pollutant emissions in coal combustion is a must to improve ambient air quality in China and particularly the severely contaminated eastern regions.

Figure 8. PM_{2.5} pollution in eastern regions is more serious (b), consistent with the spatial distribution of coal consumption intensity (a)



Source: Chinese Energy Statistical Yearbook 2011, China Statistical Press, 2012; van Donkelaar et al., 2010. Global Estimates of Ambient Fine Particulate Matter Concentrations from Satellite-Based Aerosol Optical Depth: Development and Application, *Environmental Health Perspectives*, 118 (6): 847-855

Energy resource endowment determines that coal will dominate China's energy structure for a long time to come. Hence only sustainable, clean and efficient coal use will provide prerequisites for controlling the emissions of air pollutants from coal combustion. It is also advised that the NDRC, MEP, and relevant ministries introduce policies for energy system optimization in order to push forward the gradual shift from coal to natural gas and other clean energy sources, the strategy of sustainable, clean, efficient use of coal, and technological advancement in the use and conservation of all energy sources. Major policies include:

- **Optimize the energy structure by reducing the proportion of coal in primary energy.** In the near future, massively increase the supply of natural gas and develop nuclear energy; in the mid- and long-term, develop wind, solar, biomass and other renewable energy sources aiming at a reduction of 3 to 5 percentage points in the proportion of coal to primary energy during each FYP period.
- **Optimize the spatial distribution of coal consumption by controlling regional total coal consumption.** Reduce coal consumption in Beijing, Shanghai and areas with high coal consumption intensity in their late stage of industrialization, and restrain the growth rate of coal consumption in eastern regions, so as to reduce coal consumption in regions with serious air pollution, including the Beijing-Tianjin-Hebei region, the Yangtze River Delta, and the Pearl River Delta.
- **Improve the coal consumption structure, promote the transfer of coal consumption to large-scale coal-fired equipment with best available technologies, and reduce the terminal coal consumption in the industrial and commercial sector.** The power sector's coal consumption should account for 60% and 65% of the total in 2020 and 2030 respectively.
- **Put emphasis on pollution control in the whole coal life cycle to advance coal washing and distribution.** Efforts should be made to increase the proportion of washed coal to more than 70% in 2030 to be in line with the international level.
- **Vigorously promote clean fuel adoption in households.** Reduce the direct combustion of raw coal and biomass in households and promote gas energy and briquette use.

In addition, China as the largest coal consumer in the world should develop and use the world's best coal-fired pollution control technologies, and gradually establish a leading position in clean coal utilization. Stringent emission standards and access measurement method should be introduced to promote the research, development and use of best available technologies for air pollution control, such as efficient desulfurization, denitration and dust removal, and ensure the efficient and stable operation of these technologies in the coal-fired pollution source to reduce the emissions of pollutants.

4.5. Comprehensively strengthen pollution control in mobile sources

Mobile sources have become a prominent factor in causing ambient air quality

problems. Mobile sources contribute 20% -25% of PM_{2.5} in major cities such as Beijing and Shanghai, as well as the eastern densely populated areas. Some factors such as the rapid increase in the vehicle population, weak promotion and ineffective enforcement of stage two vapor recovery or onboard refueling vapor recovery, and loose standards on summer time fuel vapor pressure have resulted in high VOCs emissions from gasoline vehicles, and hence lead to ozone nonattainment. Pollution from rapidly growing mobile sources has posed one of the greatest challenges in air quality management. Its control to a large extent determines whether regional air quality is effectively improved in China, but also majorly impacts the public satisfaction about relevant government policies and implementation. At present, both developed and developing countries are facing unprecedented challenges from the prevention and control of mobile source pollution and attach a high degree of attention to this issue. Countries across the world are active in summarizing lessons learned and exploring a more scientific, rational and efficient program for mobile source pollution control. China is the world's largest auto market and the rapid increase in the number of motor vehicles leads to severe congestion. Simultaneously pollutants which are not brought under effective control pose short and long-term hazards to the health of the residents in highly populated urban areas. For the purpose of effective control of mobile source pollutants, China should work out comprehensive policies regarding fuel quality, vehicle emissions standards and road use, covering mobile sources management, vehicle energy and urban planning.

With regard to fuel quality, it is necessary to rapidly introduce near zero sulfur levels in both diesel fuel and gasoline. Modern, efficient purification processing for mobile source emissions requires high quality gasoline, and diesel fuels, in which it is essential to achieve at least low-sulfur content (sulfur content less than 50ppm) or the best, near zero-sulfur content (sulfur content below 10ppm). In promoting low-sulfur and sulfur-free gasoline and diesel, only a few cities in China such as Beijing and Shanghai have made significant progress in the last decade. As a result of such slow advancement, the implementation of more stringent vehicle emission standards has been delayed, hindering the realization of ambient air quality improvement targets. According to studies, if low-sulfur and sulfur-free fuels were introduced across the country on the schedule that MEP intended and National Emission Standards IV for heavy-duty diesel vehicles was implemented on schedule (rather than delayed 30 months), PM emissions from new trucks would have been reduced by about 80% over the level specified in National Emission Standards III and NO_x emissions by about 30%. Such a difference in emissions will impose a 5-10-year effect on ambient air pollution over the lifetime of these vehicles. In fact, large oil refineries in China are

largely capable of producing low-sulfur and sulfur-free gasoline and diesel. Appropriate price policies and economic incentives could be effective in actualizing the market supply in the short term. It thus will play a substantial role in controlling mobile source pollution and improving ambient air quality. In light of this, it is recommended that the Chinese Government attach a high degree of attention to low-sulfur and sulfur-free fuels, and bestow the right of oil quality management on MEP. With a clarified schedule and firm targets, effective policies should be quickly carried out to advance the realization of low-sulfur fuel and sulfur-free fuels for vehicles and promote low-sulfur fuels in non-road mobile sources.

With regard to vehicles, accelerate the development and implementation of a full-range of emissions standards. International experience has shown that stringent emission standards provide essential regulatory conditions for mobile source pollution control. Over the past decade, China has developed a relatively strong emission standards system for vehicles which largely constrained emissions growth in spite of the tremendous increase in the vehicle population. However, in comparison with developed countries, China still lags behind in the stringency of its limits, the scope of coverage and reasonable implementation for which further improvement is required. For example, the emission standards for railways, waterway vessels, agricultural and construction machinery, power generation sets, and small general machinery with internal combustion engines, as well as the emission standards for vapor emissions during refueling and otherwise, need to be improved. For this consideration, government departments should accelerate the development and implementation of full-range emission standards for internal combustion engines with wide participation from all walks of life (not limited to people engaged in internal combustion engines) for opinions and suggestions. Such standards shall take into account the world's most advanced and reasonable technical requirements, and be promulgated as soon as possible. Advanced, rigorous standards are expected to actively promote the innovation and development of partial zero emissions vehicles (P-ZEV) and zero emissions vehicles (ZEV), and pose requirements on emission processes not covered by the current standards (such as VOCs emissions in gasoline refueling process). China is advised to advance the implementation of as rigorous and comprehensive as possible set of emission standards consistent with the availability of low sulfur and ultra low sulfur fuels. New diesel vehicles should be required to meet the National Emission Standards V as soon as possible but no later than in 2015 and Euro VI standards requiring active regeneration diesel particulate filters (DPF) should be required in key regions and cities by the same time. New light gasoline vehicles should be required to adopt all the emission control measures specified in National

Emission Standards V, including the on-board refueling vapor recovery (ORVR) which controls refueling vehicle emissions as soon as possible. In addition, if fuel quality conditions permit, it is encouraged to carry out retrofit projects for diesel vehicles. A clear roadmap regarding fuel quality and emissions standards for all categories of on and off road vehicles should be a high priority for MEP in the immediate future.

In the aspect of roads, create a new sustainable urban transport system.

Developed countries' experience and lessons learned show that a sustainable urban transport system is crucial to traffic pollution control. A new, characteristic urban transport system is required, which emphasizes the development and design of urban public transport, cycle track and pedestrian walkway design, and traffic optimization, and introduces such management means as low-emission zones and zero-emission zones, green passenger and freight transport, and peak traffic management. It is advised to delineate low-emission zones and zero-emission zones in cities in urgent need of air pollution control and work out appropriate management measures in 2013, so as to reduce the emissions of buses and taxis in such zones. Peak and traffic management of high-emission private cars is also recommended.

In addition to the above three, vessels have been significant emission sources polluting the air of port cities such as Shanghai, Shenzhen, Guangzhou, Nanjing and Ningbo. However, the local government is not able to effectively supervise these sources based on the existing management framework. A cooperative mechanism should be established between the Ministry of Environmental Protection and the Ministry of Transportation to identify the duty and responsibility in local vessel emission control. China should implement a vessel sulfur emissions control zone in Yangzi River Delta (YRD) and Pearl River Delta (PRD), and install the shore side electricity facilities in ports. Emission standards, oil standards and management standards should also be introduced as soon as possible for non-road mobile sources such as construction and agriculture machineries, and locomotives.