



## Two- and Three Wheelers

Module 4c

Sustainable Transport: A Sourcebook for Policy-makers in Developing Cities

## OVERVIEW OF THE SOURCEBOOK

### Sustainable Transport:

#### A Sourcebook for Policy-Makers in Developing Cities

##### What is the Sourcebook?

This *Sourcebook* on Sustainable Urban Transport addresses the key areas of a sustainable transport policy framework for a developing city. The *Sourcebook* consists of more than 26 modules mentioned on the following pages. It is also complemented by a series of training documents and other material available from <http://www.sutp.org> (and <http://www.sutp.cn> for Chinese users).

##### Who is it for?

The *Sourcebook* is intended for policy-makers in developing cities, and their advisors. This target audience is reflected in the content, which provides policy tools appropriate for application in a range of developing cities. The academic sector (e.g., universities) has also benefited from this material.

##### How is it supposed to be used?

The *Sourcebook* can be used in a number of ways. If printed, it should be kept in one location, and the different modules provided to officials involved in urban transport. The *Sourcebook* can be easily adapted to fit a formal short course training event, or can serve as a guide for developing a curriculum or other training program in the area of urban transport. GTZ has and is still further elaborating training packages for selected modules, all available since October 2004 from <http://www.sutp.org> or <http://www.sutp.cn>.

##### What are some of the key features?

The key features of the *Sourcebook* include:

- A practical orientation, focusing on best practices in planning and regulation and, where possible, successful experiences in developing cities.
- Contributors are leading experts in their fields.
- An attractive and easy-to-read, colour layout.
- Non-technical language (to the extent possible), with technical terms explained.
- Updates via the Internet.

##### How do I get a copy?

Electronic versions (pdf) of the modules are available at <http://www.sutp.org> or <http://www.sutp.cn>. Due to the updating of all modules print versions of the English language edition are no longer available. A print version of the first 20 modules in Chinese language is sold throughout China by Communication Press and a compilation of selected modules will be sold by McMillan, India, in South Asia from June 2009. Any questions regarding the use of the modules can be directed to [sutp@sutp.org](mailto:sutp@sutp.org) or [transport@gtz.de](mailto:transport@gtz.de).

##### Comments or feedback?

We would welcome any of your comments or suggestions, on any aspect of the *Sourcebook*, by e-mail to [sutp@sutp.org](mailto:sutp@sutp.org) and [transport@gtz.de](mailto:transport@gtz.de), or by surface mail to:

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##### Further modules and resources

Further modules are anticipated in the areas of *Financing Urban Transport* (July 2009), *Transport and Health* (July 2009) and *Parking Management* (June 2009) (among others). Additional resources are being developed, and Urban Transport Photo CD-ROMs and DVD are available (some photos have been uploaded in <http://www.sutp.org> – photo section). You will also find relevant links, bibliographical references and more than 400 documents and presentations under <http://www.sutp.org> (<http://www.sutp.cn> for Chinese users).

## Modules and contributors

- (i) *Sourcebook Overview and Cross-cutting Issues of Urban Transport* (GTZ)

### Institutional and policy orientation

- 1a. *The Role of Transport in Urban Development Policy* (Enrique Peñalosa)  
1b. *Urban Transport Institutions* (Richard Meakin)  
1c. *Private Sector Participation in Urban Transport Infrastructure Provision* (Christopher Zegras, MIT)  
1d. *Economic Instruments* (Manfred Breithaupt, GTZ)  
1e. *Raising Public Awareness about Sustainable Urban Transport* (Karl Fjellstrom, Carlos F. Pardo, GTZ)

### Land use planning and demand management

- 2a. *Land Use Planning and Urban Transport* (Rudolf Petersen, Wuppertal Institute)  
2b. *Mobility Management* (Todd Litman, VTPI)

### Transit, walking and cycling

- 3a. *Mass Transit Options* (Lloyd Wright, ITDP; Karl Fjellstrom, GTZ)  
3b. *Bus Rapid Transit* (Lloyd Wright, ITDP)  
3c. *Bus Regulation & Planning* (Richard Meakin)  
3d. *Preserving and Expanding the Role of Non-motorised Transport* (Walter Hook, ITDP)  
3e. *Car-Free Development* (Lloyd Wright, ITDP)

### Vehicles and fuels

- 4a. *Cleaner Fuels and Vehicle Technologies* (Michael Walsh; Reinhard Kolke, Umweltbundesamt – UBA)  
4b. *Inspection & Maintenance and Roadworthiness* (Reinhard Kolke, UBA)  
4c. *Two- and Three-Wheelers* (Jitendra Shah, World Bank; N.V. Iyer, Bajaj Auto)  
4d. *Natural Gas Vehicles* (MVV InnoTec)  
4e. *Intelligent Transport Systems* (Phil Sayeg, TRA; Phil Charles, University of Queensland)  
4f. *EcoDriving* (VTL; Manfred Breithaupt, Oliver Eberz, GTZ)

### Environmental and health impacts

- 5a. *Air Quality Management* (Dietrich Schwela, World Health Organization)  
5b. *Urban Road Safety* (Jacqueline Lacroix, DVR; David Silcock, GRSP)  
5c. *Noise and its Abatement* (Civic Exchange Hong Kong; GTZ; UBA)  
5d. *The CDM in the Transport Sector* (Jürg M. Grütter)  
5e. *Transport and Climate Change* (Holger Dalkmann; Charlotte Brannigan, C4S)

### Resources

6. *Resources for Policy-makers* (GTZ)

### Social and cross-cutting issues on urban transport

- 7a. *Gender and Urban Transport: Smart and Affordable* (Mika Kunieda; Aimée Gauthier)

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## Module 4c

# Two- and Three-Wheelers

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This revision from the original document, having been issued in 2002, was done by Mr. N. V. Iyer in the beginning of 2009. The publishers gratefully acknowledge his work.

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*\* This module draws heavily from: Masami Kojima, Carter Brandon & Jitendra Shah, Improving Urban Air Quality in South Asia by Reducing Emissions from Two-Stroke Engine Vehicles, The World Bank, Dec. 2000, <http://www.worldbank.org/html/fpd/esmap/publication/airquality.html>. Except as otherwise cited, the text in Section 3 is drawn from this paper, with adapted, updated and additional material provided by N. V. Iyer and Jitendra Shah.*

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## 1. Introduction

This module will focus on Asian developing cities, as the two- and three-wheeler vehicle fleets — and associated challenges — are far higher in Asia than in other parts of the developing world.

The consideration of two- and three-wheelers is divided into two broad categories. The first relates to transport system issues in cities with high shares of passenger trips undertaken by motorcycles. Such cities include for example Delhi, Hanoi, Ho Chi Minh, Dhaka, Denpasar and to varying extents many other developing Asian cities. This section of the module raises some key issues for urban transport systems in ‘motorcycle cities’, but does not discuss policy options and approaches in detail.

The second broad category relates to air quality issues in cities with high shares of two- and three-wheeler use. At least in the short to medium term, the emissions from two- and three-wheelers represent the most serious problem for developing cities. Recommended policy options for developing cities are then presented.

Several sections of the module are preceded by a ‘text box’ which provides the main recommendations from a major recent Regional Workshop (2001) on reducing emissions from two- and three-wheelers. Papers from this Workshop can be downloaded from the Website listed in the references section.

## 2. Two- and three-wheelers and urban transport systems

A detailed discussion of transport system issues relating to two- and three-wheelers is beyond the scope of this module. In this section some of the key issues are highlighted.

### 2.1 Two- and three-wheelers in developing Asian cities

Two-wheelers in Asian cities include mopeds, scooters and motorcycles and are used mostly for personal transportation, though in Bangkok and some other cities — including in Viet Nam and Indonesia — motorcycles are also used for public transportation or paratransit. Three-wheelers in Asia include small taxis such as auto-rickshaws in India, and Sri Lanka, baby taxis in Bangladesh and tuk-tuks in Thailand — usually for carrying three passengers — and larger vehicles such as Tempos in Bangladesh, Nepal and parts of India, which carry as many as a dozen passengers. Large proportions of two-wheelers are powered by two-stroke gasoline engines, though, in recent years, there has been a significant increase in the proportion of two-wheelers propelled by 4-stroke gasoline engines. Though many of the three-wheelers are powered by two-stroke gasoline engines, there are many which are powered by small diesel engines. A small proportion of three-wheelers use LPG or CNG (as in India and Thailand).

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*“Viet Nam, Thailand and Indonesia each have motorcycle sales in excess of one million units per year, and a motorcycle is considered family transport throughout the region.”*

Autoasia Magazine, October 2002, p5

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Two- and three-wheelers play an important role in the transport market in Asia. India, China, Viet Nam and Indonesia have a very large number of two-wheelers, which are used mostly for personal transport (see Figure 1).

Three-wheelers are typically used as short-distance taxis. In Sri Lanka some families are buying three-wheelers for private use, attracted

**Fig. 1**  
*Two-wheeler registrations in Asia and Australia.*

International Road Federation, World Road Statistics 2009



by the lower price of the vehicles relative to passenger cars. More than half of the motor vehicle fleet in China, Thailand and Malaysia consists of two-wheelers; in Indonesia, Viet Nam and Taiwan (China) the figure exceeds two-thirds of the fleet. Figure 2 illustrates the dominance of two- and three-wheelers in the vehicle fleets of Dhaka (Bangladesh), Ho Chi Minh

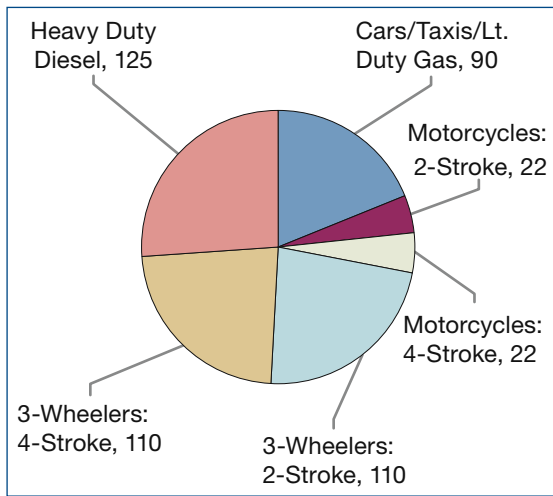
(Viet Nam), Denpasar (Indonesia) and Delhi (India). As Figure 3 shows, however, there is not always a close correspondence between the number of vehicles registered and those in use, so it is important to use reliable data in analysis.

Three-wheel taxis are perceived as less compliant with traffic regulations and more accident prone than four-wheel vehicles. They are also more



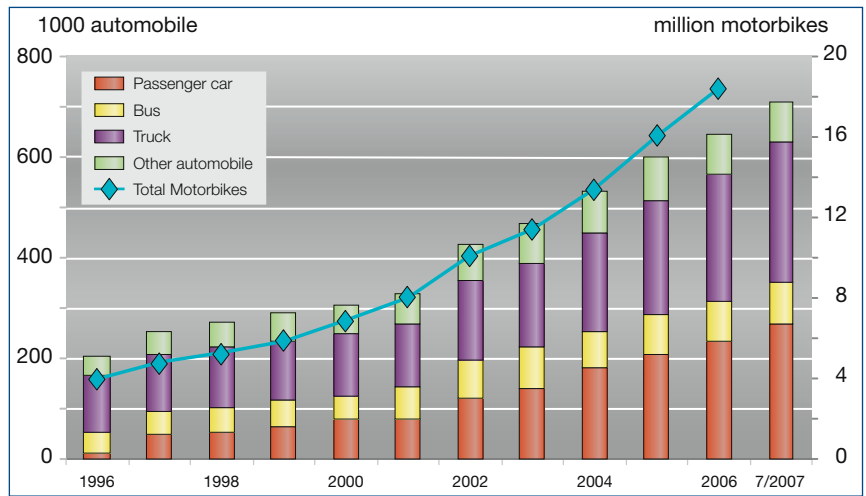
**a. Vehicle usage in Dhaka (km/day)**

Walsh, 2001, from World Bank, Urban Transport & EIP Strategy Analysis (undated)



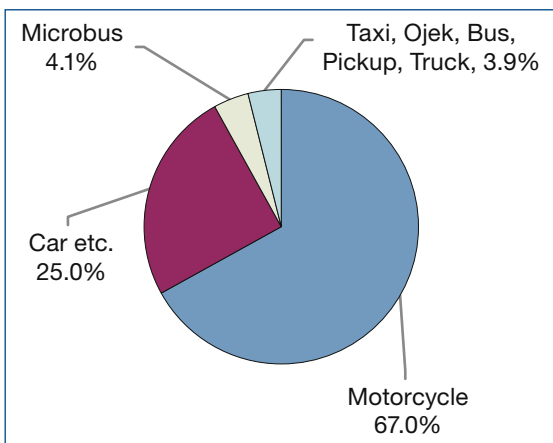
**b. Number of vehicles in Viet Nam, 1996–2007**

Dr. Nguyen Van Tai, "EST Achievements, Progress and Future Strategies", Fourth Environmentally Sustainable Transport Forum, United Nations Centre for Regional Development, Seoul, South Korea, 24–26 February 2009, <http://www.uncrd.or.jp>



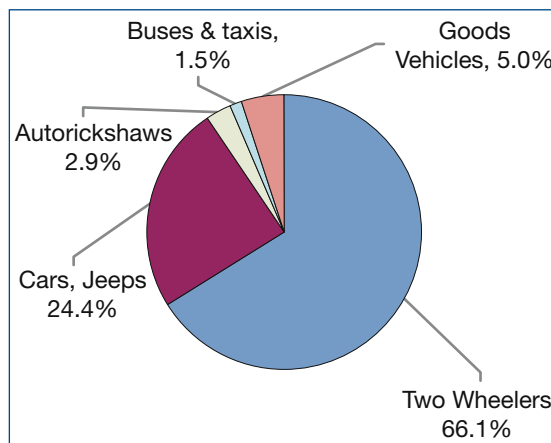
**c. Percentage of person-trips by mode, Denpasar, Bali**

BUJP, 1999



**d. Vehicle population in Delhi**

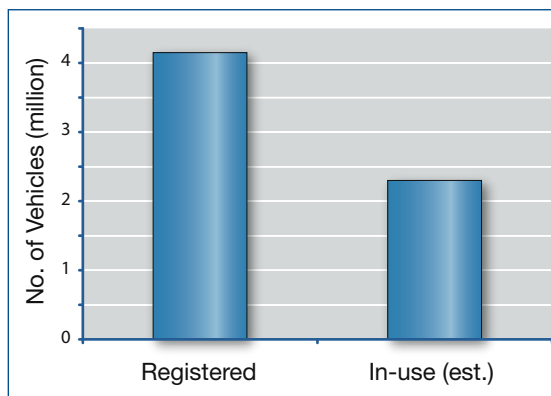
Walsh, 2001 from Sengupta, Dec. 2000



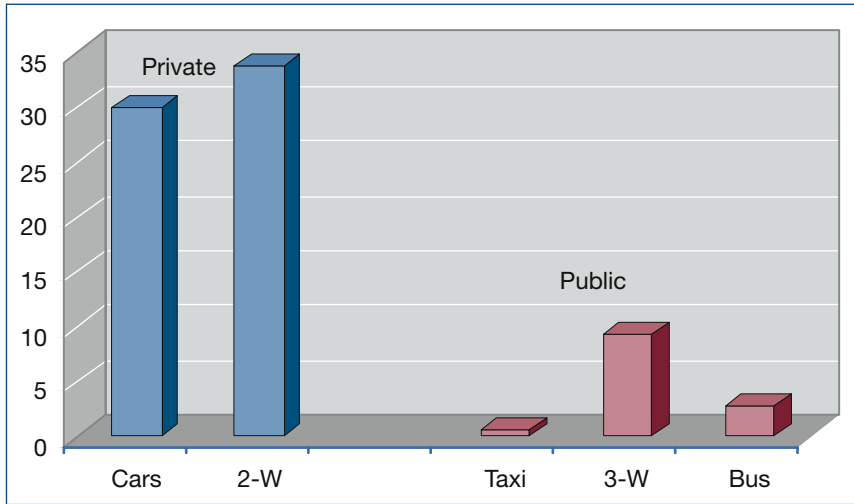
**Fig. 2a, b, c, d**  
*Various indicators of the prominence of two- and three-wheelers in selected cities.*

visible, because of their numbers, and contribute to congestion and pollution. For these reasons there is strong sentiment in some countries, notably Bangladesh, against three-wheelers powered by two-stroke engines.

An expert committee appointed by the Government of India recently completed a study of urban road traffic and air pollution in major Indian cities. This included an assessment of the share of different modes of transport in these cities (Government of India, August 2002, [http://www.petroleum.nic.in/afp\\_con.htm](http://www.petroleum.nic.in/afp_con.htm)). Findings of this study with respect to Delhi, the city with the highest motor vehicle population in the



**Fig. 3**  
*Registered data versus in-use data in Bangkok.*  
Shah, 2001



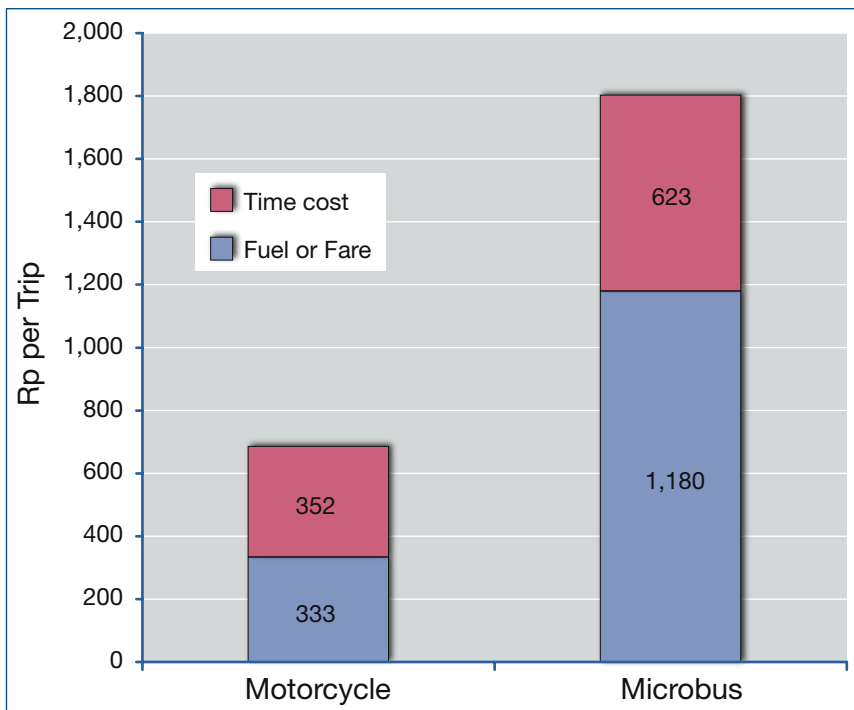
**Fig. 4** ▲  
*Share of public and private transportation in Delhi, million vehicle-km per day.*

Government of India, 2002,  
[http://www.petroleum.nic.in/afp\\_con.htm](http://www.petroleum.nic.in/afp_con.htm).  
Note: the year of the data is not stated,  
and it should be viewed as approximate

▼ **Fig. 5**

*Cost comparison for a typical 8 km trip in Denpasar.*

BUIP, 1999



**Table 1: Cost comparison for a typical 8 km trip in Denpasar, Indonesia (Rupiah per passenger)**

BUIP, 1999

Cost item	Motorcycle	Microbus	Ratio Bus/MC
Fuel or Fare (Rp)	333.0	1,180.0	3.5
Time (mins)	19.2	34.0	1.8
Time cost (Rp)	352.0	623.0	1.8
Total trip cost (Rp equiv.)	685.0	1,803.0	2.6

country (with more than 3.5 million registered vehicles) and among the most polluted cities in the world, are shown in Figure 4.

Figure 4 shows that two-wheelers account for more than half of the personal transport and three-wheelers take up a major share of the public transportation in the city. The share of buses, in comparison, is very small.

## 2.2 Public transport issues

In general, in developing cities in Asia motorcycles offer a significantly cheaper and faster mode of travel compared to public transport. Further, due to unattractive public transport services, people tend to use motorcycles even considering the disadvantages of exposure to sun and rain (especially during the wet season), and the significantly higher risk of accident compared to public transport.

Cost structures such as shown in Figure 5 and Table 1 for a typical 8 km trip in Denpasar, Bali combined with the poor service offered by public minibuses and minibuses, have led to a share of passenger trips of less than 5% in Denpasar. Similar situations apply in other ‘motorcycle cities’ such as Hanoi and Ho Chi Minh, where even less than 5% of trips are made by bus.

In the short term high levels of motorcycle usage may not appear to present a problem. After all, motorcycles are efficient users of road space, with an average occupancy in many Asian cities of around 1.5 and average occupancy of motorcycles only slightly less than car occupancy in a city such as Surabaya. TERI (1993) reported that average motorcycle occupancy in Indian cities was 1.5 and that of cars around 2.6. However, in the medium and long term such ‘motorcycle dependency’ may lead to intolerable congestion and associated air pollution. Such unsustainable trends are the result of increasing motorcycle and car ownership and usage as incomes rise.

### The outlook for a motorcycle city

Forecasts made for Denpasar, Bali by a World Bank-funded study in 1999 illustrate the fact that the ‘motorcycle cities’ seem to be on an unsustainable path. Future levels and patterns of transport demand were forecasted using a public transport planning model developed by the study (BUIP, 1999).

The numbers of motorcycles were predicted to grow by a modest average of 2.8% per year between 1998 and 2018, and the numbers of cars by 5.2% per year. Even so, by 2018, there will be 72% more motorcycles and 173% more cars on the roads. Between 1998 and 2018, the number of motorcycles per person is predicted to rise from 0.32 to 0.34 and the number of cars from 0.07 to 0.12 per person during the same period, reflecting predicted increases in household incomes.

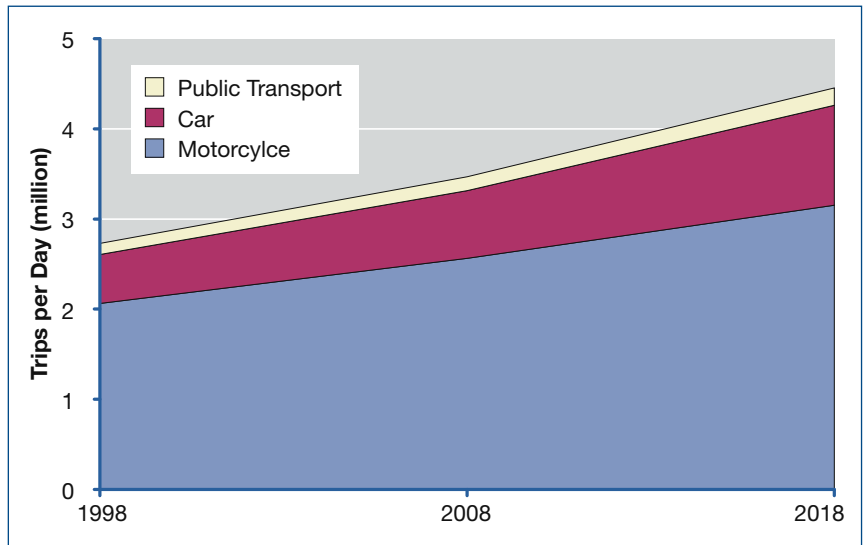
In the absence of any policy to alter the balance between private and public transport, motorcycles' share of all trips will fall from 75.6% to 70.8%, cars' share will increase from 19.9% to 24.9%, and public transport's share will continue at around its present very low level (Figure 6 and Table 2).

The implications are clear: even with all planned roads completed by 2018, there will remain serious problems of traffic saturation and associated environmental deterioration. These problems will occur in the areas least able to cope with them: the historical and cultural heart of central Denpasar and the residential suburbs.

As well as the negative implications of increasing motor vehicle dependency in dense developing cities, we can foresee that prevalence of motorcycles may support more dispersed activities in urban areas, further undermining any future role of a viable public transport industry.

The role and importance of two and three-wheelers as important modes of transport in many of the Asian cities was highlighted during a pre-event organized before the Better Air Quality — 2008 workshop held in Bangkok from 12–14 September 2008. The discussions brought out the following recommendations (<http://www.baq2008.org>):

1. Two and three-wheelers must be recognized as important modes of urban transport, now and in the foreseeable future.
2. In order to improve the overall system efficiency, steps need to be taken to:
  - Improve their operational efficiency through rationalized traffic engineering and management with particular reference to road and intersection designs and classification of roads and vehicles for better access to mobility;



**Fig. 6**  
*Predicted modal split (for motorised trips) in Denpasar, Bali, 1998–2018.*  
BUIP, 1999

- Improve their energy efficiency and reduce pollutant emissions through progressive technological improvements.
3. In urban areas, they need to be promoted as more preferable than larger motorized vehicles but should not displace non-motorized vehicles.
  4. Three-wheelers need to be promoted as the transport mode providing the “last mile connectivity” in the urban transport system.

### 2.3 Road safety issues

The prevalence of motorcycles in urban transport systems in developing cities raises serious safety concerns, in at least two areas:

- Motorcycles tend to drive bicyclists off the street, literally and figuratively. Most clearly in a city such as Ho Chi Minh, but also to varying extents in other Asian cities, rapid growth of motorcycles has coincided with rapid declines in the use of bicycles. Part of the reason is undoubtedly that bicycles are crowded out by motorcycles, with cyclists

**Table 2: Daily trips & mode split in Denpasar, 1998, 2008 and 2018**  
BUIP, 1999

Mode	1998		2008		2018	
	Daily Trips	%	Daily Trips	%	Daily Trips	%
<b>Motorcycle</b>	2,062,452	75.6%	2,562,464	73.9%	3,151,977	70.8%
<b>Car</b>	542,886	19.9%	752,669	21.7%	1,107,788	24.9%
<b>Public transport</b>	123,850	4.5%	154,027	4.4%	194,626	4.4%
<b>Total</b>	2,729,188	100.0%	3,469,160	100.0%	4,454,391	100.0%



**Fig. 7**  
*Bicycles are increasingly being ‘forced out’ of the transport system in motorcycle cities, as conditions for cycling deteriorate with an increasing number of motorcycles.*

Karl Fjellstrom, Ho Chi Minh, Jan. 2002

more likely to fall in the event of a collision with a motorcycle (see Figure 7).

- In the event of an accident, motorcyclists have little protection from injury, especially in developing cities in Asia where road safety laws are often not enforced (see margin note page 10). In Viet Nam, for example, nearly 1000 people are killed each month from road accidents, the vast majority motorcyclists. Road traffic accidents account for 96.8% of accidents in Viet Nam (“Road Toll Careers Toward Last Year’s Nightmare High”, *Viet Nam News*, 30 October 2002). Certain steps taken by Vietnamese authorities to create greater awareness among the motorcycle users to comply with the traffic laws and to wear helmets have helped to reduce the number of road accidents and injuries. The number of deaths due to road accidents has remained steady at around 12,000 per year for the last few years and has shown a decline to around 10,000 per annum in 2008 (Tai, 2009).

### 3. The problem of two-stroke engine emissions

Air quality is deteriorating in the developing cities of Asia; a by-product of rapid urbanisation. The experience in South Asia is typical in the region. Of the 1.3 billion people living in Bangladesh, Bhutan, India, Nepal, Pakistan and Sri Lanka in 1998, 350 million — 27% of the combined population — lived in urban areas. The average population growth in urban centres, 3.2% a year between 1990 and 1998, was much higher than the 1.3% growth rate for the population as whole.

A major source of air pollution is emissions from the rapidly rising number of vehicles. In India the number of registered vehicles has been tripling every 10 years, from close to 10 million in 1986 to nearly 30 million in 1996 and further to over 90 million in 2007 (see Figure 8).

The number of vehicles grew rapidly in other countries in the region as well, increasing at an annual rate of 8.2% in Bangladesh (1990–96), 13.5% in Nepal (1990–99), 8.0% in Pakistan (1990–99) and 7.3% in Sri Lanka (1990–97). In the absence of cleaner technologies and stringent control measures, the level of vehicular emissions is expected to increase at high rates.

Two-stroke gasoline engine vehicles are estimated to account for about 60% of the total vehicle fleet in South Asia. The proportion is also high in other developing Asian cities. The large number of these vehicles, their age, poor maintenance, low lubricant quality and excessive lubricant use, and traffic congestion in large cities make two-stroke engine vehicles a significant source of particulate emissions.

Two-stroke engines have several advantages over four-stroke engines. These include lower cost; excellent torque and power; mechanical simplicity (fewer moving parts and resulting ease of maintenance); lighter and smaller engines; greater operating smoothness; and lower nitrogen oxide emissions. They also have disadvantages compared with four-stroke gasoline engine vehicles, including higher particulate and hydrocarbon emissions, lower fuel economy and louder noise.

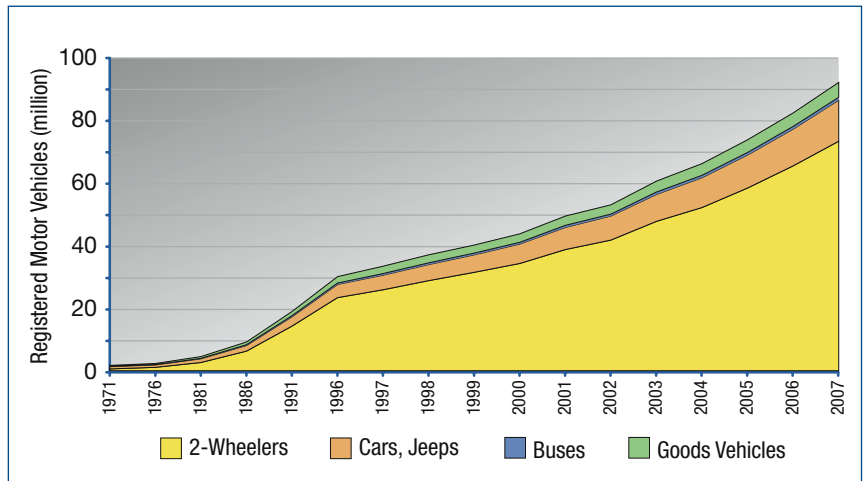


Fig. 8

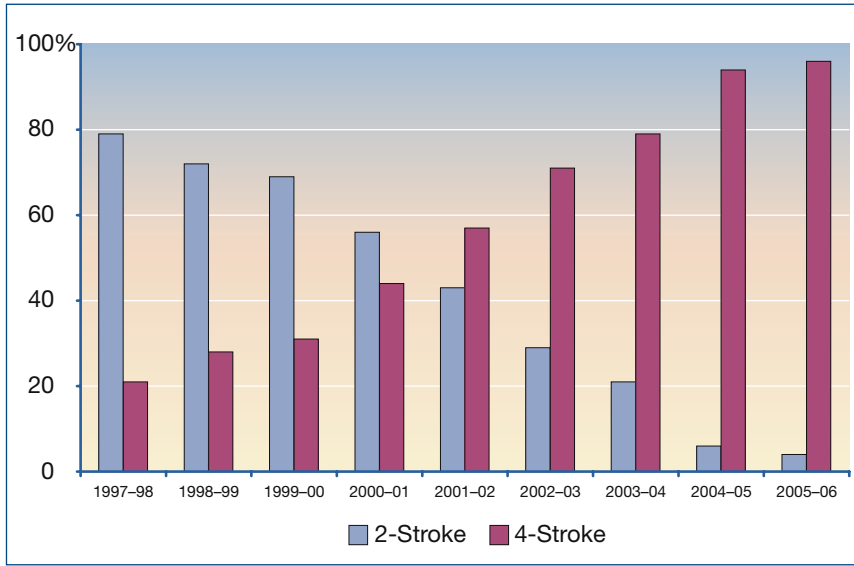
#### Number of registered motor vehicles in India, 1971–2007.

"The Indian Automobile Industry Statistical Profile 2007–2008," Society of Indian Automobile Manufacturers

#### Box 1: Background to the problem

Synthesis, Regional Workshop, 2001, <http://adb.org/vehicle-emissions>

- Nowhere else in the world is the concentration of two- and three-wheelers, both in absolute terms and as a fraction of overall road vehicle population as high as it is throughout Asia. In many cities these vehicles account for more than 50–90% of the total vehicle fleet, a situation unheard of in other parts of the world. Therefore, it is self-evident that priority must be given to the development and implementation of pollution control strategies for these types of vehicles if Asian Cities are to achieve clean air.
- Two types of engines power these vehicles, two-stroke and four-stroke. The primary difference is that lubricating oil is mixed with the fuel and burned in the two-stroke engine. The main pollutants of concern from two-stroke engines are hydrocarbons (HC) and particulate matter (PM) whereas four-stroke engines result in higher NO<sub>x</sub> emissions but lower PM, HC, CO and fuel consumption.
- There is a shift from two-stroke to four-stroke engines underway for some countries in the region. For instance, a rapid increase in the annual sales of four-stroke two-wheelers is taking place in India (Figure 9). This is attributed partly to stringent emission standards, partly to changing customer preferences, and partly to unavailability of two-stroke vehicles as manufacturers increasingly shift to four-stroke technology. Figure 10 shows that the motorcycle population in Bangkok is also undergoing a rapid transition to four-stroke engines.
- Fuel consumption for transportation usage is increasing in the Asian region. One factor driving this increase is the large and sustained



**Fig. 9**  
*Progressively increasing proportion of 4-stroke two-wheelers in India (annual sales volume).*

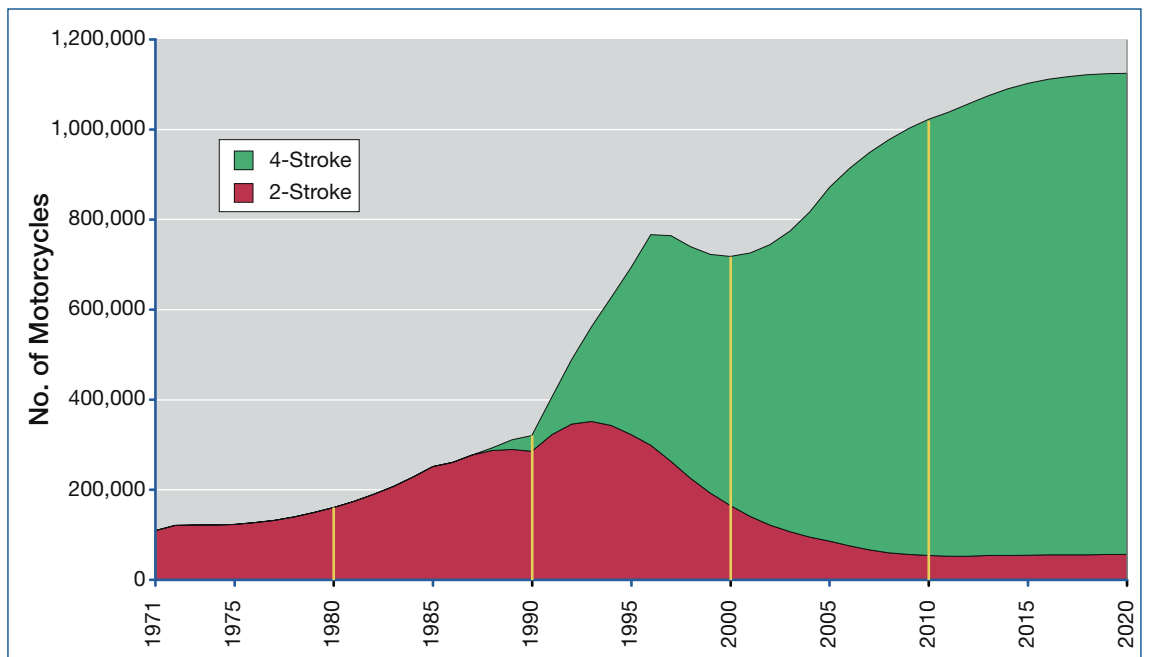
Source: M. N. Muralikrishna, "Indian Two-Wheelers", International Seminar on Fuel Efficiency, Petroleum Conservation Research Association, Chennai, 6-7 December 2007, <http://www.pcr.a.org>

growth of two- and three-wheelers. Four-stroke engines are more fuel-efficient than two-stroke engines and the shift noted above will reduce the rate of increase somewhat. Increased fuel consumption leads to increased CO<sub>2</sub>, which is an important contributing factor to the greenhouse effect.

- PM emissions from two- and three-wheelers in Asia cause or contribute to serious air quality problems in large cities, increasing premature death and illness. Increased hospital admissions for asthma and other bronchial conditions will occur. PM emitted from two-stroke engines is poorly characterized in terms of influencing factors, size profile and

organic composition. Such a characterization of PM in terms of size is important, since very small PM is believed to be most hazardous in terms of health impact. Also, characterization of HC in terms of overall toxicity is important; emissions from four-stroke engines can also contribute to high ambient levels of PM as pollutants such as NO<sub>x</sub> undergo secondary transformations in the atmosphere.

- Although information is available on specific health effects from various pollutants emitted by two- and three-wheelers from information sources outside Asia, (and this information indicates serious health impacts) there is a need for local studies to reaffirm the relationship between health and pollutants from two- and three-wheelers in Asian cities. There is also a great need to increase public awareness of these adverse health effects.
- Actual emission factors for different types of two- and three-wheelers in Asia are poorly defined. Fuel composition and lube oil, current maintenance and driving habits and the types of usage need to be investigated in terms of their impact on emission factors.
- Since developed countries have much smaller populations of two- and three-wheeled vehicles, they are not developing aggressive programs to reduce emissions from these vehicles. It will be necessary therefore, for countries in Asia to take the lead in the development and implementation of strategies to clean up these vehicles.



**Fig. 10**  
*Motorcycle population in Bangkok.*  
 Shah, 2001

### 3.1 Types of emissions

Gasoline engines contribute to air pollution by emitting high levels of particulate matter (in the case of two-stroke engines), carbon monoxide, nitrogen oxides, volatile organic compounds and lead if leaded gasoline is used. Diesel engines emit high levels of particulate matter, nitrogen oxides and sulfur oxides (if the level of sulfur in diesel is high).

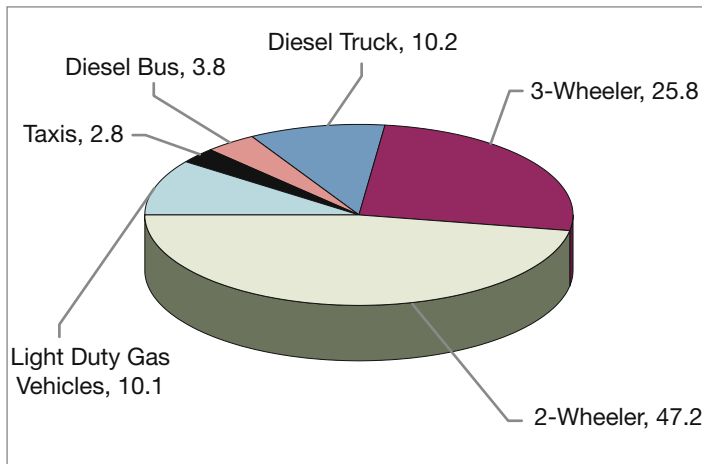
The pollutant of special concern in developing cities in Asia is small particulate matter because of its high ambient concentrations and documented impact on morbidity and premature mortality. The level of particulate matter with an aerodynamic diameter of less than 10 microns (PM<sub>10</sub>) exceeds internationally accepted standards by several times in a number of cities in

Asia. Two major contributors to high ambient concentrations of PM<sub>10</sub> in the transport sector are two-stroke engine gasoline vehicles and heavy duty diesel vehicles. The contribution of two- and three-wheelers to particulate and other emissions is illustrated in Figure 11. The relative contribution of two-wheelers to ambient PM and Hydrocarbons in recent years, however, is likely to have significantly reduced. A major reason for this is that there has been a rapid increase in the relative proportion of 4-stroke engine powered two-wheelers (see Figure 9) which have much lower emissions of PM and Hydrocarbons than those of two-stroke engines. The second reason is that most of the recent two-stroke engine powered two-wheelers use oxidation catalytic converters which can bring about a large, up to 50%, reduction in PM and HC emissions (refer

**Fig. 11a, b, c, d**  
*Contribution of two- and three-wheelers to particulate and hydrocarbon emissions in Delhi, and fine particulate emissions in two high-traffic areas of Bangkok.*

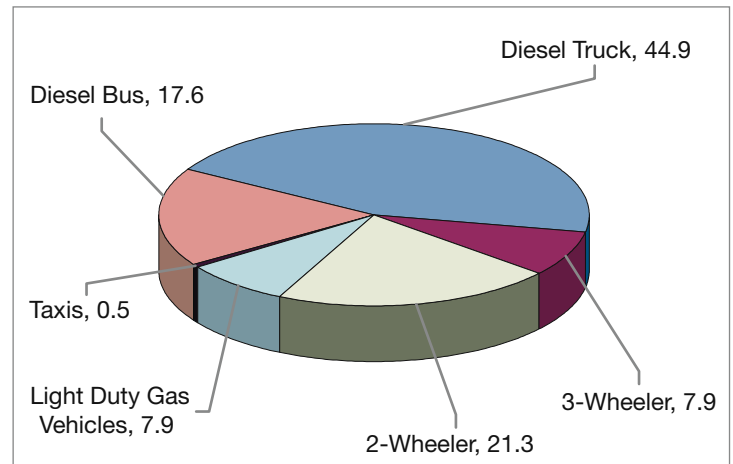
**a. PM<sub>10</sub> emissions in Delhi (%)**

Walsh, 2001, from Jitu Shah & Jian Xie, 2000



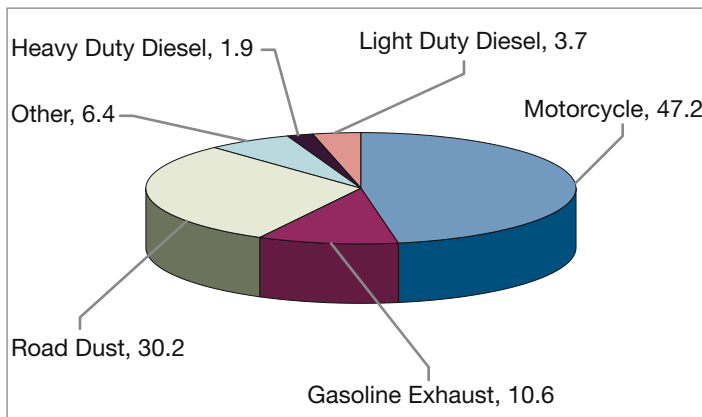
**b. HC emissions in Delhi (%)**

Walsh, 2001, from Jitu Shah & Jian Xie, 2000



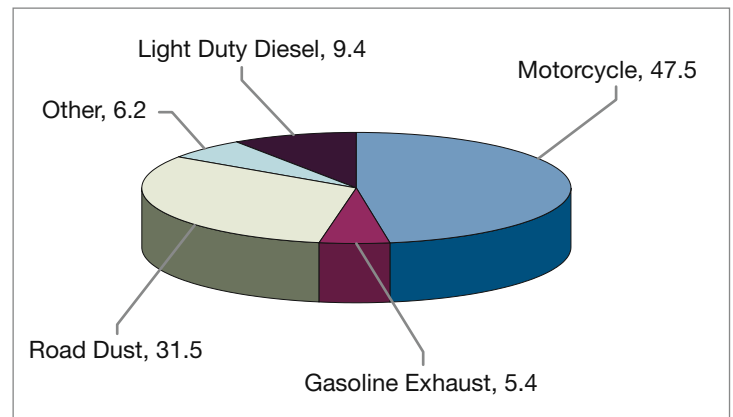
**c. Sources of particulate emissions (%) in high traffic areas in Bangkok (1996): Odeon Circle**

Walsh, 2001, from PM Abatement Strategy for the Bangkok Metropolitan Area, Draft Final Report, Radian International



**d. Sources of particulate emissions (%) in high traffic areas in Bangkok (1996): Pratunam Intersection**

Walsh, 2001, from PM Abatement Strategy for the Bangkok Metropolitan Area, Draft Final Report, Radian International



### Wearing of helmets

Many countries in Asia have legislation that makes it compulsory for motorcyclists to wear safety helmets. Though in India such a law has been in force for many years, the enforcement is extremely weak with the exception of a few cities such as Delhi and Chandigarh.

Similarly in Indonesia, even where laws are enforced, motorcyclists often wear loosely-fitted, thin plastic helmets. These cheap plastic helmets cost around US\$1.50, but provide little protection in the event of an accident.

For a more detailed discussion of road safety issues, please refer to Module 5b: *Urban Road Safety*.

Palke D.R. and Tyo M.A., SAE 1999). The other reason for the lower PM emissions is the increasing use of synthetic 2-stroke lubricating oils in reduced proportions (Rudolf *et al.*, 2005).

Emissions are higher in two-stroke engines because of the design of the engine. Gas is exchanged through ports located in the cylinder, usually opposite each other. A fresh fuel and air mixture compressed in the crankcase enters through the intake opening, while exhaust gases exit through the exhaust port. While both the intake and exhaust ports are open some of the fresh fuel and air mixture escapes through the exhaust port. Resulting in “scavenging losses,” which can amount to 15–40% of the unburned fresh charge, the exhaust contains a high level of unburned fuel and lubricant. Nitrogen oxide emissions tend to be lower because a significant portion of the combustion products still remain in the cylinder.

In two-stroke engines the crankcase is not used as an oil reservoir, as it is in four-stroke engines. Instead a small amount of lubricating oil is added to the fuel or mechanically introduced continuously. As lubrication is on a total loss (once-through) basis, incompletely combusted lubricant and other heavy hydrocarbons are emitted as small oil droplets. These oil droplets increase visible smoke and particulate emissions, with serious impact on public health because of their well-documented link to morbidity and premature mortality.

*“Two major contributors to high ambient concentrations of PM<sub>10</sub> are two-stroke engine gasoline vehicles and heavy duty diesel vehicles.”*

Table 3 shows the results from tests done in fall 2000 at ARAI (the Automotive Research Association of India), which measured particulate emissions levels of in-use three-wheelers from Dhaka (engine size of 150 cubic centimeters). The data show that 7-year old vehicles using excess “straight mineral oil” emit particulate matter up to ten times, and that 4-year old vehicles using “straight mineral oil” emit particulate matter roughly two to three times than the typical values obtained in the United States in the 1970s. For both ages of vehicles, particulate emissions are much less if the correct amount of 2T oil, formulated specifically for use in two-stroke engine vehicles, is used.

Since two-stroke engine vehicles emit significantly more unburned gasoline than four-stroke engines, they emit more organic lead if leaded gasoline is used. Organic lead is much more damaging to public health than inorganic lead formed by combustion of lead additives. Bangladesh phased lead out of gasoline in July 1999, India in February 2000. Only unleaded petrol is available throughout Sri Lanka since the year 2002 and in Pakistan since 2001. However, lead emission can be a problem in countries in which leaded petrol is still available.

A further analysis of the results obtained under this project is reported in *Bangladesh: Reducing Emissions from Baby-Taxis in Dhaka*, ESMAP Report 253/02, January 2002, <http://www.esmap.org>. Important conclusions include that:

- The mass PM emissions were high, ranging from 0.16–2.70 g/km and averaging 0.7 g/km. In constructing an emissions inventory for PM, the contribution from two-stroke gasoline engines may be substantial if these numbers are used. However, the nature of particles is fundamentally different between

**Table 3: Emissions from selected Bangladeshi two-stroke three-wheelers (grams per kilometre)**

Vehicle age	Lubricant type	Percentage lubricant	Hydrocarbons	Carbon monoxide	Oxides of nitrogen	Particulate matter
7 years	straight	8%	23	25	0.03	2.7
7 years <sup>a)</sup>	2T	3%	16	17	0.09	0.9
4 years	straight	8%	9	8	0.08	0.6
4 years	2T	3%	9	10	0.09	0.2

Source: ARAI, November 2000. Measurements are preliminary and require further analysis.

Note: <sup>a)</sup> Data taken after performing simple maintenance procedures on the vehicle.



diesel and gasoline two-stroke engines; therefore, it may be misleading to add them together. For the purpose of developing an emissions mitigation strategy, it may make more sense to keep these two categories of PM emissions separate.

- The mechanical condition of the vehicle (reflecting both vehicle technology and maintenance) had by far the greatest impact on emissions. The oldest of the vehicles tested had the highest emissions for PM, hydrocarbons and CO.
- Mass particulate emissions followed the expected trend, with the exception of vehicle service — that is, using straight mineral oil, increasing the concentration of lubricant added, and using gasoline purchased in Dhaka (which is often adulterated with kerosene) increased emissions.

### 3.2 Factors exacerbating emissions

Poor vehicle maintenance, misuse of lubricant, adulteration of gasoline, and lack of catalytic converters exacerbate two-stroke engine emissions, resulting in emissions well above applicable standards. In addition, many drivers use lubricants and fuels of poor quality.

#### Misuse of lubricant

Both the quantity and quality of lubricant used affect the level of hydrocarbon and particulate emissions from two-stroke engines. Vehicle manufacturers recommend adding 2% lubricant for two-wheelers and 3% lubricant for three-wheelers. Many drivers of three wheelers add considerably more lubricant for several reasons:

- Lack of knowledge about the correct amount to add;
- Lack of knowledge about the adverse effects of excess lubricant;
- Addition of excess lubricant to gasoline by filling station attendants at the point of sale;
- Perception that more lubricant will provide greater protection against piston seizure;
- Perception that more lubricant will increase fuel economy;
- Lower miscibility of straight mineral oil and conventional motor oils with gasoline compared to 2T oil.

Excessive use of lubricant increases combustion chamber deposits and fouls spark plugs. When

pistons and rings are badly worn, excess lubricant may postpone piston seizure for a while. The adverse social effects of much higher emissions far outweigh benefits to vehicle owners.

Lubricant requirements for two-stroke engines differ from those for four-stroke gasoline engines: good lubricity; piston cleanliness; low deposits, especially in the exhaust system; and low smoke emission. Two-stroke engine vehicles should use specially formulated 2T oil. As polyisobutene of moderate molecular weight tends to decompose without leaving heavy deposits, polyisobutene thickener in a base stock is increasingly used in lubricant. Japan has taken the lead in developing new motorcycle oils referred to as low-smoke or smokeless lubricants. Many three-wheelers do not use the 2T oil recommended by vehicle manufacturers. Instead they use straight mineral oil or new or recycled engine oil, which results in greater deposit buildup and higher emissions (see margin note). The principal reason for using these oils is their lower cost, although some drivers may be under the impression that these more viscous oils provide greater engine protection. In some countries, such as Bangladesh and Sri Lanka, 2T oil is not readily available at filling stations.

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*“Three-wheelers are driven much more than two-wheelers and require frequent maintenance.”*

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Conventional motor oils do not mix well with gasoline. Their use in two-stroke engine vehicles results in insufficient lubrication when oil does not reach the engine and high emissions when it does. Long-term use of conventional lubricants results in premature wear of the engine and higher maintenance costs.

#### Inadequate vehicle maintenance

Because they are mostly used commercially, three-wheelers are driven much more than two-wheelers and require frequent maintenance. Drivers often fail to maintain their vehicles properly. The problem of maintenance is particularly severe when drivers lease their vehicles, because neither the driver nor the owner feels solely responsible for the mechanical condition of the vehicle.

#### Reducing pollution while saving money

Many drivers in Bangladesh use mineral oil instead of 2T oil because it is less expensive. But switching to 2T oil would actually save most drivers money. Straight mineral oil in Dhaka sells for about 50 takas a liter, while 2T oil sells for about 90 takas a liter. A driver of a baby taxi who uses 6 liters of gasoline a day and drives 280 days a year would typically spend 6,700 takas a year adding straight mineral oil at 8% concentration. A driver who switched to a 3% concentration of 2T oil would spend just 4,500 takas a year—an annual savings of 2,200 takas. The switch to 2T oil would also reduce emissions and help maintain vehicles.

Source: Informal World Bank survey, 1999.

Vehicular emissions are exacerbated by the age of the vehicle fleet and the poor state of vehicle maintenance. A study in the United States found that poorly maintained vehicles, which represent 20% of all vehicles on the road, contributed about 80% of total vehicular emissions (Auto/Oil Air Quality, 1997). Recently three baby taxis in Dhaka, Bangladesh, from four to seven years old were randomly selected for mechanical inspection. The engineers inspecting the engines found evidence of considerable ad hoc, unauthorized repairs and modifications. A combination of inadequate or improper maintenance and repairs by poorly trained mechanics contributes to the poor mechanical state of many vehicles in developing Asian cities.

#### **Adulteration of gasoline**

Emissions by all gasoline vehicles are exacerbated by the adulteration of gasoline with kerosene. Kerosene has a higher boiling point than gasoline and is thus more difficult to burn. As a result more deposits build up in the engine and more unburned hydrocarbons are emitted in the exhaust gas. Anecdotal evidence suggests that adulteration of gasoline is widespread in South Asia, for example, due to the significantly lower retail price of kerosene. Limited sampling and testing of gasoline by the World Bank in Dhaka in 1998 also indicated that a significant fraction of gasoline was adulterated.

#### **Lack of catalytic converters**

Catalytic converters — installed in passenger cars in many parts of the world where unleaded gasoline is readily available — cannot be used to convert a high proportion of hydrocarbons in two-stroke engines because current designs result in greater exotherm (heat of reaction) and the sintering of precious metals, which deactivates the catalyst. The tendency of two-stroke engines to misfire under low load conditions further aggravates the problem of catalyst deactivation. Despite these limitations oxidation catalysts — which lower the emission levels of hydrocarbons and carbon monoxide and to some extent reduce the amount of fine particles emitted in the form of oil droplets — have been used in Taiwan (China) to meet increasingly tight emission standards. Beginning in 2000 these converters are installed in all new

two-stroke engine two- and three-wheel vehicles in India also to meet the stringent emission standards enforced there.

### **3.3 Impacts of emissions**

#### **Health impacts**

Research in various cities and countries has shown that  $PM_{10}$ , and especially  $PM_{2.5}$  (particles with diameters of no more than 2.5 microns, called fine particulate matter), are extremely damaging to public health. These particles are associated with respiratory symptoms, exacerbation of asthma, changes in lung function and premature death (for more background information see Module 5a: *Air Quality Management*).

The health impact of particulate matter increases as the size of the particle diminishes. Very fine particles — such as those emitted by the combustion of transportation fuels — are believed to be particularly harmful. In addition, the fact that they are emitted near ground level, close to where people live and work, suggests that vehicular emissions are even more harmful than their share in total emission loads might indicate. The health impact of oil droplet-based particles is not well understood. Most health impact studies have been carried out in countries that do not have large two-stroke engine vehicles, where the principal sources of fine particulate emissions are diesel vehicles and stationary sources. In all of these studies, sickness and death are regressed against the overall ambient particulate concentrations measured in terms of total suspended particles or  $PM_{10}$ , not against vehicular particulate emissions. Most of the particulate matter from two-stroke engines is soluble organic matter, whereas particulate matter from diesel vehicles and stationary sources contains a significant amount of graphitic carbon. Their behavior in the atmosphere in terms of nucleation, agglomeration, dispersion and condensation could be quite different. This area of research merits further investigation.

#### **Global warming impacts**

Three greenhouse gases emitted by vehicles — carbon dioxide, methane and nitrous oxide — are believed to have the potential to increase global warming. Two-stroke engines are not a major source of these emissions, however. The

transport sector accounts for an estimated 13% of carbon dioxide emissions in South Asia, ranging from 10% in Bangladesh to 48% in Sri Lanka (International Energy Agency, 1997). Emissions from two-stroke engine vehicles are relatively low because of their low fuel consumption. Two-stroke engine vehicles account for about 11% of vehicular carbon dioxide emissions (8% by two-wheelers and 3% by three-wheelers) and a very small share of methane and nitrous oxide emissions.

Only 1–2% of total greenhouse gases in South Asia can thus be tied to two-stroke engine vehicles. This very minor contribution of two-stroke engine vehicles to greenhouse gas emissions suggests that efforts to reduce such emissions should target other types of vehicles, such as heavy-duty buses and trucks, and sectors other than transport. Nevertheless, mitigation measures that reduce local pollution from two-stroke engines may lead to reduced greenhouse gas emissions as well. Examples of such measures include switching to more fuel-efficient four-stroke engines and switching to electric vehicles, especially where the electricity used to charge the vehicles is generated using a clean fuel such as natural gas. It must be noted that several countries in the Asian region are rapidly changing over from two-stroke to four-stroke engines for most of the two-wheelers. Notable among these are Thailand, Taiwan (China) and India. Viet Nam has already had a preference for four-stroke powered two-wheelers. Introduction of progressively stringent emission standards and changing customer preferences have led to these trends.

Battery driven electric vehicles of small capacities are becoming increasingly popular in China with the market reaching 20 million in 2007 (Cherry, Weinert, Xinmiao, 2008).

A detailed study of the energy consumption and life cycle emissions of the Chinese electric bikes showed that, compared to a motorcycle, electric bikes are much more energy efficient and have orders of magnitude of fewer emissions of most pollutants. The study, however, found that bicycles outperform all modes in terms of environmental impacts. A major consideration in case of electric bikes is the environmental impact of the lead used in the batteries. Lead pollution of electric bike battery production and disposal

processes are two orders of magnitude higher than buses on a per passenger-km basis (Cherry, Weinert, Ma, 2006).

A section in this module will discuss the environmental impacts of electric bikes with case studies from China.

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*“Bicycles outperform all modes in terms of environmental impacts.”*

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Recent developments in direct injection of fuel in the two-stroke engine seem to hold a promise not only to bring down the emission of pollutants, but also to reduce fuel consumption and CO<sub>2</sub> emissions (Johnson, 2001). Limited application of this technology in small two-wheelers and three-wheelers has already begun in Italy, China and India.

### 3.4 Reducing emissions from two-stroke engine vehicles

With the exception of India, Taiwan (China) and Thailand, most countries in Asia have not yet adopted strong measures to mitigate emissions from two-stroke engines. These include use of low-smoke lubricants, installation of oxidation catalysts and mechanical metering of lubricant. This section examines ways to improve the functioning of two-stroke engines. The following section looks at alternatives to two-stroke gasoline engines.

#### Vehicle technologies

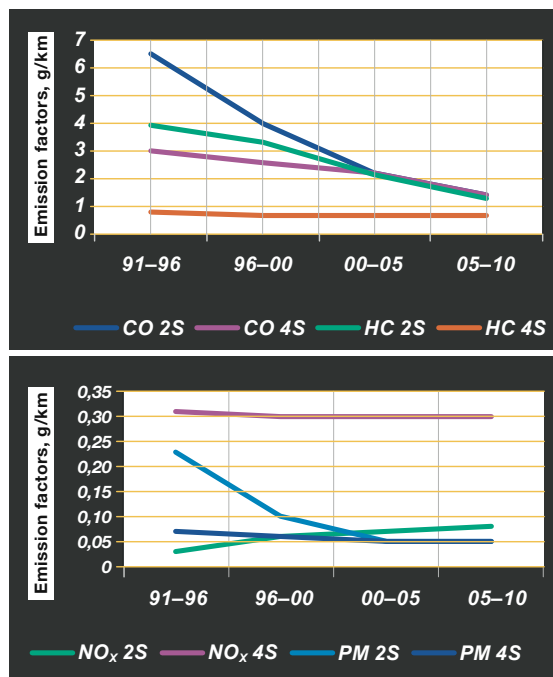
##### *Recent declines in emissions*

Emission factors of new and well-maintained two-wheelers using the correct amount of lubricant have declined in recent years. Figure 12 shows the progressive reduction over the last decade of various pollutants from two-stroke and four-stroke two-wheelers in India. Tests have shown that a scooter equipped with a catalyst, for example, emitted just 0.015 grams of particulate matter per km in a recent test, but even this emission factor is many times greater than that of a comparable four-stroke scooter.

But data on emission factors for particulate matter must be interpreted with caution. No established methodology is accepted industry wide for measuring particulate emissions from

**Fig. 12**  
*Progressive reduction of emission factors due to stringent emission norms in India.*

Transport Fuel Quality for Year 2005, CPCB, December 2000



two-stroke engines. Nearly all the work carried out on two-stroke engine vehicles has focused on reducing hydrocarbons (or the sum of hydrocarbons and nitrogen oxides), carbon monoxide and visible smoke. No in-depth study has been conducted on particulate emissions.

***“No in-depth study has been conducted on particulate matter (PM) from two-stroke engine vehicles.”***

Measurement of particulate matter emissions from two-stroke engines is difficult because oil droplets from lubricant added to gasoline on a pass-through basis account for a large fraction of particulate matter in the exhaust gas. Depending on the dilution rate and the temperature to which the line downstream of the exhaust pipe (including the dilution tunnel) is heated, these droplets can condense before being collected on filter paper. Oil samples condensed on filter papers can also be lost as a result of the passage of gas through the filter. A recent study sponsored by the European Commission has confirmed the fact that the current techniques used for measuring diesel engine PM emissions are not likely to be adequate for reproducible 2-stroke PM measurements in the future two-wheelers. Vehicles designed to comply with stringent emission standards, such as those in

India, Taiwan and Euro 3, exhibit lower PM emissions — up to 90% lower than uncontrolled vehicles. The study further concluded that adequate understanding of the health effects of engine produced PM emissions ought to be the basis of any legislative limitation of such emissions (Rudolf *et al.*, 2005).

### ***Installing catalytic converters***

Catalytic converters for two- and three-wheelers are oxidation catalysts, which reduce the level of carbon monoxide (CO) and hydrocarbon (HC) emissions but not nitrogen oxides (NO<sub>x</sub>), rather than three-way catalysts commonly installed in passenger cars, which also reduce nitrogen oxide emissions. Catalytic converters for two-stroke engines are not designed to achieve as high a level of conversion of CO and HC as those for four-stroke engine passenger cars because of the greater quantity of HC and lubricant in the exhaust gas. They typically reduce exhaust emissions by half. Catalytic converters, basically designed for reducing CO and HC emissions also reduce PM emissions from two-stroke engines. The extent of reduction varies from half (Palke *et al.*, 1999) to one third (Kojima *et al.*, 2002).

***“Catalysts deactivate more rapidly in two-stroke engine vehicles... and need to be replaced frequently.”***

Catalysts deactivate more rapidly in two-stroke engine vehicles, partly because of higher exhaust gas temperature and need to be replaced frequently. Taiwan (China) has had catalyst durability requirements for motorcycles for some time, initially set at 6,000 km and at 15,000 km today.

A recent Indian Government regulation specifies a fixed Deterioration Factor of 1.2 for two- and three-wheelers equipped with oxidation catalytic converters to account for catalyst durability. The vehicle manufacturer is given an option to carry out a durability test for 30,000 km. For three-wheelers in South Asia, which are often driven 120 km a day, 15,000 km is equivalent to less than six months of operation. For a vehicle driven 10 years or more, as many two-stroke vehicles in developing Asian cities are, the catalyst might have to be replaced up to 20 times to

maintain the original level of particulate emissions. This is clearly a problem.

In India all manufacturers of two- and three-wheeled vehicles offer their customers an emission warranty of 30,000 km. Though this was initially proposed by the manufacturers to address the durability requirement of catalytic converters, it is now offered irrespective of whether the vehicle is equipped with catalytic converters or not. Catalyst durability of 30,000 km would enable drivers to replace their catalysts at the same intervals as they have their engines overhauled. The Regional Workshop (2001) *Synthesis* notes, to be enforceable these warranties will require specific conditions regarding fuels, lubricants and maintenance, which are realistic in terms of actual in-use conditions. Government will be required to monitor the in-use performance of the catalysts, with the potential for costly recall programs.

To meet year 2000 emission standards, the three-wheelers manufactured in India are equipped with catalytic converters for both two-stroke and four-stroke engine designs.

The net-of-tax cost of the catalytic converter fitted in three-wheelers for both engines is approximately 1,100 Indian rupees, or approx. US\$25. Prices of catalytic converters depend upon the prices of the costly noble metals that go into their manufacture. Introduction of progressively more stringent emission standards necessitates the use of higher amounts of noble metals with an adverse impact on their prices. However, the recent developments of highly efficient turbulent metallic substrate technologies transform the laminar exhaust flow to a turbulent flow, significantly improving exhaust gas mixing behaviour in the catalyst, resulting in improved catalytic activity and pollutant conversion. These technologies can be exploited to reduce catalyst size & volume thereby resulting in lowered system costs due to the reduced use of costly precious metals (Shivraj, 2008).

### **Reducing scavenging losses**

A major area of research and development has been the attempt to reduce scavenging losses to increase fuel economy and reduce emissions (see Box 2). Substantial reductions have been achieved by designing better port

configurations. In India, for example, short-circuiting fuel losses have been reduced from 35% in 1991 to as low as 14% in the year 2000 model as a result of design changes (Iyer, 1999).

### **Improving gasoline quality**

The adulteration of gasoline with kerosene is likely to increase hydrocarbon and particulate emissions. Because some of the gasoline effectively bypasses the combustion chamber and is emitted uncombusted by the two-stroke engine, eliminating or reducing such toxic components as organic lead and benzene from gasoline — a worthwhile step under any circumstances — is particularly important to mitigate the health impact of toxic emissions from two-stroke engines.

The high gum content and low octane level of gasoline also increase emissions. If gasoline is unstable the gum content may become unacceptably high, leading to the deterioration of carburetor settings and increased deposits, which alter the air-to-fuel ratio. This in turn could cause the engine to misfire, damaging the vehicle and significantly increasing emissions of hydrocarbons and particulate matter comprising

### **Box 2: Reducing scavenging losses in two-stroke engines**

Adapted from Kojima *et al.*, 2000

Several technologies are being tested to reduce emissions from two-stroke engines. The goal is to retain the advantages of the two-stroke engine while gaining control over the air-to-fuel ratio and eliminating the loss of air-fuel mixture through the exhaust port.

Injecting fuel into the engine instead of introducing it through the carburetor may dramatically reduce or eliminate scavenging losses. Direct injection of the fuel into the engine also makes it possible to use leaner air-fuel mixtures.

The effectiveness of a variety of systems that could be suitable for small engines has been demonstrated in laboratories, although only one of them has been developed commercially on a limited scale (Johnson, 2001). All of these measures would require an electronic engine management system for precise control of the fuel injection timing and quantity, depending on the engine load and speed. They would thus add to the cost of the vehicle.

oil droplets. Experience in India shows that the use of gasoline with a high gum content in four-stroke engine two and three wheelers leads to an accelerated deposit build up on the intake valve and can lead to valve sticking, and, in extreme cases, to valve bending and consequential engine damage. While the minimum research octane number (RON) requirement for two- and three-wheelers in South Asia is 87. Most countries in the South Asian region have petrol RON that is above the requirement of 87. The RON of regular petrol in India is 87 and that of Premium is 91. Unleaded petrol is available throughout Sri Lanka and, from December 2003, sale of leaded petrol (lead content exceeding 0.013 g/litre) is banned. The RON of regular grade petrol in Sri Lanka is 90 and that of the premium grade is 95. Pakistan also phased out lead in the year 2001. Two grades of petrol with 87 RON and 90 RON respectively are available. Nepal also phased out lead from petrol in the year 2000 and the petrol there has a RON of 88. In July 1999, Bangladesh made a landmark decision to phase out lead though the RON was retained at 80. A low Octane Number can adversely affect the vehicle

performance due to severe engine knock, which can lead to increase in emissions (Gota, 2009).<sup>1)</sup>

### Improving enforcement

It is not enough to regulate fuel quality. In some developing countries transport fuels are routinely adulterated. For example, the addition of (lower-cost) kerosene to gasoline in South Asia, cross-contamination of diesel with crude oil, and addition of lead additives to gasoline downstream of refineries or terminals in Central Asia and the Caucasus all increases vehicle emissions. Regular fuel quality monitoring, together with costly penalties for noncompliance could help enforce fuel standards more effectively, though preventing local adulteration is likely to remain very difficult as long as there is a financial incentive to engage in the practice.

Thailand's experience (World Bank, 2001, citing J. Shah) shows the difficulty of preventing fuel adulteration in the face of contrary financial incentives. Adulteration of heavily taxed gasoline by highly subsidized kerosene was a serious problem in Thailand in the early 1980s. The

<sup>1)</sup> Gota Sudhir, Clean Air Initiative – Asia, "Personal Communication" March 2009

## Effect of Lubricant Quality and Quantity on Reducing PM Emissions

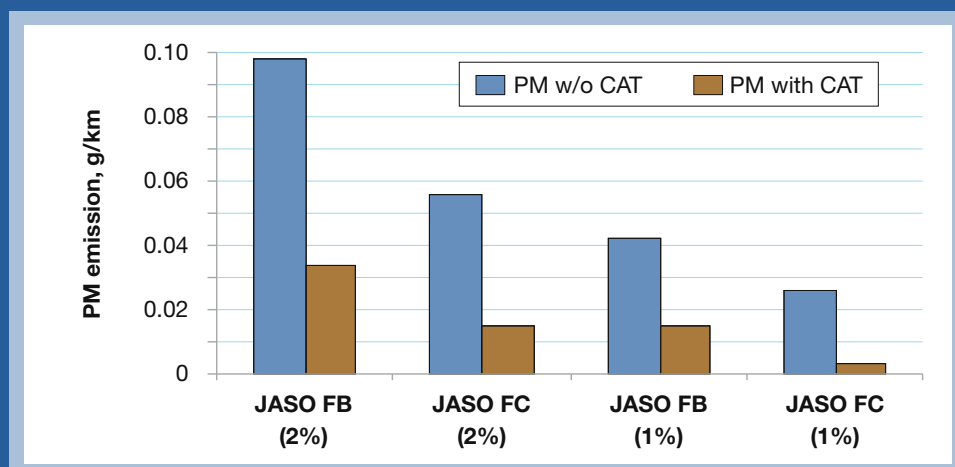


Fig. 13

*Effect of lubricant quality and quantity on reducing PM emissions.*

JASO FB: Lower Smoke Index oil  
 JASO FC: Superior Smoke Index oil  
 Use of Oxidation Catalytic Converter

Source: JAMA

Source: Iyer N. V. "Management on In-use Motorcycle Emissions – The Indian Experience", Workshop on Motorcycle Emission Control: Vietnamese and international experience, Hanoi, Viet Nam, 6 March 2007, <http://www.theicct.org>

government introduced a number of measures, including:

- dying of the kerosene blue,
- requiring it to be sold in 20 liter containers,
- extensive police enforcement efforts.

Although these measures had some effect sales of kerosene remained high until oil taxes were restructured in 1986 and the tax on kerosene increased to remove the incentive to adulterate. However, the incentive to adulterate gasoline with untaxed industrial solvents remains and such adulteration is a continuing problem.

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*“...incentive to adulterate gasoline with untaxed industrial solvents remains and is a continuing problem...”*

---

The Centre for Science and Environment (CSE), a prominent NGO, was asked by the Government authorities to make an independent study of the rampant fuel adulteration problem in India. They found that adulterants such as kerosene and a variety of solvents were mixed with petrol and diesel. While the dye method is used to detect adulteration by kerosene, it was not possible to adopt this method for the other solvents. An important observation is that, since these adulterants belong to the hydrocarbon families similar to those of the fuels, some amount of mixing was always possible without changing the overall parameters of the fuel specifications. It was thus not possible to detect them using the standard test procedures given in the national specifications (Bureau of Indian Standards) to establish compliance, and more sophisticated tests such as gas-chromatography had to be used (<http://www.cseindia.org>).

### **Improving lubricant use Standards for lubricants**

In the mid-1980s the American Petroleum Institute (API) and the Coordinating European Council for the Development of Performance Tests for Transportation Fuels, Lubricants, and Other Fluids set up a provisional two-stroke lubricant performance and service classification list. API canceled the system in 1993, deferring to the International Organization for Standardization

(ISO) global specification and the Japanese Standards Organization (JASO) system. Oil marketers continue to use the outdated test criteria established for API TC to certify air-cooled oils. The API TC classification is currently the lowest acceptable level of 2T oil quality.

In 1990 JASO created a two-stroke lubricant standard with three levels of quality (FA, FB and FC). Lubricity and detergency quality increase from FA to FC, and exhaust blocking and smoke emission improve. Maximum permissible levels of smoke density are 50% for FA oil, 44% for FB oil and 24% for FC oil. Japanese manufacturers of two-stroke vehicles identify FC (low-smoke lubricants) as their minimum requirement.

Since April 1999 in India all two-stroke engine oils sold in the country are required to meet both API TC and JASO FC specifications (that is, only low-smoke lubricating oils can be used in India). Further, as per a notification of the Ministry of Environment and Forests issued in December 1998, 2T oil can be sold in the National Capital Territory of Delhi only in sealed packages or premixed with gasoline and dispensed through the pump nozzle. This ban on unsealed packages is intended to discourage the sale of recycled and other unsuitable engine oils. The sale of premixed gasoline is intended to encourage the use of not only the suitable quality but also the correct amount of 2T oil. The Government of India, through a recent notification issued in November 2006, has extended the rule regarding the supply of 2T oil only in a premixed form to sixteen more cities.<sup>2)</sup>

### **Using the correct concentration of lubricant**

The use of the correct amount of 2T oil significantly reduces two-stroke vehicular emissions. New lubricant formulations even allow certain makes of two-wheelers to cut the lubricant requirement to just 1%.

### **Using low-smoke lubricant**

The use of low-smoke lubricant significantly reduces emissions of visible smoke. The retail

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<sup>2)</sup> GSR 714 (E), Ministry of Environment and Forests, Government of India, 17 November 2006 and GSR 778 (E), Ministry of Environment and Forests, 31 December 1998.

prices of lubricants in India in March 2000 are given in Table 4. If drivers using 6% JASO FB oil cut back the amount of lubricant to 3% and simultaneously switch to JASO FC (low-smoke lubricant), they can realize savings of about 35% in lubricant costs.

In Bangkok, several motorcycles with varying levels of visible smoke emissions were selected to see if visible smoke was correlated with mass particulate emissions. The results showed a weak correlation. Results of more recent tests on three of the Dhaka in-use baby taxis carried out at ARAI showed that the correlation between smoke and mass particulate emissions was poor below 1 g/km (Kojima *et al.*, 2002).

Limited data on the impact of switching from regular 2T oil to low-smoke lubricant on particulate emissions from the above studies also indicate that while low-smoke lubricant may reduce visible smoke, it may not reduce mass particulate emissions except when compared with that of straight mineral oil. Thus the public health benefit of using low-smoke lubricant is not clear. Other studies, particularly those done in Japan, show that significant reduction two-stroke PM emissions can be achieved by simultaneously using “low smoke” (JASO FC grade) two-stroke lubricant in lower than usual proportions (1% of fuel instead of 2%) and oxidation catalytic converters designed to reduce CO and Hydrocarbon emissions can bring about a reduction in PM emission to one tenth of the uncontrolled level.

### Metering lubricant

A mechanical lubrication system, which adjusts the amount of lubricant metered into gasoline to the engine speed and load, can control the amount of lubricant added to gasoline. Such a

Table 4: Retail prices of lubricants in India, March 2000 (Indian rupees)

Lubricant	Price of lubricant per liter	Price of 3% oil/liter of gasoline	Price of 6% oil per liter of gasoline
Two-stroke oil meeting JASO FB standard	80 – 90	2.4 – 2.7	4.8 – 5.4
Two -stroke oil meeting API TC and JASO FC standards	100 – 120	3.0 – 3.6	6.0 – 7.2
Crankcase oil meeting API standard SC <sup>a)</sup>	80 – 90	2.4 – 2.7	4.8 – 5.4

Kojima *et al.*, 2000

Note: <sup>a)</sup> API SC is a grade of crankcase oil for 4-stroke engine gasoline vehicles

### Box 3: Improving lubricant use

Synthesis, Regional Workshop, 2001,  
<http://adb.org/vehicle-emissions>

- The available data indicates that for two-stroke engines, most of the very high hydrocarbon emissions are composed of unburned fuel. Similarly, a major component of the particulate, which also shows up as a ‘white smoke’, is unburned lubricants. Banning the sale of loose two-stroke lubricants can substantially reduce excess PM and smoke emissions.
- Lowering the benzene content of the fuel can reduce the benzene content of the exhaust hydrocarbons and the toxicity of the exhaust. Therefore, some countries need to better regulate the benzene content of their gasoline to minimize this toxic risk.
- In order to use catalytic converters to reduce emissions from two-stroke engines, the use of lead free fuel is necessary. Further, catalyst performance can only be optimized with very low levels of sulfur in the fuel.
- Oxygenated blends in the fuel will reduce CO emissions from two-stroke engines; CO and HC emissions can be significantly reduced with oxygenated blends in catalytic converter equipped vehicles.
- Emissions of smoke, hydrocarbons and particulates from two-stroke engines increase as the consumption of oil increases. Premixing of oil and fuel at dispensing stations helps tremendously in controlling excess consumption. Further initial evidence indicates the use of a separate oil pump may help to optimize the oil consumption, providing good lubrication but with much lower emissions.
- Higher performance two-stroke engine oils, which allow even lower oil to fuel ratios, will further reduce oil consumption and concomitant smoke and PM emissions; the use of mineral oils that do not contain an appropriate additive package should be eliminated.
- Superior quality lube oils such as JASO FC can also reduce smoke emissions.

system reduces emissions by making it impossible for drivers to add excess lubricant to gasoline. However, mechanical lubrication may not yield any greater benefits than drivers adding the correct amount of lubricant.

### Improving maintenance

The importance of an effective inspection and maintenance program cannot be



overemphasized: proper maintenance is critical to reaping the full benefits of investments in emission mitigation (also see Module 4b: *Inspection & Maintenance and Roadworthiness*). Simple servicing procedures, such as cleaning and adjusting the carburetor, adjusting the ignition system, cleaning and adjusting or replacing spark plugs, and cleaning air filters, can reduce exhaust emission levels significantly. Air filters should be cleaned or replaced every 3,000 km. Carburetors should be tuned and cleaned every 3,000 km for two-stroke engines and every 5,000 km for four-stroke engines.

As lubricant passes through the two-stroke engine on a once-through basis, there is considerably more deposition and accumulation of carbonaceous deposits in the combustion chamber, exhaust port and silencer than in four-stroke engine vehicles. As a result more frequent decarbonization is needed. Bajaj Auto recommends decarbonization every 6,000 km for three-wheelers and 9,000 km for scooters. Four-stroke engines do not normally need decarbonization. Bajaj also recommends replacing spark plugs every 7,500 km for two-stroke engines and every 10,000 km for four-stroke engines. Decarbonization requires mainly labor, which is relatively cheap in developing cities, keeping maintenance costs low.

It is not clear whether long-run maintenance costs are higher for two-stroke or four-stroke engines. Four-stroke engines have many more moving parts (valves, camshafts, timing chains, oil pumps), which are relatively expensive because they tend to be sold by vehicle manufacturers. In contrast, parts for two-stroke engines are sold by a large number of parts suppliers. Labor costs for servicing four-stroke engines are also higher because of the higher level of skills required. Engine overhauls for two-stroke engines are more expensive, however. Minor engine overhauls, not normally required on four-stroke engines, are typically required every 30,000 km for two-stroke engines. Major overhauls, which may also be needed on four-stroke engines, are required every 90,000 km for two-stroke engine three-wheelers.



### Retrofitting Programmes

Retrofitting of emission control devices such as catalytic converters on petrol vehicles or particulate filters on diesel vehicles has been successfully done in some countries. There have not been many successful retrofit programmes for two and three-wheelers except those for converting three-wheelers to operate on CNG or LPG. Recently, 'Envirofit' a not-for-profit organization, has been pursuing an innovative programme in the Indian city of Pune where the two-stroke engine auto-rickshaws are retrofitted with a Direct Injection kit in place of the original carburetor. Actual results obtained during normal operation of three auto-rickshaws for a period of six months have shown a 35% reduction in fuel consumption, a 54% reduction in oil consumption, a 61% reduction in CO and a 74% reduction in HC + NO<sub>x</sub> (Nathan, 2008).

Earlier studies done by Envirofit in the Philippines involving the tricycles showed similar improvement in fuel efficiency and reduction in CO, Hydrocarbon and NO<sub>x</sub> emissions (Tim, Nathan, Bryan, 2004).

On account of the large fuel efficiency benefit, the retrofit, despite its high cost, could be an attractive proposition for in-use three-wheelers.

Fig. 14

*Improper lubrication practices lead to heavy white smoke emission from 2-stroke motorcycles.*

Karl Fjellstrom, Dec. 2001,  
Kuala Lumpur

#### Box 4: Fuel conversion programs for two- and three-wheelers

*Synthesis*, Regional Workshop, 2001, <http://adb.org/vehicle-emissions>

- Alternative fuels and advanced vehicle technologies offer opportunities for significant reductions in emissions of 2–3 wheeled vehicles and increases in efficiency. The different alternative fuels and technologies are in various stages of development and each has unique performance and emission characteristics.
- Two wheeled vehicles are not seen as attractive candidates for conversion to alternative fuels and there have been very few successful efforts so far to convert these vehicles with the notable exception of electric motorcycles.
- With regard to three wheeled vehicles, conversions to both LPG and CNG have been well established as a viable technology. For example, tuk-tuks in Bangkok have been operating successfully on LPG for many years. 3-wheeled vehicles are operating quite satisfactorily on CNG in India.
- For lowering PM and HC emissions, the best strategy for three-wheelers is to replace the existing gasoline fueled, two-stroke engine with a CNG or LPG fueled four-stroke engine.
- Conversion of three wheeled vehicles to CNG and or LPG is primarily a niche market at present with limited numbers of vehicles affected. The size of the market is dependent on the number of three wheeled vehicles in a given local area as well as the available fuels infrastructure.
- Conversion kits and alternative fuel systems must be subjected to a type approval process based on the local vehicles that will be subjected to the fuel switch; good quality control procedures during the installation of the kits should also be carried out.
- An alternative fuels conversion program needs an effective in-use testing program to assure that the individual conversions are performed properly and that the vehicles are subsequently maintained and used properly.
- An alternative fuels conversion program requires the active involvement of the government to assure the safety of the modified vehicles as well as the fueling system. Beyond safety, government has the responsibility to assure that an adequate fuels infrastructure is provided. This includes assuring that there is an adequate supply of fuel, that it is widely distributed throughout the affected geographical area, and that the fueling stations have appropriate design to assure rapid fueling of the individual vehicles that are presented for fueling.
- There is a great need for improvement of coordination within government and between government and the energy sector as well as the automotive industry in developing comprehensive policies on alternative fuels.
- A major impediment to the use of alternative fuels is the need to provide fueling infrastructure. Governments and the energy industry need to develop realistic policies on the development of fueling infrastructure and the necessary supportive service industry.
- To facilitate the introduction of alternative fuels, technical and financial [pricing] considerations should be dealt with simultaneously.
- Decision making on alternative fuels should be based on a well to wheel life cycle analysis. The results of this assessment should be applied to a policy framework that integrates energy, transport and environment considerations.
- Policy making on alternative fuels should initially focus on those alternative fuels such as LPG and CNG, which are most ready for large-scale use.
- The emissions impact of alternative fuels in an urban area is largely dependent on the vehicle or engine technology used, and the state of maintenance of the vehicle. As a general rule, purpose built engines for the exclusive use of CNG or LPG are generally cleaner, safer and more efficient than engines that have been modified.

### 3.5 Alternatives to two-stroke gasoline engines

Vehicle and fuel alternatives to two-stroke gasoline engines can reduce exhaust emissions. Cleaner alternatives include four-stroke engines and engines powered by liquefied petroleum gas, compressed natural gas and electricity.

LPG, CNG and electric vehicles are discussed only briefly, as these alternatives are discussed in more detail in Module 4a: *Cleaner Fuels and Vehicle Technologies*, and Module 4d: *Natural Gas Vehicles*. Further, a section of this module also discusses on the environmental impacts of electric bikes in China.

#### Four-stroke gasoline engines

Four-stroke vehicles have significant advantages over two-stroke vehicles. These include:

- Much improved fuel economy.
- Much less pollution (PM, HC, CO<sub>2</sub>, but higher NO<sub>x</sub> emissions) — “green product label” for both local and global pollution.
- Much less noise.
- Four-stroke motorcycles in the market are not much higher in price than comparable two-stroke versions. (The cost of a four-stroke engine is around 15% higher than the cost of comparable two-stroke engine, though this does not often get reflected in the market prices of products due to competitive considerations).
- Established technology.

If gasoline is retained as the fuel of choice, replacing two-stroke vehicles with four-stroke vehicles would significantly reduce hydrocarbon (Figure 15) and particulate (Figure 16) emissions. Emissions of nitrogen oxide would, however, increase.

There are no scavenging losses in four-stroke engines; a much larger percentage of the fuel is combusted in the combustion chamber, resulting in 10–20% greater fuel efficiency (Table 5). Savings from better fuel economy would easily offset the higher purchase price of four-stroke engine vehicles, making this a potentially strongly cost-effective way to reduce pollution.

Four-stroke engine two-wheelers have been on the market for some time. All motorcycles sold in the United States are of four-stroke design.

Mishuk in Bangladesh has been selling four-stroke engine three-wheelers for a number of years. Four-stroke engine three-wheelers were not available in India until mid-2000, when Bajaj Auto began marketing them there. Year 2000 model three-wheelers are equipped with catalytic converters for both two-stroke and four-stroke engines. At the time of the launch, the ex-Delhi showroom prices of these vehicles were Rs66,579 for two-stroke and Rs70,463 for four-stroke engine three-wheelers, with a price difference of Rs3,884 (US\$88). Even though the actual prices of these vehicles might have undergone changes over the years, the incremental cost of the four-stroke vehicle over the two-stroke vehicle would be in the same proportion. This incremental cost is easily recovered in fuel savings in less than a year by operators of four-stroke engine auto-rickshaws.

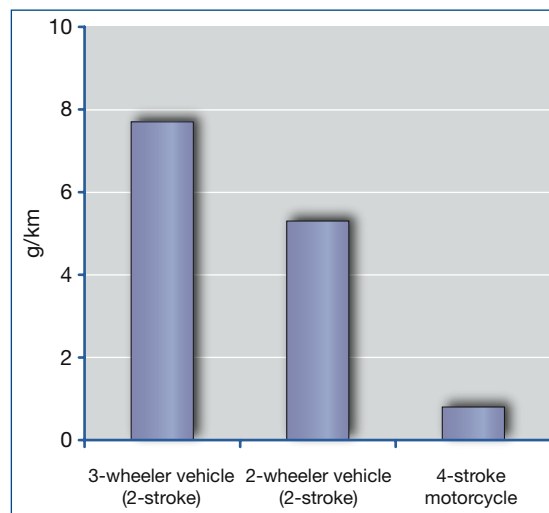


Fig. 15  
*Emission factors for hydrocarbons: two-stroke vs. four-stroke vehicles.*  
Shah, 2001

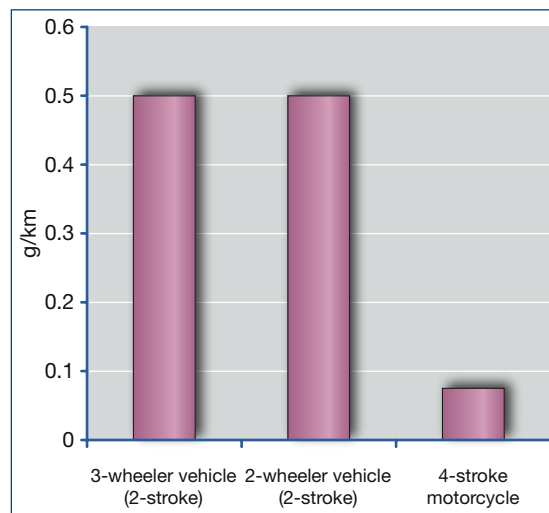


Fig. 16  
*Emission factors for fine particulates PM<sub>10</sub>: two-stroke vs. four-stroke vehicles.*  
Shah, 2001

**Table 5: Fuel economy of two-stroke and four-stroke engine vehicles**

Vehicle type	Engine type	Model year	Engine size (cm <sup>3</sup> )	Laboratory test fuel economy (km per liter)	On-road fuel economy (km per liter)
Scooter	2-stroke	Post-1996	150	55	52
Scooter	4-stroke	Post-1996	150	62	59
3-wheeler	2-stroke	Pre-1996	150	24	20
3-wheeler	2-stroke	Post-1996	150	28	25–27
3-wheeler	4-stroke	2000	175	33	30–31

Source: World Bank 2000, from ARAI test of Bajaj vehicles using the Indian driving cycle;

Bajaj laboratory tests;

ARAI and Bajaj estimates for on-road fuel economy.

Diesel three-wheelers have even higher fuel efficiency than four-stroke petrol engine vehicles., Moreover, because they are based on a four-stroke engine design, lubricant does not need to be added to the fuel. Diesel three-wheelers in India are also manufactured to meet particulate matter emission standards. However, diesel exhaust has recently been found to be more toxic than previously believed. And diesel three-wheelers are considerably noisier than gasoline three-wheelers. Diesel engines are thus probably not a good alternative to gasoline-powered two-stroke engines.

### Vehicles powered by Liquefied Petroleum Gas

Liquefied petroleum gas (LPG) is a mixture of light hydrocarbons, mainly propane/ propene and butane/butenes. It is easier to distribute and store than compressed natural gas, liquefied at pressures of 4–15 bar.

LPG is a much cleaner automotive fuel than gasoline. If LPG (or CNG) vehicles are based on a two-stroke engine design, lubricant will still need to be metered and injected into the combustion chamber, thereby partially offsetting the emission reductions achieved as a result of replacing gasoline with a gaseous fuel. Since lubricant cannot be premixed with LPG, it is metered into the vehicle engine, eliminating the possibility of over lubrication. LPG also contains fewer highly reactive hydrocarbons and has lower sulfur content than gasoline or diesel fuel. LPG does contain light olefins, highly reactive hydrocarbons that increase emissions and lower the knock-limited compression ratio, diminishing engine performance.

LPG three-wheelers, called ‘tuk-tuks’, are used widely in Thailand. Until the year 2000, use of LPG as a vehicle fuel was illegal in India since it is widely used as a kitchen fuel and attracts a large government subsidy. However, the Indian Government has since allowed the use of LPG as an automotive fuel and is making efforts to popularize its use as an environmentally clean alternative. All the major oil companies in India, most of them government owned, have drawn up plans to install LPG dispensing stations in the major cities across the country. While not as good as CNG, LPG has superior antiknock characteristics compared to gasoline. Propane has an antiknock index (the average of research and motor octane numbers) of 104, allowing LPG-powered engines to operate at slightly higher compression ratios than gasoline powered vehicles. A minimum motor octane number of 88 is specified for LPG to ensure this.

Though it is technically feasible to use LPG as a fuel on two-wheelers, the quantity of LPG that can be carried on board is less than the quantity of liquid fuel in terms of energy content. This imposes a restriction on the range of the vehicle requiring more frequent refueling. This limitation is particularly severe on two-wheelers like mopeds and motorcycles, but is less severe on scooters that are provided with a storage space.

The main problems in introducing LPG into the transport sector in many developing cities are the lack of sufficient domestic sources of supply and the inadequate distribution system, as well as a lack of investment in refueling stations. Pakistan and Sri Lanka import about 30–40% of LPG consumption. In India, the domestic production presently just equals the consumption as a kitchen fuel and most of the automotive LPG may have to be imported. There is also a need to invest in refueling equipment required to transfer pressurized LPG from storage tanks to vehicles and to ensure that no LPG escapes during refueling.

### Vehicles powered by Compressed Natural Gas

Switching to CNG reduces particulate matter and hydrocarbon emissions significantly. The combustion of CNG also yields essentially no volatile organic compounds or sulfur oxide

emissions. Moreover, because natural gas is lighter than air, on escape it will not lie on the ground or enter sewage systems. CNG is expensive to distribute and store, however, requiring compression pressure to about 200 bar.

Both Bangladesh and Pakistan are piloting the use of CNG vehicles. In Bangladesh a pilot program funded by the Canadian International Development Agency converted four three-wheelers in mid-2000; by September 2002 more than 2000 conversions had been carried out (Clean City Vehicles Workshop, IEA, Paris, 24–25 September 2002). In Pakistan a donor-funded program plans to test 10–30 vehicles in Karachi, Lahore and Quetta. In both programs one tank of CNG is estimated to have a range of about 100 km. Bajaj Auto in India has developed CNG-powered three-wheelers based on a four-stroke engine design, which it launched in mid-2000. The vehicle has been into series production since then. “Over 38,000 of these are running in the city of Delhi and 15,000 in the city of Mumbai. Nearly 10,000 of these vehicles are also operating in Dhaka, Bangladesh.”

As in the case of LPG, the use CNG as a fuel for two-wheelers imposes a limitation on the range of the vehicle. The restriction is more severe than for LPG since CNG is stored at 200 bar pressure in a gaseous form and the quantity in terms of energy equivalent is even less than that of LPG.

Vehicles can be produced to run on either CNG or gasoline. However, since they are not optimized for dedicated CNG operation, such vehicles make less efficient use of CNG, losing about 10–15% of their power output. Efficiency is also lost as a result of the extra weight of carrying two fuel systems.

Methane, which constitutes the bulk of CNG, has an antiknock index of more than 120. Vehicles that run on CNG can thus take advantage of the high octane number of the fuel and operate at a high compression ratio. In practice the composition of pipeline natural gas varies, depending on the source and processing of the gas as well as the time of the year. As a result, not only does the fuel octane number vary but the heating value can vary by as much as 25%, affecting vehicle performance. Moreover, when used as fuel in vehicles, the heavier



**Fig. 17**  
*Traditional Bangkok tuk-tuks now run on LPG.*

Karl Fjellstrom, 2001

hydrocarbons in natural gas can condense and revaporize, affecting the level of fuel enrichment. Changes in fuel enrichment affect both emissions and engine performance. The water content of natural gas is also a concern because of its tendency to form solid hydrates and corrode transmission pipes, vehicle storage tanks, and refueling stations.

The long-term viability of CNG vehicles depends on a favorable legislative and regulatory atmosphere and fuel prices that are not distorted by subsidies. Efforts to encourage the purchase of CNG vehicles through subsidization are unsustainable — as New Zealand’s failed attempt to jumpstart the conversion to CNG illustrates. New Zealand’s aggressive program of financial incentives, including subsidies, led to the conversion of 110,000 vehicles to natural gas between the early 1980s and 1986. When the government withdrew its support, however, the market for CNG vehicles essentially died: today only about 10,000 such vehicles remain on the road. As the International Association for Natural Gas Vehicles put it:

Governments that believe that all they need is a two- to three-year kick-start are wasting their time and money (Cumming, 1997 in World Bank, 2000).

For converting to natural gas to make economic sense, the retail price of CNG needs to fall to about 55–65% of the cost of the fuel being replaced. Without consistently lower prices, promotion of CNG vehicles will not be sustainable.

But governments have a disincentive to reduce the price of CNG since this would reduce their tax revenues as consumers shift from (taxed) fuels to (essentially untaxed) CNG.

*“Governments that believe that all they need is a two- to three-year kick-start are wasting their time and money.”*

Cumming, 1997 in World Bank, 2000

In countries such as India that will soon start importing liquefied natural gas on a large scale (a source of natural gas in the future), it would be difficult to keep CNG prices much lower than gasoline prices if world crude oil prices were to fall markedly. The recent finds of large Natural Gas deposits in the Krishna-Godavari basin off the Eastern coast of the country, which may go into production over the next few years may, however, radically change the CNG pricing structure and LNG import plans.

In contrast, Bangladesh, which has large natural gas reserves and extensive networks of gas pipelines in large cities, might be able to introduce CNG into the transport sector without compromising other needs in the economy. However, natural gas is effectively subsidized in Bangladesh. In 1998 the price of natural gas

was estimated to average about 25% less than its economic opportunity cost. Once the gas sector is restructured to reflect market prices, the economics of CNG vehicles will become less favorable than they are today — something that must be considered in assessing a CNG vehicle program.

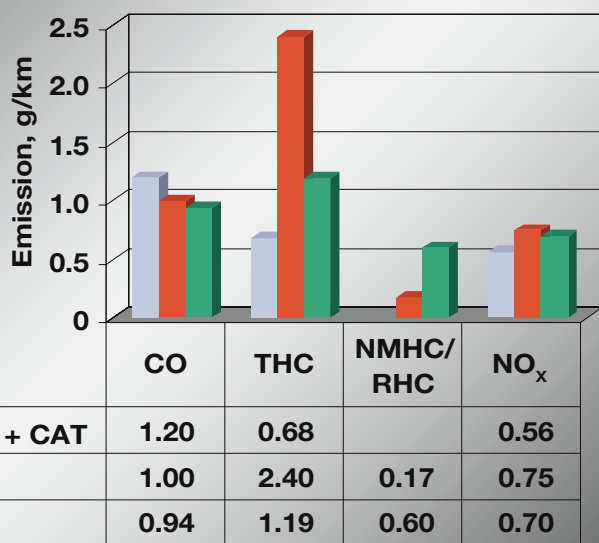
### Emission characteristics of vehicles operating on CNG and LPG

It is often believed that use of CNG and LPG in engines helps to reduce most of the emissions significantly. Actual results, however, depend upon the type of the engine. Emissions of PM and Hydrocarbons are reduced significantly when a diesel engine is converted to operate on CNG or LPG. However, the improvements are limited when an original petrol engine is converted to operate on these gaseous fuels. The comparative emission characteristics of the Indian auto-rickshaws powered alternatively CNG, LPG and petrol are shown in Figure 18 (Iyer, 2004).

The petrol version was fitted with catalytic converter. It is seen that there is a reduction of about 20% in the emission of CO with both CNG and LPG compared to petrol operation. The NO<sub>x</sub> emissions are higher by about 30% with CNG and LPG compared to the petrol version. The Total Hydrocarbon (THC) emissions actually seem to go up. However, the ‘Non-Methane Hydrocarbon’ (NHMC) emis-

sions are much lower with CNG than the THC of the petrol version. In case of LPG, the ‘Reactive Hydrocarbons’ (RHC, which are considered to be approximately half of the THC) emission is only slightly lower than that of the petrol version. Considering only NHMC is justified from the point of view of health effects of local pollution, though Methane is a potent Greenhouse Gas. NMHC emission is determined by subtracting the methane content either of the exhaust gas or that of CNG. Considering only RHC may justify considering that approximately half the volatile hydrocarbons emitted by LPG vehicles are non-reactive, which means they do not participate in the photochemical reactions in the atmosphere leading to the formation of secondary pollutants. It would, however, not be correct to assume that the

Fig. 18  
Comparative emission performance of Indian Three-wheelers with CNG and LPG.  
Iyer N. V.



NMHC: Non-Methane Hydrocarbons  
RHC: Reactive Hydrocarbons

non-reactive proportion of the Hydrocarbons emitted by all LPG engines is always half. No data on PM emissions are available since this pollutant is not routinely measured in case of Spark Ignition engine vehicles.

### Electric vehicles

Electric three-wheelers cost much more than gasoline-powered vehicles, have shorter ranges, and run on batteries that take up to 6–10 hours to recharge. Until technological changes make these vehicles more attractive, they are not expected to play an important role in developing Asian cities. However, considering their potential, several vehicle manufacturers in India are making significant efforts to develop electric three-wheelers that could become commercially viable in the foreseeable future. An Indian program under a public private partnership involving the U.S. Agency for International Development, New Generation Motors (a company that developed the drive train system) and Bajaj Auto Ltd. (a major manufacturer of two- and three-wheelers in India) has led to the development of an electric three-wheeler that may hold some promise. The vehicle uses an axial flux permanent magnet brush-less DC motor and controller that gives a superior system efficiency and hence longer range.

With a range of over 80 km per charge under actual city operating conditions, the vehicle is targeted at that half the population of ‘auto-rickshaws’ that typically operate for approximately the same distance in a ten hour day in the Indian cities — the other half having an operational range of 120 km. Through detailed life cycle cost analysis it has been indicated that this vehicle could become commercially viable if the cost of the electric drive system and accessories can result in a selling price that is no more than 25% higher than the conventional auto-rickshaw. It may be possible to achieve this price target if the vehicle is produced in large numbers. External intervention by way of fiscal incentives could perhaps help to sustain the vehicle in the market until self-supporting volumes are reached.

Electric vehicles currently operate on lead acid batteries. When the batteries are charged indoors, good ventilation is necessary, because hydrogen is emitted as lead acid batteries

recharge. Preliminary estimates in India priced the batteries at about \$40–\$50 apiece for three-wheelers that operated on eight batteries. The eight batteries and required vehicle modifications were expected to increase the cost of electric three-wheelers by about \$1,000, effectively doubling the price of the vehicles relative to gasoline-fueled three-wheelers in India.

### Box 5: Converting diesel three-wheelers to electric Tempos in Kathmandu

An important mode of public transport in Kathmandu is the Tempo, a 10-passenger three-wheeler minibuss. Before the government banned diesel Tempos in Kathmandu in 1999, about 1,500 of the vehicles operated in the city.

A pilot program to convert diesel Tempos to electricity was conducted in 1994–96 by Global Resources Institute with the support of the U.S. Agency for International Development. The electric Tempos in the pilot program, called Safa (clean) Tempos, had an operating range of 50 km and a maximum speed of 45 km/h. Their batteries weighed 360 kg, so that when full the vehicle operated close to its maximum design load. The brakes also operated close to design limits.

To allow the vehicles to travel 150 km a day, three sets of batteries were used. Specified stops loading and unloading passengers—a new concept in Nepal—were established so that the vehicles could operate on a schedule. The Safa Tempos are cleaner and quieter than diesel Tempos, and public acceptance of the vehicles has been high. Demand from passengers often exceeded available space during the pilot period.

Currently more than 600 Safa Tempos operate in Kathmandu. Most of these are used for public transportation along 17 routes. The EV industry in Nepal consists of 5 manufacturers, 37 charging stations and several hundred vehicle owners. However, because the operating cost of a Safa Tempo is higher than gasoline- or LPG-operated three-wheelers (64% and 88% higher, respectively), entrepreneurs are struggling to survive. The high operating cost for EVs is mainly due to the high electricity tariff and high cost of the battery.

Based on Kojima *et al.*, 2000, updated from IEA Clean Vehicles Workshop, Paris, 24–25 September 2002, paper from Clean Energy Nepal, <http://www.cen.org.np>.



Fig. 19

*An electric three-wheeler “Ecorick” developed under the IZET program running in Agra. The Taj Mahal is a world famous monument in Agra. No internal combustion engine vehicles are allowed in the vicinity of the monument, to protect it from vehicular pollution. The vehicle has been specially deployed for visitors who are physically challenged. A few of these vehicles have been successfully operating in Agra for the last two years to ferry tourists to various monuments.*

Courtesy of N. V. Iyer

The economic viability of electric vehicles depends in part on the price of electricity. The power sector in many developing countries is being reformed and restructured. The long-term viability of electric vehicles should be evaluated based on market pricing of electricity.

It is normally believed that electric vehicles using the conventional technologies are not expected to have widespread applications in developing countries in South and South East Asia. China has proved to be an exception with the rapid growth in the popularity of small battery operated electric two-wheelers. It is estimated that the annual production of electric two-wheelers in China is over 20 million in 2007. These bikes are powered by an electric motor of 250watts, have a limited maximum speed of 20 km per hour and a range of 50–60 km with one charge. These vehicles come either as a ‘bicycle type’ or a ‘scooter type’. Electric bikes of similar design have also started being sold in India with nearly 22,000 units sold in the year 2006 (Source: “The Indian Automobile Industry, Statistical Profile 2007–2008”, Society of Indian Automobile Manufacturers (SIAM).)

Electric three-wheelers could play a useful but limited role in extremely polluted traffic corridors. In Kathmandu, Nepal, for example, electric Tempos were introduced in 1994

(see Box 5). In 1995 the government reduced import duties on electric vehicle components from 60–5%, and duties on fully assembled electric vehicles from as much as 150–10%. In early 2000 about 500 electric Tempos operated in Kathmandu, partly in response to the ban on diesel Tempos imposed by the government in 1999. Seven plants assembled more than 200 electric Tempos in 1999. This is the world’s largest fleet of electric road public passenger transport vehicles. The future is not secure, however, as the government approved in May 2000 the import of 300 15-seat vans with the same preferential import duties accorded to the electric vehicles.

### 3.6 Policy options

A wide range of policy tools are available to city and national governments in developing cities. This section outlines policies aimed at in-use vehicles (see Box 6) as well as new vehicles.

#### Standards

In response to national standards more stringent than those of the European Union, Indian vehicle manufacturers have made engine design changes that have reduced the level of emissions and increased fuel economy. Scavenging losses have been reduced steadily, and in 2000 catalytic converters were installed for the first time. The emission standards for two-wheelers differ markedly. The emission standards in India and Taiwan (China) today rank among the most stringent in the world, reflecting the concern of the authorities with controlling emissions from vehicles that are numerous and popular because of their affordability and ease of maneuver.



Table 6: Emission limits for motorcycles<sup>1)</sup> in Taiwan, China

Engine testing condition		Pollutant	1 Jan. 2004	1 Jan. 2004	1 July 2007	1 July 2007
			2-stroke (cold test)	4-stroke (cold test)	<150 cc (cold test)	>150cc (cold test)
New	Driving cycle test	CO, g/km	7.0	7.0	2.00	2.00
		HC, g/km	na	na	0.80	0.30
		NO <sub>x</sub> , g/km	na	na	0.15	0.15
		HC + NO <sub>x</sub> , g/km	1.0	2.0	na	na
In-use	Idle	CO, (%)	3.0	3.0	3.0	3.0
		HC, ppm	2000	2000	1600	1600
In-use	Idle	CO, (%) <sup>2)</sup>	3.5	3.5	3.5	3.5
		HC, ppm	2000	2000	2000	2000

Source: Iyer N. V. "Management of In-Use Motorcycle Emissions – the Indian Experience" Inspection and Maintenance and Other Motorcycles Programs, Hanoi, Viet Nam, 6 March 2007, <http://www.theicct.org>

Note: Average cold engine tested values of CO and HC + NO<sub>x</sub> were 2.5 times those of warm engine tested values.

<sup>1</sup> Includes scooters and mopeds.

<sup>2</sup> Limits for warm-engine test conditions.

Emissions from recent two-stroke models have decreased markedly as a result of technological improvements. In Taiwan (China) — which has the largest number of two-wheelers per capita in the world — emission standards have progressively tightened significantly. The latest standards were adopted on 1 July 2007 and have the same limit values as those in Euro 3 standards for motorcycles (see Table 6).

The emission standards in Taiwan (China) also control visible smoke; smoke opacity is limited to 15% for new vehicles and 30% for in-use vehicles.

In India vehicle manufacturers faced the challenge of meeting more stringent emission standards in 1996 without using catalytic converters, which could not be used because unleaded gasoline was not widely available in India at that time (Table 7). Manufacturers had to rely solely on improvements in engine technology to meet the mandated emission limits. Today as a result of continuing technological advances, including the installation of catalytic converters, new two- and three wheelers manufactured in India emit less than 8% of the carbon monoxide and less than 18% of the hydrocarbons and nitrogen oxides emitted by vehicles manufactured in 1991. As in Taiwan (China), emission standards in India are being progressively further tightened (Table 8).

### Box 6: Two- and three-wheeler standards

Synthesis, Regional Workshop, 2001, <http://adb.org/vehicle-emissions>

Vehicle emissions can be regulated through standards for new vehicles as well as in-use standards for vehicles already on the road.

#### Standards for new vehicles

- Standards for new vehicles (based on a type approval process) tend to be the main driving force to stimulate the introduction of cleaner vehicle technologies. Experience has demonstrated both in and outside Asia that this is the most effective method to reduce average emissions over time. Currently there are a number of Asian countries that have adopted type approval standards for two-wheelers and in some cases also for three wheelers. In most of these cases standards have followed European or ECE standards. (ECE 40, 40.01 or 47).
- The European Union and the USA have been gradually tightening emission standards for two-wheelers. The engine size of motorcycles in these regions is usually much larger and the contribution of motorcycles to air pollution is smaller than in Asia. Control of this type of vehicles in Europe and USA is therefore not as high a priority as it should be in Asia.
- It is recommended that all countries adopt type approval standards for new two- and three-wheeled vehicles. In light of the large





population of two- and three-wheelers in the region and their contribution to poor air quality, the current ECE requirements are not considered adequate to protect the health of the citizens of Asian cities. Some countries, such as India and Taiwan, China have already put in place more stringent standards. Other countries in the Asian region will also have to look beyond ECE standards and should consider leapfrogging to emission standards adopted by India and Taiwan, China. This should include a cold start test and requirements for two-stroke which are as stringent as those for four-stroke engines.

- Countries with serious PM problems should consider the development of a specific PM standard for two- and three-wheeled vehicles. The adoption of a specific PM standard should be based on sound science using reliable PM measurement methods and result from an open and transparent process which involves all interested stakeholders.
- To minimize the overall cost in development and implementation of stringent type approval standards for two- and three-wheeled vehicles it is recommended that countries join together in harmonizing regulations for these vehicles. This does not mean that all countries must have the same standards in the same timeframe. Standards for enhanced environmentally friendly vehicles, which reflect the lowest levels technologically feasible, should also be adopted; vehicles meeting such standards could be encouraged through fiscal or other incentives. In addition, a two-stage approach to adopting standards with early introduction of the second step by use of fiscal or other incentives should be considered. In developing regional harmonized standards, the regional industry can play an important role.
- It was suggested that a common motorcycle engine project based on technology development and exchange be established to share technical knowledge; subsequently this could lead to common or harmonized emissions standards. Such efforts are to be initiated by the regional motorcycle industry.

#### **In-use vehicles**

- As important as standards for new two- and three-wheelers are, they must be complemented by comparable in-use requirements

to ensure that intended emission reduction goals are actually achieved. In use standards tend to ensure that vehicles are maintained and used properly to assure the maximum benefits from the emission technologies installed at time of production.

- Tight in use standards can be used to force older, higher polluting vehicles to be retired or moved away from pollution hot spots; in use standards should be based on a careful selection of the appropriate test procedures which accurately identify the gross polluters.
- In-use standards typically regulate CO under idle conditions. Certain countries also regulate smoke (opacity) and or HC, both of which are useful additional components of an in-use strategy.
- After adopting PM emission standards for new vehicles countries in the Asian region should also adopt PM requirements for in-use vehicles using reliable methods.
- In several countries there are unique categories of vehicles, e.g., the motorized tricycle in the Philippines, which is a modified version of a two-wheeler. These vehicles are used in ways that change their performance requirements and therefore their emission characteristics, a problem that must be addressed. Requiring them to continue to meet the in-use emission requirements of the original vehicle can do this. Alternatively a modified in-use standard could be developed and imposed.
- The responsibility for issuing emission standards for new vehicles typically rests with the national government. Either the national government or local government can issue in-use standards. In case of the latter, the in-use standards issued should be no less stringent than the national requirements and in some cases could be more stringent than the national standards.
- Experience from around the world has shown the importance of having a transparent system for the development of emissions standards which promotes a broad based participation in the development of these standards.
- There is a lack of capacity for regulation as well as for implementation of inspection and maintenance for two- and three-wheelers in almost all countries in the region. This hampers the implementation of the in-use standards.

**Emissions based policies**

Policymakers can deal with pollution by setting emission targets that vehicles must meet or by mandating specific types of fuel or vehicle technology in the hope of achieving emission targets. Emission-based measures provide greater flexibility to suppliers of fuels and vehicles, who can choose the lowest cost options for meeting the specified emission targets. Provided that compliance can be ensured, this approach is generally a lower-cost option for society.

However, emission-based measures are usually more difficult to monitor than technology based options. Technology based options are not likely to be a low-cost solution unless rigorous cost-benefit analysis is performed to identify the optimal technologies for each specific situation.

The distinction between emission-based and technology-based policies is not necessarily sharp, because vehicular emission standards can be made so stringent that they effectively dictate the type of vehicle or fuel that must be used.

An example is the year 2003 emission standards in Taiwan (China), which set tighter emission standards for two-stroke engines than for four-stroke engines, effectively banning two-stroke two-wheelers.

Emission-based policies set vehicular emission standards and allow the automobile and oil industries to seek the lowest-cost means of complying with the standards. Stricter emission standards are apparently pushing Indian manufacturers to build more four-stroke engine vehicles, though changing customer profile and preferences have also played a part. In the fiscal year 2006–2007, four-stroke two-wheelers constituted more than 95% of the total annual domestic sales. A similar change, however, has not taken place in case of three-wheelers in India, even though the incremental cost of purchasing a four-stroke engine three-wheeler is recovered in a little over half a year. Assuming that maintenance costs are comparable, replacing old auto-rickshaws with new four-stroke engine auto-rickshaws is therefore a cost-effective way of reducing particulate emissions. Indian experience shows that this could not happen through market forces alone and may be possible only through a state mandate accompanied by suitable incentives. The main reason for the lack of

**Table 7: Emission standards for gasoline-powered two- and three-wheelers in India, 1991-2000 (grams per kilometre)**

Year	Two-wheelers		Three-wheelers	
	Carbon monoxide	Hydrocarbons and nitrogen oxides	Carbon monoxide	Hydrocarbons and nitrogen oxides
1991	12–15 <sup>a</sup>	8–9 <sup>a,b</sup>	30	12 <sup>b</sup>
1996	4.5	3.6	6.75	5.4
1998	4.5	3.6	6.75	5.4
2000	2.0	2.0	4.0	2.0
2005 <sup>c</sup>	1.5	1.5	2.25	2.0

Kojima et al., 2000, from Society of Indian Automobile Manufacturers

Note: Tests of 1991 and 1996 vehicles were based on the warm Indian driving cycle. Tests of 1998 and 2000 were based on the cold Indian driving cycle.

- a) Emission standard depends on the reference mass of the vehicle.
- b) Limit applied to hydrocarbons only and not to the sum of hydrocarbons and nitrogen oxides.
- c) A Deterioration Factor of 1.2 is applicable. ‘Observed Emission’ x 1.2 must be below the limit.

**Table 8: Current and future proposed emission limits for motorcycles<sup>1)</sup> in India**

Engine testing condition		Pollutant	Current (Since April 2000)	From April 2005	Proposed (Oct. 2008)
			2-, four-stroke (warm start)	2-, four-stroke (warm start)	2-, four-stroke (warm start)
New	Driving cycle test	CO, g/km	2.0	1.5 <sup>2)</sup>	1.0 <sup>2)</sup>
		HC + NO <sub>x</sub> , g/km	2.0	1.5 <sup>2)</sup>	1.0 <sup>2)</sup>
		CO, (%)	4.5	3.5 <sup>3)</sup>	3.5 <sup>3)</sup>
In-use	Idle test	HC, ppm <sup>4)</sup>	2-S: 6000 4-S: 4500	2-S: 6000 4-S: 4500	tbd <sup>5)</sup>
		CO (%)	4.5	3.5 <sup>3)</sup>	3.5 <sup>3)</sup>
		HC (ppm) <sup>4)</sup>	2-S: 6000 4-S: 4500	2-S: 6000 4-S: 4500	tbd <sup>5)</sup>

Courtesy of N. V. Iyer, 2004

- 1) Includes scooters and mopeds
- 2) A deterioration Factor of 1.2 applicable for durability of emissions
- 3) Limits for warm-engine test conditions
- 4) Applicable from 1 October 2004 for vehicles manufactured after 31 March 2000
- 5) To be decided

success in case of three-wheelers is that these vehicles are used for commercial purposes and the owners or drivers of the vehicles prefer a vehicle that is simple in construction (which the two-stroke is) and cheap and easy to maintain.

### **Monitoring emissions**

While checking compliance of new vehicles may not be difficult, monitoring the performance of in-use vehicles is a far greater challenge. At a minimum, an effective inspection and maintenance program needs to be in place, together with an up-to-date vehicle registry. Even when implemented rigorously, however, inspection and maintenance have limited effectiveness because owners and mechanics can temporarily adjust vehicles, particularly older technology vehicles, so that they pass emissions tests.

One way to ensure that emissions consistently meet standards is to spot-check vehicles on the road. However, such tests are expensive to set up and administer and invite corruption.

To increase the effectiveness of inspection and maintenance programs, the frequency of inspection could vary with the age of the vehicle as well as the annual number of kilometers traveled. Commercial vehicles such as three-wheelers could be inspected more frequently than motorcycles driven for private use.

Frequent inspection is particularly important once oxidation catalysts are installed. If catalysts last about 30,000 km and taxis are typically driven in two shifts for 150 km a day, inspection and replacement of catalysts would be necessary twice a year.

Most countries in the South and South East Asia do not have an effective Inspection & Maintenance (I&M) programme for two and three-wheels. The most notable exception is Taiwan, China, which follows a decentralized inspection system operated by a large number of private centers. The system is quite effective because of the strict monitoring done by the government by linking all the private centers to a centralized computer system. In addition, surprise road-side checks are also performed from time to time.

India has the “Pollution Under Control” (PUC) certification system applicable to all types of in-use vehicles including two and three-wheelers.

The system is also decentralized but not very efficient. There are many shortcomings in the system; the most important one is the lack of strong government supervision. Another weakness is the inadequacy of the idle test to ascertain the true pollution potential of the in-use vehicle. The Automotive Research Association of India (ARAI) has devised a low cost loaded mode test that could be effectively used for this purpose (Iyer, 2007).

### **Repairing vehicles that fail inspection**

Vehicle inspection will be ineffective if vehicles that fail are not repaired promptly. The availability of adequately equipped and trained mechanics is a prerequisite for a successful inspection and maintenance program. Since four-stroke engine vehicles are more complex and require higher mechanical sophistication to service, training of mechanics should be given high priority in the coming years. There is currently a shortage of mechanics who can service four-stroke engine three-wheelers and vehicles with increasingly sophisticated technology in general, and of repair shops with diagnostic tools to service such vehicles.

Where vehicles are not driven by their owners, the incentives for regular inspection and maintenance, weak in the best of circumstances, are even weaker, since the vehicle owner who is responsible for passing inspection does not have the vehicle most of the time. This dilemma highlights the importance of finding ways to enforce emission standards and deal with noncompliance, given that neither the owners nor the drivers have an incentive to spend time having commercially operated vehicles inspected.

### **Technology-specific policies**

Measures based on fuel and vehicle technology mandate the minimum technology to be adopted. Technology-specific policies include:

- mandating higher-quality two-stroke engine lubricants,
- mandating premixing of gasoline and lubricant,
- mandating installation of catalytic converters,
- banning two-stroke engines,
- banning or providing incentives to scrap vehicles that have reached a certain age or number of kilometres traveled,

- mandating or providing incentives (tax credits, tax reduction, tax elimination, or subsidies) for replacing two-stroke gasoline engine vehicles with four-stroke engine vehicles,
- mandating or providing incentives for replacing two-stroke gasoline engines with alternative fuels such as liquefied petroleum gas, compressed natural gas and electricity,
- mandating retrofitting kits to reduce emissions, such as Envirofit's direct injection kit.

Where emission-based policies are difficult to monitor, it may make sense to adopt some of these policies. Before this is done, however, it is imperative that policymakers examine the cost-effectiveness of each option. Some measures make more sense to mandate than others. Banning the sale of unpackaged lubricant would prevent inferior quality lubricant from being added to gasoline (see Box 7). Requiring that all new three-wheelers use four-stroke technology may be reasonable given the fuel savings, provided that enough mechanics are trained to service four-stroke engine three-wheelers.

In contrast, the rationale for mandating catalytic converters is much weaker, since they can function efficiently only if several conditions are satisfied:

- Unleaded gasoline must be widely available. Ideally, leaded gasoline would be completely phased out to eliminate the chances of fueling catalyst-equipped vehicles with leaded gasoline.
- Gasoline must constitute low level of sulfur, preferably less than 500 parts per million by weight.
- Emission levels and the length of time the catalyst system must meet those levels must be specified.
- An effective inspection and maintenance system must be in place to ensure that catalytic converters are replaced as needed.

If these conditions are not met, the benefits of catalytic converters may not justify the cost of installing them. Even if these conditions are met, it still makes sense to specify emission levels for new vehicles rather than mandate catalytic converters. Retrofitting in-use vehicles with catalytic converters is problematic because misfires, which are more common in two-stroke engines, can cause temperature runaway and

catalyst sintering and damage the catalyst as a result. For this reason Bajaj Auto in India recommends that only two-stroke engine vehicles built after 1996, with lower 'engine-out' emissions, are considered for retrofitting.

Reducing particulate matter by mandating catalysts may not be cost-effective. It is difficult to estimate the impact of oxidation catalysts on particulate matter emissions because data are scarce. Assuming catalyst conversion efficiency of 50%, a particulate matter emission factor without catalysts of 0.1–0.2 grams per km, and catalyst durability of 30,000 km, the total amount of PM<sub>10</sub> eliminated by the catalyst would be 1.5–3.0 kg. This translates to US\$8,000–17,000 per ton of PM<sub>10</sub> given the net-of-tax catalytic converter cost of US\$25 apiece in India. This figure varies severalfold depending on the assumptions made about the durability of the catalyst and the amount of particulate matter reduced, but the cost figures remain on the high side compared with other PM<sub>10</sub> reduction strategies.

### ***Banning all two-stroke engines***

Banning all two-stroke engines would eliminate point-to-point transportation for millions of people in developing Asian cities and cause hardship until there are enough buses and four-stroke engine taxis to replace the large existing stock of two-stroke engine three-wheelers. Women and families, who depend on the vehicles more than other groups and the many people who use these vehicles commercially, would be particularly hard hit by a ban. Taking two-stroke three-wheelers off the road precipitously would also affect the livelihoods of tens of thousands of drivers and invite widespread agitation. Moreover, banning existing two-stroke engines without putting in place a well-documented vehicle registration system, an effective traffic police force, and transport alternatives for the current users could lead to increased harassment of drivers and corruption by traffic police. Thus rather than banning these vehicles, policymakers should consider other lower-cost options for reducing their emissions.

### ***More selective bans***

Lower cost and politically more viable options to banning all two-stroke engine vehicles are to:

- a. *Ban only older (and typically more polluting) two-stroke engine vehicles from urban areas.* This approach has already been taken in Delhi, with wide popular support (see Box 7).
- b. *Ban new two-stroke engine vehicles.* This is likely to have less socioeconomic impact than banning all such vehicles, since the cost difference between new two- and four-stroke engines is not significant. If operating and maintenance costs are taken into account, owning a four-stroke engine vehicle may be more economical than owning a two-stroke engine vehicle. Removing financial disincentives for replacing two-stroke engine three-wheelers with four-stroke engine vehicles is a high-priority.
- c. *Ban or highly tax the import of two-stroke vehicles.* An outright ban, or restricting the import or sale and use of new two-stroke engine vehicles, through taxation or other means, needs however to be considered carefully. Such a policy can be disruptive of industries that prefer a performance standard

that they could achieve at the lowest cost to their customers. Such a policy may, therefore, be useful for countries that do not have the capability to enforce strong new and in-use emission standards, thereby ensuring that inadequately controlled two-stroke engine vehicles do not enter the market.

All of these three options would be best pursued if the following conditions are met: (i) alternatives to the vehicles being removed are readily available and market-tested; (ii) these alternatives are affordable, which may require the lowering or elimination of import duties or other taxes on new vehicles (see below); and (iii) sufficient credit exists for vehicle owners and drivers to be able to finance the purchase of the newer vehicles.

### Economic and fiscal instruments

Whether or not the technology-specific measures are adopted, economic policy options exist to encourage the removal of older and more polluting vehicles from polluted cities. These

#### Box 7: The Supreme Court role in Delhi

Adapted from Kojiima *et al.*, 2000

In July 1998 the Supreme Court of India stipulated several measures affecting two- and three-wheelers in Delhi to combat air pollution:

1. Banning the sale of loose 2T oils at filling stations and service garages, effective December 1998.
2. Mandating that filling stations mechanically meter lubricant to be mixed with gasoline at the point of gasoline sale for two-stroke engine vehicles, effective December 1998.
3. Mandating the replacement of all pre-1990 autos and taxis with new vehicles using clean fuels, effective March 2000.
4. Introducing financial incentives for replacing all post-1990 automobiles and taxis with new vehicles using clean fuels, effective March 2001.

The first three measures have been implemented. The third measure effectively required that pre-1990 auto-rickshaws be retired from Delhi and replaced with auto-rickshaws powered by compressed natural gas. The only two "clean" fuel options at that time were natural gas and electricity, since use of liquefied petroleum gas was not yet legalized. No electric-powered auto-rickshaws are commercially available for sale in India today.

The fourth measure has had an interesting history. The Delhi government offered financial incentives until March 2000 to replace auto-rickshaws 15 years old or older with new vehicles meeting the April 1996 emission standards. Although both two-stroke and four-stroke engines were permitted in principle, only two-stroke engine auto-rickshaws were available during this period. The incentive package consisted of complete exemption from sales tax (6% until 2000, when it was raised to 12%) and subsidized loans from the Delhi Finance Corporation. The loan repayment period, ranging from three to five years, could be negotiated. As of April 2000, the financial package was offered only for the replacement of old auto-rickshaws with new auto-rickshaws running on compressed natural gas or electricity.

Auto-rickshaw owners' response to the measures has been overwhelming. By March 2000 nearly 20,000 old auto-rickshaws had been replaced by new ones. While the order allowed owners to sell their old vehicles outside the National Capital Territory of Delhi, most owners chose to scrap their vehicles. Pollution was thus not transferred to other parts of the country, and there was no possibility of these old vehicles migrating back to Delhi.

options include providing tax incentives for renewing vehicles, offering cash for older vehicles to get them off the road, ensuring credit for purchasing new vehicles, and liberalizing the trade in new vehicles. Not all options are equally recommended.

### ***Tax incentives for vehicle renewal***

The structure of taxes and other vehicle charges, such as annual registration fees, should be carefully reviewed and revised if necessary where such structures do not capture the cost of pollution. For example, the import tariffs or sales taxes on cleaner alternatives to auto-rickshaws (whether new vehicles or parts for vehicle retrofitting) should not be so high as to discourage their purchase — since the public health benefits to be gained are high. Similarly, annual registration fees based solely on the market value of the vehicle, rather than on market value and pollution emitted, would be too low to discourage the use of older vehicles in urban areas. In assessing each of these measures, policymakers need to weigh the socio-economic cost of making it more expensive to own old vehicles against the health benefits of reducing vehicular emissions.

### ***Accelerated retirement of two-stroke vehicles (motorcycle upgrade program; trade-in subsidy)***

Government offering cash payments for older vehicles to remove them from the road can distort the market and have the perverse effect of keeping older vehicles in use. If the government offers to buy older vehicles, the price of those vehicles, many of which may be on the verge of being scrapped, will rise. A vehicle is typically scrapped when the cost of repairing it exceeds the market value of the vehicle after repair. The higher prices of older vehicles may have the unwanted effect of inducing some owners to keep and repair their old vehicles rather than scrapping them. Moreover, because vehicle prices are typically higher inside urban centers than outside, non-urban owners of old vehicles would have an incentive to bring their vehicles to urban centers and sell them there. These problems indicate that cash payment by the government for old vehicles is not the best use of limited public resources.

### ***Ensuring adequate credit is available***

Rather than offering cash payments, the more valuable role for government is helping to ensure the availability of credit through regular credit and micro-credit markets to urban public transport vehicle owners and drivers. This would facilitate their replacing older auto-rickshaws — as well as larger vehicles, such as diesel and two-stroke engine gasoline Tempos — with cleaner ones.

### ***Raising public awareness***

Emissions from two-stroke engines and repair costs can be reduced by encouraging owners to carry out regular maintenance and use lubricant specifically manufactured for use in two-stroke engines at concentrations recommended by the vehicle manufacturer. Mass public education will be needed to induce vehicle owners to adopt these “win-win” measures.

Governments, donors and non-governmental organizations have sought to raise public awareness about emissions in South Asia, for example.

- The Hydrocarbon Development Institute of Pakistan has distributed pamphlets and stickers containing basic information on the quality and quantity of gasoline and lubricant.
- In Dhaka, Bangladesh, the joint United Nations Development Programme–World Bank Energy Sector Management Assistance Programme (ESMAP) carried out a series of training sessions for mechanics and auto clinics for three-wheeler taxi drivers in late 2000. The program was based on the idea that the first step toward adoption of good practice is dissemination of accurate information by mechanics to taxi drivers (ESMAP, 2002).
- A major public awareness campaign in Delhi, India, in late 1999 led to more than 66,000 vehicles participating in free inspection and maintenance clinics for two-wheelers (Iyer, 2000) (see Box 8).
- The Society of Indian Automobile Manufacturers’ (SIAM) drive to promote computerization of the in-use emission inspection centres in many cities has improved the confidence of the public in the system and increased the number of vehicles voluntarily reporting for certification. The system developed by SIAM minimizes manual intervention in the

inspection process and includes a photograph of the tested vehicle's license plate in the certificate, thus improving the credibility of the test centres. Though initially SIAM carried out this program as a demonstration exercise at its own expense, many test centres are now volunteering to up-grade to computerized ones since this improves their revenues. In Bangalore, where SIAM put up two demonstration centres, more than 100 private test centres have already computerized their facilities. Several state authorities now mandate the use of the computerized system developed by SIAM.

Although public awareness initiatives have been taken in Asia, many drivers still do not adequately maintain their vehicles. Much more needs to be done to improve public understanding of the importance of proper vehicle maintenance.

### **Identifying stakeholders**

The Regional Workshop in Hanoi (2001) identified the following groups of stakeholders:

- *National government agencies;*
- *Local government agencies;*
- *Industry* (motorcycle producers, fuel producers, catalyst suppliers, maintenance industry);
- *Intermediate groups* who can play a role in advocating for and implementation of pollution reduction campaigns;
- *End users.* Within the end users group it is important to differentiate between users who depend on two- or three-wheelers for a living, such as rickshaw drivers and users who use the vehicle for personal transportation; and
- *Breathers.*

The industry manufacturing two- and three-wheeled vehicles have a strong awareness of the emissions produced by the vehicles they produce. Increasingly they have started to modify the designs of their products to ensure compliance with the increasingly more stringent emission standards. It is important for the manufacturing industry that regulators develop medium-term plans for both new type standards and in use standards.

### **Box 8: Reducing emissions and improving performance: I/M clinics in Delhi**

*Adapted from Kojima et al., 2000*

To reduce emissions, the Society of Indian Automobile Manufacturers (SIAM) and other Indian companies sponsored voluntary inspection and maintenance clinics for two-wheelers in Delhi in 1999. The clinics, funded in part by the U.S. Agency for International Development, were held simultaneously in four locations in three phases over four weeks. SIAM member companies provided 45 instruments and 200 staff. Major vehicle manufacturers staffed and ran repair and information booths. Instrument manufacturers were on site to check instrument calibration and ensure the accuracy of emission measurements. The government of Delhi authorized SIAM to issue "Pollution under Control" stickers and stationed traffic police personnel at the clinic sites. The clinics were widely publicized in the media, with appeals made by dignitaries, celebrities and top-ranking government officials. The cost of this successful program was about US\$2.50 per driver.

Simple maintenance tasks were performed at the clinic, and booklets on maintenance and fuel-saving driving tips were distributed. Vehicles were

first checked for carbon monoxide and hydrocarbon emissions while idling. If the vehicle failed (that is, if carbon monoxide emissions exceeded 4.5% of the exhaust gas or hydrocarbon emissions exceeded 9,000 parts per million) it was taken to a repair booth where the carburetor was adjusted and emissions measured again. If the vehicle failed the second emissions test, the spark plugs were cleaned and adjusted and the air filter cleaned. A third emissions test was then run. After testing the vehicle was taken to the safety booth, where the driver received a booklet of safety and maintenance tips.

About 80% of participating vehicles passed the idle carbon monoxide test; 95% of the remaining 20% passed the test after minor repairs. Seventy-five vehicles that initially failed the emission tests were tested for fuel consumption. Fuel economy improved from an average of 39–47 km per liter after minor repairs, demonstrating the benefits of performing simple maintenance tasks. One of the four clinics had a smoke meter, and smoke measurements were taken of failing vehicles before and after the minor maintenance. Smoke emission levels fell after minor repairs.

For an analysis of the data collected during these clinics refer to Sujit Das *et al.*, 2001



### Promoting alternative modes of travel

One way of reducing emissions from two- and three-wheelers is to develop and promote alternative modes of transport, such as walking, cycling and public buses. These topics are covered elsewhere in this *Sourcebook*. We note here only that restrictions imposed on the use of private motor vehicles — *e.g.*, increased parking tariffs — should also be applied to motorcycles. This is important as a precondition for the establishment of a viable public transport industry.

### 3.7 Future directions

Two-stroke engines make up much of the total vehicle fleet because they are relatively inexpensive, perform well in terms of power and speed, and are easy to repair. Precisely because two-stroke engines are so numerous and popular, any policy decision to address emissions from these vehicles must take socio-economic consequences into account. A large-scale, immediate ban on gasoline powered two-stroke engine vehicles would be extremely difficult and costly, but fortunately numerous small and cost-effective improvements are available. Public awareness raising — about the health impact of emissions, the engine/fuel/lubricant parameters that increase emission levels, simple steps drivers can take to reduce emissions, and the advantages and disadvantages of various measures tabled for mitigating air pollution — make emissions reduction easier even with the existing vehicle fleet.

Conventional two-stroke engine vehicles may eventually be phased out in Asia, to be replaced by comparable but cleaner alternatives that still meet the social and economic needs of the public. These may include advanced two-stroke engines using electronically controlled fuel injection that have the potential to achieve emission levels as low as, or, even lower than those of four-stroke engines while retaining the advantages of the two-stroke design. Dynamic partnerships among government, industry, and the public will be crucial in the development of, and commitment to, achieving air quality goals. A transition period is likely, probably a number of years, during which in-use two-stroke engine vehicles in large urban centers are phased out.

Under these circumstances, the importance of promoting good practice in lubricant use in

in-use two-stroke engine vehicles cannot be over-emphasized. In this “win-win” situation vehicle emissions can be dramatically reduced and vehicle maintenance made easier at virtually no cost.

### 3.8 Electric bikes-impacts of potential regulation on mobility and environment

This section is a contribution from Dr Christopher Cherry, Asst. Professor, Dept. of Civil Engineering, University of Tennessee – Knoxville. This section is based on his study sponsored by Clean Air Initiative-Asia, the UC Berkeley Center for Future Urban Transport – A Volvo Center of Excellence, and the National Science Foundation.

Electric bikes have risen in popularity over the past several years, from several thousand sold in 2000 to 16–18 million sold in 2006 (Jamerson and Benjamin 2007). Estimates of total vehicle population range from 30–50 million currently in China. The adoption rate of this mode has far outpaced growth in automobile ownership and has created new challenges for the transportation system and environment in Chinese cities. Proponents of electric two-wheelers tout them as environmentally friendly vehicles, reducing local air pollution and providing high mobility to users. Opponents suggest that they are unsafe, polluting and the cause of many of China’s traffic problems (Ribet 2005). In fact, several cities have begun banning or heavily restricting electric two wheeler use in their cities (Guangzhou Daily 2006).

There are two classes of electric two-wheelers, bicycle style electric bikes and scooter style electric bikes (Jamerson and Benjamin 2007), shown in Figure 20. Electric bikes have a range of 40–60 kilometers on a single charge and cost between US\$150–300. Electric two-wheelers are loosely regulated by size, weight and maximum speed and are thus classified as bicycles (China Central Government 1999; China Central Government 2004). As such, they are allowed the same privileges and adhere to the same regulations as bicycle riders, including shared right of way in bicycle lanes.

The environmental impacts, countered by the benefits to the transportation system, primarily mobility and access increases, are discussed in this section. Two case studies are conducted to identify the *net* impact environmental emissions, and mobility to the transportation system in the event of an electric bike ban in the cities

of Shanghai or Kunming. Towards the end policy implications and other policy decisions that must be considered are discussed.

### **Positive and negative impacts to transportation system**

Electric two-wheelers, like any mode of transportation, have positive and negative impacts to the transportation system. Electric bikes contribute to congestion, they emit pollution, and users are injured and killed in traffic crashes. To counter the negative impacts, they provide mobility in a city, increasing productivity and access to jobs or other destinations. The relevant question is the extent that electric two-wheelers perform better or worse on these metrics than alternative modes of transportation. If electric two-wheelers were taken out of the choice set, the distribution of the shift to alternative modes (cars, buses, bicycles or walking) would determine whether the policy to remove electric two-wheelers increased or decreased the negative externalities of the transportation system. Any policy analysis related to use of electric two-wheelers must first identify what modes electric two-wheeler users would take in the absence of this mode and then identify the net positive and negative impacts based on environmental, safety and mobility metrics.

### **Case Studies—What are impacts of e-bike ban in Kunming and Shanghai**

In the two case study cities a travel survey is conducted, gathering information about electric bike user origins, destinations, and trip length. More than 50% of electric bike users are previous bus riders and would shift back to the bus if electric bikes were banned (Cherry and Cervero

2007). This has significant implications on bus capacity constraints and emissions. While this is an interesting and somewhat surprising finding, a similar study conducted in Shijiazhuang found that electric two-wheelers are mostly displacing traditional bicycle trips, as one might expect (Weinert, Ma *et al.*, 2007). This could be because Shanghai and Kunming both have exceptional bus systems. Given the predominant alternative mode given by user surveys allows inference of the total yearly displaced kilometers traveled by mode. For instance, in 2006 Shanghai had about 1,000,000 electric two-wheelers. According to the survey, 56% of all trips would shift to bus if electric bikes were banned. The average yearly travel of electric bike users that would otherwise choose bus is 2,975 km, so the total displaced passenger kilometers travelled from the bus is 1,666,000,000 km (1,000,000 e-bikes x 56% x 2975 yearly vkt). Figure 21 shows the distribution of responses from survey respondents (annual travel and mode split) in Shanghai and Kunming. From these data, net impacts can be calculated by mapping impact rates (such as SO<sub>2</sub> emissions/km) of switching from electric bikes to alternative modes.

The negative environmental and safety impact rates in Shanghai and Kunming are shown in Table 9. The first seven columns show the lifecycle emission rates of criteria pollutants, including production, use and disposal phases. Electric two-wheelers in Shanghai and Kunming have different emission rates because Shanghai has a 99% reliance on coal electricity generation, while Kunming relies on 48% coal and 52% hydro power. However, compared to Shanghai, Kunming has a larger percentage of scooter style electric bikes, which have higher electricity use and thus emission rates, compared to bicycle style electric bikes. Electric bikes perform better on some metric and worse on others compared to alternative modes. Most notably, electric bikes perform better than other motorized modes on NO<sub>x</sub>, CO<sub>2</sub>, and energy use rates. However, they emit much more lead (Pb) pollution into the environment from poor production and recycling processes in addition to relatively low recycling rates (Mao, Lu *et al.*, 2006). The last column shows the mobility characteristics (average speed) of each mode.

**Fig. 20a, b**  
*Bicycle style and scooter style electric bikes.*



Combining data from Figure 21 and Table 9 results in *net* increases or decreases in impacts to the transportation system if electric two-wheelers were banned in these case study cities. For instance, banning electric bikes would decrease lead emissions, but increase greenhouse gas emissions and reduce mobility. These net impacts are shown in Table 10. The positive numbers suggest a net increase in impacts, while the negative numbers suggest a net decrease in impacts as a result of a ban or some other policy that forced electric two-wheeler users back to their previous modes.

From Table 10, it is clear that electric two-wheelers provide clear benefits and costs to the transportation system. For instance, banning electric two-wheelers in Kunming would cause former electric two-wheeler riders to shift to a host of alternative modes. *An electric two-wheeler ban would induce a mode shift that would ultimately increase energy consumption and CO<sub>2</sub>, NO<sub>x</sub> and SO<sub>2</sub> emission. Electric bike users stand to spend an additional 145 hours per year commuting, reducing their productivity.* The biggest drawback of electric two-wheelers is the significant increase in lead (Pb) emitted

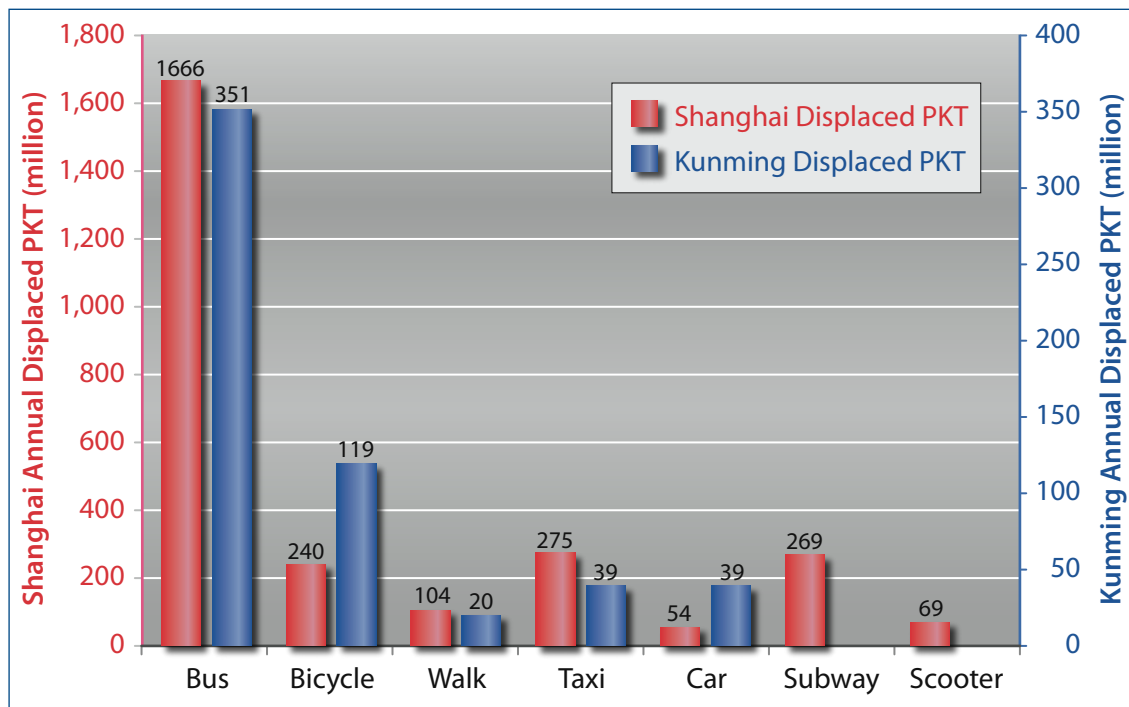


Fig. 21  
Displaced PKT by Mode-Shanghai and Kunming.

Table 9: Impact rates of competing modes in Shanghai and Kunming

(units: grams/passenger/km unless otherwise noted)

	CO <sup>a)</sup>	CO <sub>2</sub>	HC <sup>a)</sup>	NO <sub>x</sub> <sup>a)</sup>	SO <sub>2</sub>	PM	Lead <sup>b)</sup> (Pb)	Avg. Speed km/h
Bus <sup>c)</sup>	0.16	48.43	0.02	0.27	0.02	0.06	0.005	7.1
E-bike Shanghai	Unk	29.25	Unk	0.03	0.18	0.15	0.353	14.5
E-bike Kunming	Unk	23.17	Unk	0.02	0.11	0.16	0.378	14.7
Bicycle	0.00	4.70	Unk	0.00	0.01	0.06	0.000	11.0
Car <sup>d)</sup>	9.43	306.00	1.11	1.01	0.69	0.28	0.299	15.0

Notes:

Unk = Unknown

- a) Only the use phase was included due to data availability (production phases emissions are unknown)
- b) Assumes reported recycle rates for auto industry and 100% recycle rate for e-bikes. The ratio of scooter style ebikes to bicycle style ebikes is 50/50 in Shanghai and 70/30 in Kunming.
- c) All calculations assume an average bus is loaded to capacity-50 passengers. The average speed of buses is estimated using average access time, wait time, operating speed and trip distance in both cities as outlined in Fudan News 2004; Kunming University of Science and Technology 2005
- d) Emission rates from cars were adopted primarily from (Sullivan, Williams *et al.*, 1998)

**Table 10: Net yearly impact per electric bike banned from roadway**  
(Units: Impact per electric two wheeler removed per year, unless noted)

	CO <sub>2</sub> (kg/yr)	NO <sub>x</sub> (g/yr)	SO <sub>2</sub> (g/yr)	PM (g/yr)	Lead (Pb) (g/yr)	Energy (kWh/yr)	Yearly Travel Time (hr/yr)
Shanghai	+119	+815	-129	-121	-664	+521	+126
Kunming	+128	+830	+8	-140	-774	+557	+145

Note:

- + indicates a net increase of system impact if electric two wheeler is removed  
(example: remove an electric bike from the system and CO<sub>2</sub> emissions increase by 119 kg/yr)
- indicates a net decrease of system impact if electric two wheeler is removed  
(example: remove an electric bike from the system and Pb emissions reduce by 664 g/yr)

into the environment. For every electric bike removed, 774 grams of lead would be removed from the environment. This is a very difficult and complex problem and should be remedied by significant improvement in battery production and recycling practices or shifts to more environmentally benign battery technology. The direction of impacts is similar in Shanghai.

Notably, banning electric bikes increases PM emissions in both cities. However, much of this PM emission is released at factories and power plants, away from the city. Therefore the exposure of people (and thus public health impacts) to such pollution is likely lower than tailpipe emissions (Marshall, Teoh *et al.*, 2005; Zhou, Levy *et al.*, 2006). Moreover, the large decreases in NO<sub>x</sub> emissions provide health benefits that likely outweigh the health costs of increased PM emissions (Health Effects Institute, 2004).

### ***Policy recommendations related to electric bikes***

Electric two-wheelers have entered the market and grown as a significant mode share in Chinese cities. Much of this growth is in response to increasing trip length, restrictions on motorcycle use, and public transit service struggling with congestion and oversubscription. Many policy makers have praised electric two-wheelers, while others have criticized them. This section quantifies a few of the more significant impacts of electric two-wheelers on the transportation system.

Electric two-wheelers provide many benefits that are quantifiable, such as reduced emissions of many criteria pollutants, increased safety, and increased mobility. These benefits do come at a cost, primarily a large increase in lead pollution throughout the lead acid battery supply chain

in China. Alternative battery technologies are available and commercially viable, however, the market does not encourage adoption because of their higher cost (Weinert, Burke *et al.*, 2007). Because of their benefits to the transportation system, economic incentives or regulation should be introduced that prompts a shift from lead acid batteries to more expensive Li-ion or NiMH batteries that have fewer environmental externalities.

This section does not specifically address safety, though some analysis has shown that electric two-wheelers have a relatively good safety record (Cherry 2007, Ni 2008). This mode does provide high quality car-like mobility at a fraction of the cost. One potential policy is the development of a synergistic system where electric two-wheelers work to support high quality transit systems as feeders or providing transportation for short trips, both services difficult to provide with fixed route transit service. In conclusion, when considering a broad range of costs and benefits, an electric two wheeler with a cleaner battery technology is one of the most cost effective modes of transportation China can offer.

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## 4.2 Internet resources

- An excellent collection of presentations from the Regional Workshop, *Reduction of Emissions from 2–3 Wheelers*, 5–7 September 2001, can be downloaded at <http://adb.org/Documents/Events/2001/RETA5937/Hanoi>.
- Centre for Science & Environment (CSE), <http://www.cseindia.org>. CSE is a well-informed and active NGO. CSE is also actively involved with the Clean Air Initiative-Asia and currently holds the co-chairmanship of its Coordinating Committee.
- Clean Air Initiative for Asian Cities, run by the World Bank, the ADB and others, <http://www.cleanairnet.org/caiasia>. Information on all topics under air quality management and linkages to various environmental activities in the region. It has a discussion space on various topics and ideas in the region.
- Tata Energy Research Institute (TERI), <http://www.teriin.org>. The site contains useful information on energy and environment related issues in India. The Institute has carried out studies on GHG emissions and environmental pollution for ADB.
- US Environmental Protection Authority, <http://www.epa.gov>. Provides extensive information on all technical aspects of environmental health, including air pollution and WHO guidelines for various pollutants.



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