Transportation and the Environment in China

by Michael P. Walsh

At first glance, concerns regarding motor vehicle pollution in China seem misplaced. With a population more than four times as large as the United States (1.22 billion versus 268 million) the number of cars, trucks, and buses in China is a mere fraction of that in the United States (less than fourteen million in China versus 210 million in the United States). On a per capita basis, China has one of the lowest vehicle populations in the world, as illustrated in Table 1.

According to Table 1, it is clear that among these countries only India has a lower vehicle ownership density than China. However, to stop at this superficial overview would be very misleading. In recent years, the vehicle population in China has been increasing sharply, with much of this growth taking place in cities. Nationally, the annual growth of vehicles has averaged approximately fourteen percent per year. One result of this rapid growth has been the emergence of serious air pollution problems, especially in cities. Furthermore, the growth in vehicles in China is expected to continue and perhaps even accelerate in coming decades, increasing concerns regarding further environmental degradation. Chinese policymakers have begun to respond to the growing problem of air pollution. For example the government has initiated a public reporting system whereby a growing number of Chinese cities are now routinely reporting their current air quality, as illustrated by the most recent data summarized in Table 2 (following page). As Table 2 shows, several cities have an air pollution index above 400 for total suspended particulates (TSP), which means these cities measured TSP levels above 875 mg/m^3 (micrograms per cubic meter).

Table B illustrates that most Chinese cities already have serious air pollution problems particularly with TSP and nitrogen oxides (NO_x). As this information has become publicly available, citizen pressure has been building to push the government to take action to lower the pollution levels. Strategies are therefore being developed and implemented at both the national and local levels to counteract this problem. Most notably, at the national level, China has completed an environmental technical assistance project, sponsored by a World Bank loan, to develop an Action Plan with the objective of assuring that by 2010 the air quality levels in China's major cities meet the second class of national standards.[1] One trend which could help China attain these national air quality standards has been actions by large cities, particularly Beijing, to develop local pollution control strategies. The purpose of this article is to review and analyze the proposed national Action Plan and recent municipal government actions to alleviate pollution problems in China. To place the Action Plan and local actions in context, I will first outline current information on vehicle use, air quality, and infrastructure investment.

Table 1. Vehicle Ownership Density

Country	Vehicles/ 1000 People
United States	785
Australia	591
Japan	560
Germany	553
Austria	513
Portugal	395
Greece	290
Bulgaria	235
Romania	135
Mexico	135
Chile	105
Venezuela	95
Thailand	73
Egypt	29
China	10
India	8

Source: Data: "World Vehicle Demographics." *Financial Times Automotive World.* (April 1999.)

The Current Situation in China

Vehicle Growth and Roads

The total number of motorized vehicles in China, although very low by Western standards, is growing rapidly and has already risen to about 1.4 million in Beijing and over one million in Guangzhou. For the country as a whole, the number of vehicles in 1998 climbed to about fourteen million cars and trucks and twenty million motorcycles. Much of the growth has been in private passenger cars, especially in recent years. The demand for personal cars in China rose by an average of 28.1 percent over the past five years and is expected to hit one million cars annually by the year 2000.[2] In spite of an almost doubling in the number of public transit vehicles from 1993 to 1997 (see Table 3, following page), the total passengers carried has remained constant across the country's cities, with many actually showing declines.[3]

With regard to driving patterns and average speeds, many existing roads have already reached their maximum capacity and are saturated during long periods of each day. Substantial road building is underway in all large cities and over the past five years, the investment for road infrastructure in the large cities has doubled.[4] The results of this investment are clear in Shanghai, which boasts an impressive improvement in increasing road length, road area, and road area per capita by nineteen percent, forty-two percent, and thirty-nine percent, respectively, between 1991-1997 (See Table 4, following page). However, the expansion in the city's road infrastructure pales in comparison to the vehicle growth that has averaged fifteen percent per year since the mid-1980s.[5]

Table 2. Compilation of Air Pollution Data for Chinese Cities

City	Air Pollution Index	Chief Pollutant
Beijing	500	TSP
Tianjing	424	TSP
Shijiazhuang	201	TSP
Qinhuangdao	136	TSP
Taiyuan	311	TSP
Huhehaotei	408	TSP
Shenyang	184	TSP
Dalian	70	TSP
Changchun	369	TSP
Haerbin	118	TSP
Shanghai	128	NOx
Nanjing	108	TSP
Suzhou	138	TSP
Nantong	228	TSP
Lianyungang	178	TSP
Hangzhou	152	NOx
Ningbo	82	TSP
Wenzhou	77	TSP
Hefei	82	TSP
Fuzhou	59	TSP
Xiamen	38	-
Nanchang	113	TSP
Jinan	328	TSP

Source: http://www.usembassy-china.org.cn/english/sandt/index.html, which is the webpage for the Environment, Science, and Technology Section of the U.S. Embassy in Beijing.

Air Quality and Pollution from Mobile Sources

One of the challenges for policymakers in China is that air quality monitoring data in Chinese cities are limited, especially in high traffic areas. Based on the available data, however, it is clear that national NO_x air quality standards are currently exceeded across large areas, including, but not limited to, high traffic areas. Before 1992, the annual average concentration of NO_x in Shanghai was lower than 0.05 mg/m^3, which complies with the Class II air quality standards in the People's Republic of China (PRC). But since 1995, the NO_x concentration in Shanghai has increased slowly, from 0.051 mg/m^3 in 1995 to 0.059 mg/m^3 in 1997.[6]

In Beijing, NO_x concentrations within the Second Ring Road that encircles the city center increased from 99 mg/m^3 in 1986 to 205 mg/m^3 in 1997, more than doubling in a decade. Moreover, carbon monoxide (CO) and NO_x concentrations on Beijing's trunk traffic roads and interchanges exceed national environmental quality standards all year round.[7] Recent data also indicate that standards for ozone, formed by the photochemical reaction of NO_x and hydrocarbons (HC), have been exceeded in several metropolitan areas during the last decade.

On average, mobile sources are currently contributing approximately forty-five to sixty percent of the NO_x emissions and about eighty-five percent of the CO emissions in typical Chinese cities.[8] Recent data collected in Shanghai, for example, show that in 1996, vehicles emitted eighty-six percent of the CO, fifty-six percent of the NO_x, and ninety-six percent of the non-methane hydrocarbons (NMHC) of the total air pollution load in the downtown area.[9] In Beijing in recent years, the NO_x concentration shows a clear increasing trend. Annual average NO_x concentrations, average concentrations during the heating season, and those during the non-heating season in 1997 were 133 mg/m^3, 191 mg/m^3, and 99 mg/m^3, respectively. These emissions were seventy-three percent, sixty-six percent, and eighty percent higher than those ten years ago. The annual daily average NO_x concentration in 1998 was 14.3 percent higher than in 1997. Since the amount of coal burned has remained stable for many years, Beijing local authorities attribute the increases in these pollutants to vehicular emissions.[10] Poor vehicle maintenance is one leading cause of mobile source pollution problems. This deficiency in vehicle maintenance is reflected in the high failure rate in the existing, relatively lenient Inspection and Maintenance (I/M) programs. Poor training of inspectors has meant repair workers lack the necessary professional knowledge and expertise in repair and maintenance service of emission equipment.[11] Many vehicles seem to be

Table 3. Public Transit in Chinese Cities

City	Number of Public Transit Vehicles (Standardized Vehicle Equivalents)		Total Passengers Carried (Millions)	
	1993	1997	1993	1997
Beijing	4890	8548	2863	3374
Tianjin	2193	2896	397	536
Shenyang	2406	2359	537	625
Changchun	1031	2249	310	341
Harbin	1344	3139	612	543
Shanghai	8521	16237	5627	2637
Nanjing	2412	2360	500	499
Wuhan	1971	4355	1251	943
Ghangzhou	2338	4611	664	1074
Chongqing	2090	2479	753	502
Chengdu	1408	1618	288	293
Xian	871	1418	355	299
Total of 12 Cities	31,475	52,269	14,156	11,667
Average of 12 Cities	2623	4356	1180	972
Total of 666 Cities	88,606	168,566	27,259	27,348

Source: Wu Yong, "Targeting Sustainable Development for Urban Transport," Urban Construction Department of the Ministry of Construction, and Li Xiaojiang, unpublished paper, Chinese Academy of Urban Planning and Design, April 1999.

operating with a rich air fuel mixture, which while producing relatively good drivability and low NO_x emissions, leads to high fuel consumption and excessive CO and HC emissions. Furthermore, the vehicle technology being produced tends to be primarily carburetor-equipped with mechanical rather than electronic controls. Recently collected emissions data in China show that current vehicles are typical of the cars used in the United States in the late 1960/ early 1970s.[12]

In light of the above information on car trends in China, it appears likely that the growth in the overall vehicle population will continue at a high rate for the foreseeable future. As noted in a recent study,

> Credit facilities and installment payments, which China's commercial banks have promised to introduce, are expected to push forward the car-buying momentum. A survey conducted among 600 urban families in Beijing by the China Economic Climate Monitoring Center says that well-to-do families account for eleven percent of the population, families that enjoy a relatively comfortable standard of living represent fifty-three percent, and those that have adequate food and clothing, thirty-four percent. The first category has put car purchases high on their consumer agenda, and the second is expected to have similar lifestyles and hopes within five to ten years. This will spur on the private car sector.[13]

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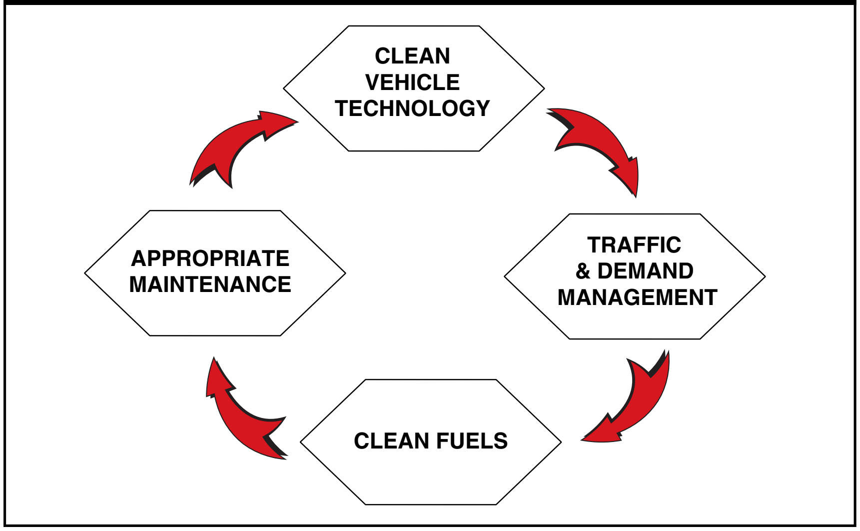
Economic growth and consumers' desires are pushing the growth of vehicle population at a much faster rate than roads are being constructed. The number of roads approaching saturation will likely increase and the period of time when these roads will be overloaded will lengthen, which will result in more frequent and severe air quality peaks in localized areas. This congestion means that national air quality standards for NO_x, CO, and ozone will increasingly be exceeded in many cities. In addition, roadside particulate problems will likely increase, leading to serious health problems. Based on data collected in the World Bank project, it is clear that with the increase in diesel vehicles particulate matter (PM)

Table 4. Paved Road Length and Per Capita Paved Road Area of Shanghai (1991-1997)

Year	Length of Paved Road (Km)	Area of Paved Road (10^4 m^2)	Per Capita Road Area (m^2)
1991	4817.6	6004.8	4.67
1992	5043.2	6386.7	4.95
1993	5105.3	6569.2	5.07
1994	5192.3	6862.2	5.28
1995	5420.3	7399.9	5.69
1996	5599.3	8058.5	6.17
1997	5712.7	8503.2	6.51

"Strategy for Sustainable Development of Urban Transportation and Environment—for a Metropolis with Coordinating Development of Transportation and Environment toward the 21st Century," Shanghai Municipal Government, January 10, 1999.

Figure 1. Elements of a Comprehensive Vehicle Pollution Control Strategy



and NO_x will also rise. Since diesel particulates have been identified as a likely human carcinogen, this risk will increase as well. The World Bank data stress that based on the vehicle growth projections, it can be concluded that a successful program to reduce air pollution and its local and regional effects will depend on the success in controlling mobile emissions sources.[14] In light of these dangerous pollution trends, the National Environmental Protection Administration—now upgraded to the State Environmental Protection Administration (SEPA)—undertook a study of national and local plans, which could help alleviate the growing emissions from mobile sources. The SEPA study and its conclusions are presented below. This article then concludes with examples of recent municipal government actions to control vehicle emissions.

SEPA Technical Plan To Address Vehicle Pollution

Generally, the goal of a motor vehicle pollution control program is to reduce emissions from motor vehicles in-use to the degree necessary to achieve healthy air quality as rapidly as possible or, failing that for reasons of impracticality, to the practical limits of effective technological, economic, and social feasibility. Achievement of this goal generally requires a comprehensive strategy encompassing emissions standards for new vehicles, clean fuels, and programs designed to assure that vehicles are maintained in a manner that minimizes their emissions. Finally, to complete this comprehensive strategy, an effective program for traffic and demand management that limits the demand for and use of all vehicles must be formulated. Ideally, to be politically feasible, these emission reduction goals should be achieved in the least costly manner. Figure 1 illustrates the elements of a comprehensive vehicle pollution control strategy.

Standards for permissible levels of exhaust and evaporative emissions from motor vehicles should be based on a realistic assessment of costs and benefits keeping in view the technical and administrative feasibility of proposed countermeasures. Technological approaches to achieve the desired emission standards may include fitting new vehicles with emission control devices, such as catalytic converters or particulate traps, requiring such devices to be retrofitted to existing vehicles, and modifying fuels or requiring the use of alternative fuels in certain vehicles. Emissions may also be reduced through traffic and demand management strategies and policy instruments, such as higher taxes for vehicles that will be driven in high pollution areas during rush hours. However, many of the potential benefits of these countermeasures will be squandered if regulatory and economic instruments do not create the incentives for vehicle owners, manufacturers, and fuel suppliers to comply with the standards and change their behavior to achieve the desired goals. A key element of the overall strategy, therefore, must be effective enforcement to ensure maximum compliance with standards.

To develop a national strategy for addressing vehicle pollution, SEPA, with support from the World Bank, pulled together a team of experts from a variety of government agencies and technical institutes and universities to study the vehicle pollution issues. Taking Beijing and Guangzhou as typical cities, the study analyzed the main reasons for the serious vehicular pollution in China. The study determined the average emission rates for the existing vehicle fleet and its contribution to urban air pollution and predicted the future vehicular development and pollution. Another important component of the study was a comparative analysis of foreign experiences on controlling vehicle emission pollution and evaluated the feasibility and cost-effectiveness of implementing the internationally-advanced technologies and management systems in China. Finally, the study defined the vehicular emission control targets and corresponding technology and management strategy.

Emissions Standards for New Vehicles

To determine the appropriate national emissions standards to adopt in China, estimates were made by World Bank and SEPA analysts regarding the potential emissions reductions that such standards could achieve. The costs and cost-effectiveness of these standards were evaluated and compared. The costs of various standards to reduce NO_x are presented in Table 5. Most of the strategies considered for new vehicles were based on European regulations, for China had previously adopted the first generation of European emissions standards. Moreover, the largest car manufacturer in China is a European company—Volkswagen. The important exception was the inclusion of Japanese and Taiwanese strategies for motorcycles. These strategies were considered, because most motorcycles in China are manufactured in Japan and Taiwan.

It can be seen that all but the last three strategies considered would cost less than U.S. $2000 per ton of NO_x reduced. Keeping emission costs below U.S. $2000 indicates a very cost-effective level based on international experience. From this broad analysis, several potential scenarios were developed in the World Bank/SEPA study to represent packages of measures for all categories of new vehicles. In selecting strategies to be adopted, several factors were taken into account, including the following:

- Air quality need;
- Potential effectiveness of the measure;
- Cost of the measure, including

Table 5. Cost Effectiveness of Various New Vehicle Emission Strategies

Vehicle Type	Strategy	Tons NO_x Reduced[a]	Cost	Cost Effectiveness[b] (US$/Ton)
HDDV	EU2	2.2487	$946	$421
Jeep	96/69	0.8602	$42	$49
LDDV	94/12	0.7694	$396	$515
LDGV	94/12	0.704	$382	$543
Jeep	93/59	0.6993	$139	$199
LDDV	91/441	0.6239	$100	$160
LDGT2	96/69	0.5859	$370	$632
LDGV	91/441	0.5714	$394	$690
LDDT	96/69	0.5037	$370	$734
HDDV	EU1	0.4814	$721	$1,498
Mini Vehicle	96/69	0.4468	$316	$706
LDGT2	93/59	0.4449	$385	$866
LDDT	93/59	0.4061	$100	$246
Mini Vehicle	93/59	0.347	$344	$992
MC	Japan	0.1893	$216	$1,142
MC	Taiwan 91	0.1884	$224	$1,190
HDGV	EU2	0.1183	$322	$2,726
MC	Taiwan 94	0.0658	$309	$4,699
HDGV	EU1	0.0219	$416	$18,995

Source: "China's Strategies for Controlling Motor Vehicle Emissions," Summary Report, December 1997.
[a]Relative to current requirements. [b] In making this estimate, all other benefits of the standards were ignored. The entire costs were ascribed to NO_x control even though in most cases, substantial CO and/or HC reductions would also occur. HD-Heavy Duty, LD-Light Duty, DV-Diesel Vehicle, GV-Gas Vehicle, GT2-Heavy Duty Gas Vehicle; MC-Motorcycle

hardware, maintenance, and fuel economy;
- Overall cost effectiveness; and,
- Technical feasibility.

Considering each of the above factors, the choice of standards that promote the lowest emissions in new vehicles were narrowed down to the two scenarios summarized in Table 6. The options for final consideration were:

• **Scenario 2:** Adopting the standards which were introduced in Europe in 1992 followed four years later by the new 1996 European standards and completing enforcement by 2000.

• **Scenario 4:** Adopting the standards introduced in Europe in 1996 and completing enforcement by 2002.

Analysts at SEPA determined that both scenarios are very cost effective (See Table 7). After considering all these factors, as well as the technological capability of the domestic vehicle industry, SEPA and its support team recommended Scenario 2 as the minimum requirement for new vehicles. However, SEPA will consider Scenario 4 as an alternative and provide fiscal incentives to encourage Scenario 4 vehicles and engines. In addition to these emission regulations for new vehicles, the report specified some regulations that SEPA should issue for limiting emissions in existing vehicles.

Table 6. Proposed Scenarios for New Vehicles in China

Scenario	Vehicle Type	2000	2002	2005
2	Passenger Cars	91/441		94/12
	Light Duty Vehicles	93/59		96/69
	Heavy Duty Vehicles	Euro 1		Euro 2
	Motorcycles	ECE 40.01		Japan
4	Passenger Cars		94/12	
	Light Duty Vehicles		96/69	
	Heavy Duty Vehicles		Euro 2	
	Motorcycles		Japan	

Source: "China's Strategies for Controlling Motor Vehicle Emissions," World Bank Summary Report, December 1997.

Proposed Measures for In-Use Vehicles

In addition to setting emission standards for new cars, the World Bank/SEPA study highlighted four main areas for controlling emissions in existing vehicles:

• **Inspection and Maintenance** (I/M): Analysis indicated that creating a well-functioning I/M program could be one of the most cost-effective options considered and one that could have a rapid impact. After 2002, a loaded mode test procedure, the ASM test, will be adopted for catalyst-equipped vehicles and 100 percent of the vehicles will be required to be tested and 100 percent will need to pass the test in order to be driven. In combination with new vehicle standards, this I/M program will better enable the national NO_x targets to be met.

• **Retrofit Programs:** The study also concluded that national retrofit regulations should be issued for two primary reasons: 1) to assure that retrofit programs being introduced around the country are adequately considering important factors such as fuel quality and vehicle maintenance; and 2) to assure that retrofits actually achieve the claims made by retrofit companies. The final report recommends that a performance standard be used as a basis for approving systems.

• **Fuel Programs:** The study team also recommended that SEPA should issue regulations regarding the quality of fuels and fuel additives and enforce these standards and specifications in the fuel distribution system.

• **Non-Technical Measures:** In addition to technical measures outlined above, cost-effective, non-technical measures, such as traffic controls or tax incentives for cleaner vehicles or fuels should also be developed. These types of measures should be implemented locally. However, national support through technical investigations, financing, and necessary legislation will be needed to facilitate cooperation at the local level. Notably, local representatives from Guangzhou and Beijing were very involved in designing this component.

Table 7. Cost Effectiveness of the Scenarios

Scenario	Cumulative NO_x Reduction (10^4 tons)	Cumulative Costs (10^6 \$)	Cost-Effectiveness (\$/Ton)
2	97	441	450
4	120	389	320

Source: "China's Strategies for Controlling Motor Vehicle Emissions," World Bank Summary Report, December 1997.

Table 8. Projected Overall Vehicle Emissions in 2010

Vehicle Category	HC	CO	NO_x
LDGV	36.8%	52.1%	47.1%
LDGT1	13.5%	17.2%	15.3%
LDGT2	10.7%	13.5%	13.4%
HDGV	2.9%	3.3%	6.6%
HDDV	1.8%	1.0%	11.9%
MC	30.4%	7.9%	0.8%
JEEP	3.8%	5.0%	4.8%

Source: "China's Strategies for Controlling Motor Vehicle Emissions," World Bank Summary Report, December 1997.

Potential Impact of Proposed Standards and Programs

Even after adoption of the new and in-use management and technical measures noted above, the air pollution problems in China's major cities will not be completely solved. While emissions would be much lower without controls, ambient NO_x levels are still projected to remain higher than the targets. Specifically, while area-wide CO problems should be eliminated, it is expected that even with the implementation of emission standards, levels near roadways will still be unhealthy. Furthermore, ozone and PM levels will likely worsen from today's levels without focused efforts to address their emissions and precursors. In the future, to address these remaining problems it will be important to focus on those vehicle categories for which additional control measures appear feasible and potentially effective. In this regard, it is useful to understand the relative importance of the various vehicle categories to projected overall vehicle emissions in 2010 as summarized in Table 8 above.

Based on the data presented in Table 8, it is clear that light duty gasoline fueled cars and trucks will need to remain a primary focus of control efforts in the future. In this regard, it is important for Chinese planners to remain abreast of technological advances and other developments around the world. Therefore, after the standards contained in the Action Plan are implemented, it will be valuable for SEPA to analyze the potential feasibility and cost effectiveness of utilizing the even more stringent Euro 3 requirements in China. Notably, these Euro 3 requirements are going to be introduced in Europe in the year 2000.

Progress on Implementing the Action Plan—Municipal Government Leadership

China has moved rapidly and aggressively to implement the Action Plan strategy. What is striking has been the strong push by large municipal governments to implement these strategies ahead of schedule and at times adopt standards stricter than those in the Action Plan. Below is an overview of five areas in which progress is being made at both the national and municipal level.

• **Unleaded Gasoline:** In March 1997, the decision was made to phase out the production and sale of leaded gasoline across the entire country by 1 July 2000. By July 1997, Beijing had already stopped sales of leaded fuel in the city center and by October the ban had spread to Shanghai and Guangzhou.

• **New Vehicle Standards:** In 1998, the State Council decided to introduce Euro 1, catalyst-based emission standards for all new cars sold in the country as of 1 April 2000. Beijing again took the lead by phasing in these European auto standards that require all new cars to be equipped with catalysts as of 1 January 1999, one year ahead of the national schedule. Of the 64,000 new vehicles sold in Beijing since the beginning of 1999, 46,000 cars comply with the Euro 1 standards and the remaining 18,000 vehicles not meeting these standards are motorcycles, agricultural tractors, and trucks. To regulate these vehicles, Beijing will implement more stringent exhaust standards (Euro 1) for both Heavy Duty Gas Engines (HDGE)[15] and Heavy Duty Diesel Engines (HDDE) with steady state mode test methods, and to agricultural transport vehicles using the free acceleration mode. The standards were put in force by 1 June 1999.

Furthermore, the government of Beijing has a plan to retrofit 14,000 taxis to become dual fuel vehicles gasoline (Liquefied Petroleum Gas—LPG). Among them, 10,000 taxis should be finished before the middle of September 1999 and the remainder by the end 1999. The city government also requires taxi companies with more than 300 taxis must build their own LPG refueling stations. Notably, some public buses will also be changed to use dual fuel. The government wants to change the diesel buses in downtown—inside the second circle road—into gasoline buses, because some national leaders consider the diesel engine to be the worst pollutant source. Notably, the Shanghai municipal government and numerous other large cities are pursuing retrofit strategies as well. This rapid and progressive work by city governments on emission control standards is linked to the publicizing of air quality data in Chinese cities, which has led to public pressure on local authorities to address the problem.

Table 9. SEPA Proposed Schedule for Heavy Duty Standards

	Certification	Production
Euro 1 Standards	July 1, 2000	July 1, 2001
Euro 2 Standards	January 1, 2003	July 1, 2004

Nationally, SEPA is planning to introduce heavy duty standards according to the data presented in Table 9. It should be noted that the State Supervision Bureau (SSB) is in a dispute with SEPA over which organization has authority to issue new vehicle standards. The SSB would most likely delay the introduction of Euro 2 standards until 2005 for certification and delay production standards until 2006.

• **Vehicle Retrofit:** In early March 1999, the Beijing Environmental Protection Bureau (EPB) had a meeting with car manufacturers from all around the country and informed them that all manufacturers whose vehicles had been sold in Beijing should be responsible for the pollution of these vehicles. As a result of the discussions, all domestically produced cars sold in Beijing, which were manufactured between 1995 and 1998, must be retrofitted with a vehicles manufacturer developed kit designed to meet the Euro 1 standards. For cars with carburetors, this means installing a three-way catalyst, an oxygen sensor, an air injector, and an electronic control unit to manage the air-fuel ration at a cost of approximately $375 per vehicle. The scope of the cars needing to be retrofitted, will be the total cars registered between 1 January 1995 and 31 December 1998. Manufacturers were required to finish the work by December 1999. Approximately 80,000 vehicles have been retrofitted to date in Beijing with estimated emissions reductions averaging about seventy percent. When completed, approximately 200,000 vehicles will be retrofitted. Similar programs are going on in other cities.

• **Fuel Conversions:** Orders have been placed for 300 new Cummins Compressed Natural Gas (CNG) engines to be installed in existing buses, replacing diesel engines. No more buses with diesel engines are planned to be purchased and new regulations will require that new buses and taxicabs are fueled by CNG or have the capacity to be dual-fueled (LPG and unleaded gasoline). Approximately 15,000 vehicles have been converted to CNG or dual-fuel as of November 1999 and it is expected that this exceeded 17,000 by the end of 1999. Diesel to CNG conversions are estimated to result in about ten to twenty percent less CO and HC emissions. The Beijing Environmental Protection Bureau has also apparently decided to ban the sale of diesel vehicles altogether in Beijing.

• **Other:** The Beijing Environmental Protection Bureau is actively pursuing loaded emission testing capability for the I/M program, as are other cities in China. The I/M program is the primary enforcement tool for vehicle retrofits and alternate fuel conversions, as well as for the overall maintenance of the vehicle fleet. Another new policy recently introduced by the Beijing Environmental Protection Bureau (EPB) is the requirement to force the retirement of vehicles that have accumulated more than 500,000 kilometers in use. This policy led to the scrapping of approximately 58,000 vehicles, mainly taxis, by the end of 1999.

On 1 June 1999, SEPA issued new control standards for motor vehicle gasoline designed to minimize hazardous risks of benzene, olefins, aromatics, lead, and other chemicals. In addition, detergents which could clean deposits effectively will be required to be added to motor vehicle gasoline. For olefins, the requirements were implemented in Beijing, Shanghai, and Guangzhou as of 1 July 1999 and will be mandatory for the entire country after 1 January 2003. The Beijing EPB is also trying to work with the Petroleum Ministry on further improvements of fuel quality, especially as it pertains to detergents. Currently the Beijing EPB and the Petroleum Ministry are developing Stage I vapor controls at service stations. In the year 2000, a pilot program to raise money to fund pollution control work has been set up in approximately thirty major cities. This pilot project requires the levy of a 300 to 600 Renminbi pollution fee on all vehicles and the funds will be dispersed to local governments to use as they see fit to remedy vehicle pollution in their area.

Conclusion

The vehicle population in China has been growing rapidly over the past decade and will likely continue to do so for the foreseeable future. Without significant effort to constrain the environmental damage that these vehicles can cause, already serious air pollution problems will become critical. To prevent further severe air pollution, the Chinese government—with funding provided by the World Bank—has developed a national strategy for reducing motor vehicle pollution. Key components of the strategy include unleaded gasoline, tight standards on all categories of new vehicles, and a substantially upgraded I/M program. Institutional improvements to enable the strategy to be implemented have also been developed. A great deal of additional work will be needed but it is believed that the work carried out to date under this project provides a good basis upon which to build in the future. Several important elements of the strategy have now been implemented and most notably have been the additional controls that municipal governments are introducing to complement the national strategy.

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Endnotes

[1] "China's Strategies for Controlling Motor Vehicle Emissions," World Bank Summary Report, December 1997.

[2] "Private Car Purchases on the Rise in China," *China Auto*, 9:1 (January/February 1999).

[3] "Targeting Sustainable Development for Urban Transport," Wu Yong, Urban Construction Department of the Ministry of Construction, and Li Xiaojiang, Chinese Academy of Urban Planning and Design, April 1999.

[4] "Strategy for Sustainable Development of Urban Transportation and Environment—for a Metropolis with Coordinating Development of Transportation and Environment toward the 21st Century," Shanghai Municipal Government, January 10, 1999.

[5] Ibid.

[6] Ibid.

[7] "Urban Transport and Environment in Beijing," Beijing Municipal Environment Protection Bureau, Beijing Municipal Public Security and Traffic Administration Bureau, and Beijing Urban Planning, Design and Research Academy, January 15, 1999.

[8] "China's Strategies for Controlling Motor Vehicle Emissions," December 1997.

[9] "Strategy for Sustainable Development of Urban Transportation and Environment," January 10, 1999.

[10] "Urban Transport and Environment in Beijing," January 15, 1999.

[11] Ibid.

[12] "China's Strategies for Controlling Motor Vehicle Emissions," December 1997.

[13] *China Auto*.

[14] "China's Strategies for Controlling Motor Vehicle Emissions, "World Bank Summary Report", December 1997.

[15] Since all heavy-duty engines in Europe are diesel, the gasoline-fueled engine standards will be set to United States 1982 requirements.

Present and Future Pollution from Urban Transport in China

By He Kebin and Cheng Chang

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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