Present and Future Pollution from Urban Transport in China

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For the past twenty years, as China has shifted away from a planned economy, free market reforms have created dynamic economic growth and produced a more mobile and affluent society. China is now a country with a population on the move. The economic reforms have not only prompted a huge migration of people from rural to urban areas, but have also stimulated trade and movement of goods within and outside China's borders. From the late 1980s to the late 1990s, overall travelling distances (person/kilometer) of citizens increased by more than 100 percent and average travelling times and distances per capita increased by fifteen to thirty percent.[1]

The number of vehicles nationwide has grown considerably over the past decade and by 1998 the national vehicle population grew to over thirteen million, with Beijing and Shanghai accounting for approximately 14.4 percent of total vehicles nationwide. In Beijing City, the growth rate of motor vehicles has averaged between fifteen and twenty percent per year in the past decade. Current trends indicate that ten to twenty percent of this vehicle growth in China is in private cars, which not only threaten to replace the bicycle as primary means of transport, but are also competing strongly with public transport.[2] Policymakers and citizens in China have become concerned as the massive growth of vehicles in the large cities has considerably exacerbated air pollution and traffic congestion.

In this article we will first outline the current trends of vehicle growth and pollution in Chinese urban areas. We then examine recent research linking vehicular pollution to growing health problems in China. The article concludes with a discussion of how the national and municipal government policies are responding to this pollution problem and we outline some proposals for necessary future policies.

Vehicle Production and Transport Infrastructure in China

Compared with industrialized countries, the total pollutant emissions from automobiles in typical cities in China is alarming. Tokyo had four million vehicles in the 1990s, but the vehicle emission level remained at 100,000 tons and 50,000 tons of carbon monoxide (CO) and nitrogen oxides (NO_x), respectively. In 1998, a mere 1.31 million motor vehicles in Beijing emitted 129,000 tons and 115,000 tons of CO and NO_x, respectively.

While China's vehicle fleet is not very large, the average emission factor per vehicle is very high; in fact it is several times higher than vehicle emissions in industrialized countries. China's vehicle emission levels are comparable with the emission levels that existed in Europe and the United States in the 1960s and 1970s. This high level of pollution emissions from vehicles is mainly due to the underdeveloped manufacturing technologies utilized in the Chinese automobile industry and poor maintenance of automobiles. For example, the Beijing Jeep 212 consumes thirteen to fifteen liters of fuel per 100 kilometers and overall has a weak power performance. This fuel consumption rate is between fifty and100 percent greater than the same type of jeep manufactured in industrialized countries. The Red Flag Auto, produced by the First Automobile Works Company, represents another example of inefficient and out-dated engine types. The most highly polluting types of vehicle in China, particularly in terms of CO emissions, are heavy

Table 1. Comparison of Urban Road Density

City	Road Density (km/km^2)	Percent of Road Area	Road Area Per Capita (m^2)
Beijing (China)	6.8	7.1	4.7
Shanghai (China)	7.6	12.6	5.4
Guangzhou (China)	7.0	7.7	5.2
Dalian (China)	12.6	6.46	5.7
Tokyo (Japan)	18.9	14.9	10.9
Osaka (Japan)	18.0	17.5	14.4
London (U. K.)	18.1	24.1	28.0
New York (U.S.A)	8.0	16.6	26.3

Sources: China International Cooperation Committee of Environment and Development, *Proceedings of Symposium of Urban Transportation and Environment,* (April 1999): 48-58; and *China Statistical Yearbooks,* 1978-1998, Beijing.

and middle duty gas trucks, which emit 200 grams of CO per kilometer, compared to European cars which emit fifty grams of CO per kilometer. Because China is in the process of moving from a planned to a free market economy, many large auto manufacturers cannot afford to obtain the technology to build more advanced and cleaner vehicles. Compounding the already low quality automobiles is the fact that drivers tend to ignore maintenance, which would help their vehicles run cleaners.[3]

Despite recent investment increases in transportation infrastructure in Chinese cities, the average speed of vehicles has actually decreased, especially for public vehicles. In rush hour the speed of public vehicles on many lines approaches walking speed. The punctuality rate for public transport vehicles has decreased from seventy percent in 1990 to 8.4 percent in 1996. The greater number of private vehicles is creating more traffic congestion, which has led to the cancellation of thousands of public transportation routes in cities across China. This decrease in public transport has spurred an increase in private vehicle purchases and taxi services, which, in turn, has increased traffic congestion; a vicious cycle.

Road construction has not been able to keep up with the significant growth in the number of public and private vehicles. Over the past decade, the average road area per capita has remained comparatively low—less than six square meters per capita. Table 1 compares urban road density and road area per capita in cities in China and industrialized countries. The explosion of car purchases and lack of new roads has meant that in cities such as Beijing, the average velocity of vehicles on main roads at rush hour was only thirteen to nineteen kilometers per hour in 1998. Over the past few years, the rush hour road load in Beijing has increased from 700 vehicles to 918 vehicles per

Table 2. Transportation Information for Seven Chinese Cities (1997)

	Beijing	Shanghai	Chongqing	Guangzhou	Shenzhen	Dalian	Guiyang
Urban resident population in 1997 (in ten thousands)	646.2	860	250	392.38	379.64	259.7	100.34
Specialized public bus lanes (km)	54	None	9.49	None	80	26.58	4.4
Length of subway in use (km)	42	21.3	None	12.7	None	None	None
Length of subway currently under construction (km)	11	None	None	None	14.8	None	None
Average rush hour speeds (km/h)	13-19	< 25	20	18-20.5	20	15-20	25
Number of clean fuel motor vehicles	809	1231	n.a.	136	1000	225	None
Average daily value of CO emissions (mg/m^3) on urban roads	5.2	n.a.	10.4	2.54	n.a.	2.47	n.a.
Average daily value of No_x emissions (mg/m^3) on urban roads	0.133	0.059	0.068	0.141	0.054	0.056	0.033

kilometer. To summarize, because large and medium-sized cities have inadequate and congested roads, vehicles must drive at low speeds and low driving speeds increase the emissions of CO and NO_x. In order to paint a picture of transportation challenges in China, Table 2 presents information on public transportation, subways, and NO_x emissions in seven major Chinese cities.

Urban Air Pollution

In 1995, the United Nations ranked three Chinese cities—Beijing, Lanzhou, and Taiyuan—among the top ten most severely polluted cities in the world. The concentration of NO_x exceeds national ambient air quality standards (NAAQS) in most of China's largest cities. As Table 3 illustrates, eighty-one percent of cities with a population over two million exceed the NAAQS for NO_x concentration. Slightly over half of China's cities with a population between one and two million also exceed NAAQS for NO_x. Currently, weekly air quality reports for thirty-two cities indicate that NO_x has became the main pollutant in eight major cities (Beijing, Guangzhou, Shanghai, Wuhan, Hefei, Dalian, Shenzhen, and Zhuhai). Statistical data show that there is drastic growth in the number of respiratory health problems due to vehicular pollution.[4] We will discuss more on the air pollution-health nexus below.

The capital city, Beijing, is one of the most polluted cities in China with vehicle emissions as the leading source of air pollution (See Table 4). In 1997, the concentrations of vehicular pollutants in central Beijing exceeded the second class NAAQS many times. In 1997, emissions of CO, lead, and NO_x in Beijing were exceeded four, twenty-two, and thirty-five times, respectively. In order to control and mitigate the severe situation of vehicle pollution, the Beijing municipal government announced new emission standards for new cars in August 1998 and put these standards into effect in 1 January 1999. These new standards are stricter than the current national standard. Despite enforcement of these standards, the number of vehicles continues to grow in Beijing, so it is too early to know the efficacy of the new standards on decreasing pollution. Beijing and other municipal governments will need to create and enforce even stricter emission standards in the future.

In 1997, the CO and NO_x emissions from motor vehicles in Shanghai rose to 380 thousand tons and

Table 3. NO_x Pollution in Chinese Cities by Population

City Population (in 1000's)	Number of Cities		NO_x Average Concentration (mg/m^3)		NO_x Percentage of Cities Exceeding Second Class National Ambient Air Quality Standards	
	Year 1994	Year 1998	Year 1994	Year 1998	Year 1994	Year 1998
> 2000	9	11	0.074	0.077	19.5	81.82
1000-2000	19	23	0.065	0.056	17.9	52.17
500-1000	14	44	0.039	0.037	3.3	11.36
200~500	27	133	0.038	0.035	3.4	13.53
< 200	16	111	0.031	0.030	1.3	12.61

Table 4. Vehicle Emissions in Beijing

Pollutant	Emission (10 thousand tons)		Percentage of Total Emissions	
	Year 1995	Year 1998	Year 1995	Year 1998
CO	107.5	129	76.8	82.7
NO_x	9.38	11.59	40.2	42.9

Department of Environmental Science and Engineering, Tsinghua University, et al. *Research Report of Planning of Vehicle Emission Pollution Control in Beijing City*, 1999 (12):105-144.

81.5 thousand tons, respectively.[5] The emission and contribution of pollutant concentration from vehicles in downtown Shanghai City are listed in Table 5. In the city of Guangzhou, the pollutant emission and the contribution from vehicles have also steadily increased. Seventy percent of vehicles in Guangzhou cannot meet the mandated emission standard, which explains why the concentration of NO_x has increased since the mid-1980s.[6] Table 6 is a summary of pollution of NO_x and CO from 1990 to 1996, from which the gradually aggravated situation of air quality from vehicles in Guangzhou could be concluded.

While the CO emission problems are well acknowledged more attention should also be devoted to the problem of fine particulate matter. Although the particle emissions from vehicles have a mean diameter of 1 mm and constitute only a small amount of total suspended particles (TSP), they pose severe hazards to human health. Research on the harmful health effects from fine particles, however, is only at a nascent stage in China. In 1998, the concentrations of particulate in Beijing and Guangzhou were 379 and 205 g/m^3, respectively, which exceeded second class national ambient air quality standards. Furthermore, if compared with the WHO standards for particulates—60-90 g/m^3, the two cities exceed the standards by three to five times. Unfortunately current Chinese standards are not as strict as the World Health Organization standards.

The number of days that Ozone (O_3) concentration exceeds National Ambient Air Quality Standards in Chinese cities has increased from an average of forty days in 1988 to seventy-five days in 1994. The HC and NO_x emissions from vehicle sources can further react in the air and form secondary pollutants such as O_3 and Peroxyacetyl Nitrate (PAN). The combination of these pollutants will lead to the formation of photochemical smog, which not only obscures visibility, but also can be very detrimental to human health. Numerous large Chinese cities—such as Lanzhou, Chongqing, and Guangzhou—are already blanketed with smog as a result of the increase of HC and NO_x emissions from vehicles. In May 1995, photochemical smog appeared in Chengdu City for the first time, and in June of the same year, it occurred in Shanghai City.[7]

Table 5. Vehicle Emissions in Shanghai

Pollutant	Emissions (10 thousand tons)		Percentage of Total Emissions	
	Year 1995	Year 1996	Year 1995	Year 1996
CO	10.40	19.7	76	86
NO_x	3.04	4.9	44	56
NMHC	2.41	4.32	93	96

Sources: Lu Shuyu, "Vehicular Pollution Control Strategies in City Shanghai, Shanghai," *Environmental Sciences*, 17:3 (1998):1-3 and Chen Changhong et al., *Pollution Load of Vehicular Exhaust in City Shanghai, Shanghai Environmental Sciences,* 16:6 (1997):26-29.

Health Effects of Vehicular Air Pollution

In 1997, the Institute of Environmental Health Monitoring at the Chinese Academy of Preventive Medicine conducted a study on the exposure levels of vehicular emissions on human health, particularly on the immune system.[8] Passive personal samplers on the road measured the exposure levels of traffic policemen,

Table 6. Vehicular Pollutant Concentration and Pollution Index in Guangzhou (1990-1996)

	1990	1991	1992	1993	1994	1995	1996
Concentration of NOx (mg/m^3)	0.137	0.112	0.107	0.115	0.116	0.123	0.151
Contribution of NOx (%)	36.1	33.5	33.0	35.9	35.4	36.0	42.9
Pollution index of NOx	2.60	2.24	2.14	2.30	2.32	2.46	3.20
Concentration of CO (mg/m^3)	3.16	2.91	2.89	2.71	2.89	2.91	2.96
Contribution of CO (%)	10.9	10.8	11.1	10.9	11.1	10.6	9.90
Pollution index of CO	0.79	0.72	0.72	0.69	0.72	0.73	0.74

Source: Department of Environmental Science and Engineering, Tsinghua University et al., *China's Strategies for Controlling Motor Vehicle Emissions—Summary Report,* 1997.

bicyclists, and riders. The results showed that nitrogen dioxide and carbon monoxide exposures ranged from 0.219-0.349 mg/m^3 and 9.17-41.10 mg/m^3, respectively, for traffic policemen at eight crossroads. Nitrogen dioxide exposures ranged from 0.208-0.377 mg/m^3 for nineteen bicyclists who bicycled on the road to and from work. The level of pollutant exposure on the streets where the study took place exceeded the NAAQS.

In 1995, Ye Shunhua and others investigated and monitored the immune systems of bus drivers and conductors on the Yuejiang tunnel bus line in Shanghai. Their study found that the levels of peripheral blood lymphocytes, T-cyto rosette formation, IgA (Immunoglobulin A), and fibro-mucoprotein are much lower in the bus drivers than in the control group—workers at an arboretum.[9] These enzymes provide protective mechanisms for cells. Another study conducted in Xian showed that the Superoxide Dismutase (SOD), Glutathione (GSH), and Glutathione Peroxidase (GSH-px) levels in bus drivers and conductors were lower than the control group, while the level of Malondialdehyde (MDA) was higher. It was concluded that exposure to vehicular exhaust changed levels of these enzymes which can be detrimental to human immune defenses. Another study analyzed the movement of spermatozoon and blood-lead concentration in traffic policemen's semen. The results revealed lower semen mobility, higher blood-lead concentration, and repressed activity of semen succinate dehydrogenase.[10]

A survey investigating health effect determinates was carried out by the Department of Environmental Science and Engineering, Tsinghua University, Beijing.[11] The results and conclusions are the following.

1) In the peripheral blood of the on-duty traffic policemen in the four areas of Beijing, both carboxhemoglobin (COHb) saturation and blood-lead concentration are remarkably higher than control group. Saturated COHb will cause chronic oxygen deficiency and potentially lead to heart and brain illnesses. The differences have statistical significance. Furthermore, the results show good negative correlation ($r=0.8862$, $P<0.05$) between COHb and blood-lead concentration. The dynamics of absorption mechanisms in the human body and the mutual influences of CO and lead should be further researched.

2) Determination of Peak Expiratory Flow (PEF) is a common index used to assess lung function and measure chronic lung congestion. The average PEF in urban areas in China appears to be lower than in suburban areas. This is potentially caused by the heavier vehicular air pollution in urban areas. However, the results in this particular study showed no remarkable statistical significance in the differences of urban and suburban PEF levels. This was most likely due to the small sample size and highlights the need to conduct more studies with larger samples in the future.

3) The analyses of health conditions of traffic policemen in Beijing highlighted that the degree of self-reported symptoms of discomfort (breathing, eyes, and feelings of overall fatigue) is increasing for the street duty professionals. The study also reported that the rate of respiratory illnesses in traffic policemen is five percent higher than the city average.

One study carried out in twenty-eight provinces and autonomous regions in 1990s revealed that, while the average lead level in blood in the overall population does not appear to increase, spot checks in several provinces revealed that the lead level in forty percent of the children exceeded safe thresholds.[12] Not surprisingly, the blood-lead content of children in towns is higher than in rural areas, which indicates that children are increasingly vulnerable to lead emissions from vehicles. The study also reported that the blood-lead concentration of children who lived in industrial areas is between 200 and 400 g/L, which greatly exceeds the international standard of 100 g/L. In the city of Guangzhou, the blood-lead concentration of the children living near roads is between 142-167 g/L and the blood-lead concentration in traffic policemen is approximately 116 g/L. Overall, these recent health studies in China have helped to communicate the harmful impact of vehicular emissions on human health to Chinese policymakers.

Recent Vehicular Emission Control Policies in China

Over the past few years, as pollution in urban areas has significantly worsened in China, the national and municipal governments have passed vehicle emission policies and regulations. Below, we outline some of the more recent policy developments at the national and municipal levels.

National Policies in 1999

1. The *Emission Standard for Exhaust Pollutants from Light-Duty Vehicles* (GWPB1-1999) was issued by SEPA and went into effect on 1 January 2000. This policy sets emission standards for Light-Duty Vehicles equivalent to EURO1 standards. These new emission standards also establish acceptable emission values after a cold start; emission values from the crankcase of the spark-ignition engine; evaporative emission values from the spark-ignition engine; as

well as several engine durability criteria.

2. *Standard for Hazardous Contents in Gasoline* (GWPB001-1999) was issued by SEPA and went into effect on 1 January 2000. These standards place stricter limitations on the hazardous contents of gasoline than previous Chinese standards. The regulated hazardous contents include: benzene, olefin, aromatics, manganese, iron, copper, lead, phosphorous, and sulfur.

3. *Technical Policy on Vehicular Emission Control* was issued by SEPA on 8 December 1999. This policy focuses on emission and fuel technology requirements, such as emission reduction technologies for new vehicles, emission reduction technologies for in-use vehicles, fuel quality requirements, exhaust purification equipment, and testing devices.

Municipal-Level Policies

1. Beijing: The Beijing Technical Inspection Bureau (effective 1 January 1999) issued *Emission Standard for Exhaust Pollutants from Light-Duty Vehicles* and these standards are equivalent to EURO1 standards.

2. Shanghai: *Emission Standard for Exhaust Pollutants from Light-Duty Vehicles* was issued by the Shanghai Technical Inspection Bureau—effective 1 July 1999. These standards equal EURO1 emission standards.

3. *Emission Standard for Pollutants at Dual-Idle Speed from Vehicle with Petrol Engines* was issued by Beijing Technical Inspection Bureau—effective 1 July 1999. These standards established idle and high-idle testing methods for CO and HC emissions for in-use vehicles. By regulating high-idle emissions, high-emitting vehicles can be better identified.

4. *Emergency Measures for Improving Air Quality in Beijing* were initiated in December 1998. The measures were designed to be implemented in three phases.

i. Phase1—from December 1998 to February 1999—included measures to promote scrapping of old vehicles and inspection for in-use vehicles. The first phase was limited to in-use trucks and also required that manufacturers take the responsibility for required retrofitting. During this phase light engine vehicles need to meet new standards for LPG and CNG in order to be granted green labels.

ii. Phase 2—from March 1999 to September 1999—included the limited use of heavy engine vehicles, new management rules for maintaining mini-buses and taxis; requirements to construct CNG and LPG gas stations in order to improve the infrastructure for CNG and LPG vehicles.

iii. Phase 3—from October 1999 to March 2000—includes requirements for visual inspections of diesel vehicle emissions; limitations on the use of diesel vehicles; rules for retrofitting taxis into dual-fuel engines; fuel quality controls; and, rules to mitigate the emissions from petrol stations.

Proposed Standards for New Vehicle

As a whole, the recently amended NAAQS in China now regulate many pollutants—such as nitrogen dioxide, carbon monoxide, ozone, particulate matter (PM_{10})—stricter than most other countries. Standards for total suspended particles (TSP) are, however, not nearly as strict as those of the other pollutants/in other countries.[13] In most areas of North China, the concentration of total suspended particulate (TSP) often greatly exceeds the standard.

Using shorter time periods to measure average emissions could strengthen the future amendments to the NAAQS. For example, second class sulfur dioxide (SO_2) standards are currently measured by a yearly average and twenty-four hour average concentration. It would be useful in future amendments if an eight-hour average concentration standard for O_3 was added. In order to meet future vehicle emission control goals, stricter standards for new vehicles will be adopted over the next decade. In the next two years, the emission standards for new cars will reach the level of those in Europe in the 1990s. By 2010 the standards will be completely phased-in and China's emission standards will match that of industrialized countries.[14]

Standards vary according to the type of vehicle; for example, vehicles lighter than 3.5 tons will be required to meet the more stringent standards and when fully implemented in new cars, the CO emissions should decrease by sixty-six percent. HC and NO_x will be forty-three percent lower than current new cars. Vehicles heavier than 3.5 tons will be required to decrease CO emissions by ninety-four percent and emissions of HC and NO_x by eighty-nine percent. Targeted reductions in emissions from heavy-duty diesel vehicles will be lowered in three stages over the next five years. One goal of the NAAQS is by 2004 to decrease CO, HC, and NO_x emissions by seventy-one, sixty-nine, and sixty-one percent, respectively.

Lead-Free Gasoline Program

There exist many problems in the quality of fuels available on the Chinese market. Moreover, the dangers of leaded gasoline have recently become a major policy focus. After studying the many lead-removal programs in industrialized countries, the Chinese leadership has decided to implement its own lead-removal policies. The State Council issued the regulation on forbidding the production, distribution and utilization of leaded gasoline by September 1998, requesting that the forty-seven key cities must stop selling leaded gasoline by 1 July 1999. The State Council decided to consolidate the fuel market and close down small refineries that could not meet these lead-free regulations and adopt the best available technologies. Lastly, the whole country must cease producing leaded gasoline by 1 January 2000, and stop selling it by 1 July 2000. Accomplishing this target on schedule is one of the most important tasks in motor vehicle pollution control in recent years.

Broader Strategies for Lowering Vehicular Emissions

While the vehicular emission standards outlined above will be key to improving urban air quality in China, a broader mix of policies targeting vehicular pollution will be needed to meet these standards. In this final section we present and critique Chinese policies that focus on infrastructure, public transport, new technologies, and inspection and maintenance (I/M) programs.

Construction and Utilization of Infrastructure

Although the urban road infrastructures in China has been greatly enhanced over the past two decades, the overall investment into transport construction is much lower than that in developed countries. China is many years away from building high-efficiency and sustainable cities with quick transport systems. Since 1978, the growth rate of the vehicle population has been much higher than that of road length. Moreover, due to limitations in municipal funding and lack of areas within cities, the construction of urban roads can not meet the demand of increasing transport. Two major infrastructure priorities should be stressed in the future. First, the total capacity of roads should be steadily enhanced. Second, the layout and construction of road networks utilize space wisely and allow traffic to move faster. These goals can be accomplished by targeting the construction of cloverleaf junctions, overhead roads, tunnels, and supplementary roads. Enhancing public transport will also relieve some of the stress and congestion on roadways.

Current trends indicate that ten to twenty percent of vehicle growth in China is in private cars.

Development of Urban Public Transport

Municipal governments are beginning to emphasize the improvement of public transport, which is a trend not only reflected in finance budgets, but also in the continually increasing public services, such as the number of buses and usage priority lanes. In 1996, the Beijing municipal government was the first city to adopt special public transport lanes on Chang An Road and this model has been replicated in many more cities.

With the deepening of reform in the public transport industry, many large cities have begun to allow privatization of public transport operations, which relieves the city of subsidy programs and has decreased municipal deficits. It should be noted that passenger flow on public transport has increased slowly and has even decreased in a few cities. In addition to public buses, many Chinese municipal governments wish to build subways as an effective and clean public transport system. While urban railway transport is a high-capacity and fast transport system, few Chinese cities have railway transport, due to the fact that subway and light rail are much more expensive than other kinds of transport systems. Currently only four Chinese cities have built subways.[15] Even in these cities with subways, not all of these subways have become the main means of transport for commuters because of the high-ticket prices. Currently, nearly twenty cities are applying for the permits from the China National Planning Committee and Ministry of Construction to build subways. Even with permits, however, subway construction will be slow in these cities due to the necessary large investment and maintenance costs. For smaller cities and the areas outside the center large metropolises, the alternative programs of closed special roads for buses, overhead roads, or trolley cars are other potential options to consider. Table 7 shows the magnitude of railway transport in the four metropolises of China.[16]

Application of Intelligent Transportation System (ITS)

At present, China witnesses the most rapid development of road construction in the world. It is anticipated that it will take another twenty years of construction for China to create a complete road network, at which time most developed countries in the world will be utilizing intelligent transportation systems (ITS). China should strive to develop and coordinate both road infrastructure and ITS simultaneously in order to enhance public transport efficiency and traffic safety to mitigate the environmental impacts of transport. Internationally, ITS has grown from the applications of electronic and information technologies to road transport. Throughout the 1980s, the Chinese Ministry of Communications carried out various research programs for expressway monitoring systems, tolling systems, and traffic safety security systems.[17] These completed studies represent the beginning foundation for developing ITS in China.

Monitoring Network for Vehicular Air Pollution

Most large cities in industrialized countries have dozens of environmental monitoring stations, which take measurements of general air quality and specific traffic pollution. Currently, only a few Chinese cities, most notably, Beijing, Shanghai, Shenzhen, Guangzhou, Wuhan, and Yantai have installed auto-monitoring systems. In China, the monitoring networks for vehicular air quality are very weak, therefore, the data on urban air quality from the monitoring stations only reveals the general status of air quality such as levels of SO_2, NO_x, particulate matter (PM), and settled dust. Tokyo has seventy-six monitoring stations, in which thirty-two traffic environmental monitoring stations provide data of CO, NO_x, NO_2, HC, and O_3. Carbon Monoxide is measured in a small number of Chinese cities, but the pollutants of hydrocarbon and ozone, which are related to motor vehicles, are not included in the routine monitoring. In addition to expanding the number and scope of monitoring stations, Chinese monitors should also more work to gather sufficient and more concise data. The U.S. Environmental Protection Agency has been working to set up air quality monitoring stations in China and this type of cooperation should continue.

Scrapping of Old Vehicles

China is a developing country with many old automobiles running on the roads, which are a major source of urban air pollution. In 1997, a newly amended *Vehicle Elimination Standard* on scrapping old vehicles was formulated and mandated by the State Environmental Protection Administration and other government agencies in China.[18] The new standard specifies that vehicles with emissions exceeding the National Emission Standards after repairs or the installation of filtering devices should be scrapped. In 1996 and 1997, the planned number of scrapped vehicles nationwide was 300,000 per year. Surprisingly, the actual numbers were 340,000 and 347,000, respectively. Between 1998 and 2000 China planned to increase the number of scrapped vehicles by 50,000 vehicles each year.

Catalytic Converter Requirements

As was discussed earlier in this article, alternative fuels—compressed natural gas (CNG) and liquefied petroleum gas (LPG)—have been introduced in twelve Chinese cities. While these alternative fuels could decrease the emissions of hydrocarbon (HC) and carbon monoxide (CO), they do not lower emissions of nitrogen oxides (NO_x), which are major pollutants in Chinese cities. With the phase-out of leaded petroleum, more additives containing oxygen may be added into gasoline, such as MTBE, which could lower the emission of NO_x.

Based on the experiences in several industrialized countries, the utilization of the three-way catalytic converter represents an ideal option for controlling NO_x as well as HC and CO emissions. After evaluating the performance of catalytic converters produced in China after driving 50,000 kilometers, some researchers concluded that Chinese-made catalytic converters are only twenty to thirty percent as effective as those made in foreign countries.[19] This highlights the need to devote more research and development into Chinese-made three-way catalytic converters. In China the percentage of vehicles with carburetors is very high, but the contents of sulfur and lead in fuel are also very high. Although the pace of the lead phase-out for automobile gasoline has sped up and will be introduced nationwide on 1 July 2000, in actuality leaded petroleum will still exist in the market for a long

Table 7. Railway Transport in Four Urban Centers

City	Subway Established	Subway Length (km)	Planned Subway Construction	Planned Light Rail Construction
Beijing	1969	40.3 (1987)	12.3 km	44.3 km
Shanghai	1993	16.1 (1994)	284 km	179 km
Tianjin	1980	7.4 (1984)	2nd & 3rd line	44 km
Guangzhou[a]	1998	12.7 (1998)	23.21 km (2nd line)	

[a] Source for Guangzhou information: www.gzmtr.com/html

time. Therefore, research and production of sulfur-proof and lead-proof three-way catalytic converters to filter out lead emissions is greatly needed.[20]

National Clean Vehicle Action

With the goal of significantly lowering pollution from vehicular emissions and cleaning air by developing advanced and new technologies, twelve Chinese cities began the implementation of the "Clean Vehicles Action" in 1999. This policy aims to promote linking the current science and technology industries with experiments in cities. The Clean Vehicles Action includes several goals:

- To speed up the production of clean fuel motor vehicles.
- To expedite the matching application of closed-loop electronic fuel injection system and three-way catalytic converters.
- To emphasize the spread of high-efficiency and low emission gas-fired technology buses and taxis.
- To enhance the construction of adding-gas stations and other necessary infrastructures.
- To build up satisfactory service system for clean fuel vehicles.
- To reinforce research and development of electric and hybrid vehicles, which will be the basis of a new automobile industry of China.

Even before this National Clean Vehicle Action policy, China had already begun to introduce clean technology vehicles. By the late 1990s, the number of clean natural gas (CNG) and liquefied petroleum gas (LPG) vehicles rose to more than 10,000 and approximately seventy gas stations to fuel such vehicles were built.[21] Beginning in November 1998, twelve cities in China began experiments in developing and using CNG and LPG vehicles and gas stations. Throughout the year, clean gas engine vehicles developed at a steady pace and Table 8 provides some comparisons of LPG and CNG vehicles in these demonstration cities.[22] Table 9 shows the magnitude of LPG and CNG vehicle increase in seven of these cities. Clearly, the number of gas stations lags behind the increase in vehicles. Although the number of CNG and LPG buses and taxis account for only ten percent of the total vehicles in use, they account for forty to fifty percent of the miles driven on Chinese urban roads. Cleaner fuels will help all cars to run clean and this policy could be easier to implement than vehicle inspection and maintenance programs.

Advanced Vehicle Technologies

Development and application of vehicles using clean alternative fuels will open up new methods to prevent and control vehicular pollution in

Table 8. Number of CNG/LPG Vehicles and Gas Stations in Twelve Demonstration Cities (1998)

City/Province	Classified Capacity of Gas-Vehicle		Gas Stations		Supply Capacity of Gas	
	CNG	LPG	CNG	LPG	CNG ($x10^8 m^3/a$)	LPG ($x10^4$ t/a)
Shanghai	None	300	None	None	None	Imported as needed
Xian	78	None	1	None	3.67	None
Wulumuqi	400	100	2	2	1.8	3.06
Guangzhou	None	210	None	1	None	Imported as needed
Shenzhen	None	1800	None	1	None	Imported as needed
Chongqing	300	None	3	None	1.0	None
Hainan Province	3	52	1	2	5.24	30
Sichuan Province	3500	None	34	None	5.13	None
Beijing	300	600	2	4	15.0	10
Tianjin	None	80	None	3	4.0	105
Changchun	None	40	None	1	3.6	30-40
Ha'erbin	None	350	None	3	0.18	56
Total	4581	6232	43	24	n.a.	n.a.

China. In order to meet the increasingly strict emission standards, the main manufacturers in the world are trying to develop diversified low-pollution vehicles using alternative power, such as vehicles that run on natural gas, liquefied petroleum gas, methanol, ethanol, biological fuels, hybrid fuels, hydrogen, electricity, and solar energy. Among this long laundry list of alternatives, natural gas vehicles and liquefied petroleum gas vehicle are currently the most practical and popular clean energy vehicles. As discussed above, twelve cities in China are experimenting with CNG and LPG public transport. Hybrid fuel and electric vehicles represent other promising clean vehicle technologies in the future.

Fuel cell vehicles are viewed as one of cleanest future technologies, but the technology for marketing fuel cells in China is not yet mature. Nevertheless, because of China's severe pollution problems, the Chinese government should promote fuel cell technology so that it could be put into use, which in turn will help to create a market for it.[23] In light of the currently available electric vehicle technology, a Chinese Ministry of Science and Technology study has outlined the future potential of for developing electric vehicles in China.[24] The study identified the following goals:

• To develop electric vehicles driven by storage battery for buses and other public transportation vehicles. Nickel-hydrogen battery and lithium battery should be applied as soon as possible to ensure the performance and reliability.

• To encourage the production of hybrid vehicles and promote the use of such vehicles on buses in cities to improve the urban air quality.

• To promote the innovation of fuel cell vehicles as a long-term strategy. China should strive for commercial use of fuel cell vehicles by 2010.

• To establish the production and supply system for methanol to complement the industrialization of fuel cell vehicles.

Municipal Inspection and Maintenance (I/M) Programs

The extant municipal I/M programs generally include yearly inspections, first-class maintenance, second-class maintenance, and vehicle overhaul. I/M programs also mandate that buses and taxis be inspected and repaired regularly. Beijing City has adopted and systematically carried out the policy of compelling inspections and vehicle maintenance.[25] Although I/M programs are only a few years old, studies of the I/M policies in several large cities, such as Beijing, Shanghai, and Guangzhou, reveal that they have been fairly effective in lowering vehicle emissions.[26] For example, in Beijing, the emissions from vehicles have been cut down by an average of thirty-seven to sixty percent in the operating mode of dual idling, and lowered by a total of twenty-eight to forty-eight percent. In Shanghai City, the emission concentrations of CO and HC have been decreased on average by thirty-nine percent. However, more reductions could be accomplished with stronger maintenance programs and stricter supervision. Cost-benefit analyses show that the implementation of I/M program is inexpensive and effective in lowering polluting emissions.

The experience of Shenzhen City in mandating yearly emission inspections of vehicles is representative of the challenges Chinese cities face in effectively implementing I/M programs. From 1991 to 1995, the yearly emission inspections in Shenzhen City were performed at inspection stations, which were established by five enterprises overseen by the police and transportation departments of Shenzhen. Due to the lack of coordination and limited knowledge of government regulations and laws, the enterprises responsible for the inspections were not reliable in the I/M work and No_x emissions continued to grow in Shenzhen City. Notably,

Table 9. Growth in Liquefied Petroleum Gas (LPG) and Clean Natural Gas Vehicles (CNG) and Stations

City/Province	Number of LPG/CNG Vehicles		LPG/CNG Gas Station	
	12/1998	11/1999	12/1998	11/1999
Shanghai	300	10000	7	17
Shenzhen	1800	2800	1	2
Chongqing	300	430	3	6
Beijing	900	12000	6	19
Changchun	40	326	1	1
Ha'erbin	350	1200	3	10
Sichuan Province	3500	5000	34	n/a

the city's Environmental Protection Bureau (EPB) was not permitted to take part in the I/M program's supervision, due to historically poor institutional cooperation between the EPB and the city traffic administration. The enterprises performing the yearly inspection of vehicles increased to eleven in 1997 and because air quality continued to worsen, the city government decided to allow the Shenzhen Environmental Protection Bureau to assign experts to emission stations. These EPB representatives now actively supervise the inspections according to national regulations and NO_x emissions have begun to drop.[27] In Shenzhen and other cities the lack of cooperation between various city departments on controlling local emissions will hinder the effectiveness of I/M program and other pollution control policies. The empowerment of EPBs in this area is a promising trend.

It will take time and considerable investment to strengthen the existing regulations, to develop technologies of internal-combustion engine, to improve fuel quality, and to adopt other measures to mitigate vehicle emissions. Inspection and maintenance (I/M) programs offer an inexpensive and effective means to lower emissions in the short term. Without proper maintenance even vehicles with advanced pollution control devices can exceed emission. Therefore, I/M systems clearly should be part of a long-term effective policy tool in China's pollution control strategy. Comprehensive cooperation and more stringent supervision have to be reinforced. The settings of major characteristic parameters for future projects on the system of inspection and monitoring could be similar to the following:

- To adopt concentrated I/M systems and maintain yearly inspections.
- To adopt ASM method in testing electronic fuel injection vehicles ($HC/CO/NO_x$).
- To adopt dual-idle method in testing carburetor vehicles (HC/CO).
- To adopt free acceleration smoke monitoring measurement in testing diesel vehicles.
- To institutionalize inspections within existing government transportation bureaus.

Moreover, there exist some shortcomings of I/M programs that must quickly be addressed. For example, the data in road inspections should be more detailed and exact, including running mileage of vehicles, classification of vehicle type, and exhaust volume. Databases of I/M information should be updated regularly so as to monitor and understand the scope of vehicles lacking maintenance. The current emission standards were mainly referenced singly from Europe, so the future standards will need to be more comprehensive. Training programs for workers in repair shops should be expanded, for the current quality of workers is very low.

Conclusion

Since China is facing severe pollution from urban transportation, Chinese leaders must formulate comprehensive technology, economic, and transport policies to encourage the development of clean emissions technology and create incentives for producers and consumers to meet air quality standards. Below we integrate various policies and programs discussed in the previous section into three policy areas—technology, economic, and transport.

- **Technology Policy.** Technology policy should mainly focus on the advanced technologies in combustion, super low emission, and alternative power. In manufacturing conventional vehicles, the Chinese auto industry is somewhat outdated and only in nascent research stage for electric automobiles and hybrid vehicles. In order to catch up with the developed countries in future, China must target specific advanced technologies in certain areas, for example, developing engines specifically for using CNG or LPG; producing catalytic converters to remove NO_x; and promoting particulate-capturing emission technology.
- **Economic Policy.** In order to decrease and prevent vehicular pollution, economic policy can be used to guide production and consumption towards cleaner emissions technology and cleaners fuels. For instance, considering the relation between engine displacement and pollutant emission, Chinese policymakers should create economic policies to encourage the manufacturing of vehicles with small cylinder volume. Thus, if the number of automobiles were equal, the exhaust emission would be much lower. The Clean Vehicles Action, which was discussed above, was begun less than a year ago, but it is encouraging that many cities have been actively adjusting their economic policies to promote its implementation. In 1998, the national government successfully adopted the measures to tax leaded oil more steeply than lead-free oil, which helped create incentives to speed up the phase-out of lead gasoline.
- **Transport Policy.** Transport policies, such as limiting the use of high-polluting vehicles, creating incentives for commuters to choose public transport, improving the traffic management equipment and methods, and adopting ITS, could considerably decrease traffic congestion and pollution in urban areas. In some metropolises such as Beijing and

Shanghai, instituting high-occupancy vehicle lanes has helped to mediate traffic congestion to some extent.

Vehicle emissions pose considerable threats to human health and quality of life in Chinese cities. Policymakers in China have made great progress in setting standards for emissions and fuels. However, in order to meet these standards, national and municipal governments will need to emphasize policies to strengthen infrastructure, expand public transport, and promote the development of clean vehicle technology.

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Endnotes

[1] *China Economics Times*, April 14, 1999 and *China Statistical Yearbook*, 1978-1998.

[2] China International Cooperation Committee of Environment and Development. *Proceedings of Symposium of Urban Transportation and Environment*, (April):1-10, 1999.

[3] Department of Environmental Science and Engineering, Tsinghua University. *China Road Transport Pollutant Emission Report—for Different Types of Vehicles*, October 1999.

[4] Department of Environmental Science and Engineering, Tsinghua University, et al. *Research Report of Planning of Vehicle Emission Pollution Control in Beijing City*, December 1999.

[5] Lu Shuyu. "Vehicular Pollution Control Strategies in City Shanghai," *Shanghai Environmental Sciences*, 1998, 17(3):1-3 (in Chinese) and Chen Changhong, et al. "Pollution Load of Vehicular Exhaust in City Shanghai," *Shanghai Environmental Sciences*, 16 (6):26-29, 1997 (in Chinese).

[6] Department of Environmental Science and Engineering, Tsinghua University, et al. *China's Strategies for Controlling Motor Vehicle Emissions—Summary Report*, 1997.

[7] Guo Yijun et al., "Vehicle Emission Pollution and Its Control," *Chongqing Environmental Sciences*, 19 (3):9-13, 1997 (in Chinese).

[8] Song Ruijin et al., "Study on Exposure Level of Human to the Exhaust of Motor Vehicles," *Journal of Environment and Health*, 15 (5):196-198, 1998 (in Chinese).

[9] Peng Baocheng et al., "Investigation of Immune Systems of Bus Drivers and Conductors on Yuejiang Tunnel Bus Line," *China Public Health*, 11 (2):65-66, 1995 (in Chinese).

[10] Fei Qiuling et al., *Modern Preventive Medicine,* Beijing 1998 (in Chinese).

[11] Department of Environmental Science and Engineering, Tsinghua University, et al. *Research Report of Planning of Vehicle Emission Pollution Control in Beijing City,* (12):145-150, 1999.

[12] Zheng Yisheng et al., "Economic Loss Caused by Environmental Pollution in the Mid-1990s in the PRC," *Management World*, February 1999 (in Chinese).

[13] Chinese State Environmental Protection Agency (SEPA). *National Environmental Quality Report*, 1997 and SEPA, *Standards of Ambient Air Quality*, 1996.

[14] *China Environment Daily*, July 21, 1998.

[15] China International Cooperation Committee of Environment and Development. *Proceedings of Symposium of Urban Transportation and Environment*, April 1999.

[16] Xi Guohua et al., "Study and Development of Rail Transportation System in Large Cities of China," *Electric Drive for Locomotive*, no. 3:1-3, 1999.

[17] Research Institute of Highways. *A Study on the Developmental Strategy of the ITS in China*, May 1998.

[18] Department of Environmental Science and Engineering, Tsinghua University, et al. *Summary Report*, 1997

[19] Chinese Association of Environmental Protection Industry. *Collection of Papers in the Symposium of Industrialization and Development Strategies in Vehicular Catalytic and Cleaning Technologies*, (April):35-40, 1999.

[20] Ibid:30-34.

[21] *Collection of Papers at the Meeting of "Air Improvement Program—Clean Vehicles,* Beijing, (April):25-27, 1999.

[22] Chinese Ministry of Science & Technology. 1999 *Beijing International Automobile Environmental Protection Technology Presentation Seminar*, December 1, 1999.

[23] He Kebin et al., *Assessment Methods and Applications of Alternative Fuel for Vehicles Globally, Nationally and at the City Level,* Tsinghua University, 1999.

[24] Chinese Ministry of Science and Technology. *1999 Beijing International Automobile Environmental Protection Technology Presentation Seminar,* Beijing, December 3, 1999.

[25] Wang Xuechun. *Study on In-use Vehicle Inspection/Maintenance (I/M) Program in Beijing.* Master's Thesis, Tsinghua University, (June):6-8, 1999.

[26] Department of Environmental Science and Engineering, Tsinghua University. *Report: Demonstration of Typical Cities for Controlling Vehicle Emissions in China*, December 1999.

[27] Zhou Zhanming et al., "Analysis of Environmental Behavior in City Shenzhen's Yearly Inspection Stations," *China Environmental Monitoring,* 15(1):12, 1999.

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