Strategies for controlling pollution from vehicular emissions in Beijing

Qidong Wang* and Kebin He

Department of Environmental Science and Engineering,
Tsinghua University,
Beijing 100084, P.R. China
E-mail: qdwang@nsfc.gov.cn E-mail: hekb@tsinghua.edu.cn
*Corresponding author

Tiejun Li

Department of Air Environment Management,
Beijing Environmental Protection Bureau,
Beijing 100044, P.R. China
E-mail: tiejunli1@sina.com

Lixin Fu

Department of Environmental Science and Engineering,
Tsinghua University,
Beijing 100084, P.R. China
E-mail: fuchen@tsinghua.edu.cn

Abstract: Beijing is one of the most polluted cities in the world, which is caused by surprising vehicular growth in the past decade. This paper describes the severe situation of vehicular emission pollution in Beijing, and discusses the following strategies for mitigation: improving fuel quality, controlling the exhaust from new vehicles, controlling the emissions from vehicles in use through, e.g., inspection/maintenance (I/M), renovating in-use vehicles, scrapping of old vehicles, incentives to encourage replacement of vehicles still in their service life and road infrastructure and traffic policies. The paper concludes that the abatement of vehicular pollution requires an integrated approach, with the combined use of transport policies, the enforcement of vehicle-related regulations and improvements of vehicle technology.

Keywords: fuel quality; new vehicles; in-use vehicles; incentives; emission standards; road infrastructure; transport policy.

Reference to this paper should be made as follows: Wang, Q., He, K., Li, T. and Fu, L. (2005) 'Strategies for controlling pollution from vehicular emissions in Beijing', *Int. J. Environmental Technology and Management*, Vol. 5, No. 1, pp.87–106.

Biographical notes: Qidong Wang is a PhD candidate at Department of Environmental Science and Engineering, Tsinghua University, Beijing 100084, P.R. China and Associate Professor at the School of Chemical and Engineering, Beijing Technology and Business University, Beijing. His research field focuses on vehicle emission pollution control related to transportation and real-world vehicle emission factor, inventory and models.

Kebin He, PhD, is Professor in the Department of Environmental Science and Engineering, Tsinghua University, Beijing 100084, P.R. China; He is the director of the International Cooperation Office of Tsinghua University and the expert on energy policy and environment pollution control.

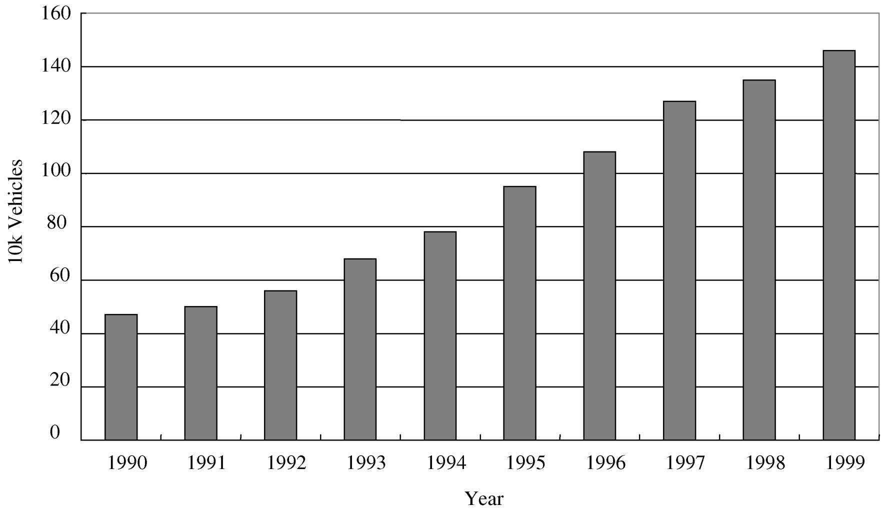
Tiejun Li is Deputy Director of Department of Air Environment Management, Beijing Environmental Protection Bureau, Beijing 100044, P.R. China. Li is responsible for mobile source emission control in Beijing.

Lixin Fu is Associate Professor and the director of air pollution research in the Department of Environmental Science and Engineering, Tsinghua University, Beijing 100084, P.R. China. He is an expert on vehicle emission control.

1 Introduction

In recent years, as many measures had been adopted to dissolve coal-burning pollution problems, such as pollution factories' conveying and more natural gas input to Beijing, concentrations of sulphur dioxide (SO_2) and total suspended particulates (TSP) in the air of urban and suburban Beijing became controllable. But, motor vehicles are becoming the major source of CO, HC and NO_x air pollutant emissions. During the 1990s, the average growth rate in Beijing was as high as 17.4% (Fu et al., 2001). At the end of 1997, the vehicle number in Beijing was 1.27 million, in 1998 1.37 million, in 1999 reached 1.46 million and at the end of 2002, it will be 2 million. Figure 1 shows the growth in the vehicle population in Beijing from 1990 to 1999.

Figure 1 Growth in the vehicular population in Beijing (He et al., 2002)



As a result of the rapid growth in the vehicle population, absolute emissions, the vehicular emission contribution rate (vehicle emission amount (tons)/total emission amounts (tons)), and the concentration contribution rate (concentration of vehicle source (mg/m$^{3)}$/concentration of total air (mg/m^3)) showed a significant increase (see Table 1).

Table 1 Vehicular emissions and their contribution rate in Beijing

Contents		*1995*			*1998*		
		Emission (10^4 t/y)	*Emission Contribution Rate* (%)	*Concentration Contribution Rate* (%)	*Emission* (10^4 t/y)	*Emission Contribution Rate* (%)	*Concentration Contribution Rate* (%)
Vehicular emission sources	CO	107.51	76.8	76.0	129.00	82.7	84.1
	NO_X	9.34	40.2	68.0	11.50	42.9	72.8
Settled sources	CO	32.50			27.00		
	NO_X	14.00			15.30		

Table 1 shows that regardless of the absolute emissions or contribution rate of vehicle exhaust pollutants (CO, NO_x), the concentration contribution rate in 1998 is relatively higher than emission contribution rate. Compared to 1995, the proportion of vehicular pollution increased in 1998.

As the vehicle population in Beijing is expected to continue to increase at a high rate, there is an urgent need to identify existing problems and adopt strategies for controlling vehicular pollution. The remainder of this paper discusses strategies under consideration in Beijing, followed by some general concluding remarks.

2 Strict management of fuel types for automobiles

The US Automobile Manufacturers Association (AAMA), Association des Constructeurs Européens d'Automobiles (ACEA), and the Japan Automobile Manufacturers Association (JAMA) proposed the 'Worldwide Fuel Charter' that was declared in January, 1999. In this documentation, gasoline and diesel are divided into four categories: the first category comprises fuels for markets with minimal requirements for emission control; fuels are considered primarily in terms of fundamental vehicle/engine performance concerns, not emissions. The second category comprises fuels for markets with stringent requirements for emission control and other market demands – for instance, countries and regions that have carried out Euro I or Euro II regulations. The third category comprises fuels for markets with advanced requirements for emission control and other market demands – for example, countries and regions that have carried out Euro III or Euro IV regulations. The fourth category comprises fuels for markets with *further* advanced requirements for emission control and that enable sophisticated NO_x technologies. Since Beijing adopted the Euro I period regulations on January 1, 1999, its fuel falls into the second category. With respect to further unleaded gasoline requirements and the current situation in Beijing (see Table 2).

In Beijing, it is difficult for the fuel quality to meet newer standards even in China: the sulphur content of gasoline and diesel is relatively high; the olefine hydrocarbon content of gasoline is relatively high; the unleaded gasoline is not really lead-free; and finally, the engine oil contains phosphorus and sulphur.

To address the problems relating to automobile fuel, the Beijing government issued regulations and adopted policies for meeting national standards for unleaded gasoline. First, the six-month process for phasing out leaded gasoline began in June 1997 and finished in early 1998. Secondly, the production, distribution and utilisation of automobile fuels were standardised; brands were established, trademarks registered and the units of production displayed. Thirdly, the quality of inspection of automobile fuel was strengthened.

Table 2 Additional requirements for unleaded gasoline and the current situation in Beijing

Items	*Requirements*	*Beijing Requirements or Fact*	*Note*
Octane rating	Nos. 91, 95 and 98	Nos.90, 93 and 95	No. 90, the most in the market
Sulphur	<0.02%	0.15%	Mass percentage
Lead	0.005 g/l	0.013 g/l	–
Phosphorus	No detection	No rule	–
Manganese	No detection	No rule	–
Silicon	No detection	No rule	–
Oxygen	<2.7%	No rule	Mass percentage
Olefine hydrocarbon	<20%	No rule (30–40%)	Volume percentage
Aromatic hydrocarbon	<40%	No rule (20–25%)	Volume percentage
Benzene	<2.5%	No rule (3–4%)	Volume percentage
Volatility	Taken as vapour pressure and distillation	–	–
Other requirements	Sediment <1 mg/l; Colloid <70 mg/l	Colloid with the same requirements; for others, no rule	–

The fuel components have a direct influence on vehicular emissions. Changing the content of some components of gasoline (diesel) results in a change in vehicular emissions. When stricter vehicular emission standards are adopted, fuel then becomes a key factor in the implementation of a comprehensive clean automobile action as long as vehicle emission control technologies remain unchanged.

In general, conforming to newer emission regulations requires both vehicular emission control technologies and corresponding fuel. The petroleum products in China do not meet the new regulation requirements in many aspects; thus, we must consider improving the process of Chinese industry when we establish the implementation timetable of new emission regulations (Renyi, 1999).

3 Regulating emissions of new vehicles

In Beijing, five steps were taken to regulate the emission of new vehicles: the establishment of emission standards for new vehicles, the approval of new production vehicles emission, market entrance permission, random testing of new vehicles and the restriction of vehicles being registered in Beijing if they were not originally sold in Beijing.

3.1 Implementation of vehicle and motorcycle emission standards

Since 1994, Beijing has issued eleven local vehicular emission regulations. They cover light-duty vehicles, heavy-duty engines, motorcycles and agri-transportation vehicles. Eight of these 11 regulations are related to emissions from new vehicles. On August 25, 1998, the Beijing Environmental Protection Bureau issued '*Emission Standards for Exhaust Pollutants from Light-Duty Vehicles*' (DB11/105-1998) (equal to EURO I), which was put into effect January 1, 1999. One year later, on July 9, 1999, SEPA issued standards restricting pollutants from exhaust of light vehicles (GWPB1-1999) (equal to EURO I), which took effect from January 1, 2000. It stipulates type approval of light vehicle emission pollutants and emission standards value of production conformity inspection tests and durability requirements for exhaust control devices. Because Beijing is subject to greater pressure for regulating vehicular emissions, it tries to enforce stricter vehicular emission standards and stay a step ahead of other places in China. Beijing will implement EURO II standards on Jan. 1, 2003, and plans to carry out EURO III vehicle emission standards on Jan. 1, 2005 and EURO IV in the near future.

Tables 3 and 4 show pollutants type approval test exhaust standard values for vehicle types I and II, and Table 5 shows EURO III and EURO IV vehicle emission standards implemented in Europe.

Table 3 Type approval test standards of vehicle type I (g/km) (SEPA, 2000)

Experimental Phase	*Pollutants*		*Exhaust Standards*
First phase: (Jan. 1, 2000–June 30, 2004)	CO		2.72
	$HC + NO_x$[a]		0.97 (direct-injection diesel engine1.36)
	PM[a,b]		0.14 (direct-injection diesel engine 0.20)
Second phase: (start from July 1, 2004)	CO	Ignition engine	2.20
		Compression-ignition engine	1.00
	$HC + NO_x$[c]	Ignition engine	0.50
		Compression-ignition engine	0.70 (direct-injection diesel engine 0.90)
	PM[c]	Compression-ignition engine	0.08 (direct-injection diesel engine 0.10)

[a]The exhaust limit valid time of vehicles using direct-injection diesel engine for driving force listed in the table is two years.

[b]Only applicable for vehicles using compression-ignition engine for driving force.

[c]The exhaust limit valid time of vehicles using direct-injection diesel engine for driving force listed in the table is four years.

On August 23, 2000, Beijing issued standards regulating motorcycle exhaust pollution (DB 11/120-2000) that is equivalent to EU 97/24/EC and became effective FROM January 1, 2001 (see Table 6). Other areas in China implement much looser standards, such as GB14621-93.

Table 4 Type approval test standards of vehicle type II (g/km)

Referential Weight (RM), kg		*RM ≤ 1250*	*1250 < RM ≤ 1700*	*RM > 1700*
First phase (Jan. 1, 2001–30 June, 2005)				
CO		2.72	5.17	6.90
$HC+NO_x$ [a]		0.97(1.36)	1.40(1.96)	1.70 (2.38)
PM[a,b]		0.14(0.20)	0.19(0.27)	0.25 (0.35)
Second phase (starts from July 1, 2005)				
CO	Ignition engine	2.20	4.00	5.00
	Compression-ignition engine	1.00	1.25	1.50
$HC+NO_x$ [c]	Ignition engine	0.50	0.60	0.70
	Compression-ignition engine	0.70(0.90)	1.00(1.30)	1.20(1.60)
PM[c]	Compression-ignition engine	0.08(0.10)	0.12(0.14)	0.17(0.20)

[a]The exhaust limit valid time of vehicles using direct-injection diesel engine for driving force listed in the table is one year.

[b]Only applicable for vehicles using compression-ignition engine for driving force.

[c]The exhaust limit valid time of vehicles using direct-injection diesel engine for driving force listed in the table is three years. Values in brackets are standards for direct-injection diesel engine.

Table 5 Europe Latest Emission Standards(for type I, <6 persons/seat, GVW ≤ 2500 kg)

Regulation No.	*Fuel*	*CO* g/km	*HC* g/km	*NO_x* g/km	*$HC+NO_x$* g/km	*PM* g/km	*Implementation Date*
98/69/EC Euro III	Gasoline	2.30	0.20	0.15	–	–	Type approva2000.1.1
	Diesel	0.64	–	0.50	0.56	0.05	Conformity 2000.1.1
98/69/EC Euro IV	Gasoline	1.0	0.10	0.08	–	–	Type approval 2005.1.1 Conformity 2006.1.1

Table 6 Beijing exhaust pollutants standards for motorcycles (Beijing Exhaust Pollutants Standard for Motorcycle DB 11/120-2000)

Test Conditions	*Pollutants*	*2001.01.01 (2-Stroke)*	*2001.01.01 (4-Stroke)*	*2004.01.01*
Idle speed test	CO (%)	1.5	1.5	
	HC (ppm)	3000	300	
Driving cycle test	CO (g/km)	4.5	4.5	3.5
	$HC + NO_x$ (g/km)	3.0	3.0	2.0

3.2 Market entrance permission, random testing of new vehicles and restriction of re-registering vehicles in Beijing

Beijing implemented EURO I on January 1, 1999, and vehicles (less than 3.5 ton) that cannot meet the standard may not be sold or registered in Beijing. This means that manufacturers who want to sell vehicles in Beijing sell those which conform to the standards, and can be certified as such, or they will lose the Beijing market. New vehicles, in addition to being required to receive type approval, are also subject to random testing designed to carry out the conformity inspection. Because other cities lag behind Beijing in terms of vehicle emissions standards, cars originally registered outside Beijing must meet Beijing's emissions standards before they can be re-registered (for example, as a result of change in ownership) in Beijing. Green environmental marks are granted to those new vehicles complying with the new emission standards, which were implemented on January 1, 1999, and to vehicles already in use that comply with the new emission standards after renovation. Vehicles with the green environmental marks can enjoy exemption from road tests and random testing, and would not be restricted on roads when there is an air pollution alarm.

4 Emission control for vehicles in use

4.1 Methods for testing vehicle emissions

The methods for testing vehicle emissions depend on the type of emission regulations the particular vehicle is subject to. The stricter the requirement for vehicle emission regulation, the closer the test methods' driving cycle must be, comparable to a real driving cycle. In Beijing, the dual idle speed method is the current vehicle testing method, and the simplified driving cycle method will be brought into use from 2003.

4.1.1 The dual idle speed method (Beijing Environmental Protection Bureau, 1994)

Testing of vehicles already in use distinguishes between vehicles using gasoline and those using diesel. In China, idle speed testing (GB/T 3845-93) is basically adopted by most vehicle testing stations, but dual idle speed testing (DB11/044-1999) is adopted by all vehicle testing stations in Beijing, i.e., the testing will check vehicle emissions at two speeds: idle speed and high idle speed (2000 r/min). Though idle speed and dual idle speed testing methods cannot really reflect the vehicle's real running condition, the two testing methods are widely used because they can be easily set up, are fast and have low costs. Table 7 below shows the degree to which the various inspection tests are able to measure emissions from various types of vehicles.

In Table7, it is assumed that the dual-idle speed method can capture the total real emission conditions from each vehicle type; the other two methods cannot cover. Thus compared to dual idle speeds, using a single idle speed to check the vehicles cannot guarantee that the vehicle meets emissions standards, which also means that these vehicles cannot be controlled effectively in the following period. To ensure that vehicles meet Beijing's current standards, then, it is reasonable and necessary to adopt the dual idle speeds testing method for checking vehicle exhaust pollutants.

Table 7 Percentage of vehicle emissions captured by different emissions tests (Xuechun, 1999)

	Dual Idle Speed (%)	*High Idle Speed* (%)	*Idle Speed* (%)
All vehicles	100	76	83
Passenger car	100	88	75
Light duty vehicles I	100	60	92
Light duty vehicles II	100	75	86
Jeep	100	77	85
Heavy duty vehicles	100	76	71

4.1.2 The simplified driving cycle method (Xiaoyu et al., 2001)

The simplified driving cycle method is the simplification of the driving cycle method, which is a test that uses a dynamometer to test how the vehicle operates on a predefined driving cycle curve, thus simulating the vehicle's road performance. This method can simulate the vehicle's acceleration, deceleration and cruising by loading or unloading the vehicles. The driving cycle test can check the working condition of each part of the vehicle and can supervise and control the exhaust emission condition by adding emissions detecting equipment.

The precision of the simplified driving cycle method differs somewhat from the loading and unloading of vehicles in the driving cycle method. Other differences include the following: the mechanical ports are subjected to less strict environmental standards; the driving cycle is derived from the whole driving cycle curve; the running process is relatively simple; it is less time-consuming; and it is adapted to inspecting large-scale vehicles. In Beijing, the driving cycle method depends on 'Beijing Gasoline Vehicles Steady-state Loading and Unloading Pollutants Exhaust Standard DB11/DXX-2000 (recommended)' (Beijing Environmental Protection Bureau, 2000).

Because the driving cycle method can accurately simulate the vehicle's running exhaust condition on the road, it is better equipped than the idle speed testing method to detect whether or not vehicles meet environmental standards. If the driving cycle testing method is assumed to be exact, then we can calculate the commission rate (the percentage of vehicles measured not to meet emissions standards) and omission rate (the percentage of emissions not captured by the test) of idle speed method relative to driving cycle method. The results are illustrated in Table 8.

In Table 8, the assumption is that the driving cycle test method is 100% correct. Relative to driving cycle test method, the sum of the commission rate and the omission rate of idle test is quite high, its average value ranging from 40% to 50%. Thus the driving cycle for testing exhaust emissions has some clear advantages over the idle speed method. So, we proposed that the driving cycle method should be used as much as possible in developed areas in China, especially in Beijing.

Table 8 The accuracy of the idle speed test compared to the driving cycle method (Xiaoyu, 2001)

Vehicle Test Categories	*Carburettor Vehicles*	*Renovated Carburettor Vehicles*	*EPI Vehicles*
Number of vehicles tested	66	39	50
Number of vehicles that did not meet emissions standards according to the idle test	28	17	14
Number of vehicles that did not meet emissions standards according to the driving cycle test	33	13	21
Number of vehicles that failed both the idle test and driving cycle test	12	8	6
Commission rate%	24%	23%	16%
Omission rate%	32%	13%	30%
The sum of commission rate and omission rate of idle test%	56%	36%	46%

4.2 Vehicle inspection/maintenance (I/M) and results in Beijing

Implementing inspection and maintenance (I/M) system is the main measure for controlling vehicle emissions and its results will reflect the vehicles' control level.

4.2.1 The inspection of vehicles

The inspection of vehicles includes annual inspection, roadside inspection, random tests in parking lots and vehicle inspections for cars entering Beijing. Annual inspection and roadside inspection are the main parts of inspection.

The idle test CO curves of accumulative percentages on passenger cars in Beijing are shown in Figure 2. Figure 2a shows the annual inspection data (source from Beifang Automobile Inspection Field) and Figure 2b shows roadside inspection data (source from Beijing Research Academe of Environmental Sciences).

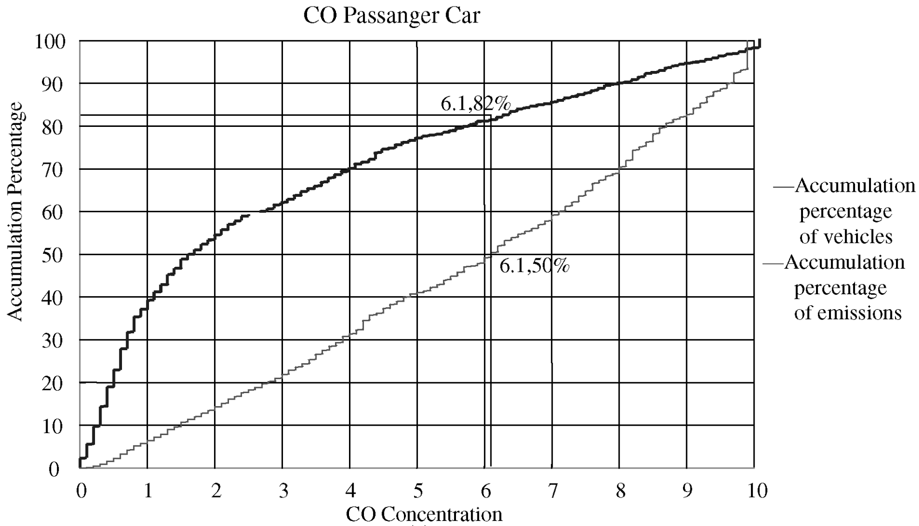
4.2.2 Vehicle maintenance

Vehicles that do not meet current standards must be upgraded before they may be driven on the road. These vehicles may be repaired in the maintenance stations set up by automobile manufacturers and maintenance enterprises administered by the department of maintenance management. In other words, those manufacturers who sell automobiles in Beijing have to build their maintenance stations to carry out maintenance services. Furthermore, all maintenance enterprises that are responsible for auto emission treatment must be equipped with a tailpipe exhaust analyser for checking tail gas free of charge.

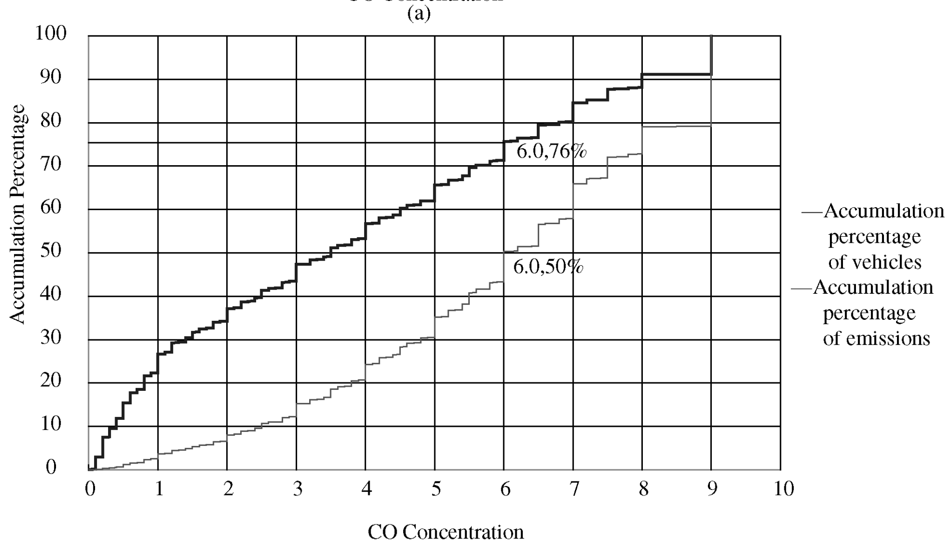
4.3 Upgrading in-use vehicles

In order to further reduce serious vehicle emission pollution in Beijing, great efforts were made to upgrade in-use vehicles. The emphasis involves the renovation of traditional gasoline and diesel vehicles and the development of gas-fuelled vehicles.

Figure 2 Idle test CO curve of accumulative percentages for passenger car from (a) annual inspection data, and (b) roadside inspection data



(a)



(b)

4.3.1 Renovation of traditional gasoline and diesel vehicles

4.3.1.1 Electric control air replenishing plus TWC

In 1999, Beijing implemented technical renovation of closed-loop, electronic fuel injection or electric control air replenishing plus three-way converter (TWC) for light vehicles registered after 1995. The statistics of vehicles with implemented status show that by the end of 1999 nearly 120,000 vehicles more closely. It is estimated that the total number of vehicles for renovation is 150,000.

Using data from 31,718 vehicles obtained in December 1999, a further analysis of the dual idle speed exhaust test result of renovated vehicles gave the following tentative conclusions:

The emission results of the idle speed test before and after renovation show a clear improvement. Comparing the idle speed exhaust of an in-use vehicle before and after renovation shows a decrease rate of exhaust density at low idle speed of CO: 97.8%; HC: 89.1%; at high idle speed: CO: 97.1%; HC: 89.5%.

- The decrease in single vehicle exhaust before and after renovation is clear. The driving cycle test results of some of the vehicles before and after renovation show that the single vehicle emission factor decrease rate of vehicle in use is CO: 78%–90%; HC+NO_x: 71%–88%.

4.3.1.2 Fuel economy

Since renovated vehicles require the engine-working point to approximate the theoretical air–fuel ratio, the fuel consumption of renovated vehicles is usually increased and thus the fuel economy decreases. According to the results of a multiple driving cycle tests, the fuel consumption of Red Flag and Citroen increased by 7.8% and 5.1%, respectively, and that of Santana decreased slightly (–4%). After renovation, the dynamic feature change of the above vehicle models is normal, so that the renovation does not greatly affect the application performance under normal application conditions.

As a tentative estimation and taking the deterioration factors under consideration, the decrease effect of this renovation technology is sampled as: CO, HC-80%; NO_x-70%; the service life is two years or 50,000 km. Given this data, renovation of 150,000 vehicles can reduce annual emissions of pollutants by the following amounts:

CO: 120,000 tons/year; HC: 18,000 tons/year; NO_x: 6400 tons/year

It can be seen that after renovation of these vehicles, pollutant exhaust can be decreased to some extent. Compared with the total exhaust pollutants amount of the vehicles of the whole city, the decrease rate is 5–8%. Since the renovation vehicles are mostly saloon cars (sedans), their NO_x exhaust factor is small so that the decrease proportion of NO_x is less than CO and HC. Given the vehicle pollution-sharing rate in Beijing and the fact that saloon cars occupy a larger proportion of the vehicles running in the urban area, it can be calculated roughly that the air quality improvement rate of NO_x is around 7%, and the air quality improvement rate of CO is around 8–9%. On the two sides of the communication lines and during non-heating seasons, the improvement rate for air quality is higher.

4.3.1.3 Vacuum time delay valve

Another renovation measure in Beijing with large coverage range is to install a vacuum timing valve in in-use vehicles manufactured before 1995. As a tentative estimation, assuming the decrease rate of this measure for NO_x is about 10%, and around 400,000 vehicles are to be renovated (in 1995, total 960,000 vehicles). The result can be analysed as below:

NO_x decrease amount: 4,000 tons/year, NO_x emission reducing 5%; NOx air quality improvement rate 5%.

The above calculation and analysis are based on the precondition that each technical measure works normally with a completed quality guarantee system. Vehicles with a vacuum timing valve should be inspected and maintained regularly in order to discover malfunctions in the engine and its exhaust control device so as to keep proper exhaust decrease effect.

4.3.2 Development of natural gas-fuelled vehicles in Beijing

With the impending strict environmental regulations and continuous improvement in technologies, gas-fuelled vehicles have developed to the third generation technology.

4.3.2.1 First generation gas-fuelled vehicles

The first generation vehicles use a mechanical mixing chamber that has the same disadvantages as the traditional carburettor automobiles: the distribution of strokes is not uniform, and the regulatory precision not accurate. The first generation is the primary stage of developing vehicles, and has improved results for vehicle exhaust pollution compared to gasoline vehicles, but the power loss is greater. And the first generation vehicles do not meet the Euro I standard yet. The detailed pollutant reduction results for first generation vehicles are shown in Table 9.

Table 9 Development of natural gas-fuelled vehicles: three generations (National Gas-fuelled Vehicles Important Documents and the Related Standards Compilation, 2000a)

Items	*Vehicle Categories*	*CO Reduction (%)*	*HC Reduction (%)*	*NO_X Reduction (%)*	*Power Loss (%)*
First generation	LPG vehicles	50–60	40–50	0–10	2–5
	CNG vehicles	60–70	50–60	20–30	15–20
Second generation	LPG vehicles	75–85	75–85	70–80	1–4
	CNG vehicles	80–90	80–90	75–85	5–15
Third generation	LPG vehicles	85–95	85–95	80–90	0
	CNG vehicles	90–99	90–99	85–95	0

4.3.2.2 Second generation gas-fuelled vehicles

The characteristics of second generation gas-fuelled vehicles are that they use an electronic control-mixing chamber, their controlling precision is higher than first generation vehicles and they are equipped with closed loop control and TWC equipment. Of these second generation vehicles, some are dual-fuelled alteration vehicles and the others are dedicated vehicles. The capability of the second generation gas-fuelled vehicles is improved further, and their power capacity is improved slightly. The second generation vehicles can meet the Euro II standards. The detail pollutants reduction results for second generation vehicles are illustrated in Table 8.

4.3.2.3 Third generation gas-fuelled vehicles

The characteristics of third generation gas-fuelled vehicles are that they adopt electronic injection (EPI), matching closed loop control and dedicated TWC equipment, almost all are dedicated gas-fuelled vehicles, and new vehicles occupy a rather high percentage. This kind of vehicle can meet Euro III, Euro IV and super low-emission vehicle standards of California. Their power capability is close to that of gasoline and diesel vehicles. The detailed pollutant reduction results for third generation vehicles are illustrated in Table 8.

Overall, the first and second generation vehicles are transitional, especially the first generation technology, in the sense that these common carburettor gasoline vehicles are directly altered to dual-fuelled vehicles in a makeshift manner. Overseas manufacturers at large currently adopt the third generation technology, and dedicated gas-fuelled vehicles are being developed.

4.3.2.4 Pushing gas-fuelled vehicles based on Beijing's local conditions

At present, the gas-fuelled vehicles are most commonly altered type of in-use vehicle, and the technology level lies in the first period.

Vehicles that use CNG or LPG by the reasonable system matching not only emit less HC and CO than the same level technology gasoline vehicles that are not equipped with an exhaust cleaning system, but the fuel expense is also slightly lower (depending on local natural gas prices). Accordingly, different areas in China can create incentives to upgrade alternative fuel vehicles. Because carburettor vehicles are the most common type of vehicle throughout China, and the new regulations only aim at new vehicles, this means that even though the first generation gas-fuelled cannot meet Euro I standards, we have to push to adopt dual-fuel vehicles system in order to reduce the in-use carburettor vehicle emissions.

Compared to gasoline and diesel vehicles, gas-fuelled vehicles have excellent emission performance. Based on the consideration of environmental protection and optimising the energy configuration, CNG and LPG are regarded as the most alternative fuels in the twenty first century. Table 10 shows that the estimation of NO_x reduction for renovating gasoline vehicles to LPG, CNG vehicles in Beijing.

Table 10 The estimation of NO_x reduction for renovating gasoline vehicles to LPG and CNG vehicles in Beijing (National Gas-fuelled Vehicles Important Documents and the Related Standards Compilation, 2000b)

Items		*Public Buses*	*Taxi*	*Mini Buses*	*Environmental Sanitation Vehicles*	*Postal Use Vehicles*	*SpecialtyFreight Vehicles*	*Official Vehicles*	*Total*
Year 2000									
LPG	Vehicle numbers	1700	20000	2000	200	500		5000	29400
	Reduction (t/y)	173.4	450	125.0	32.9	16.0		12.5	805.7
CNG	Vehicle numbers	2300			300	1000	2000	10000	15600
	Reduction (t/y)	1171.3			246.4	160.0	267.5	125.0	1970.2
Total reduction (t/y)		1344.7	450	125.0	279.3	176.0	267.5	137.5	2780.0
Concentration lessen ($\mu g/m^3$)									1.7

Table 10 The estimation of NO_x reduction for renovating gasoline vehicles to LPG and CNG vehicles in Beijing (National Gas-fuelled Vehicles Important Documents and the Related Standards Compilation, 2000b) (continued)

Items		*Public Buses*	*Taxi*	*Mini Buses*	*Environmental Sanitation Vehicles*	*Postal Use Vehicles*	*SpecialtyFreight Vehicles*	*Official Vehicles*	*Total*
Year 2002									
LPG	Vehicle numbers	1900	60000	4000	400	1000		5000	72300
	Reduction (t/y)	478.7	13830.8	2000.0	525.7	256.0		12.5	17103.7
CNG	Vehicle numbers	3500	5000		1000	1500	10000	25000	46000
	Reduction (t/y)	3126.9	1784.6		2086.4	416.0	3691.5	725.0	11830.4
Total reduction (t/y)		3605.8	15619.2	2000.0	2612.1	672.0	3691.5	737.5	28938.2
Concentration lessen ($\mu g/m^3$)									17.9

4.4 Enforcement of regulations governing scrapping of vehicles

With the increasing of driving distance, vehicle emission performance deteriorates linearly, having an increasingly detrimental impact on air quality. At present, heavily polluting in-use vehicles already out of their service life account for 20% of the vehicle fleet while emitting 50% of the total vehicle emitted CO and HC. Therefore, enforced scrapping must be conducted over those heavily polluting vehicles already exceeding their driving distance limit or service life. By 2002, the scrapping of the existing 60,000 in-use vehicles manufactured before 1992 will be completed. In addition, incentives to encourage replacement of vehicles still in their service life can be considered to improve the overall quality and technical level of the vehicle fleet.

Elimination of old vehicles from Beijing includes three aspects: transferring the vehicles to areas outside Beijing, stopping the vehicles from driving and scrapping. Figure 3 shows the volume of old vehicles scrapped from 1998 to 2001.

From Figure 3, we can see that the volume of old vehicles scrapped decreases gradually from 1998 to 2001.

Therefore, with stricter emission control of both new and in-use vehicles, the NO_x concentration began to decrease in 1999 and became stable from 2000, though the vehicle population in Beijing is growing significantly. The situation is illustrated in Figure 4.

Figure 3 The volume of old vehicles scrapped from 1998 to 2001

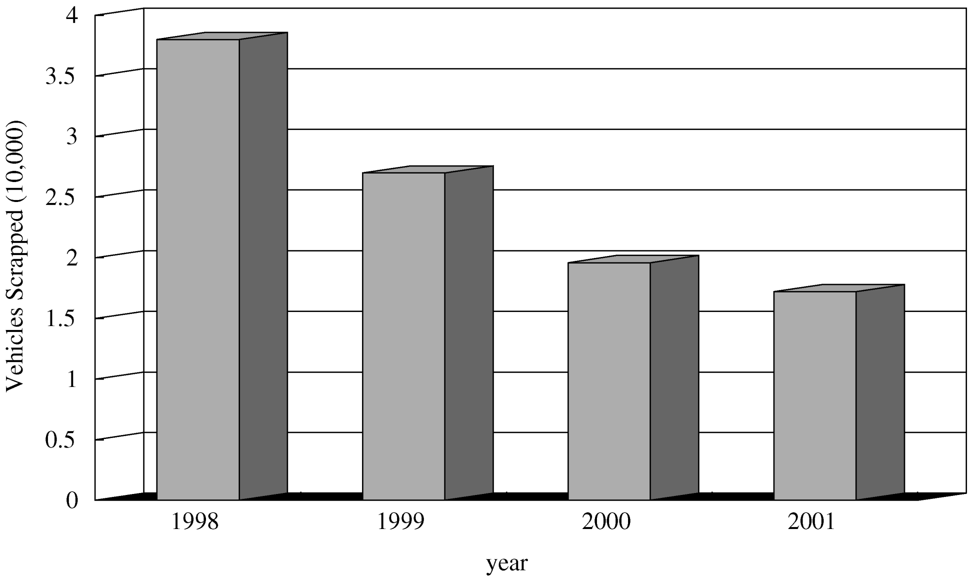
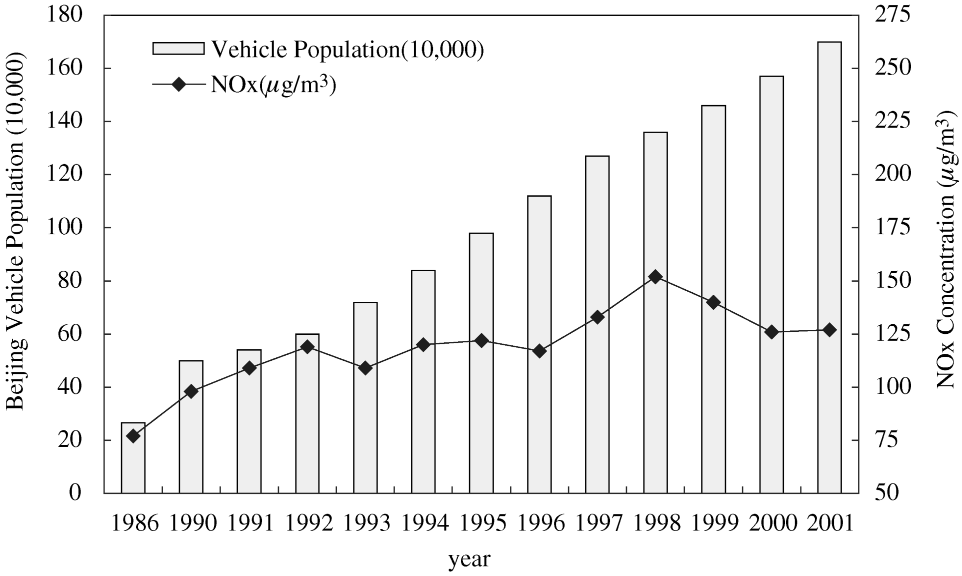


Figure 4 NO_x in Beijing ambient atmosphere



5 Road infrastructure and traffic policy

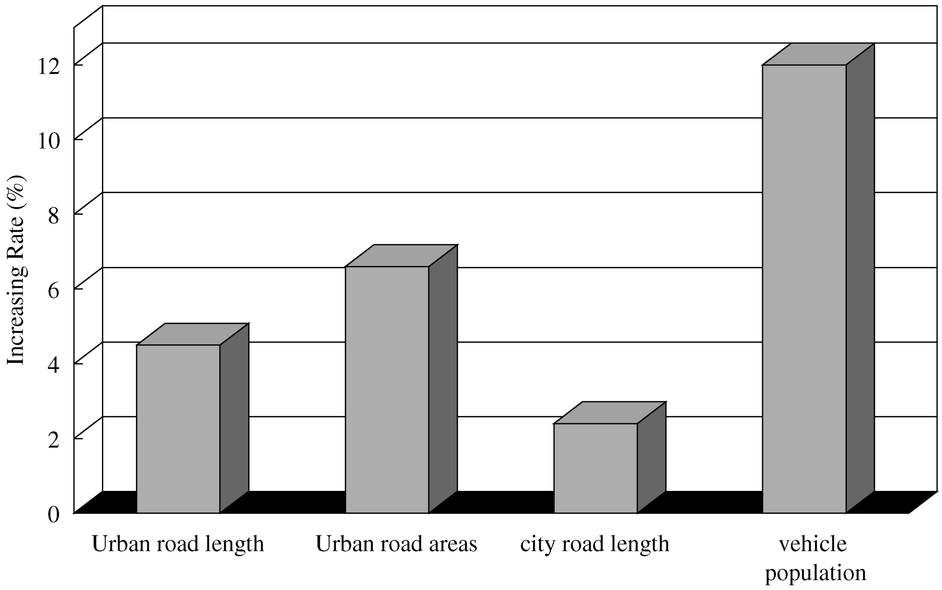
Since the mid 1980s, an increasing vehicle fleet in the urban area has meant that traffic congestion is becoming more and more serious. With the continuous increase in vehicle flow density on the traffic roads in the urban area, pollutants emitted by vehicle are increasing greatly, especially NO_x and CO. This implies that we must pay great concern to traffic and environmental issues in Beijing and find a way to solve the existing problems.

5.1 Traffic and environmental issues in Beijing

Traffic and environmental issues in Beijing lie in the following aspects:

First, traffic congestion is caused by deficient road infrastructure, particularly broken road capacity balance and structure balance as well as defects in land utilisation structure. The increasing inability of the road network to meet traffic demands, the high percentage of broken roads along the length of trunk roads, secondary trunk roads and branch roads, and the spatial distribution defects of the road network results in serious traffic issues, which is reflected in the continual increases in vehicle flow density on urban trunk roads and in vehicle flow at intersections. From 1994 to 1997, the per kilometre lane vehicle load rose from 700 to 918; during peak hours, the number of high flow intersections (vehicle flow exceeding 10,000 per hour) increased from 29 to 45. Figure 5 shows the comparison of the road situation to vehicle increase during the 'Ninth five-year' period in Beijing. Currently, the situation in Beijing is even more serious.

Figure 5 Comparison of the road situation due to vehicle increase during the 'Ninth five-year' period in Beijing



Secondly, radial traffic with the urban area as the centre occupies a dominant position in Beijing's traffic structure, which aggravates the intensive traffic situation. Currently, the traffic load entering and leaving the urban area accounts for 27.8% of the total traffic population in the city. Vehicle flow generation and attracting intensity in the urban area is 5.1 times that in the suburb, which turns the urban area into high traffic density. The more important reason is the urban area is over-populated and over-constructed despite deregulation in land utilisation structure adjustment.

Thirdly, even though investment in traffic facilities has been increased in recent years, the overall average driving speed is decreasing, especially the performance of public buses and trolley buses. During peak hours, bus speed on some bus lanes is even close to walking speed. Bus punctuality has decreased from 70% in 1990 to 8.4% in 1996. Traffic congestion has resulted in reduction of over 1,000 bus tours per day. In 1997, special bus lanes were developed on some traffic trunk lines, leading to an increase in bus speed and certain improvements in public passenger transport.

Finally, the concentration of air pollutants in the traffic environment shows a gradient distribution from the urban area to the outer area. Annual average CO and NO_x concentrations in the atmosphere within the Second Ring Road are 15% and 24% higher than those between the Second Ring Road and the Third Ring Road. The direct cause of this phenomenon is the high vehicle flow density on the urban road and serious traffic congestion, which means that vehicles operate at idle speed for longer periods, they move at slow speeds, they accelerate and decelerate quickly, etc. Furthermore, at these driving modes, they will emit more NO_x, HC and CO than under stable operation. Therefore, its clear that vehicle emission is not only affected by the number, quality and technical level of vehicle fleet, but also closely related with urban transportation conditions.

5.2 Improvement in road infrastructure and traffic policy

Moderate total transport population and a relatively balanced distribution of traffic flow will be realised through rationalising land utilisation structure and land development intensity. Uncontrolled development and intensified concentration of high volume building as well as land development progress in the urban area will be brought into strict control. Traffic impact assessment is required for developing all types of new large-sized public buildings to prevent increasing over-intensified traffic sources. This is an important approach to keep moderate traffic environment and prevent traffic congestion from the source.

Based on the population, resource and productivity development level, a bus rapid transit (BRT) system should play a dominant role in urban transport system of metropolitan Beijing. The long-term target is to establish an aboveground and underground rail system. In the short term, the focus is put on development of public buses and trolley buses to serve the passengers and tackle traffic pollution. Rapid rail transportation has been proved to be the best solution for urban transport. In developed countries, rapid rail systems carry 50%–80% of the transport volume. However, in Beijing rail systems carried only 11% of the total public passenger transport volume in 1999. Although we have invested heavily in rail transportation in recent years, Beijing still falls behind the developed countries. As an advanced rail transport system is costly and requires a long construction period, it cannot be taken as an immediate solution. Moreover, as a traffic trunk system in the urban transport system, a rapid rail system also requires ground trunk and branch public bus and trolley bus routes as support. Therefore, development of public buses can serve both the immediate and the long-term demands. Beijing's situation of development of public buses and trolley buses in 1998, 2000 and 2001 is illustrated in Table 11.

Table 11 The development of public buses and trolley buses in Beijing

Year	*Vehicle Number*	*Running Lines (Route)*	*Route Length* (km)	*Special Lane for Buses* (km)	*Passenger Carrying Capacity per Year* (100 million)	*Average Passenger Capacity per day* ($10^{4)}$/d)
1998	5400	320	6170	10	32	877
2000	9970	420	9276	33	38	1041
2001	11,580	461	11,072	147.2	38.8	1062

Efforts are being made to raise the driving speed of vehicles so as to reduce the vehicle emission factor (the emission amount for vehicles driving one kilometre g/km). In 1999, the main policy was to build a rapid road system, i.e. the function division of the existing road network and lane traffic load are under adjustment, there are plans to set up the two roads and ten connecting trunk roads as the framework, and 22 secondary trunk roads and branch roads were under renovation to eliminate the interference between local traffic and passing traffic on the urban road network and allow roads having different functions in the urban area to play their respective roles. Even now, the fifth and sixth ring roads, urban track system and some trunk and secondary trunk roads are under construction. When the three-dimensional transportation system is basically finished, the second and third ring during peak hours are expected to reach 45 km/h and 50 km/h, respectively, and driving speed on the main connecting trunk roads is expected to reach 30 km/h.

Steps are being taken to not only construct an improved urban transportation system, but also to manage the transportation system. Management should depend on science and use road source fully, i.e. to develop intelligent transportation system. The hands of policemen should not control the traffic lights, which depend on traffic flow and temporal distribution; thus, the traffic lights should be automatic. Moreover, a tax on traffic pollution is under consideration. On the one hand, levying pollution charges can encourage emissions control for in-use vehicles and speed up scrapping of old vehicles; on the other, it can collect funds for controlling traffic pollution.

6 Conclusions

Along with the improvement in vehicle technical levels, especially emissions control technology, stricter requirement are being considered for fuel quality. The quality of existing fuel already falls behind the requirement of vehicles with a high technical level, and has become one of the factors affecting emissions. The petroleum products in China do not meet the new regulation requirements in many aspects; thus, we must consider improving the process of Chinese industry when we establish the implementation timetable of new emission regulations.

Stricter vehicle emission standards have been issued and are being implemented in steps. This is an effective measure for reducing emissions from new sources. Green environmental marks are granted to those new vehicles complying with the new emission standards, which were implemented on January 1, 1999, and the in-use vehicles complying with the new emission standards after renovation. Vehicles with the green environmental marks can enjoy exemption from road tests and random testing, and would not be restricted on the road when there is an air pollution alarm.

The enforcement of in-use vehicle emissions control is carried out in six ways.

- With the driving cycle test method, the sum of fault-inspection rate and missing-inspection rate of idle test is quite high, its average value ranging from 40% to 50%. The driving cycle for testing exhaust emission has some advantages over the idle method. We thus proposed that the driving cycle method should be used as much as possible for the developed areas in China, especially in Beijing.
- A car that is not in compliance with environmental standards in an annual inspection will not be permitted to be driven on the road; and cars that are not found to be compliant in roadside inspections, will have their plates temporarily confiscated by the traffic administration department.
- All vehicles failing to meet the emission standards in various tests are required to conduct treatment by installing matching emission purification facility, and will be allowed to be on the road only after complying with the emission standards.
- The renovation of traditional gasoline and diesel vehicles: electric control air replenishing plus TWC and vacuum time delay valve.
- Compared to gasoline and diesel vehicles, gas-fuelled vehicles have excellent emission performance. Based the consideration of environmental protection and optimising the energy configuration, CNG and LPG are regarded as the most promising alternative fuels in the twentyfirst century.
- Enforcement of vehicle scrapping regulations will be undertaken. Forced scrapping must be enforced for those heavy polluting vehicles already exceeding their driving distance limit or service life.

With respect to the construction and management of the transportation system, efforts will be focused on regulating urban transport demands, adjusting urban road networks and transport structures, improving transport operation conditions, formulating and enforcing gradually stricter regulation and standards. The necessary technical and economic approaches will be adopted to control vehicle emissions. The overall objective is to reduce vehicle emission by steps for improvement of atmospheric environment in Beijing while the overall transport population keeps increasing.

Acknowledgements

This paper is based on a joint research project between Research Center for Contemporary Management and Institute of Energy, Environment, and Economy (IEEE), Tsinghua University, China, and the Center for International Climate Change and Environmental Research – Oslo (CICERO), Norway. The authors greatly acknowledge the financial support from World Wide Fund for Nature (WWF), China Programme and the Research Council of Norway.

References

Beijing Environmental Protection Bureau (1994) 'Beijing technology supervision bureau', DB11/044-94, *Vehicles Dual Idle Speeds Pollutants Standard*, Beijing, China.

Beijing Environmental Protection Bureau (2000) *Emission Standard for Exhaust Pollutants from Light-duty Gasoline Vehicle under Short Transient Driving Cycle* (DB11/123-2000).

Beijing Exhaust Pollutants Standard for Motorcycle (2001) DB 11/120-2000, effective on Jan. 1, 2001.

Fu, L., Hao, J., he, D. and He, K. (2001) 'Assessment of vehicular pollution in China', *Journal of the Air & Waste Management Association*, Vol. 51, pp.658–668.

He, K. *et al.* (2002) *Annual Report*, sponsored by Energy Foundation, p.5.

National Gas-fueled Vehicles Important Documents and the Related Standards Compilation (2000a) *Gas-Fueled Vehicles Demonstration Cities Development Layout and Favorable Polices*, Beijing, ROC, pp.29–46.

National Gas-fueled Vehicles Important Documents and the Related Standards Compilation (2000b) *The Estimation of NO_x Reduction for Renovated LPG, CNG and Other Kinds of Vehicles in Beijing*, p.44.

Renyi, Q. (1999) 'The relation between the implementation of China vehicles emission new regulations and oil products', *Auto Technology*, Vol. 17, No. 2, pp.1–4.

SEPA Standard (GWPB1-1999) (2000) *Emission Standard for Exhaust Pollutants from Light-Duty Vehicles*, effective, State Environmental Protection Administration, Beijing.

Xiaoyu, X. (2001) 'Light duty vehicles steady-state driving cycle method testing study', *Master's Thesis*, Tsinghua University.

Xiaoyu, X. *et al.* (2001) 'Light duty vehicles steady-state driving cycle method testing study', *Environmental Pollution and Control*, Vol. 23, No. 6, pp.280–283.

Xuechun, W. (1999) The study on I/M system of in-use vehicles in Beijing', *Master's Thesis*, Tsinghua University.