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Current Air quality problem and control strategies for vehicular emissions in China

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Abstract

China has experienced very rapid economic development in recent yearsUrban air has very high concentrations of various pollutants, including sulphur dioxide (SO_2), oxides of nitrogen (NOx), ozone (O_3) and particulate. This paper reviews the changes in air quality in the cities like Guangzhou over the past 15 years, and notes that a serious vehicular-related emissions problem has been superimposed on the traditional coal-burning problem evident in most Chinese cities. As NOx concentrations have increased, oxidants and photochemical smog now interact with the traditional SO_2 and particulate pollutants, leading to increased health risks and other environmental concerns.

Any responsible NOx control strategy for the city must include vehicle emission control measures. This paper, using Guangzhou as a case, reviews control strategies designed to abate vehicle emissions to fulfill the city's air quality improvement target in 2010. A cost-effectiveness analysis suggests that, while NOx emission control is expensive, vehicular emission standards could achieve a relatively sizable emissions reduction at reasonable cost. To achieve the 2010 air quality target of NOx, advanced implementation of EURO3 standards is recommended, substituting for the EURO2 currently envisioned in the national regulations. Related technical options, including fuel quality improvements and inspection/maintenance (I/M) upgrades (to ASM or IM240), are assessed as well.

Key words: Air quality; Vehicle emission standards; Inspection and maintenance (I/M); Cost-effectiveness; Guangzhou, China

China has been long suffered from serious air pollution characterized by high ambient concentrations of SO_2 and particles. The reason is that more than 75% of primary energy comes from coal combustion. Air pollution in China has long been characterized by high concentrations of SO_2 and particles caused by coal burning , which provides 75% of total primary energy consumption. Ambient concentrations of SO_2 and total suspended particles (TSP) in most big cities, are much higher than national air quality standards (NAAQS) and the guideline of WHO. In 1995, total SO_2 emission in China reached 23,7 million tons, one third of China's territory suffered from serious regional acid deposition. Since 1980, great efforts have been put to abate SO_2 and particles emissions from coal combustion. Ambient SO_2 concentration, especially TSP concentration dropped gradually (World Bank, 1997a)

However, in the process of economic development within last decades, vehicular population increases dramatically. Pollution related with traffic exhaust is getting worse recently in some big cities in China. In 1995 the total amount of vehicles in China were more than 20 million with an average annual increase rate of 15%, most of the vehicular increment are in some mega cities such as Beijing, Shanghai and Guangzhou. Pollutants such as NOx, CO, VOCs and fine particle emits in large amount from vehicles and show great negativeimpact on human health and ecosystem. More important, under favorable condition such as intensive sunlight, low humidity and low wind speed, ambient NOx and VOCs (volatile organic compounds) will react, and oxidants like ozone and H_2O_2 will be produced and accumulated, leading to photochemical smog (Zhang et al, 1998). These secondary pollutants are more harmful and therefore will be great threats to human health and agricultural ecosystems.

Photochemical smog pollution will be of increasing important in next century in China. As ground-level ozone concentrations are already very high in some big cities, it's not surprising to foresee that this problem will rapidly spread all over China together with the future economic development, especially in mid and west of the territory, if no effective control strategies are addresses in this field. As a consequent, ozone pollution will be a regional issue. High level of oxidants in both urban and rural area, causing heavy damage to human health and agricultural yield, are going to be essential important for the sustainable development in China.

1. Air quality and emissions in Guangzhou One of the first Chinese cities opened to outside world, Guangzhou has played an important role in the country’s economic development since the early 1980s. Guangzhou’s own vehicle population has increased dramatically with that growth, at an average annual rate of 16.5%. From 1980 to 1996 the number of motor vehicles in Guangzhou rose from 36,000 to 584,000; and from 1987 to 1996, the number in four suburban counties increased from 56,000 to 323,000. In 1997, there were 610,000 vehicles in the city, more than two-thirds of them motorcycles. Traffic in the city has become extremely congested. One driving cycle study showed that the average driving speed was only 14.1 km/hr, with high frequencies of both idling time and acceleration (Xie, 1998). Because of Chinese vehicular production technology, difficult road conditions, and the city’s driving cycle, emission factors for vehicles in Guangzhou are much higher than those in Europe and the United States.

As a result of these factors and its rapid economic growth, Guangzhou has suffered from serious NOx pollution. Ambient NOx concentrations in Guangzhou are among the highest in China’s cities, and photochemical smog is a severe air quality problem in the city (Zhang et al.1998).

Automatic air quality monitoring was initiated in the urban areas of Guangzhou in 1985. At that time, six monitoring sites were selected, representing industrial; commercial; mixed industrial-residential; heavy-traffic; residential; and background areas. Figure 1 plots the annual average concentration of NOx, SO_2 and CO in Guangzhou since that time. It shows that SO_2 concentrations fluctuated during the late 1980s and early 1990s, with a peak in 1988 and a low concentration (51 g/m^3) in 1993, and it has started to build up again since that time. In the late 1980s, CO concentrations were high, and then decreased slightly over time. Meanwhile the annual average NO_X concentrations increased, from 0.06 mg/m^3 in 1984 to a maximum of 0.152 mg/m^3 in 1996. The earlier concentration was only slightly above the Class I National Ambient Air Quality Standards (NAAQS) for NOx, the most stringent standard designed to protect the natural ecology and human health. Today, it is more than 50% higher than the Class III NAAQS, a less stringent standard that focuses on toxic illnesses from high pollutant levels. Figure 1 also shows considerable variations in the concentrations of this pollutant.

Prior to the 1980s, the main air quality problems in Guangzhou were associated with particulate and SO_2 pollution, and the acid rain caused by coal burning. From the mid-1980s, a series of projects was initiated by the central government to address acid deposition issues in China; the scientific understanding of formation processes of such deposition in South China was a key component in these projects. Control strategies based on these projects were suggested to decision-makers, and control measures were adopted in the Guangzhou area. From the late 1980s, ambient SO_2 concentrations showed significant reductions, although they remain high when compared with WHO guidelines. It is noteworthy that ambient SO_2 concentrations appear to be increasing again, since 1993. The ambient NO_X concentrations have increased significantly, in conjunction with the sharp increase in the vehicle population. Figure 2 plots the ratio of NO_X to SO_2 annual average concentrations, along with the increase in vehicle population. Since 1985, the NOx/SO_2 ambient ratio in Guangzhou has been going upward, from a factor of 2 in the mid-1980s to about 4 in the mid-1990s. The spatial distribution of NOx concentrations revealed that street canyons with condensed traffic had the highest concentrations in the city, and that traffic areas were the most seriously NOx-polluted areas amongst all the monitoring sites.

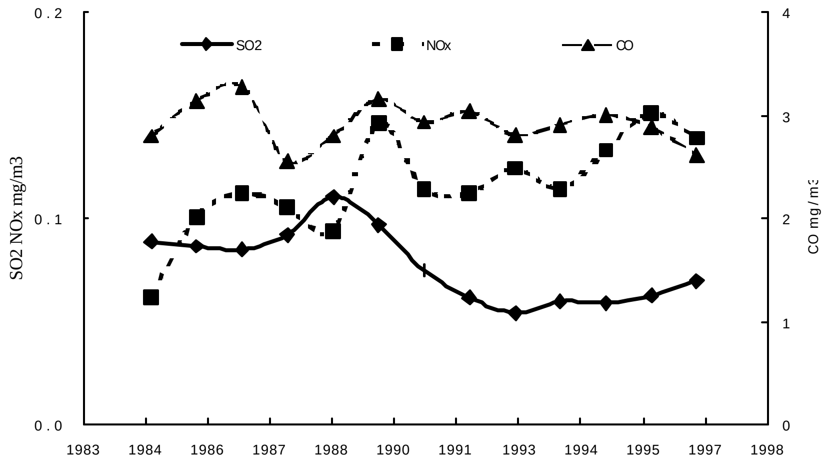

Figure 1. Annual average concentrations of ambient SO_2, NOx and CO in Guangzhou.

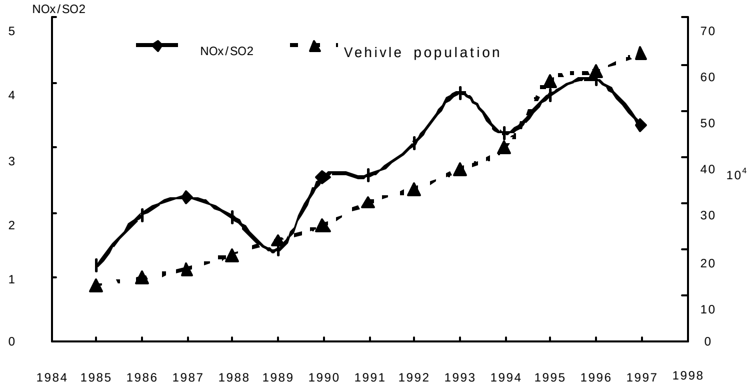

Figure 2. NO_X/SO_2 ambient ratios and vehicle population in Guangzhou.

On an emissions basis, Figure 3 shows that industrial and mobile sources dominated the emissions of air pollutants in the city in 1995. Sulphur dioxide was primarily emitted from industrial sources, while CO was mainly emitted from mobile sources. Though vehicles contributed only 38% of the NOx in the urban area of Guangzhou, these are the sources that will be increasing significantly in the next decades (Zhu, 1999).

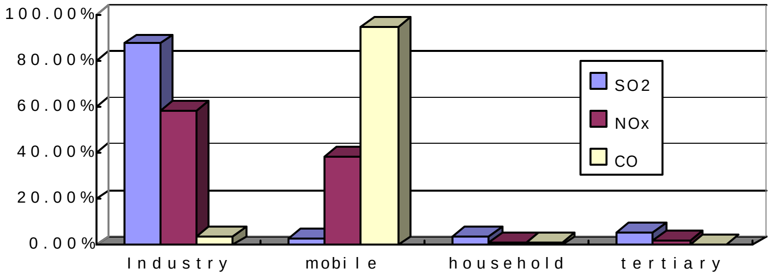

Figure 3. The contribution of different sources to emissions of SO_2, NOx and CO in Guangzhou City

In addition to concerns about NOx, under favourable conditions (such as intensive sunlight, low humidity and low wind speed), ambient NOx and volatile organic compounds (VOCs) will react to form photochemical smog (Zhang et al., 1998). Guangzhou has abundant VOCs in its atmosphere, and as a result of the increasing NOx concentrations, the concentrations of ozone and other oxidants have also increased in recent years. Pollution control strategies for NOx are therefore urgently needed in the city, including those addressing emissions from motor vehicles.

2. Assessment of current vehicle emission control measures

Emission standards have been used in China to regulate emissions from new vehicles. For in-use vehicles, measures such as inspection/maintenance (I/M) programmes, fuel quality control, and the retirement of old vehicles have been employed. Guangzhou has adopted all of these control measures. The current measures have not been adequate to control NOx, however, because of the use of inefficient technology, poor enforcement, or inadequate management practices.

2.1 Vehicle emission standards

Guangzhou does not have its own municipal emission standards for motor vehicles. Instead, a series of national emission standards have been employed for specific vehicles in the city (Gu et al., 1997). These standards can be applied to determine the conformity of new vehicles. Except for exhaust pollutants from diesel vehicles, emission standards now cover most pollutants emitted by vehicles, and the limit values are set according to vehicle category, type, and year that the vehicle was produced. The current limit values in vehicle emission standards are higher than those of USA, Europe and Japan(Asif et al., 1996; Gu et al., 1997). Emission standards and measurement methods for in-use vehicles are needed, however, as are other relevant regulations to support the standards. Similarly, China employs evaporative emission standards that are as strict as those of developed countries (Gu et al., 1997). There are few testing laboratories with the ability to conduct the evaporative tests and/or compliance testing, however, and it thus seems unlikely that evaporative emissions from vehicles in China are currently meeting such standards.

Given the situation in China, the development of vehicular emission standards must be addressed with great care. If the emission standards are not in accordance with the economic and technical capabilities of the manufacturers, the standards will not be met. Further, validation and compliance must be recognized as an important element in their adoption. Most vehicle emission standards in China have been developed directly on the basis of foreign standards. Even though foreign standards have proved to be useful elsewhere, their adoption in China has proven to be problematical, with considerable delays in achieving compliance.

There exists a fundamental contradiction between vehicle emission regulation and the vehicle industry’s development policy in China. The automobile industry is one of the mainstay industries in China, and plays an important role in the national economy. But there has been no set of strict, systematic vehicle emission control regulations and standards set in place to guide the industry’s development. Instead, existing standards have been set at levels that Europe achieved in the 1970s, and these lenient standards cannot act as a driving force for upgrading vehicles. The country’s increased exposure to international trading norms will place pressures on this important domestic industry.

2.2 Current I/M programme

An effective inspection and maintenance (I/M) programme can significantly reduce emissions from vehicles (Pidgeon et al, 1993). I/M programmes help identify vehicles in which maladjustments or other mechanical problems are causing high emissions. They also ensure that the benefits of control technologies are not lost through poor maintenance and tampering with emission controls. Generally, 10-15% of a city’s vehicles cause a disproportionately high percentage of all emissions (Asif et al., 1996). The emission standards for the I/M programme should be set such that the highest-emitting vehicles fail, and must be repaired. There are more than 4000 vehicle maintenance and repair shops in Guangzhou, so the basis for such correction is well established.

Vehicle emission inspections began in 1985, including annual inspections, random on-road inspections, and the re-inspection of vehicles that are repaired after failure in the previous test. The idle test was employed in the current I/M system, and this was conducted as part of a safety check programme. The current I/M programme in Guangzhou includes a test for exhaust emissions of HC and CO; a visual inspection to insure the proper installation of the emission control devices; and a functional check of these devices.

The idle test is useful in cars with little or no emission controls, to identify maladjustments that cause high emissions. It does not work as well for cars that are equipped with electronic fuel injection, because in this type of fuel system, idle emissions are not proportional to emissions under load (Weaver and Chan, 1994). Further, the idle test cannot adequately measure NOx emissions. NOx is produced at high temperature when the engine is working hard, and too little NOx is produced during idle (when there is no load on the engine) for high emitting vehicles to be identified. A dynamometer test simulating the resistance that a car will encounter on the road is therefore needed to identify high NOx-emission vehicles (whether electronic fuel injection or carbureted) (U.S. EPA 1996, 1998).

The current I/M system in Guangzhou helps reduce emissions to some extent. However, this system has been operated by a number of governmental parties who have functions other than environmental protection (i.e., public security, safety checks, etc.), and the role of the local Environmental Protection Bureau (EPB) has never been fully realized.

2.3 Current scrappage and old vehicle retrofit practices

A regulation that accelerates the scrappage and replacement of older vehicles has been in effect since 1986 in Guangzhou, and was modified in 1997. Passenger cars and minivans are limited to 12 years of service, and motorcycles must be removed from the road after 15 years. Although they dominate the current vehicle fleet, no motorcycles have been allowed to register since June 1998.

A policy requiring older vehicles to be retrofitted with emission controls has also been adopted in China, but the retrofit measures vary from city to city. Guangzhou has required retrofits for certain in-use vehicles since 1996, mandating, for example, that rare-earth element catalytic converters be installed in vehicles that fail the road inspection. Emission reductions on the order of 60% for CO and HC, and 30% for NOx have been reported (Freed, 2000). The converters are manufactured in China, but unfortunately only have a durability of six months to one year. Beijing has conducted a larger campaign to retrofit older vehicles in the city. Their three-way catalyst (TWC) retrofit kit is more costly, but it does have improved durability over the rare-earth catalysts. For older vehicles that will soon be forcibly retired (i.e., scrapped), the potential for the retrofit to reduce emissions is obviously quite small.

3. Strategies to control vehicle NOx pollution

3.1 Cost-effectiveness analysis

Since 1990, NOx emissions from stationary sources have leveled off somewhat, but vehicular NOx emissions have increased. Controlling and reducing emissions from motor vehicles will play an important role in controlling NOx emissions in the city, and it is important that such reductions be accomplished in a cost-effective manner.

3.1.1 Emission standards

In 2000, the emissions of passenger cars in China will have to meet the European 91/441/EEC (EURO1) requirement. The other light duty vehicles and trucks (LDV and LDT), vehicles with the weight below 3.5 tons, must meet 93/59/EEC requirements after 2000. It is expected that all light vehicles, including cars, must meet the 94/12EC (EURO2) requirement in 2004. The timetable of EURO1 (91/542/EC) for heavy-duty vehicles (HDV) and motorcycles is around 2001 and EURO2 (91/542/EEC) around 2005 (SEPA, 1999).

Vehicular emissions in Guangzhou can be estimated from the permitted emission levels in the standards, the number of vehicles and the kilometers traveled. The reduction potential can then be obtained from the difference between the projected emissions and the emissions that would have resulted if no action had been taken for emission abatement (see Table 1). This is a rather conservative assumption of the reduction potential, since it assumes that the emission reduction programmes are operating effectively and that vehicles comply with the standards.

Table 1. Reduction potential of new vehicle standards — EURO1 and 2 (10^3t)

Year\Pollutant	NOx	CO	HC
2000—year end	5.0	163.2	4.0
2010—year end	20.9	501.0	27.9

To meet EURO1 standards, electronic fuel injection and three-way catalytic converters are required for light-duty vehicles. It was estimated that the incremental cost of installing this system would be 7100 yuan RMB (1 yuan RMB = 0.121 US Dollar) per vehicle, and that the incremental operating cost would be 3270 yuan RMB per vehicle. For heavy-duty vehicles, the incremental cost will be 10,000 yuan RMB per vehicle, and the incremental operating cost will be 5400 yuan RMB per vehicle between 2000 and 2010. This assumes that no additional European standards will be adopted. The cost-effectiveness of the standard was then estimated to be 6760 yuan RMB/ton NOx reduction during 2000 to 2010 (assuming all costs are assigned to accomplish the reduction of this pollutant).

3.1.2. Gasoline quality improvement

Fuel composition and properties are factors that can influence vehicular emissions significantly (AQIRP, 1993). One major advantage of fuel modifications for emission control is that they can take effect quickly. Once vehicles begin operating on the modified fuel, emissions are reduced from the entire fleet of a city. This is in contrast to vehicle emission controls installed on new vehicles, which are typically phased-in over at least a decade (accompanying the turnover of the vehicle fleet). Also, fuel modifications might make possible the use of other vehicular emission control technologies (e.g., removing lead from gasoline enabled the introduction of catalytic converters), and fuel changes may also increase the effectiveness of other technologies (U.S. EPA, 1999).

Changing the quality of diesel fuel is technically difficult and very costly (Lee et al, 1998), and was not addressed in this analysis. The effect of gasoline fuel quality improvements on vehicular emissions can be estimated, however, by using the Complex Model, developed in the U.S. Auto/Oil Air Quality Improvement Research Program (AQIRP). This programme tested vehicle emissions, fuel composition and properties over a six-year period (beginning in 1989), utilizing dynamometer testing and the Federal Test Procedure (FTP) (AQIRP, 1993).

The use of such a model in other countries could present problems, since fuel composition, vehicle technology and driving cycles are likely to be different. New emission standards for light-duty vehicles are to be implemented nationwide in China from 2000, however, which will require the installation of technologies similar to US 1989-1990 cars (fuel injection, three-way catalysts, closed loop control). By 2010, most of the vehicles in Guangzhou will have this technology installed (i.e., scrappage regulations will cause the removal of most earlier-technology vehicles). Driving cycle and other data analyzed by the Beijing Automotive Research Institute (BARI) similarly suggest that the model would be appropriate for Guangzhou in 2010 (Wang, 2000).

This still leaves fuel composition differences between the US and China. With only this remaining difference, however, it should be possible to use the model as a guide to decide how fuel properties affect a particular pollutant, the direction of the effect, and a rough estimate of the magnitude of impact. In such a manner, the model can provide guidance in determining which fuel modifications will lower NOx from vehicles.

Since sulphur is an impurity in gasoline that will be harmful to catalytic converters, sulphur content reduction is the most efficient option in term of vehicular NOx emission abatement, compared with olefin or aromatics content reduction (Freed, 2000). Since the gasoline used in Guangzhou and throughout China has a high sulphur content, such removal is urgently needed. At present, cost data for fuel quality improvements are not readily available in China. The effectiveness and cost of sulphur reduction, based on the U.S. model and data, were therefore considered in this work. It should be noted, however, that the refinery cost is not linearly related to the percentage reduction of sulphur. Slight decreases in sulphur content in gasoline in Guangzhou will be technically feasible and relatively cheap, compared to the United States, where sulphur is already at a low level and further reductions will be more costly. Therefore, the costs for Guangzhou fuel quality improvements should be conservative if based upon U.S. data.

Assuming that fuel consumption in the year 2010 for vehicles will remain at present levels, the total cost of fuel improvements can be determined, as shown in Table 2.

Table 2. Cost-effectiveness (C-E) of gasoline improvement in 2010

2010	Passenger Car	Minivan	Taxi	LDT	Total
Fuel consumption (litres/100km)	8.5	10	8.5	13.5	
Annual fuel consumption (10^8 Litres)	3.24	4.43	2.58	4.80	15.1
Incremental cost for reducing sulphur from 400 ppm to 300ppm (10^6 yuan RMB)	3.55	4.84	2.82	5.24	16.45
NOx C-E (yuan RMB /ton)	46900	43400	48000	57500	48900

CO C-E (yuan RMB /ton)	610	530	700	550	580
HC C-E (yuan RMB /ton)	38500	23500	30500	31800	29600

3.1.3. I/M programme

Since the idle test is not effective for measuring vehicular NOx emissions, a loaded test would be necessary for any NOx control strategy in Guangzhou. Two loaded dynamometer tests are currently in wide use in other countries: the acceleration simulation mode (ASM) test and the IM240 transient test (Weaver and Chan, 1994; U.S. EPA, 1996) (see Table 3).

Table 3. Comparison of ASM and IM240 tests

	ASM	IM240
Test method	The test is run under steady state mode conditions. It measures CO and HC concentration emissions (not mass) with NDIR, and NOx.	The IM240 operates the vehicle over a transient driving cycle for 240 seconds. It measures dilute mass emissions with a constant volume sampler (CVS) and uses a dynamometer with flywheels to simulate the effect of the vehicle inertia. It needs dynamometer, video drivers aide, computer, CVS, and FID for HC, NDIR for CO, chemiluminescence analyzer for NOx.
Equipment cost (USD)	40,000	100,000
Test time	2 minute test	4 minute test
Capability	The IM240 test correlates better with the official laboratory test (FTP) than the ASM test and may identify 19% more excess NOx emissions than the ASM test. The ASM measures only concentration and cannot be used for emission factor or fleet characterization (inventory) purposes or to assure emission control component durability or retrofit effectiveness with accuracy.	

The potential effectiveness of such loaded tests in China was evaluated, since cities like Guangzhou plan to upgrade their I/M systems for stringent in-used vehicle emission control (Wang, 2000). Since there are no ASM or IM240 testing programmes in operation in Chinese cities, effectiveness data were mainly derived from U.S. operations. The effectiveness of ASM and IM240 has been validated by laboratory tests in China, however, and it has been estimated that the ASM replacement for the idle test can achieve reductions of 17.8% of HC, 16% of CO and 10.9% of NOx emissions, and that IM240 replacement for the idle test can reduce HC, CO and NOx emissions by 23.9%,19.4% and 13.4%, respectively (Wang, 2000).

In the United States, the cost of ASM has been determined to be $15.63/test, which is calculated based upon a 5-year period, 7.5 cars/hour, and 117,000 cars in 5 years (Freed, 2000). This analysis estimated costs to be 60-80 yuan RMB/test for ASM, and 120 yuan RMB/test for IM240 in Beijing. It has been assumed that the repair cost is 100 yuan RMB for a vehicle that fails the ASM test, and 200 yuan RMB for a vehicle that fails the IM240 test. A failure rate of 30% was also assumed. The results of the cost-effectiveness of ASM and IM240 are outlined in Table 4 (again allocating all costs to each pollutant).

Table 4. The cost-effectiveness of ASM and IM240 in 2010 (yuan RMB/ton)

	NOx	CO	HC
ASM	48270	780	6990
IM240	70700	1160	9370

A similar cost-effectiveness analysis was performed for control measures that have already been adopted in Guangzhou, focusing on NOx emission abatement. Table 5 compares the reduction potential and the cost-effectiveness of all options. From this Table, it can be noted that, except for the VTDV, whose cost and effectiveness of NOx reduction rely principally upon the advertising of its producer, all the other control measures are very costly in term of reducing NOx emissions. It should also be noted, however, that the implementation of new vehicle emission standards has much greater reduction potential and is more cost-effective than other options.

Table 5. The emission reduction potential and cost-effectiveness of different options

Control option		Reduction potential in 2010 (tons)	Cost-effectiveness (yuan RMB/ton)	Subtotal Cost in 2010 (10^6 yuan RMB)
EURO1 and EURO2 emission standards for new vehicles according to national regulation		20880	6,790	142
Fuel improve-ment	Sulphur in gasoline reduced from 400ppm to 300ppm	340	48,870	17
	Sulphur in gasoline reduced from 400ppm to 200ppm	830	38,400	32
I/M programme	ASM	1570	48,270	76
	IM240	1930	70,700	136
Scrappage		3460	56,000	194
Retrofit	VTDV[a]	0	716[c]	0
	TWC for LDGV	180	132,000	24
	TWC for HDGV	0	26,900[c]	0
	RTD[b] for HDDV	0	83,400[c]	0

Notes: a: VTDV is the use of a vacuum time-delay valve.

b: RTD is retarding fuel injection timing.

c: These retrofit measures have no reduction of NOx in 2010 because all of the vehicles that would have needed the retrofit will have been retired. Their cost-effectiveness was estimated based upon the accumulated cost and NOx reduction from the year 2000 until the retirement of the vehicles.

3.2 Selection of NOx control strategies

China has pledged to eliminate environmental deterioration by 2010, and a major portion of its pollution control efforts will have to occur in the country's urban areas. Over the next decade, Guangzhou is likely to continue its high rate of economic growth, and NOx abatement will thus be very challenging for the city.

3.2.1. NOx emission reduction targets

The year 1995 was set as the base year, and 2010 the target year, for this analysis. Vehicular emissions are estimated based upon emission factors (Chan and Reale, 1994), the increase of vehicle population (Zhu, 1999), and annual kilometres traveled according to:

$$EQ_{PE} = \quad (E_{CVi} \quad A_{PVi} \quad M_{Vi})/100 \qquad (1)$$

In which EQ_{PE} are emissions in the projection year, 10^4t;

E_{Cvi} is the emission factor of vehicle type I in the base year, g/km;

A_{Pvi} is the number of vehicles of type I in projection year, 10^4;

M_{Vi} is the annual average travel kilometres of vehicle type I, 10^4 km;

and 100 is a conversion factor.

If no emission control strategies were implemented after 1995, vehicular emissions in such a 'do-nothing' scenario in the base year and the projection year are shown in Table 6.

Table 6. Vehicular emission under a 'do-nothing' scenario in the target year (10^3t)

Year	NOx	CO	HC
2000	24.34	418.76	34.26
2010	59.38	1186.93	97.44

Assuming that ambient concentrations are linearly correlated with total emissions, the emission limit of certain pollutant (TQ_P) in the target year can be determined from the air quality targets:

$$TQ_P=EQ_{PC}\times S_P\times\eta_P /C_{PC} \qquad (2)$$

In which: TQ_p is the tons of emission from vehicles in target year;

EQ_{PC} is the total emissions of a pollutant in base year (t/a);

S_P is the target ambient concentration of NOx in the target year, mg/m^3;

η_P is the vehicular emissions as a percentage of total emissions in target year, %;

and C_{PC} is the ambient concentration in base year, mg/m^3.

According to the Guangzhou municipal environment protection planning department, air quality needs to be at or below the Class II NAAQS (which since 1998 has been based upon NO_2 instead of NOx) by 2010. The predicted proportion of vehicular emissions to total emissions (sharing rate) will be 45% in 2010 for NOx and 96% for CO. It was assumed that the proportion of vehicular emissions to total emissions in 2000 is approximately the same as in 1995. Since there is no annual average ambient air quality concentration standard for CO, a limit of half of the daily average value was taken as an approximate target. In Table 7, the emission limits are obtained from equation (2). For the NOx estimation, it was assumed that NO_2 accounts for 80% of the NOx in Guangzhou, based upon monitoring data of NO, NO_2, and NOx in recent years.

Table 7. The emission limit estimate in Guangzhou for the vehicle contribution to NOx and CO

		Concentration or air quality target (mg/m^3)	Total emissions (ton)	Sharing rate of vehicular emissions (%)	Vehicular emission or emission limit (ton)
CO	1995	2.91	32.17	0.84	26.96
	2000	3.00	33.16	0.84	27.79
	2010	2.00	22.11	0.96	21.23
NOx	1995	0.14	6.91	0.25	1.75
	2000	0.10	5.08	0.25	1.29
	2010	0.10	5.08	0.45	2.29

In 2010, the difference between the ‘do-nothing’ emissions and the emission limit is the reduction target, and is shown in Table 8.

Table 8. The reduction target in Guangzhou for the vehicle contribution to NOx and CO.

Year	NOx (10^3 ton)	CO (10^3 ton)
2000	11.4	140.8
2010	36.5	974.6

3.2.2. Scenario analysis

Based upon the assessment above, and the experience of vehicular emission control in the United States and other nations, three scenarios were developed for consideration of Guangzhou’s decision makers: a) a background scenario suggesting that Guangzhou follow only the national timetable for vehicle emission control; b) a more aggressive (but still moderate) scenario indicating adoption of a gasoline quality improvement programme, ASM testing and strong retrofit requirements; c) an enhanced scenario, in which EURO3 standards are adopted and implemented in the city (to the year in 2004 when the national regulations would adopt EURO2). These scenarios are summarized in Table 9.

Table 9. NOx emission control scenarios in Guangzhou (2010)

Scenario	Description	Reduction potential (10^3ton)	Cost-effectiveness (yuan RMB/ton)	Total cost (10^6 yuan RMB)
Background	National emission standards; national fuel quality standard; national regulation of scrappage; idle test I/M.	24.3	15,210	370
Moderate controls	National emission standards; national regulation of scrappage; sulphur in gasoline reduction; ASM testing; retrofit in-use vehicles with TWC or RTD.	26.9	29,920	805
Enhanced controls	Advanced implementation timetable for EURO3 emission standards; sulphur in gasoline reduction; accelerated mandatory retirement of buses and taxis determined by the accumulated mileage; ASM or IM240 testing; retrofit in-use vehicles with TWC or RTD.	39.9[a] 40.2[b]	26,292[a] 27,765[b]	1,049[a] 1,116[b]

Notes: [a] ASM test I/M.

[b] IM240 test I/M.

This cost-effectiveness analysis illustrates the very significant impact that changes in the exhaust emission standards can make, particularly when compared to other alternatives. Table 9 shows that the enhanced scenario has the highest reduction potential, and is also more cost-effective than the moderate one. Considering the reduction target in Table 8, the enhanced scenario is actually the only option that would satisfy the air quality requirement of NOx in 2010 in Guangzhou.

In order to consider substituting EURO3 for EURO2, it is necessary that the EURO3 standards be technologically feasible. China should be able to follow the lead of other countries in this area, although it may have to import much of the necessary control technology. Even under such an arrangement, however, considerable change will still be required on the part of the automobile industry in the country.

3.3. Additional measures

3.3.1. Durability testing

When a car fails to pass an I/M test, it is either because the owner did not maintain the emission-related components, or the emission controls were not durable for 80,000 km (as the EURO1 regulations require). Since it almost impossible for the owner to show that the manufacturer was at fault by installing emission control parts that deteriorated too quickly, the owner is inevitably left to pay for these repairs. Generally, manufacturers are not going to spend more money on emission control equipment than that required to simply meet the emission regulations. If the government has no compliance programmes to determine whether the manufacturers comply with the rules, the incentive for the manufacturer to build durable emissions control systems is diminished.

Such a compliance programme can be developed by taking a sample of cars from the road and measuring their emissions by the same test that was used during type approval testing, having assured that these cars have been given proper maintenance before testing. If a statistically significant sample of properly maintained cars fails any pollutant standard, the manufacturer must be penalized for not complying with the durability requirements of the emission standards.

The durability programmes must be conducted in addition to the I/M test, since an I/M test cannot determine if the controls are durable. I/M testing cut points (I/M standards) are set at levels several times the new car emission standards, which are those the manufacturer must meet for 80,000 km. Emissions from a vehicle could thus double or triple before it failed an I/M test, permitting a considerable amount of excess pollution. The I/M station is not equipped to determine which part caused the failure, or whether improper maintenance by the owner caused increased emissions.

In the U.S., if the compliance test shows that the manufacturer is at fault, it must repair all of the cars of the model and year represented by the sample that was tested. (During the first 10 years of the durability testing programme, 30 to 40% of all cars built were found to exceed emission standards significantly due to deteriorating or broken emission equipment. Three to four million cars were required to be repaired by the manufacturer each year.) If repair is impractical (a condition that may occur in other countries similar to China), a substantial monetary penalty could nonetheless be obtained from the manufacturer in order to provide a deterrence (Freed, 2000).

3.3.2. Control of non-road engines

Non-road engines (vehicles that operate mainly off-road) include airport ground support equipment (e.g., aircraft pushback equipment, baggage tugs, belt loaders, maintenance vehicles, ground power units, general service trucks), marine engines, locomotives and construction and agriculture equipment. In the early 1990s, NOx emission inventory studies from several cities in the U.S. indicated that NOx from diesel equipment was a much greater proportion of the inventory than had been expected (Freed, 2000). At present, no data are available for non-road equipment operating in the region of Guangzhou. Nevertheless, it is likely that significant NOx and PM emissions emanate from construction, agriculture, and marine engines, and from stationary engines such as pumps and generators. The establishment of emission standards for new non-road engines and the installation of retrofit equipment on engines in-use provide a likely opportunity for NOx reductions at relatively low cost. It is likely that the NOx emission factors for this equipment are very high compared with gasoline-fueled vehicles, even considering their unique driving cycles. Since the first application of controls to an industry is usually the least expensive on a yuan RMB per ton of NOx reduced basis, the establishment of emission standards for non-road equipment should be considered --especially if an inventory shows that the present or future population of such equipment is significant and growing.

3.3.3. Alternative-fueled vehicles

Alternative fuels are valuable today in limited markets where their environmental and energy benefits outweigh their increased cost and risks. Vehicle engines that are designed and built to operate on alternative fuels like LPG or CNG can achieve substantial emission reductions, and may provide useful options for a city to control air pollution. This is because such engine designs take advantage of the physical and chemical properties of the fuel to achieve a high level of performance and low emissions.

Natural gas has very high octane. Octane is a measure of the ability of a fuel to resist premature combustion. If the octane number is relatively low, the fuel will begin to burn before the optimum compression pressure is reached in the cylinder and power will be lost. The octane of natural gas is 130 compared to 'high octane' gasoline at 92 and regular unleaded gasoline at 87. This permits the engine designer to increase the compression ratio of the CNG engine to 11 or 12, compared to gasoline engine ratios of 9.5 to 10. The higher compression of the air-fuel mixture before ignition by the spark increases the useful energy derived from the fuel. There can be a 10% increase in power from CNG because of the higher compression and other basic engine design features. LPG engines can also have a higher compression ratio due to LPG's higher octane as compared to gasoline.

On the other hand, engines that are converted from gasoline or diesel fuel to use an alternative fuel were designed to optimize the properties of the gasoline or diesel fuel. The lower compression ratio of a gasoline engine means that the high octane of CNG is not put to use, and the conversion often results in a 5 to 10% power loss.

Emission test results from fuel-injected, gasoline vehicles equipped with closed-loop feedback control systems which were retrofitted to operate on CNG and LPG have been inconsistent. The emissions have not equaled the superior emission data from dedicated alternative-fueled engines that were designed and built to run on the alternative fuel. The likelihood of success in converting gasoline-fueled, carburetor-equipped vehicles that comprise almost all of China's car fleet is even more problematic.

4. Conclusions

In the process of very rapid economic development, especially the sharp increase in vehicle population, Guangzhou is suffering from very serious NOx and photochemical smog pollution. The air quality problem has become quite complex, with various pollutants (SO_2, NOx, O_3, particulate) all existing at relatively high concentrations in the atmosphere. NOx plays a key role, affecting environmental oxidation, acidification, and potentially eutrophication in the region, over and above its own health and environmental impacts. As the government intends to keep the economic growth rate at a high level over the next decade, accomplishing air quality improvements will be quite challenging. Although a cost effectiveness analysis suggests that vehicular NOx control is quite expensive, Guangzhou must implement an aggressive vehicle emissions control programme if it hopes to meet its health-based environmental quality targets. Such a programme must go beyond the present approach and provide for advanced implementation of EURO3 standards, fuel quality improvements, loaded I/M programmes, etc. Only under such programmes can Guangzhou hope to demonstrate that Chinese cities can accomplish both economic growth and environmental protection.

References

Air Quality Improvement Research Program (AQIRP), 1993. Auto/oil air quality improvement research program, Phase I. Final report. Auto/Oil Coordinating Research Council Inc., Atlanta, GA.

American Automobile Manufacturers Association, European Automobile Manufacturers Association, and Japan Automobile Manufacturers Association, 1998. World-wide fuel charter.

Asif, F., S.W. Christopher, and P.W. Michael, 1996. Air pollution from motor vehicles standards, and technologies for controlling emissions. The World Bank, Washington, D.C.

Chan, L. and M. Reale, 1994. Emissions factors generated from MOBILE5a. Engine, Fuel, and Emissions Engineering, Inc., Sacramento, CA.

Freed, Charles N., 2000. Personal communication.

Gu, Runnan, Benxiu Zeng, and Yulan Yuan, 1997. Evaluation of international and domestic vehicle emission standards. Proceedings of the First Conference on Vehicle Pollution Assessment in China, Beijing , pp. 803-808.

Lee, R., J. Pedley, and C. Hobbs, 1998. Fuel quality on heavy duty diesel emissions: a literature review. International Fall Fuels and Lubricants Meeting and Exposition, San Francisco, CA. October.

Pidgeon, W.M., D.J. Sampson, P.H. Burbage, et al., 1993. Evaluation of a four-mode steady-state test with acceleration simulation modes as an alternative inspection and maintenance test for enhanced I/M Programs, EPA-AA-AQAB-93-01, U.S. Environmental Protection Agency, Ann Arbor, MI.

State Environmental Protection Administration (SEPA), 1999. Technical policies of vehicular emission control in China. SEPA, China.

United States Environment Protection Agency (USEPA), 1996. Acceleration simulation mode test procedures, emission standards, quality control requirements, and equipment specifications-technical guidance. EPA-AA-RSPD-IM-96-2, Ann Arbor, MI, July.

United States Environment Protection Agency (USEPA), 1992. Control of diesel fuel quality. Federal Register 64 :26142-26158, Washington, DC.

United States Environment Protection Agency (USEPA), 1998. IM 240 & Evap Technical Guidance. EPA420-R-98-010, August.

United States Environment Protection Agency (USEPA), 1999. Tier 2 motor vehicle emission standards and gasoline sulphur control requirements. Notice of Final Rulemaking.

Walsh, M.P., 1995. Technical notes. Mimeo. Arlington, VA.

Wang, Shaoxia, 2000. Cost-effectiveness analysis of vehicular NOx emission control measures in Guangzhou. Masters thesis. Peking University, Beijing.

Wang, Shaoxia, Min Shao, Kai Tian, Yuanhang Zhang, 2000. A pilot study on cost effectiveness analysis of NOx emission control in Guangzhou City. Environmental Science Research 13(1) 28-31.

Weaver, C.S. and L.M. Chan, 1994. Analysis of CARB ASM and IM240 data. Memorandum. Engine, Fuel and Emissions Engineering, Inc., Sacramento, CA.

Xie, Shaodong, 1998. Study on the pollution caused by vehicular emissions in Guangzhou. Postdoctoral program report. Peking University, Beijing.

Zhang, Yuanhang, Kesheng Shao, Xiaoyan Tang and Jinlong Li, 1998. The study of urban photochemical smog pollution in China. Acta Scientiarum Naturalium Universitatis Pekinensis 34 (2-3) 392-400.

Zhu, Changjian, 1999. The prediction of vehicle growth in Guangzhou. Sino-Norway Cooperation Project report. Guangzhou.