Managing Motorcycles:

Opportunities to Reduce Pollution and Fuel Use from Two- and Three-Wheeled Vehicles

icct
THE INTERNATIONAL COUNCIL
ON CLEAN TRANSPORTATION

The goal of the International Council on Clean Transportation (ICCT) is to dramatically improve the environmental performance and efficiency of personal, public and goods transportation in order to protect and improve public health, the environment, and quality of life. The Council is made up of leading regulators and experts from around the world that participate as individuals based on their experience with air quality and transportation issues. The ICCT promotes best practices and comprehensive solutions to improve vehicle emissions and efficiency, increase fuel quality and sustainability of alternative fuels, reduce pollution from the in-use fleet, and curtail emissions from international goods movement.

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Design layout and format by Yulee Kim
Printed on 100% recycled paper with soy-based ink

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Primary research was conducted during 2007 and 2008. Advances in policy development in 2009 may not be reflected in this report.

The authors would like to thank our many colleagues around the world that have generously contributed their time and insight in reviewing and commenting on the draft version of this report. We are especially grateful for Mr. Narayan Iyer's thorough review of the report's initial draft. Any errors are the sole responsibility of the authors. We would also like to thank the William and Flora Hewlett Foundation and the ClimateWorks Foundation for their continued support. We are particularly grateful to the following International Council on Clean Transportation participants who have closely reviewed this report and support its finding and recommendations.

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1. EXECUTIVE SUMMARY

For millions of people living in large cities in the developing world, two- and three-wheeled motorcycles offer convenient, affordable access to motorized transportation. Nowhere is this trend more evident than in Asian countries, where motorcycles comprise up to 95 percent of motor vehicles on the road. Two-wheelers generally offer flexible personal mobility while three-wheelers fill the gap for larger families and commercial transport. Once dominated by bicycles, pedestrians, and buses, urban areas around the globe are transforming to accommodate growing ranks of motorcycles.

Increased mobility from two- and three-wheeled vehicles carries a hefty societal cost, however. Air pollution is a major public health concern. The rapid growth of two- and three-wheelers, especially cheap and easy to maintain two-stroke models, has contributed to severe deterioration of the urban environment. Motorcycle populations in Asian cities, and increasingly in cities in Africa and Latin America, are significant and growing. Energy demands are also growing as transportation systems motorize. For those nations who cannot satisfy increasing demands for fossil fuels with local resources, this sets up a pattern of costly oil imports. Energy consumption also translates into increasing carbon dioxide emissions and mounting concerns about climate change. From altered weather patterns to agricultural impacts to increased transmission of diseases, these impacts pose the greatest challenges for developing countries. And worsening traffic congestion and accidents raise concerns regarding traffic safety.

As mobility continues to increase with affluence worldwide, eliminating unintended consequences from transportation will become more urgent. Cleaner, more energy efficient, and safer motorcycles would not only improve public health and the environment, they could also play a role in a more globally sustainable passenger transportation sector.

Much of the regulatory focus on motorcycles to date in India, Thailand, and China has centered on strategies to reduce conventional motorcycle emissions. Some of these policies, especially those that led to the phase-out of two-stroke motorcycles, have had additional benefits of improving motorcycle fuel economy and reducing carbon emissions. Regulators, however, are quickly realizing that further gains in both emissions and fuel economy will require more targeted policies.

The purpose of this report is to identify how nations can best manage their growing ranks of two- and three-wheelers. National and local decision makers will need focused and well-designed policy tools, including regulations and incentive strategies, to improve the environmental performance of these popular vehicles. The policy guidance provided in this report stems from the cumulative experience of regulators and other experts in the field. While the recommendations are primarily aimed at countries that are just beginning to regulate motorcycles, this report may also prove helpful to policymakers who are seeking to improve motorcycle policies that have already been adopted.

Local conditions vary greatly around the world. Social, political, and economic factors, as well as the resource availability, affect each nation's capacity to address transportation, local air quality, climate change, and energy issues. These factors must undoubtedly be taken into account when designing policies to ensure they can be successfully implemented. Still, numerous overarching principles apply when advancing environmental and energy goals for two- and three-wheeled motorized vehicles.

- Programs and policies should be designed in a coordinated fashion to provide multiple benefits
- In-use performance is the key policy metric, and special consideration should not be given to specific technologies
- Policy opportunities offer solutions worldwide, but the path to achieve them does not have to necessarily be the same everywhere
- Both fiscal and regulatory policies should be used in complementary ways to affect behavioral changes
- Vehicles and fuels comprise a system making lifecycle considerations an important part of sound policymaking
- Specific attention is needed to identify and prevent gross emitters and gas guzzlers
- Near-term and future zero-emission technologies merit consideration, based on their cost effectiveness and market potential
- It is important to work across jurisdictions to strengthen programs and send consistent signals to the marketplace

There are moves afoot to address the environmental and energy issues associated with motorcycles. Impacted countries and regions are at varying stages of adopting standards and fiscal policies to reduce motorcycle emissions and fuel consumption. China, India, Taiwan, Thailand, and the EU have been the leaders in developing elements of a comprehensive approach to managing motorcycles through standards and other strategies ranging from bans to economic incentives. The following opportunities have been identified to better manage motorcycles throughout Asia and elsewhere in the world where these vehicles are gaining market share.

1. Adopt increasingly stringent emission standards for new motorcycles that force the development of zero-emission technology
2. Implement a comprehensive compliance program to enforce new vehicle emission standards
3. Enact standards for fuel and lubricating oil quality and consider pre-mixing lube oil
4. Employ strategies to address in-use motorcycle emissions, including in-use emission standards, retrofit and replacement programs, and inspection and maintenance programs
5. Develop strategies to promote the use of cleaner and energy efficient advanced motorcycles
6. Develop strategies to improve motorcycle fuel efficiency, including CO_2 emission standards, fuel economy standards, and associated incentives

In Europe, farther tightening emission standards on motorcycles is a low priority as two-wheelers are a relatively small contributor to air pollution and three-wheelers are essentially non-existent in most

EU nations. Therefore, an opportunity exists for large motorcycle countries in Asia to define the next level of motorcycle emission standards. This effort needs to happen in parallel with strategies to reduce motorcycle fuel use. The recently completed World Harmonized Test Cycle could be a platform for the next set of norms throughout Asia and beyond.

As the share of motorcycles in cities and nations' fleets grows throughout Asia and the rest of the developing world, policymakers must rely on an array of strategies to minimize the unintended societal consequences attributed to these proliferating motor vehicles. Without appropriate regulations and incentives, business-as-usual trends will continue and problems will mount. Motorcycles can be better managed to create a future where two- and three-wheeled motorized vehicles offer more sustainable mobility to a growing portion of the world's population. If managed well, motorcycles can serve an important role in the transportation system of many nations.

2. INTRODUCTION AND REPORT APPROACH

Asia has the world's highest concentration of motorized two- and three-wheeled vehicles. From scooterettes in India to tuk-tuks in Thailand to electric bicycles in China, these vehicles dominate the Asian urban landscape. Ownership and use are also increasing in rural areas where distances traveled are greater and fuel quality may be less reliable. These trends are serving to worsen energy and the environment impacts worldwide. And while motorcycles are currently among the most fuel efficient motorized modes of personal transportation, rapid growth in population coupled with the increasing popularity of larger and less efficient models are eroding this sector's energy and emission performance.

If Asian cities are to achieve healthy air, provide sustainable energy systems, maintain road safety, and reduce greenhouse gas emissions, they must deal with two- and three-wheeled motor vehicles. This requires a comprehensive strategy, one that can be adapted and used throughout the world.

The purpose of this report is to identify opportunities to better manage emissions and fuel use from two- and three-wheelers. The focus is Asia. Today, China and India produce the majority of the two- and three-wheelers sold. Although the largest share of these motorcycles is destined to local markets, exports to neighboring countries and beyond are growing rapidly. Indeed motorcycle sales are soaring in many Asian countries and motorcycles are increasingly popular in Latin America, Africa, and elsewhere. Moreover, the ability to better manage motorcycles extends beyond Asia and the developing world. European nations, including Italy, Spain, Greece, and others, will all benefit from cleaner motorcycles. And while they are not the focus of this report, noise and safety concerns raised by motorcycles also merit attention as part of a comprehensive motorcycle strategy.

The policies discussed in this report are based on the experience of regulators in major motorcycle countries and regions, such as China, India, Thailand, and the European Union, as well as the recommendations of other experts in the field. This report reviews current trends in motorcycle emissions and fuel efficiency technology and performance, summarizes policy approaches to improve motorcycle emission and energy performance, and discusses what is required to implement these policies.

The choices China, India, and others make to control motorcycle emissions and fuel use will have a significant impact within their borders and throughout the world. China, for example, has adopted its first set of fuel economy standards in 2009 while simultaneously implementing an enhanced version of Euro 3, the latest European emission standards. The Euro program is emerging as the global norm with countries such as Thailand and Vietnam adoption standards based on the European program. India has maintained its unique program with standards based on the Indian Driving Cycle. Current motorcycle emission standards in China, India, the EU and elsewhere are not directly comparable in terms of their relative stringency. On the fuel consumption front, both China and India are breaking new ground. China has adopted standards that are just coming into force in 2009. India is currently developing a labeling program that may lead to standards in the near future.

Case studies are used in this report to highlight lessons learned during policy development and implementation of a wide array of motorcycle strategies. Local conditions, resources, and capacity to address transportation and air quality issues, vary greatly around the world. The local situation must undoubtedly be taken into account when designing policies to ensure they can be successfully implemented. The ICCT has identified a broad set of eight principles that should guide all transportation and air quality policy making. A further discussion of these principles, summarized in Text Box 2-1, can be found in ICCT's Bellagio Memorandum on Motor Vehicles published in 2001.


Bellagio Memorandum on Motor Vehicle Policy
Principles *for* Vehicles *and* Fuels *in* Response *to*
Global Environmental *and* Health Imperatives
Consensus Document: 19-21 June, 2001
Bellagio, Italy
The Energy Foundation

The recommendations in this report are primarily aimed at countries that are just beginning to develop new motorcycle control programs. They are also relevant to those seeking to improve or enhance their existing motorcycle programs. The report is designed to provide sufficient background information on all the issues discussed to provide utility to a wide audience. For a more advanced technical discussion, readers can refer to the

TEXT BOX 2-1. THE ICCT'S EIGHT OVERARCHING PRINCIPLES FROM THE BELLAGIO MEMORANDUM

- Design programs and policies that reduce conventional, toxic, and noise pollution and greenhouse gas emissions in parallel, and ensure that future technologies provide major improvements in each of these areas.
- Base policies solely on performance compared to societal objectives, and not give special consideration to specific fuels, technologies, or vehicle types.
- In both industrialized and developing countries, expect and require the best technologies and fuels available worldwide; it is not necessary or cost-effective for developing nations to follow, step by step, the same path of incremental improvements that was taken by the industrialized nations.
- Use combinations of economic instruments and regulatory requirements; make-related policies complementary.
- Treat vehicles and fuels as a system, and move toward standards based on lifecycle emissions (including vehicle and fuel production, distribution and disposal) in policies.
- Prevent high in-use emissions with more realistic and representative test procedures, greater manufacturer accountability, improved inspection and maintenance programs, on-board monitoring and diagnostics, and retrofit and scrappage programs.
- Consider the relative cost-effectiveness of near-term measures and the market potential of future technologies.
- Work across jurisdictions, both nationally and internationally, to strengthen programs and give cohesive signals to affected industries.

companion technology review prepared for the ICCT titled, Air Emissions Issues Related to Two- and Three-Wheeled Motorcycles, available to download on the ICCT's website at http://theicct.org/.


FIGURE 3-1. ELECTRIC BICYCLE IN CHINA

The sections that follow cover the different environmentally related aspects of two- and three-wheeled vehicles. The next section, Section 3, provides background on motorcycles. It describes the types of vehicles classified as motorcycles, tracks their population and growth, discusses the role of motorcycles in urban mobility, their impacts on the urban environment, fuel consumption, climate change, and safety, and provides a synopsis of the global motorcycle industry. Section 4 focuses on motorcycle technologies, starting with conventional vehicles and touching upon near- and longer-term vehicle advances. Fuel issues are also raised here given their import regarding motorcycle emission control improvements. Section 5 reviews policy frameworks for dealing with new vehicles, in-use vehicles, and fuels. Section 6 explores opportunities to reduce motorcycle emissions and energy use. Policies for new vehicles are discussed, as are measures for motorcycles already in use. Section 7 presents findings and provides the ICCT recommendations and policy guidelines for reducing two- and three-wheelers' emissions and fuel use.

Most of the research done in this report was conducted in 2007 and 2008. All other data cited from sources prior to these years are specified accordingly.

3. BACKGROUND ON MOTORCYCLES

3.1 TYPES OF MOTORCYCLES

Visit any country in Asia, and elsewhere around the globe, and you will see a colorful assortment of motorized vehicles in many different varieties. Two- wheelers are described in Text Box 3-1. These vehicles typically carry up to two adult passengers for their own personal mobility. But they can also be used to carry small freight or to convey passengers for commercial purposes.

TEXT BOX 3-1. TWO-WHEELER TYPES

Although there are no strict definitions for each two-wheeler type, following are some features that help distinguish among them.

Moped - Bicycle frame equipped with pedals, engine less than 50 cc, and top speed limited to 50 km/hour

Scooter - Step through frame with full metal or plastic covers; wheels less than 36 cm; engine typically between 50 to 250 cc

Scooterette - Scooter-like frame with performance similar to a moped, popular in India

Motorcycle - Two-wheelers that do not fit in previous categories, typically larger wheels and engine size, including off-road dirt bikes


FIGURE 3-2. SCOOTER IN INDONESIA

Electric bicycle - Bicycle frame equipped with pedals, supplemented by electric power from a storage battery

Electric scooter - Slow-speed scooter propelled almost entirely by electricity

Hybrid Two-wheelers - Two-wheelers using an electric motor along with an internal combustion engine; can travel over 50 km/hour

TEXT BOX 3-2. THREE-WHEELERS IN ASIA

Three-wheelers do not abide by strict definitions, but are generally used for passenger and good commercial transportation. Names vary widely by country and by the type of transportation service provided. In India and Sri Lanka, three passenger three-wheelers operating as taxis are known as *auto rickshaws*. *Baby taxis* are commonly known as three-wheelers in Bangladesh. Diesel three-wheelers with six-passenger or goods movement capacity are called *tempos* in India, Sri Lanka, and Bangladesh.

Three wheelers can be made by well-established manufacturers, such as Bajaj that dominates the market for three-passenger three-wheelers in the Indian subcontinent. But in some countries, small local vehicle assemblers make most three-wheelers; this is the case of *tuk-tuks* in Thailand or the *tricycles* in Philippines. The tricycles further distinguish themselves from the rest of the three-wheelers because they are essentially two-wheelers outfitted with a sidecar for passenger transportation.

FIGURE 3-3. TUK-TUK IN CENTRAL BANGKOK

Beyond two-wheelers, motorized three-wheelers customized with decorative paintings are a quintessentially Asian mode of commercial passenger and goods transport. These vehicles trace their origins to the 19th century human-powered wheel cart. Most carts were eventually replaced by cycle-powered and then motor-powered three-wheelers in the 20th century. The motorized versions popular in Asia were originally patterned after Italian models from the 1960s.

Three- wheelers, also known as auto rickshaws, baby taxis, mishuks, tuk-tuks, tempos, and tricycles, are described in Text Box 3-2. Three-wheeled vehicles are used to carry passengers and goods. Most passenger three-wheelers are configured to carry three passengers but some models are outfitted with six passenger seats. In practice, actual passenger loading can be much higher. Although the majority of three-wheelers are gasoline fueled, some cargo three-wheelers are diesel fueled. Three-wheelers provide low cost and flexible transportation for city dwellers and businesses. They are important contributors to urban economies. For example, each three-wheeler in India is estimated to support at least two families (Iyer 2003).

For simplicity, in this report the term "motorcycle" refers to all types of motorized two-and three-wheeled vehicles. When the discussion requires a distinction in motorcycle types, the specific wheeled vehicle is spelled out.

3.2 MOTORCYCLE POPULATION AND GROWTH

In 2005, there were about 300 million two- and three-wheeled motorcycles in use worldwide (Meszler 2007). By 2020, the global motorcycle population is expected to double (Sperling and Gordon 2009). Table 3-1 presents the top twenty countries in terms of the percentage of motorcycles in their overall vehicle fleet. This list provides a general indication of where worldwide motorcycles provide a significant portion of personal and commercial transportation. The share of motorcycles in each country or region's current vehicle fleet varies widely, from Vietnam estimated at 95 percent to Suriname at 27 percent.

TABLE 3-1. TOP TWENTY COUNTRIES/REGIONS BASED ON PERCENTAGE OF MOTORCYCLES IN VEHICLE FLEET (IRF 2007, NSO 2000, BPS 2006, Nguyen 2008, Gong 2008)

COUNTRY/REGION	CONTINENT	TWO- AND THREE-WHEELERS	OTHER VEHICLES	PERCENT MOTORCYCLES
Vietnam (2007)	Asia	22,000,000	1,157,895	95%
India (2003)	Asia	47,525,000	12,834,000	79%
Maldives (2004)	Asia	14,448	3,905	79%
Cambodia (2000)	Asia	1,609,839	457,396	78%
Indonesia (2005)*	Asia	28,556,498	9,599,780	75%
Thailand (1999)*	Asia	13,297,951	6,032,217	69%
Taiwan (2002)	Asia	11,983,757	5,871,198	67%
Pakistan (2004)	Asia	3,947,951	2,066,769	66%
China (2006)	Asia	81,310,000	49,860,000	62%
Sri Lanka (2002)	Asia	923,467	796,105	54%
China, Macao (2004)	Asia	72,528	67,134	52%
Bangladesh (1999)	Asia	147,205	141,450	51%
Malaysia (2003)	Asia	6,164,958	6,654,290	48%
Mauritius (2004)	Africa	129,500	159,909	45%
Myanmar (2003)	Asia	172,892	263,114	40%
Bhutan (2002)	Asia	8,371	14,052	37%
Philippines (2002)	Asia	1,470,383	2,717,290	35%
Uganda (1999)	Africa	63,769	120,048	35%
Greece (2004)	Europe	2,600,714	5,259,428	33%
Suriname (2004)	South America	39,693	106,412	27%

The data in Table 3-1 are mainly drawn from the International Road Federation, *World Road Statistics publication 2006*, but the vehicle population estimates reported in these documents are for different calendar years. As such the ranking should not be seen as a strict indication of the respective rank of each country/region's motorcycle fleet. These data show that the overwhelming majority of motorcycle-dominated countries are in Asia, with a couple of representatives from Africa (Uganda and Mauritius), one from Europe

FIGURE 3-4. MOTORCYCLE OWNERSHIP PER 1,000 PEOPLE (MESZLER 2007)

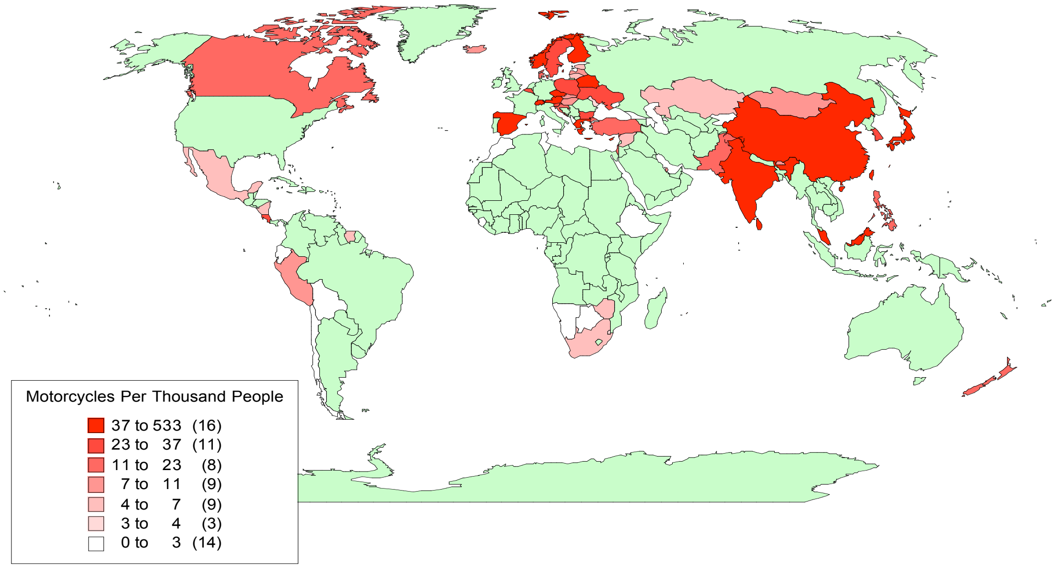


TABLE 3-2. AVERAGE MOTORCYCLE POPULATION GROWTH RATE IN SELECTED ASIAN COUNTRIES (1989-2002) (MESZLER 2007)

COUNTRY/REGION	ANNUAL POPULATION GROWTH RATE (1989-2002)	AVERAGE ANNUAL GDP GROWTH RATE (1989-2002)
China	25%	9%
Nepal	16%	5%
Vietnam	15%	7%
Philippines	14%	3%
Cambodia	13%	6%
Laos	11%	6%
India	10%	5%
Indonesia	9%	5%
Thailand	9%	6%
Bangladesh	7%	5%
Sri Lanka	7%	5%
Pakistan	7%	4%
Hong Kong	5%	4%
Taiwan	5%	6%
Malaysia	5%	7%
Japan	5%	2%
Singapore	3%	7%

(Greece) and one from South America (Suriname).

The importance of motorcycles in Asia is further illustrated in Figure 3-4, which presents motorcycle ownership per one thousand people. The number of countries in each category is noted in parentheses in the legend. In terms of their ownership compared to four-wheeled vehicle ownership, only in Asia do motorcycles dominate the landscape in what are sometimes referred to as "motorcycle countries" and "motorcycle cities" (GTZ 2004). These nations and regions include China, India, Indonesia, Thailand, and Taiwan, which each have large motorcycle populations that constitute the majority of in-use vehicles.

Motorcycle populations in Asia are growing rapidly, as shown in Table 3-2. In China, Vietnam, Philippines, and India, motorcycle ownership has increased by more than 10 percent a year. This has been fueled, at least in part, by economic expansion in these countries. Between 1989 and 2002, most Asian countries' GDP growth at a rate that was several times larger than the average 2.5 percent annual GDP growth worldwide, fueling motorization and motorcycle ownership.

3.3 MOTORCYCLES AND URBAN MOBILITY

Two-wheelers are mainly used as personal vehicles for urban mobility. In some cities, such as Bangkok or Hanoi, they are also used for commercial passenger transportation. Three-wheelers have wider applications. In Asian and other cities, these vehicles are commonly used for commercial passenger, family, and goods transport (GTZ 2004).

Motorcycles have several advantages over other motorized transportation modes, both real and perceived. They are highly maneuverable in congested conditions, offer easier parking, and provide door-to-door connectivity. However, compared to other forms of motorized transport, motorcycles are generally not as safe and may also be more polluting.

When it comes to cost, motorcycles and cars have many inherent trade offs. Their perceived low cost ownership and operation is the result of distorted tax and road pricing policies along with other hidden subsidies. If tax policies that favor personal transport are removed, cars and motorcycles are more expensive than public transport. For example, in India the total tax burden on buses are 2.4 times higher than on personal vehicles. Moreover, their high rate of involvement in accidents (see Box on Safety) imposes costs on all travelers.

Congestion is another confounding issue. When public transportation service is limited, infrequent, or over-crowded, the time spent to complete a trip can be significantly longer than the time needed with a motorcycle. Yet, buses must share congested roads with growing ranks of motorcycles and cars, taking transit more time to travel along its designated route. And with far smaller occupancy rates than transit, motorcycles are responsible for more than their fair share of time stuck in traffic.

Whether and what type of motorized vehicle people acquire often comes down to household economics without much consideration given to social costs. In terms of affordability, in India, for example, the retail price of a two-wheeler ranges from $450 for an entry level moped or scooterette to $1,325 for a premium class motorcycle (Iyer & Badami, 2007). In comparison the recently announced low-cost car, the Tata *Nano*, is expected to sell for $2,500 (Giridharadas 2008). As recently as 2007, the lowest priced car offering in India was about $5,000 (DWS 2007). Low priced, entry-level, small cars are directly aimed at a market segment dominated by motorcycles. As a family vehicle, cars like the Nano could replace more than one motorcycle owned by a middle-class household, accelerating the transition from two- to four-wheeled vehicles. Vehicle exports could lead to similar accelerated transitions in many of the Asian motorcycle countries. While concerns have been raised about whether these cars can comply with safety and environmental standards and there is little guarantee of emission compliance over their lifetimes, these concerns are even more pressing for the motorcycles they seek to replace.

TABLE 3-3. PASSENGER TRIPS BY TRANSPORTATION MODE IN VARIOUS ASIAN CITIES (WRI 2007)

MODE	DELHI (2001)	HANOI (2003)	PUNE (2000)	XI'AN (2000)
Walk	33%	22%	29%	23%
Cycle, pedicab	4%	29%	14%	25%
2-wheeler, motorcycle	14%	42%	29%	5%
Private car	7%	1%	6%	5%
Bus	40%	6%	14%	37%
Rail	<1%%	--	<1%	--
Other	2%	0.4%	8%	5%

With perceived cost and other practical advantages, it is not surprising that motorcycles account for a large and growing share of trips in the main cities of Asian motorcycle countries (GTZ 2004). Directly comparable data on motorcycle's share of passenger transport in Asia cities is difficult to obtain. Studies vary widely in their methodology and types modes surveyed. Nevertheless, the information compiled in Table 3-3 offers some indication of the importance of motorcycles in providing personal mobility to urban dwellers in Asia. In these cities, the proportion of motorcycles trips is currently several times larger than the

TEXT BOX 3-4. MOTORCYCLE ACCIDENTS AND URBAN SAFETY

In urban areas in most developing countries, pedestrians, cyclists, and two-wheeler users account for the overwhelming majority of road killed and injured in traffic accidents (WHO 2004). A sampling of these statistics in india is presented in Table 3-4. Many of these accidents stem from challenges posed by modes with varying speed and visibility sharing the roads. Motorcycle safety in Asia is especially problematic. In India, 27 percent of road deaths involve motorcycle users, in Thailand the estimate is 70 percent or more, and in Malaysia motorcycles are implicated in approximately 60 percent of all deaths in traffic (WHO 2004).

Head injury is the leading cause of death to motorcyclists. An important factor in the severity of the outcome in road accident for motorcycle users is the low use of protective gear, such as helmets and safety equipment on the vehicles including headlights. Often three-wheeler vehicle manufactured by low-volume local producers do not incorporate basic safety features. Finally, the lack of or low funding levels for agencies dedicated to accident prevention limit public education efforts. Sustainable motorcycle policies must address the public health burden caused by motorcycle accidents.

TABLE 3-4. PERCENTAGE OF ROAD USERS KILLED AT DIFFERENT LOCATIONS IN INDIA, BY TRAVEL MODE (MOHAN 2006)

LOCATION	LORRY	BUS	CAR	TSR	MTW	HAPV	BICYCLE	PEDESTRIAN	TOTAL
Mumbai	2	1	2	4	7	--	6	78	100
New Dehli	2	5	3	3	21	3	10	53	100
Highways[a]	14	3	15	--	24	1	11	32	100

TSR: three-wheeled scooter taxi; MTW: motorized two-wheelers; HAPV: human and animal powered vehicles.
[a] Statistical summary of 11 locations, not representative for the whole country (tractor fatalities not included).

share of private car trip. Non-motorized trips, especially walking trips, are a large fraction of all trips in all three cities. The patterns seen here are replicated in many other motorcycle cities. Motorcycles, buses, and cars share the roads with large numbers of bicyclist and pedestrians. Unfortunately this situation is often dangerous, as is described in Text Box 3-4 on urban safety.

3.4 MOTORCYCLES AND AIR POLLUTION

Motorcycles, as with all other internal combustion engine-powered vehicles, emit the products of full and partial fuel combustion. Several of these emitted products have been identified as direct or indirect causes of air pollution. These include particulate matter (PM), carbon monoxide (CO), nitrogen oxides (NO_x), hydrocarbons (HC), sulfur oxides (SO_x), which varies with the fuel's sulfur content, and lead compounds if the fuel used is leaded. Exposure to these pollutants is associated with a host of serious health effects including premature death, aggravated respiratory and heart disease, and neurological damage. The US Environmental Protection Agency and World Health Organization have additional information on the societal impacts of air pollution (US EPA 2005, US EPA 2006, WHO 2005).

In addition to conventional air pollutants, motorcycles and other motor vehicles emit toxic compounds that are also of public health concern. Exposure to benzene, formaldehyde, acetaldehyde, acrolein, 1,3-butadiene, and polycyclic aromatic hydrocarbons (PAH) present in motorcycle emissions has been associated over the long term with increased cancer risk, while short-term exposure is associated with respiratory and neurological effects (US EPA 2007a).

A limited number of studies have evaluated the contribution of motorcycles to conventional and toxic urban air pollution inventories and pollutant exposure in Asia. However, the findings of the few studies published to date are compelling. Table 3-5 summarizes the contribution of two- and three-wheelers to transportation-related emission inventories in four Asian cities. In all of these cities, ambient pollutant concentrations are often above the national standards and/or World Health Organization (WHO) guideline values (Wangwongwatana 2007, Roychowdhury et al. 2006, Le 2007). The contribution from motorcycles varies in each city by fleet composition (proportion and type of two-and three-wheelers in the fleet) and by fleet emission profile and performance. In general, motorcycles are significant contributors of HC, PM, and CO emissions. Motorcycle fleets dominated by uncontrolled four-stroke motorcycles, such as in Ho Chi Minh City, can also be a significant source of nitrogen oxides.

TABLE 3-5. TWO- AND THREE-WHEELER CONTRIBUTIONS TO URBAN TRANSPORTATION EMISSION INVENTORY (SUKSOD 2001, MESZLER 2007)

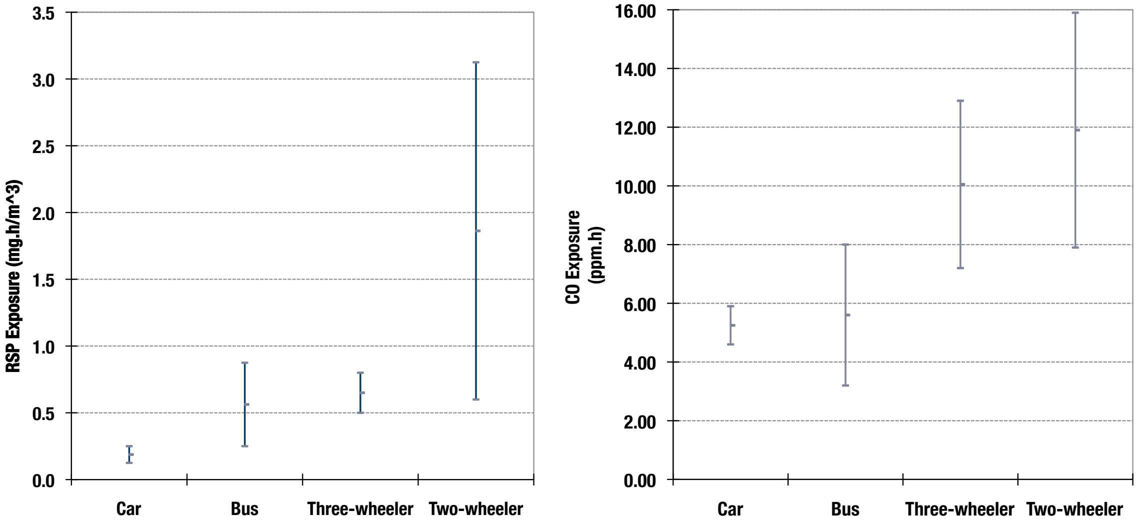
LOCATION	PM-10	HC	CO	NO_X	CO_2
Bangkok, Thailand (1997)	14%	70%	32%	<1%	n/a
Delhi, India (2001)	n/a	70%	50%	n/a	n/a
Dhaka, Bangladesh (2000)	42%	60%	26%	4%	n/a
Ho Chi Minh, Vietnam (2000)	n/a	90%	70%	12%	40%

Motorcycles have been identified as the largest source of particulate emissions at busy traffic intersections, accounting for almost half of the emissions measured (Roychowdhury, et. al., 2006). Moreover, a study of toxic air emissions from vehicles in Bangkok, Thailand found a strong correlation between motorcycle traffic patterns and air-borne benzene concentrations. The author concluded that motorcycles, especially two-stroke motorcycles, had “a high impact on the overall benzene concentration in Bangkok” (Leong et al. 2002).

Three studies provide an assessment of exposure to pollution during motorcycle trips. Exposure levels represent the amount of pollution in the air a person breathes while in a given location or while undertaking a specific activity. A study of particulate matter exposure in Taiwan found that subjects riding motorcycles were exposed to some of the highest levels of commute particulate exposure (Lung et al. 2007). Compared to all the other indoor and outdoor microenvironments and activities evaluated in the study, pollution exposure while riding motorcycles was second only to the level reached when subjects were passing by factories.

A study in Delhi, India found the highest levels of fine particulate exposure (referred to in the study as *respirable* suspended particles or RSP) and CO occurred during commute activities on two- and three-wheelers (Saksena et al. 2007). These results are illustrated for both pollutants in Figure 3-2. Mean exposures to RSP and CO were among the highest of all indoor and outdoor microenvironments and activities. The integrated daily average exposure across all subjects was found to be several times the Indian residential standard. The integrated CO 8-hour exposure was just under the standard, however the authors found that some subsets of the population were exposed to levels up to 40 percent higher than the standard.

FIGURE 3-5. RSP AND CO EXPOSURE FOR DIFFERENT COMMUTE MODES IN DELHI (SAKSENA ET AL. 2007)



The same research team measured PM_{10} and CO concentrations using personal monitors while traveling using various transportation modes (bus, car, motorbike, and walking) on four roads in Hanoi, Vietnam (Saksena et al. 2006). As shown in Table 3-6, the highest mean concentrations for both pollutants were measured while traveling on motorcycles. The researchers also found that mean concentrations increased during rush hour. The results of this study are not directly comparable to the results obtained in Delhi due to differences in sampling methods.

TABLE 3-6. PM AND CO AIR CONCENTRATIONS ACROSS TRANSPORTATION MODES IN HANOI, VIETNAM (SAKSENA ET AL. 2006)

RESULT TYPE	PM_{10} (µg/m^3)					CO (ppm)				
	Bus	Car	MC	Walking	All	Bus	Car	MC	Walking	All
Measurements	16	32	32	16	96	16	32	32	16	96
Mean	262	408	580	495	455	11.5	18.5	18.6	8.5	15.7
CV (%)	45	59	34	38	50	72	66	47	83	66
GM	242	343	547	460	397	9.2	15.7	16.3	5.1	1.88
GSD	1.46	2.07	1.38	1.32	1.56	2.61	1.65	1.46	2.65	1.88

Key – MC: motorcycle; CV: coefficient of variation, GM: geometric mean, SGD: geometric standard deviation

These three studies do not, however, provide estimates of the portion of pollutant exposure that is directly linked to motorcycle emissions. Their results are nonetheless important in understanding the impact of motorcycle use on public health. Indeed, motorcycles, the most popular transportation mode in the cities studied, are linked to the highest levels of in-use exposure to harmful pollutants.

And while many studies do not differentiate between the pollution impacts of various motorcycles, the impact from three-wheelers' on urban air quality is considerably more significant. In India, three-wheelers were found to contribute between 6 and 24 percent of automotive particulate matter in five large cities, significantly more than their share of the vehicle population (Roychowdhury et al. 2006). Another study found that passengers of three-wheelers were exposed to higher levels of particulate matter compared to passengers traveling by bus or car (Saksena et al. 2007).

Air pollution from three-wheelers is primarily due to the high proportion of high-emitting two-stroke engines, the use of inferior quality and excessive quantities of lubricating oil, and poor maintenance practices. In addition, three-wheelers' duty cycle consists of long hours of operation in congested traffic conditions leading to increased emissions.

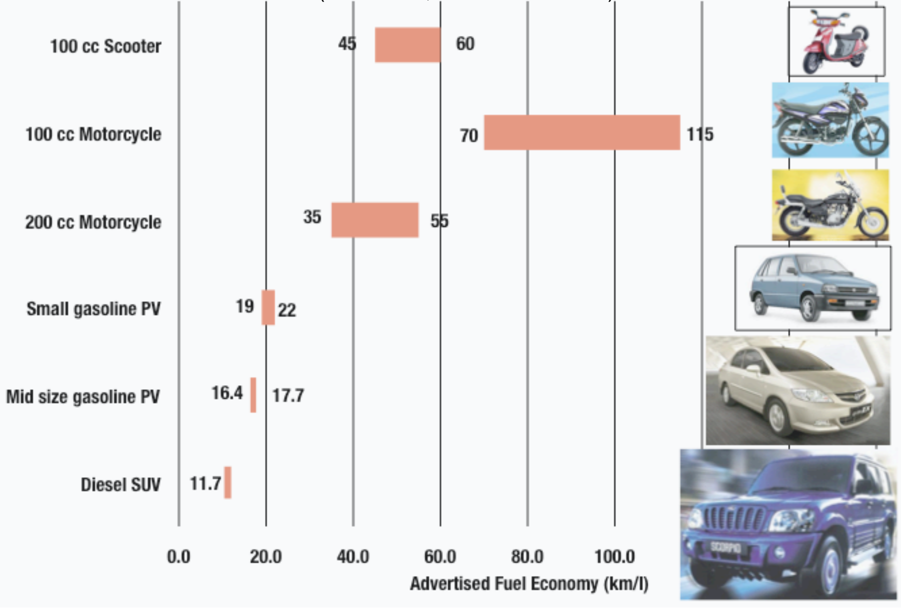
Many countries in the developed and developing world regulate both the concentrations of air pollutants and their by-products (such as smog, haze, and reduced visibility) in ambient air as well as the amount released from vehicle tailpipes, factory stacks, and other sources. The standards regulating pollutant emission levels are a key component of any comprehensive strategy to improve air quality. Motorcycle emissions standards are further discussed in Section 5 on policy frameworks.

3.5 MOTORCYCLES, FUEL CONSUMPTION, AND GREENHOUSE GASES

One of the main advantages of motorcycles is their generally higher fuel efficiency, due to their small engines and lightweight frames compared to other personal motorized vehicles. In most markets, an entry-level motorcycle can be several times more efficient than the best performing passenger vehicle model. For example, in India the popular Maruti 800 gasoline car is advertised at 19 to 22 kilometer per meter (km/l) whereas a Honda Hero motorcycle is advertised at 70 to 115 km/l. Figure 3-3 provides the advertised fuel economy performance for some popular passenger car and motorcycle offered on the Indian market.

Despite advertised information about the fuel efficiency benefits of motorcycles over cars, standardized data on motorcycle fuel economy is scarce. Emission standards have served as the key driver in modernizing motorcycle pollution controls. This can have the indirect effect of improving motorcycle fuel economy. In terms of managing vehicle fuel economy directly, most regulatory efforts have focused on automobile fuel economy, or CO_2 emission standards. Only recently has motorcycle fuel economy even been considered. Still, motorcycle performance data has not been systematically compiled. This lack of standardized data could be remedied if other motorcycle countries follow the leadership of China who is implementing motorcycle fuel economy regulations or India in enacting motorcycle fuel economy labeling. These policy

FIGURE 3-6. ADVERTISED FUEL ECONOMY FOR POPULAR CARS AND MOTORCYCLES IN INDIA (DWS 2008, CARDEKHO 2008)



programs are further discussed in Section 5.2.

Fuel economy estimates vary by motorcycle type and size, as well as by in-use duty cycle. There are also significant variations from country to country or region to region. For example in India, small two-stroke engines tend to be tuned to a lean air-fuel ratio, achieving higher fuel efficiency than small motorcycles that are tuned to run rich in order to optimize power (Meszler 2007). The fuel economy for 100-150 cc Indian motorcycle is estimated to range from 45 to 70 km per liter of gasoline (Iyer & Badami, 2007). In China, the fuel economy of similarly sized two wheelers will be set at 40 km/liter (Wang 2008). In contrast, the most efficient non-hybrid passenger vehicles available today have a fuel economy estimated at nearly 30 km/l (Ward's 2007, ICCT 2007b).

TABLE 3-7. INDIA MOTORCYCLE FUEL ECONOMY ESTIMATES BY VEHICLE AND ENGINE TYPE
(INDIAN DRIVING CYCLE) (GTZ 2004)

VEHICLE TYPE	ENGINE TYPE	ENGINE SIZE (cc)	MODEL YEAR	LABORATORY FUEL ECONOMY (KM/L)	ON-ROAD FUEL ECONOMY(KM/L)
Scooter	Two-stroke	150	Post-1996	55	52
	Four-stroke			62	59
Three Wheeler	Two-stroke	150	Pre-1996	24	20
		150	Post-1996	28	25-27
	Four-stroke	175	2000	33	30-31

Additional test data on motorcycle fuel economy in India by motorcycle characteristics are compiled in Table 3-7. As is discussed in greater technical detail in the Section 4.1, fuel use varies by motorcycle type. Two-stroke motorcycles are in general less fuel-efficient than four-stroke motorcycles due to scavenging losses. An uncontrolled four-stroke engine can be up to 35 percent more fuel efficient than a similarly sized two-stroke engine (Meszler 2007). An interesting trend highlighted for three-wheelers in this table, is that the emissions standards implemented in India in 1996 and strengthened in 2000 are also linked to improvements in fuel economy.

Indeed a common control strategy used to meet vehicle tailpipe standards is to reduce exhaust emissions through improvements in engine combustion efficiency. As a result, a model year 2000 four-stoke three-wheeler was estimated on road to be more than 50 percent more efficient than pre-1996 two-stoke model. Laboratory-measured fuel economy showed a 38 percent improvement between pre-1996 two-stroke and a model year 2000 four-stroke.

Motorcycles, as well as all other motorized vehicles, contribute to the growing amounts of CO_2 and other GHG emissions from transportation sources in the atmosphere. With less than half the carbon dioxide per passenger-kilometer of a car, fossil fuel-powered motorcycles still can have significantly greater emissions than public transit and electric vehicles, as shown in Table 3-8. Although motorcycle's contributions to the global CO_2 inventory are modest (less than 1 percent according to MES estimates) two- and three-wheelers are the dominant source of transportation CO_2 in many motorcycle cities. For example, it is estimated that 40 percent of the transportation CO_2 emissions in Ho Chi Minh City in 2000 were due to motorcycles (GTZ 2004).

TABLE 3-8. GREENHOUSE GAS EMISSIONS FROM VEHICLES IN DEVELOPING COUNTRIES (SPERLING AND SALON 2002)

	LOAD FACTOR (AVERAGE OCCUPANCY)	CO_2 EQUIVALENT EMISSIONS PER PASSENGER-KM (FULL ENERGY CYCLE)
Car (gasoline)	2.5	130-170
Car (diesel)	2.5	85-120
Car (natural gas)	2.5	100-135
Car (electric)[a]	2.0	30-100
Scooter (two-stroke)	1.5	60-90
Scooter (four-stroke)	1.5	40-60
Minibus (gasoline)	12.0	50-70
Minibus (diesel)	12.0	40-60
Bus (diesel)	40.0	20-30
Bus (natural gas)	40.0	25-35
Bus (hydrogen fuel cell)[b]	40.0	15-25
Rail Transit[c]	75 percent full	20-50

Note: All numbers in this table are estimated and approximations, and are best treated as illustrative. See case study reports in this transportation series from the Pew Center on Global Climate change for details and differences across cities and countries.

[a] Ranges are due largely to varying mixes of carbon and non-carbon energy sources (ranging from about 20-80 percent coal), and also the assumption that the battery electric vehicle will tend to be somewhat smaller than conventional cars.

[b] Hydrogen is assumed to be made from natural gas.

[c] Assumes heavy urban rail technology ("Metro") powered by electricity generated from a mix of coal, natural gas, and hydropower, with high passenger use (75 percent of seats filled on average).

In addition to CO_2, other motorcycle emissions have climate impacts. Black carbon, the main heat-absorbing fraction of particulate matter, is several hundred to a thousand times more effective at warming the atmosphere than carbon dioxide on a mass basis. Its effects are particularly strong at the regional level. Over Asia, black carbon emissions have already lead to major melting of the Himalayan glacier that feeds the Ganges and Yellow rivers, it is darkening skies over India, and it is on track to cause a major monsoon failure in 2020 (Ramanathan 2007). VOCs, NO_x, and CO emissions contribute to the formation of ground level ozone or smog, which also has positive climate forcing effect. Methane (CH_4) emissions, especially from natural gas fueled motorcycles, can also be a cause of concern as methane is a potent greenhouse gas.

3.6 MOTORCYCLE INDUSTRY

The motorcycle industry is rapidly expanding due to the popularity of motorcycles, as shown by the growth rates in Table 3-9. Motorcycle manufacturing is a diverse sector that includes a large number of local manufacturers as well as custom vehicle producers, both in developing and developed countries. There are, however, clear market leaders among this diverse group. Japan-based multinational companies such as Honda, Kawasaki, Suzuki, and Yamaha dominate the two-wheeler sector's world market. In several Asian countries, these multinationals have developed joint venture agreements with local manufacturers. Hero Honda Motors, a joint venture between India's Hero Group and the Honda Motor Company, has been the largest two-wheeler manufacturer in the world since 2000 (HeroHonda 2007).

TABLE 3-9. TWO- AND THREE-WHEELER PRODUCTION BY MAJOR PRODUCING COUNTRY/REGION (2003 THROUGH 2006) (FEC 2007, SIAM 2007, AISI 2008, TAI 2008, NGUYEN 2008, JAMA 2007, ACEM 2007, MCTEN 2008)

COUNTRY/REGION	2003	2004	2005	2006
China	n/a	n/a	17,767,200	21,443,500
India	5,978,964	6,904,274	8,043,120	9,000,292
Indonesia	2,814,054	3,897.250	2,466,457[a]	N/A
Thailand	2,378,491	2,867,295	3,548,132	3,547,659
Vietnam	1,412,683	2,134,088	2,187,870	2,553,593
Japan	1,830,905	1,739,584	1,791,585	N/A
European Union	1,273,090	1,368,822	1,351,255	N/A
The Philippines	310,000	475,000	600,000	N/A

[a] 2005 data through June 2005.

China, the world's largest two-wheeler producing country ahead of India, is home to eight companies who manufactured over one million motorcycles each in 2006 (FEC 2007). Chinese manufacturers produced over 20 million motorcycles in 2007, 30 percent of which where destined to export. This represents a doubling in the export percentage compared to 2005. Table 3-10 provides motorcycle production statistics, by major manufacturing country/region, from 2003 to 2006. Note that there may be some double counting, as production statistics often include completely "knocked down"

TABLE 3-10. SELECTED MAJOR MOTORCYCLE MANUFACTURERS (ALPHABETIC ORDER) (ICCT 2007a)

MANUFACTURER	HEADQUARTER COUNTRY/ REGION	TWO-WHEELER	THREE-WHEELER
Bajaj Auto	India	x	x
BMW	Germany	x	
China Jialing Group	China	x	
Chongqing Jianshe Yamaha Motor Co.	China	x	
Ducati	Italy	x	
Grand River Group-Haojue	China	x	
Harley-Davidson	United States	x	
Hero Honda	India	x	
Honda	Japan	x	
Kawasaki	Japan	x	
KTM	Austria	x	
Kymco	Taiwan	x	
Lifan Group	China	x	
Luoyang Northern Ek Chor Motorcycle Co.	China	x	x
Loncin	China	x	
Piaggio	Italy	x	x
Peugeot	France	x	
Qianjiang Motorcycle Group	China	x	
Suzuki	Japan	x	
SYM	Taiwan	x	
Triumph	United Kingdom	x	
TVS Motor Company	India	x	
Yamaha	Japan	x	
Zongshen Industrial Group	China	x	

units built for export. For example, completely disassembled units produced in Thailand exported and assembled in Vietnam can be counted as units manufactured in Vietnam.

In Europe, North America, and other regions where larger, more powerful two-wheelers are preferred, BMW, Ducati, and Harley-Davidson also account for a significant portion of the two-wheeler market share. Peugeot and Piaggio, manufacturer of the Vespa, are important manufacturers of small motorcycles in Europe. As advanced as European motorcycle markets are, two-stroke motorcycles are not being phased out in the EU there despite their damaging effects on air quality and public health.

Indian automaker Bajaj Auto Ltd. is the leading three-wheeler manufacturer in India as well as many South-east Asian, South American, Latin American, and African markets (Bajaj 2007). Table 3-10 identifies three manufacturers in India, China, and Italy who specialize in three-wheelers.

The next section offers background on those conventional motorcycle technologies and fuels configured and manufactured in Asian countries. It also takes a look into the future at alternative fuels and next generation motorcycle technologies emerging in Asia.

4. MOTORCYCLE TECHNOLOGIES

Three major trends are currently shaping the horizon of future technologies in the motorcycle sector. The first trend is the progressive harmonization of emission standards and test procedures towards stringent global norms as discussed in the next section. The second is the transition in new motorcycle sales from two-stroke engines to four-stroke engines. The third trend is the increasing popularity of larger, more powerful motorcycles in markets traditionally dominated by smaller mopeds and scooters.

4.1 CONVENTIONAL MOTORCYCLE TECHNOLOGIES

Up until the last decade, two-stroke engines were the dominant engine type for motorcycles. However, customer preference for motorcycles equipped with more fuel-efficient four-stroke engines, and regulatory programs aimed at curbing emissions from two-stroke engines, have eroded two-stroke motorcycles' market share in some countries. Two- and four-stroke engines, as their names indicate, differ from each other in the number of piston strokes required for the engine to produce power. The fundamental distinctions between these conventional motorcycle engines types are discussed in Box 4-1.

Two-stroke engines remain the preferred engine type for the smallest and lowest cost motorcycle models in Asia. This is due to their size, simple technology, ease of maintenance, and cost advantage over four-stroke engines.

In Thailand, Taiwan and elsewhere throughout Asia, there is a growing trend toward larger motorcycles. This increasing market share of motorcycles compared to scooters and mopeds is reinforcing the shift towards four-stroke engines. Figure 4-1 shows the decline of the percentage of new two-stroke sales in Thailand since 1994 and a similar pattern in Taiwan.

TEXT BOX 4-1. TWO-STROKE VERSUS FOUR-STROKE ENGINES

In a two-stroke engine, gas exchange takes place through ports located in the cylinder. A fuel and air mixture, compressed in the crankcase, enters through the inlet/intake port, while exhaust gases exit through the exhaust port. The intake and exhaust ports are opened simultaneously during part of the cycle. This creates a scavenging effect to help expel the exhaust gas and fill the cylinder with a fresh air/fuel mixture. However, part of the fuel-air mixture escapes through the exhaust port along with the old exhaust gases. Such “scavenging losses” can amount to 15 to 40 percent of the unburned fuel-air mixture. As a result, the exhaust of two-stroke engines contains a high level of unburned fuel and lubricant resulting in large hydrocarbon and particulate matter emissions. (GTZ 2004).

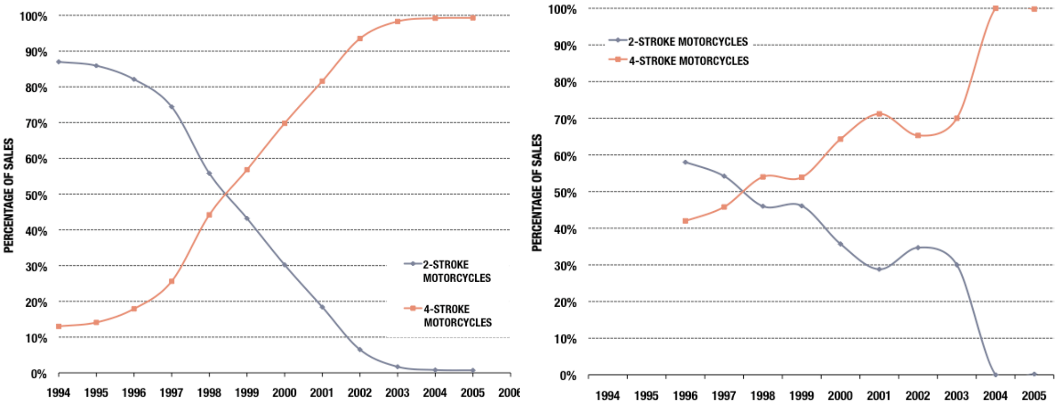
In four-stroke engines, gas exchange takes place through valves. The four-stroke sequence begins with an intake/induction stroke followed by a compression stroke, then a power stroke after ignition, and finally an exhaust stroke. When similarly sized two- and four-stroke engines operate at the same speed, the two-stroke engine completes twice as many power strokes as the four-stroke engine. A four-stroke engine requires a valve train and a camshaft to operate the intake and exhaust valves. The four-stroke engine is consequently larger, heavier, has more moving parts, and is more expensive to purchase and maintain than a two-stroke engine with the same power rating.

Two- and four-stroke engines also differ in their use of lubricating oil. In two-stroke engines, oil is added to the fuel or added to the air-fuel mixture in the combustion chamber and then burned when ignited or exits unburned as part of the scavenging losses. In a four-stroke engine, oil remains in a sealed system and is recirculated from a reservoir in the crankcase to the rest of the engine (Roychowdhury et al. 2006). Only a small fraction of the lubricating oil in a four-stroke engine is burned.

Emissions of unburned fuel are the principal cause of the poor environmental performance of uncontrolled two-stroke engines. Two-stroke engines have similar CO emissions as four-strokes, but far higher HC and PM emissions and higher fuel consumption. Two-stroke engines tend to produce NO_x at a lower rate than four-stroke engines because combustion products in two-stroke engines do not fully exit the cylinder during the exhaust stroke. This internal exhaust gas recirculation (EGR) lowers peak combustion temperatures, which in turn limits NO_x formation in two-stroke engines (Meszler 2007). However, the decrease in NO_x emissions is much smaller than the increase in HC or PM emissions.

Bulkier four-stroke engines are typically better suited for larger motorcycles than for small scooters and mopeds. With growing prosperity in countries such as India and China, consumers are purchasing larger motorcycles as symbols of economic success. Since 1998, essentially all the growth in the two-wheeler sector in India has been in the “motorcycle” category, as compared to the “scooter” and “moped” categories. In 2004, more than 4 million motorcycles were sold in India. In comparison less than one million scooters and one million mopeds were sold, about the same amount as in 1994 (Iyer & Badami 2007).

FIGURE 4-1. **SHARE OF NEW MOTORCYCLE SALES BY ENGINE TYPE IN THAILAND AND TAIWAN** (WANGWONGWATANA 2007, CHEN 2007)



Thailand **Taiwan**

In general, a shift to four-stroke engines coupled with increasingly stringent emission standards is expected to have a positive impact on the fleet average emission rate. Enabling these trends are technologies developed to improve emissions of both two- and four-stroke engines. The following sections discuss two- and four-stroke engines and present specific emission reduction technologies needed to meet current and future emissions standards with conventional gasoline and diesel engines. A more detailed description of the emission impacts of these different motorcycle technologies can be found in the report titled, *Air Emissions Issues Related to Two- and Three-Wheeler Motorcycles,* available on the ICCT's website.

4.1.1 CONTROL TECHNOLOGIES FOR TWO-STROKE ENGINES

For mopeds, the smallest motorcycle category, two-stroke engines remain most manufacturers' preferred option. This is mainly due to the cost and power to weight ratio advantage these engines provide to small and lightweight vehicles.

The primary goal of two-stroke emission improvement technologies is to reduce scavenging losses that occur when fuel and oil escape the combustion chamber before they are ignited (See Text Box 4-1). One of the most promising strategies is the application of electronically controlled direct fuel injection. In a direct injection engine, only air enters through the intake port. Fuel is separately injected directly into the combustion chamber after the exhaust port has closed so that only air is present during scavenging. In some systems, compressed air is used to assist with injection pressure, eliminating the need for expensive high-pressure fuel injectors. By eliminating scavenging losses, direct injection improves two-stroke engine fuel economy by about 40 percent and reduces emissions of HC and CO by 80-90 percent, and reduces PM by 50 percent (Meszler 2007). As direct injection engines are typically run lean (with a low fuel to air ratio), nitrogen oxide emissions are expected to be 50 percent higher than an uncontrolled two-stroke engine, similar to a four-stroke engine (Meszler 2007). Motorcycles with direct injection are currently on the market in Europe and are being developed for sale in the Indian market. Direct injection technology is also available as a retrofit and is currently being marketed for two-stroke three-wheeler applications (see Case Study 5 in Section 6).

Two-stroke emissions can be further reduced through the use of after-treatment technologies such as oxidation catalysts that help reduce CO, HC, and PM emissions by oxidizing them with O_2. Oxidation catalysts are used in many commercially available motorcycles in Europe, Asia, and North America. It is expected that oxidation catalysts – a proven cost-effective technology to control CO, HC, and a portion of PM emissions – will be increasingly used to meet future standards. Unleaded fuels are required for durable operation of catalytic after-treatment technologies and fuels low in sulfur and phosphorus will avoid degradation of catalyst performance. A more detailed discussion of fuel quality requirements can be found in Section 5.

There had been earlier concerns about the durability of oxidation catalysts in two-stroke motorcycle applications. Recent test results show that newer designs can remain effective over 30,000 km, currently the longest regulatory durability limit (Meszler 2007). However, the average motorcycle life is estimated to be several times 30,000 km.

This highlights the need for greater durability limits along with enforcement throughout a motorcycle's life. Without a comprehensive inspection and maintenance program, it is almost impossible to ensure that a catalyst is operational and is replaced when it fails.

While two-stroke engines are characterized by their low NO_x emissions, additional controls may still be required to meet increasingly stringent standards. Three-way catalytic converters, another after-treatment technology, are not only effective at oxidizing CO and HC present in the exhaust gas, but they also reduce NO_x emissions. To function optimally, three-way catalysts require precise control of air-fuel ratio to achieve stoichiometric conditions that cannot be achieved with carburetor technology. Three-way catalysts will most likely not have significant penetration into the two-stroke engine market without further engine combustion optimization, such as electronically controlled fuel injection. Moreover, this emission control may not be cost effective. The technical difficulties and economic realities of tightly controlling NO_x without after-treatment may eventually lead to a total phase-out of two-stroke engines in markets where stringent standards are in place in the most heavily-polluted cities (Iyer & Badami 2007).

4.1.2 CONTROL TECHNOLOGIES FOR FOUR-STROKE ENGINES

The main strategy for controlling emissions from four-stroke engines consists of improvements in fuel injection to optimize fuel combustion and the addition of exhaust after-treatment. In the near term, a system of port fuel injection and an oxidation catalyst assisted by secondary air injection are adequate to meet currently adopted standards (Iyer & Badami 2007). In port fuel injection systems, the fuel is injected into the cylinder intake port near the intake valve, producing better fuel distribution and combustion efficiency. The oxidation catalyst, as described in the previous section, oxidizes CO and HC in the exhaust stream. Because most engines are set to run at a rich air/fuel ratio, a secondary air injection system must be added ahead of the catalyst. This introduces more oxygen into the exhaust stream and further promotes the elimination of CO and HC from the exhaust (Meszler 2007).

Further emission reductions, beyond those required to meet standards set by the major regulatory programs will most likely require the use of three-way catalytic converters in place of an oxidation catalyst. Ensuring the effectiveness of the three-way catalyst necessitates precise control of the air/fuel ratio. Better control, through port fuel injection with a feedback system in the exhaust, ensures the necessary stoichiometric conditions in the catalyst. Emission reductions compared to an uncontrolled carbureted four-stroke engine are estimated at 90 percent for CO, 85 percent for HC, and 25 percent for NO_x (Meszler 2007). A small number of commercially available motorcycle models, including some models from BMW and Harley-Davison, are currently equipped with three-way catalysts.

After-treatment systems used in four-stroke engines also require fuel that is unleaded and low in sulfur and phosphorus. Durability issues highlighted in the previous section also apply to catalysts on four-stroke engines. Regulatory mechanisms must be put in place to ensure that emission control equipment functions optimally over the full useful life of each motorcycle. These mechanisms can include more realistic durability limits and inspection and maintenance programs.

4.1.3 CONTROL TECHNOLOGIES FOR EVAPORATIVE EMISSIONS

The more volatile portions of gasoline that evaporate and escape in gaseous form from the fuel system cause evaporative emissions. There are four types of evaporative hydrocarbon or fuel vapor emissions from a vehicle’s tank and fuel systems. Diurnal evaporative emissions are caused by increases in ambient temperature during the day. Running loss emissions are fuel vapor emissions that occur due to heating of the fuel in the gas tank and fuel lines while the vehicle is operating. Hot soak emissions occur after a vehicle has been turned off and engine heat continues to heat up the tank and fuel system. And refueling emissions occur when the fuel tank is filled up and the liquid displaces vapors in the tank and forces them into the air.

The main strategy to control evaporative emissions is the application of a system to capture the evaporated hydrocarbons. Carbon canisters are very effective at capturing vapors and are universally used on vehicles and motorcycles. The canisters capture evaporative emissions from the tank and fuel system when the engine is not running. When the engine is running it draws the captured vapors from the canister and combusts them. This low cost option has been used in motorcycles in California since the late 1970s and in Taiwan since the 1990s (Meszler 2007, Chen 2007). In addition, a fuel tank cap without holes can further reduce evaporative emissions. The system should be fully sealed to prevent fuel leakage. These are two effective ways to limit evaporative emissions.

4.2 CONVENTIONAL FUEL PRODUCTS

The choice of fuel and lubricating oil, as well as their production quality, affects how motorcycles perform in terms of emissions and fuel economy. Poor quality fuel and lubricating oil contains contaminants such as heavy metals that are linked to serious health impacts. Secondly, certain fuel and oil components, including metals, sulfur, and phosphorus, can negatively impact the performance of emission control technologies. Finally, overuse of poor quality lubricating oil can lead to excessive smoke and particulate matter emissions. Regulating fuel, oil, and vehicles as a system can minimize these impacts. The policy frameworks regarding fuels are discussed in Section 5.

Gasoline is the primary fuel for motorcycles and the main focus of this discussion. Diesel is used in some three-wheeler applications, particularly in India, but is not a significant motorcycle fuel in most of the world.

Sulfur occurs naturally in the raw crude oil that is used to make gasoline and diesel fuels. Some of this sulfur is removed during the fuel refining process. But sulfur remains in final fuel products sold. Sulfur in fuel can negatively impact the performance and durability of after-treatment devices such as oxidation and three-way catalysts. The current most stringent motorcycle exhaust standards require the use of exhaust after-treatment devices. The effectiveness of these controls can be impaired if very high fuel sulfur levels are present in the fuel.

Worldwide, sulfur levels in gasoline and diesel have been declining. However a wide range in sulfur content of fuels remain. The

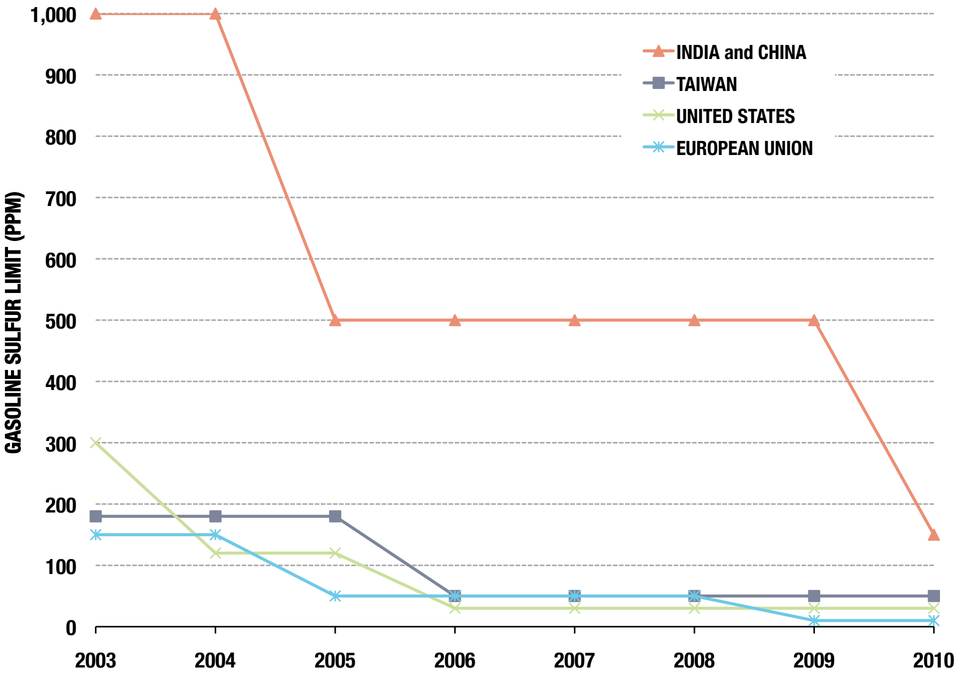


FIGURE 4-2. HISTORICAL GASOLINE SULFUR LEVELS IN TAIWAN, INDIA, THE UNITED STATES AND THE EUROPEAN UNION, 1994-2010 (ICCT 2007a, PCFV 2007)

sulfur levels of fuel sold in many developing countries is 10 to 100 times higher than sulfur levels found in Europe, the United States and Japan. Figure 4-2 illustrates the progressive desulfurization of gasoline in India, China, the European Union, and the United States. In large cities in India and China gasoline at 50-ppm sulfur levels, lower than the national standards, is available.

Fuel additives enhance or suppress fuel properties mainly during combustion. These include chemicals, metals, minerals or other compounds. Metal-based additives containing lead, manganese and ferrocene have been a source of public health concern for decades.

Lead alkyl was used as an octane enhancer for nearly seventy years before it was phased out of most of the world's gasoline supply beginning in the 1970s. Fuel containing this additive emitted lead particles as a byproduct of fuel combustion. Lead is a potent neurotoxin that is associated with health impacts ranging from permanent brain and nervous system damage to learning disabilities and behavioral problems in children. In adults it can produce reproductive, nerve, and memory problems (US EPA 2007b).

Other metal additives of concern include methylcyclopentadienyl manganese tricarbonyl (MMT), a manganese-based compound, and ferrocene, an iron-containing compound. Both are used as an octane enhancer and have been marketed as lead alkyl replacements. Similar to lead alkyl, the use of MMT and ferrocene additives in gasoline results in the emission of manganese and iron oxide particles in vehicle exhaust (ICCT 2004). Chronic exposure to manganese has been associated with neurological impacts indicated by symptoms similar to Parkinson's disease (ICCT 2008). Although there are very few studies on the health effects of exposure to ferrocene combustion products, animal studies have shown cellular damage after exposure (Walsh 2006). The use of MMT and ferrocene in gasoline damages important vehicle engine components including spark plugs, sensors, valves and catalytic converters by depositing metallic compounds on their surfaces (ACEA 2001). As with lead, these additives prevent emission control equipment from functioning at their full potential.

Evidence of the significant public health impacts associated with the use of metal additives in fuel has prompted scientists and physicians to take a firm position to end their use. In the June 2006 *Declaration of Brescia on Prevention of Neurotoxicity of Metals,* a group of scientist and physicians representing 27 nations called for the cessation of the use of lead and manganese from all gasoline (Landrigan et al. 2006). In general, the precautionary principle is advised when considering any additives that may be associated with public health impacts. Under the precautionary principle, an action can only be taken once those proposing the action provide proof that no irreversible damage would result.

It is important to note that not all fuel additives are problematic. Some types of additives can have beneficial effects on vehicle emissions. In particular, detergents, which reduce deposits on engine and fuel system components, have a positive impact on engine performance and durability. Detergent additives are composed of organic chemicals that can dissolve existing deposits and prevent additional deposit formation.

In two-stroke engines, lubricating oil is introduced in the air-fuel mixture stream at the time of intake. When poor quality oil is used and/or too much oil is added to the fuel, the engine may produce an excessive amount of smoke and higher than usual particulate matter emissions. The use of excessive amounts of inappropriate lubricants like mineral oil or recycled automotive oil can also lead to degradation of engine components.

In three-wheelers, visible smoke emission is due to excessive lube oil consumption because of abnormal wear of piston rings/ cylinder liner. The purpose of piston rings is to maintain a pressure tight seal between the piston and cylinder wall, to aid in controlling oil, to permit proper lubrication of the cylinder and to assist in the cooling of the piston. The quality of the piston ring is important factor. With poor quality piston rings, it is possible that lubricating oil from oil sump leaks into the combustion chamber, causing smoke.

4.3 ALTERNATIVE FUELS AND NEXT GENERATION MOTORCYCLE TECHNOLOGIES

In addition to ensuring that new conventional motorcycles have increasingly better emissions controls, most successful comprehensive programs also encourage the development and use of alternative fuels and advanced propulsion technologies, including zero and near-zero emission motorcycles. This section discusses experiences with the use of alternative fuels, such as compressed natural gas (CNG) and liquefied petroleum gas (LPG), and it discusses efforts to improve and promote electric and hybrid-electric technologies.

4.3.1 ALTERNATIVE FUEL PROGRAMS

Alternatives to conventional gasoline and diesel transportation fuels are sought for a wide range of reasons. Alternative fuels hold out the potential to develop local resources with a lower cost to the national economy than imported fuels. Clean alternative fuels can produce fewer emissions of harmful pollutants and life-cycle greenhouse gas emissions. The actual benefits of shifting to alternative fuels, however, vary widely. Fuel availability, clean infrastructure investment, vehicle performance, local practices and habits, economic costs, other impacts play a role in determining whether social benefits result from alternative fuel use. These must be weighed against private costs, including the incremental vehicle cost or retrofit cost, incremental maintenance costs, and the incremental cost of the alternative fuel, if any. If benefits exceed costs, then a transition is warranted and policies may be required to facilitate changes in current practices.

For motorcycles, the primary alternative fuels are compressed natural gas (CNG), liquefied petroleum gas (LPG), ethanol, and electricity. CNG has been used principally in three-wheeler applications. These vehicles can accommodate the larger and heavier pressurized tank needed for the compressed gas. The history of the CNG three-wheelers program in Delhi, India, is reviewed in Case Study 1 below. This case study highlights the policy design and institutional structures

CASE STUDY 1. CNG THREE-WHEELER PROGRAMME IN DELHI, INDIA

BY ANUMITA ROYCHOWDHURY, CENTER FOR SCIENCE AND ENVIRONMENT (DELHI, INDIA)

In 1998, the Supreme Court of India mandated one of the world's first natural gas vehicle programs as part of an air pollution control strategy. The program, which took effect in 2000, has helped to stabilize pollution levels in the city. In the first stage all passenger three-wheelers were targeted for this program. In 2006, the Delhi government expanded the scope of the program and mandated registration of all new three-wheeled freight vehicles to run on CNG. And there may be considerable opportunity to expand the program's scope if it is determined that CNG vehicles' benefits exceed their costs.

CNG three-wheeler industry in India is largely a domestic. Domestically-built four-stroke engine models dominate the Delhi fleet with three-seat capacity. Out of 55,000 CNG three wheelers, two-thirds are new, domestic OEM (original equipment manufacture) powered by four-stroke engines. The remainder is retrofitted two-stroke vehicles running on CNG.

CNG systems consist of a high-pressure fuel tank, a pressure regulator, and a gaseous carburetor. In two-stroke applications, a lubricating oil pump and separate oil tank are included. CNG installations involve high pressure fuel tanks (200 bar pressure) that require more space and are heavier than gasoline tanks with the same vehicle range. The vehicles currently operating in Delhi are not fitted with catalytic converters. Emission controls may be needed to control tailpipe exhaust of noxious pollutants. The cost of the transition to CNG can be a potent barrier to implementation. The upfront capital cost of an OEM-built CNG three-wheeler is about 25 percent higher than its gasoline counterpart. The cost of retrofitting three-wheelers is nearly $700 (US Dollars). However, cheaper CNG fuel prices – nearly 60 percent lower than the price of gasoline – help to recover the initial investment within a short time. And the Delhi government provides subsidized loans to reduce the cost of transition to CNG.

Design failures and poor maintenance can undermine the effectiveness of the program. Quality concerns surfaced in Delhi in 2004 when some 168 three-wheelers were found emitting excessive amounts of white smoke. Surveys by the Department of Transport found one-half of the offenders were four-stroke OEM vehicles while the other half were two-stroke retrofitted models. Further investigation uncovered lubricating oil leakages, leading to incomplete combustion, causing excessive white smoke emissions due to rapid deterioration of piston rings. Vehicles had to be redesigned and good maintenance practices were reemphasized. Limited remote sensing data in Delhi and Pune, summarized in Table 4-1, show emission trade-offs in the in-use emissions profile of the two fleets. The Delhi fleet runs almost entirely on CNG and has higher CO and NO_x emissions but lower HC and visible smoke emissions compared to the Pune fleet, which is predominantly gasoline fueled. These comparisons are not perfect, however, as the cities' fleets are not otherwise the same. Delhi's motorcycles are mainly 4-stroke while Pune's mostly 2-stroke.

required for implementing a transition to alternative fuels.

LPG has also been used in three-wheeler applications, although smaller tank requirements make it an option for two-wheelers as well. LPG can be stored at relatively low pressure (below 15 bar pressure) for automotive applications. LPG is widely used in thee-wheelers in Bengaluru, Chennai, Hyderabad, and Pune (India), which unlike Delhi and Mumbai are not located near a natural gas supply pipeline. Thailand also has significant experience with LPG use given that most three-wheelers in Bangkok are LPG fueled (PCD 2007).

Cities currently embarking on natural gas and any other alternative fuel programs will have to overcome technical, institutional, and market barriers for successful implementation and maximum emissions gains. Just because a vehicle runs on alternative fuels does not necessarily mean it is cleaner. Alternative fuels must abide by the policy frameworks detailed in the next section in order to address motorcycle emission and energy issues.

TABLE 4-1. EMISSION FACTORS FOR THREE-WHEELERS IN DELHI AND PUNE (ESP 2004)

POLLUTANT	EMISSION RATE (g/Kg)	
	DELHI CNG FLEET 4-STROKE	PUNE GASOLINE FLEET 2-STROKE
CO	244	226
HC	150	252
NO_x	7.4	0.5
Smoke	6.9	32.2

4.3.2 ELECTRIC AND HYBRID MOTORCYCLES

Zero tailpipe emission technologies have long been held up as the ultimate solution to transportation-related pollution problems. Electric motorcycles have been available for several decades, but they have only recently begun to enjoy commercial success, primarily in China.

With lighter removable battery packs and with extended operation ranges, newer battery-electric two-wheelers available in China are now competing with smaller combustion engine motorcycles and conventional bicycles. Case Study 2 describes potential environmental benefits, associated costs, and the factors that have lead to the commercial success of this next generation motorcycle technology.

Electric motorcycles, with their zero tailpipe emissions, can significantly improve urban air quality. However, their overall emission benefits will depend on the environmental impact of power generation. Concerns have also been raised regarding land use impacts from lead used in battery packs. Lead contamination from battery production, during use, and after disposal can be significant and produce important health impacts. Policies required to improve the environmental performance of electric motorcycles are explored further in Section 6.

CASE STUDY 2. THE GROWING RANKS OF E-BIKES IN CHINA

JONATHAN WEINERT, UNIVERSITY OF CALIFORNIA (DAVIS, USA)

Today's electric bikes, or e-bikes, come in two varieties: those propelled by human pedalling supplemented by electrical power from a storage battery (bicycle-style) and low-speed scooters propelled almost solely by electricity (usually with perfunctory pedals to satisfy legal "scooter" status). Typical bicycle-style and scooter-style e-bikes are pictured.

Technologically, e-bikes consist of a hub motor, controller, and valve-regulated lead-acid (VRLA) battery. Bicycle-style e-bikes typically have 36-volt batteries and 180-250 Watt motors. Scooter-style e-bikes typically have larger 48-volt batteries and higher-powered, 350-500 Watt, motors. Electric bikes are regulated not to exceed 20 kilometers per hour (km/hr), but many scooters are capable of traveling at speeds in excess of that limit, and some are advertised to reach 40km/hr.

FIGURE 4-3. BICYCLE AND SCOOTER STYLE ELECTRIC

In general, e-bikes consume 1.2-1.5 kilowatt hours (kWh) of electricity per 100 kilometer (km). On a single charge (typically 6-8 hours), they can travel 25-50 km. Electric bike batteries are removable and rechargeable using a standard electrical outlet, so they require no new re-charging infrastructure.

E-bikes are gaining an increasing share of two-wheeled transportation throughout China, They provide an inexpensive and convenient form of personal mobility. In many cities like Chengdu and Suzhou, they have even surpassed the share of bicycles in use. Annual e-bike sales in China reached 17 million in, up from only 40,000 in 1998 (Weinert et al. 2006). Today, there are an estimated 20+ million e-bikes in China, the majority of which were purchased over the past five years.

The cost of owning and operating an e-bike is the lowest of all personal motorized transportation in China. Figure 4-4 compares the life-cycle cost of an e-bike compared to other modes including cycling, transit, and gasoline or LPG scooters.

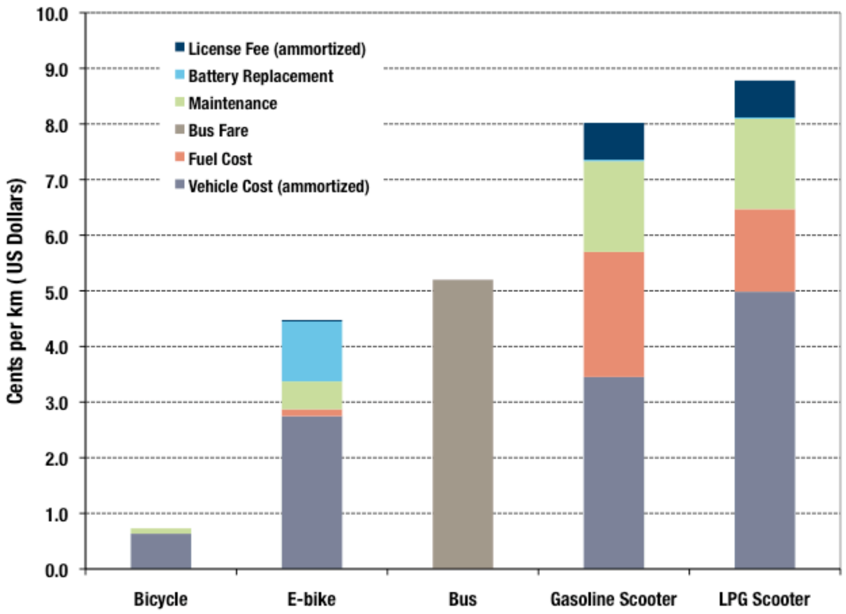


FIGURE 4-4. COST COMPARISON OF COMMON URBAN TRAVEL MODES IN CHINA (WEINERT ET AL. 2006)

E-bikes are an extremely energy efficient mode of personal transportation with zero vehicle emissions. In cities battling poor air quality, they are having positive effects by displacing noxious emissions from gasoline-powered scooters. They also have a positive impact on climate change since in-use carbon emissions per km travelled are roughly four times lower than scooters and 14 times lower than cars, as seen in Figure 4-5.

These climate change benefits can be maximized when fuel cycle emissions are kept to a minimum using renewable energy to generate electricity. So while e-bikes provide zero tail-pipe emissions, they do emit pollution from power plants, which are 75 percent coal fired in China (Cherry 2006). This results in increased emissions of certain pollutants, particularly SO_2, which is particularly problematic in Chinese cities. Other pollutants are low, compared to alternative modes (Cherry 2006).

Lead emissions from battery production and recycling are the most serious environmental problem with e-bikes. Lead emissions per passenger kilometer are several orders of magnitude higher for electric bikes than for buses (Cherry 2006). Unregulated (or under regulated) production and recycling practices within the lead and battery industries result in the loss of an estimated that 30-70 percent of the lead into the environment.

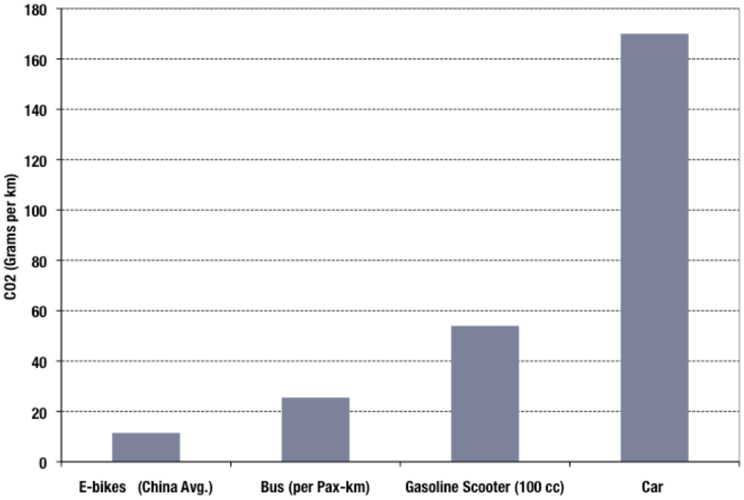


FIGURE 4-5. LIFECYCLE CARBON EMISSIONS OF TRANSPORTATION MODES IN CHINA (CHERRY 2006)

Research efforts are underway to develop commercial hybrid technology for motorcycles. Taiwan has identified hybrid technology as a key component of their Stage 5 emission regulation program. Hybrid motorcycles would allow significant downsizing of the internal combustion engine and would improve fuel economy and emissions. For example, a 50 cc engine coupled with an electric motor could power a 100 cc motorcycle. Research and development activities are ongoing not only in government laboratories like those in Taiwan, but also in the research facilities of most major manufacturers. Honda and AVL presented concept vehicles as early as 1997 and 1999, respectively (Wang et al. 2000) and R &D activities continue among major manufacturers and potentially new market entrants.

Fuel cell technology is also currently being explored for motorcycle applications in India and in Taiwan (Tso and Chang 2003). Fuel cell motorcycle proponents expect that fuel cell technology will be able to achieve zero tailpipe emissions without some of the performance and range issues encountered with battery electric motorcycles (Tso and Chang 2003). Commercial availability of these vehicles is still uncertain as research and development is still in its early stages. As with CNG and LPG fuel, fuel cell motorcycles will require the availability of hydrogen through a new network of fueling stations.

5. POLICY FRAMEWORKS

5.1 MOTORCYCLE EMISSION STANDARDS

This section covers the regulatory practices that lead to the adoption of best available emission control technologies in new motorcycles. The discussion focuses on existing regulatory programs, in particular the programs developed in nations and regions where motorcycles significantly contribute to air pollution. Taiwan, India, Thailand, and China have been leaders in developing elements of a comprehensive strategy to control emissions from motorcycles, including the adoption of increasingly stringent emission standards.

It is important to review the air quality management framework in which these policies fit. Regulations and fiscal policies aimed at reducing emissions can improve vehicle performance or change usage patterns. Both of these outcomes can reduce pollution exposure and associated health impacts. Considerations such as cost and cost effectiveness (cost per amount of emission reduced) are often used to prioritize among various control measures. Fuel use policies fit in similar energy conservation and greenhouse gas management frameworks.

A new motorcycle emission control program includes standards and a compliance process to ensure that manufacturers comply with adopted standards. Emission standards are typically expressed as the mass of a specific pollutant to be emitted over a distance traveled by the vehicle (i.e., grams/kilometer). During the type-approval process, manufacturers must demonstrate that their pre-production models meet the emission standards over their useful lifetime, represented by an accumulated distanced traveled (or *durability distance*). Motorcycle policies are discussed below.

5.1.1 EXHAUST EMISSION STANDARDS

Even though standards for new motorcycle emission levels took decades to phase in after they were first adopted in the US in the late 1970s and in Europe in the late 1980s, the standards adopted in Taiwan and India became more stringent over a shorter time period. Pollution from motorcycles is a much larger concern in Taiwan, India and many other Asian cities, regions and countries compared to the US or even in Europe. Historical and current emission standards and their basis are detailed in the Appendix.

Motorcycle emission standards typically prescribe an emission limit for carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NO_x). In some programs the HC and NO_x emission limit is combined because these pollutants react together to form ozone, or smog, and their relative concentrations in the air affect the chemical reactions that form pollution. Particulate matter emissions have recently been subjected to limits in the EU, Taiwan, and India for diesel three-wheelers but are not typically included in gasoline motorcycle standards. A further discussion of PM emissions and standards is found in Text Box 5-1. Other pollutants emitted by motorcycles such as sulfur oxides (SO_x) and lead controlled by regulating fuel quality.

Definitions related to exhaust emission standards, including for driving cycles, durability, and cold start testing, are detailed below.

TEXT BOX 5-1. REGULATING PARTICULATE EMISSIONS FROM MOTORCYCLES

Controlling PM emissions from non-diesel two- and three-wheelers has long focused on regulating hydrocarbon and oil combustion emissions. Most of the particulate matter emitted by motorcycles is composed of semi-volatile hydrocarbon from incomplete fuel combustion and, for two-stroke motorcycles, additional PM from lubricating oil combustion. For all motorcycles, the primary reduction in HC is achieved by eliminating scavenging losses in 2-stroke engines, either by shifting to 4-stroke engines or by adding direct injection. Further reductions are available by improving the engine combustion efficiency and perhaps using exhaust after-treatment technologies. For two-stroke motorcycles, using improved lubricating oil, such as the low smoke (or “2T”) oil required in many countries, is expected to reduce particulate emissions. Inspection also helps. Thailand, for example, conducts opacity tests as a way to monitor visible smoke emissions.

The shift in sales away from high PM emitting two-strokes to lower emitting four-strokes (see Section 4) along with increasingly stringent HC emissions standards requiring after-treatment should be sufficient to reduce gasoline PM emissions to low levels.

A *driving cycle* is a timed sequence of speeds and loads developed to represent real-world driving patterns. Compliance with emission standards is established and verified on the basis of performance over a driving cycle. The EU and Taiwan as well as many other regions and countries’ emission limits are currently based on the ECE R47 drive cycle for mopeds or ECE R40 for all other motorcycles. These drive cycles were developed by the United Nations Economic Commission for Europe (UNECE). The UNECE, through the World Forum for Harmonization of Vehicle Regulation (also referred to as WP29), has recently developed the harmonized World Motorcycle Test Cycle (WMTC). This new test cycle is designed to represent a global average driving pattern. Completed in 2005, the WMTC will facilitate harmonization of regulatory programs in the future. Amendments to the test cycle – those that better represent conditions in regions with smaller displacement engines and low traffic speeds – were submitted by India and adopted in 2007. Contracting parties to the WP 29 process are expected to eventually incorporate the test cycle and other adopted technical regulations within their standards.[2] Those who are not contracting parties are considering adopting this cycle as well. Euro 3 standards include optional limits based on the WMTC. Many nations are expected to adopt WMTC standard procedures in the coming years.

Durability requirements are designed to ensure that vehicles meet emissions limits over the vehicle’s useful life, defined by distance traveled in kilometers. Although the EU does not require durability testing, the latest updates of regulatory programs in China, India, Japan, Taiwan, Thailand, and the US include durability requirements that range from 6,000 to 30,000 km depending on motorcycle size. With average annual mileage in Asia estimated at 8,000 to 10,000 km for two-wheelers and 40,000 km for three-wheelers, these durability requirements only guarantee emission performance for one to three years (Meszler 2007). Clearly, current durability requirements do not yet reflect real world useful life and the opportunity exists to extend them in future updates of these regulatory programs. Extended motorcycles lifetimes are expected to be very long especially throughout Asia as mobility grows and these vehicles are sold and resold.

Specifying *deterioration factors* is another way to build durable emission performance into a regulatory program. Manufacturers have to demonstrate compliance with emission levels at some percentage below the stated standards. The percentage chosen is meant to represent the expected deterioration of emissions performance over the motorcycle's useful life. Deterioration factors, while based on extensive laboratory testing, is best used to complement in-use emission system durability testing. The proposed Indian standards include deterioration factors of 1.2 for two-wheelers and 1.1 to 1.2 for three-wheelers. Manufacturers can either test at pre-deterioration levels (10 to 20 percent below depending on the vehicle or pollutant type) or demonstrate compliance from a motorcycle with 30,000 accumulated kilometers.

Cold start emission testing simulates emission performance when a vehicle is started up after being parked for some time. Until recently, all motorcycle emission testing were performed after the engine had been running and was no longer cold. This is referred to as *warm* or *hot start* testing. Cold start testing is especially important when testing motorcycles equipped with catalytic converters. Catalysts attain their maximal effectiveness once exhaust temperatures reach a certain level and cold start testing captures the higher pollutant exhaust levels before they are operational. Test procedures in China, Japan, Taiwan, Thailand, the EU, and the US require cold start testing. India's proposed standards for 2008-2010 call for a cold start, but test procedure details describe testing after the engine has run for a short period. Although a step in the right direction, this variation on cold start testing will not include a critical portion of the cold start exhaust flow.

In addition to exhaust emission standards, new motorcycle emission control programs can include limits on *evaporative emissions*. Evaporative emissions are non-exhaust hydrocarbon emissions that escape from the fuel system during vehicle use and while at rest. These evaporative emissions can provide a significant contribution to a motorcycle fleet's overall hydrocarbon emission inventory. The regulatory limit on evaporative emissions is typically 2 grams emitted during the sealed housing for evaporative determination (SHED) test. During the SHED test, the motorcycle is placed in a temperature controlled and sealed enclosure, and HC evaporative emissions are measured while the temperature is changed to match variation in ambient temperatures over a day. Currently only China, Thailand, Taiwan and the US have adopted evaporative emission standards (Meszler 2007, Wangwongwatana 2007). The US has also set tank and fueling system hose permeation limits at 1.5 g/m^2/day and 15 g/m^2/day, respectively, for motorcycles produced starting in 2008 (Meszler 2007).

Adopting emission standards is a necessary first step in controlling pollutant exhaust from new motorcycles. However, emissions limits are only meaningful if they result in the adoption of best available control technologies that are accompanied by validated test procedures and compliance process. The sections that follow discuss the evolution of technologies used to meet standards, the cost effectiveness of these technologies, and compliance and enforcement features for motorcycles. The primary focus is how best to supplement performance and testing requirements in order to enhance the effectiveness of emission standards.

5.1.2 EVOLUTION OF MOTORCYCLE TECHNOLOGIES AND EMISSION REGULATORY PROGRAMS

To better understand how technologies are used to meet the goals of regulatory programs, it is useful to see how technologies have been introduced to meet emission standard limits over time. Table 5-1 summarizes the evolution of control technologies for new motorcycles in Taiwan since 1988 and in India since 2000. It is clear from the progression shown in the figure that the introduction of tighter standards has fostered the development and implementation of improved control technologies. The table also projects the introduction of future technologies to meet forthcoming standards, such as the Stage 5 standard in Taiwan and the Bharat III standard (and later) in India. Further tightening of standards would reduce and eventually close the existing gap between motorcycle and passenger car emissions.

Details of both the estimated emissions profile and cost of motorcycles according to past, current and future emission standards in India are presented in Table 5-2. Each step forward on the path to cleaner motorcycles results in a modest increase in motorcycle price, between five and 16 percent compared to the previous standard (Iyer & Badami 2007). In many cases the increase in motorcycle price is partially offset by gains in fuel efficiency and a reduction in oil consumption.

Alternative technologies play a role in regulatory emission reduction goals. In Taiwan, electric motorcycles and hybrid motorcycles (more recently) are an integral part of the strategy to improve motorcycle emission performance. It is expected that electric motorcycles will replace two-stroke models in the long term in India (Iyer & Badami 2007).

5.1.3 COST EFFECTIVENESS OF MOTOR VEHICLE REGULATORY PROGRAMS

Cost effectiveness analysis considers emission reduction potential and incremental cost when comparing different technology options. Cost effectiveness can be calculated by dividing the annualized incremental cost by the difference in emissions between a baseline and an improved technology, amortized over the vehicle's life. The result is a cost per amount of pollutant reduced. Calculations can cover both individual technologies as well as technology combinations. The technology combinations reflect the type of enhancements discussed in the previous section for control programs that require dual emission reductions (e.g., $HC + NO_x$). Cost effectiveness can be calculated with and without the fuel savings. A negative cost effectiveness means that the technology pays for itself over a designated timeframe.

The baseline for cost effectiveness calculations is typically an uncontrolled conventional motorcycle engine. Calculations are based on global average prices and are intended to represent the incremental retail price of motorcycles equipped with emission control equipment. The assumptions about vehicle life, fuel price, and discount rate must be specified. Regional variations in those factors, as well as in the incremental technology costs, can be expected. It is important for policymakers to assess cost effectiveness on a regional or local level when comparing potentially beneficial technology pathways.

Studies show that technology options to control motorcycle emissions are very cost effective, even without accounting for fuel savings (Meszler 2007). The cost effectiveness estimates range from approximately -\$500 to \$300 per ton for HC, CO, NO_x, and PM combined. Several emission control options pay for themselves in less than half of the expected vehicle life. Different jurisdictions select different cost effectiveness set points depending on economic, social, and political factors. In California, for example, mobile source control measures below \$14,000 per ton of NO_x, reactive organic gases (ROG or VOC), and PM combined are considered cost effective (ARB 2005).

TABLE 5-1. EVOLUTION OF CONTROL TECHNOLOGIES IN TAIWAN AND INDIA (TEPA 2006, IYER 2006, IYER AND BADAMI 2007)

<table>
<tr><th>COUNTRY/
REGION</th><th>88</th><th>89</th><th>90</th><th>91</th><th>92</th><th>93</th><th>94</th><th>95</th><th>96</th><th>97</th><th>98</th><th>99</th><th>00</th><th>01</th><th>02</th><th>03</th><th>04</th><th>05</th><th>06</th><th>07</th><th>08</th><th>09</th><th>10</th><th>11</th><th>12</th></tr>
<tr><td>TAIWAN</td><td colspan="3">Stage 1</td><td colspan="7">Stage 2</td><td colspan="6">Stage 3</td><td colspan="3">Stage 4[a]</td><td colspan="6">Stage 5</td></tr>
<tr><td>Two and Four-stroke engines</td><td colspan="3">Carburetor
Recycle blow-by gas</td><td colspan="7">Carburetor
Recycle blow-by gas
Carbon canister
Oxidation catalyst
Secondary air injection
Alternative: Electric Motorcycle</td><td colspan="6">Carburetor (most models)
Open-loop fuel injection (few models)
Recycle blow-by gas
Carbon canister
Oxidation catalyst
Secondary air injection
Alternative: Electric Motorcycle</td><td colspan="3">Carburetor (most models)
Open-loop fuel injection (some models)
Closed-loop fuel injection (few models)
Recycle blow-by gas
Carbon canister
Oxidation catalyst + Secondary air injection (most models)
Three-way catalyst (few models)</td><td colspan="6">Closed-loop fuel injection
Recycle blow-by gas
Carbon canister
Oxidation catalyst + Secondary air injection
or Three-way catalyst
Alternative: Hybrid motorcycle</td></tr>
<tr><td>INDIA</td><td colspan="12"></td><td colspan="5">Bharat Stage I</td><td colspan="5">Bharat Stg. II</td><td colspan="3">Bharat Stage III</td></tr>
<tr><td>Two-stroke engines</td><td colspan="12"></td><td colspan="5">Carburetor
Oxidation catalyst
Secondary air injection</td><td colspan="5">Improved Carburetor
Improved oxidation catalyst
Secondary air injection</td><td colspan="3">Air assisted direct injection
Electronic engine management
Oxidation catalyst</td></tr>
<tr><td>Four-stroke engines</td><td colspan="12"></td><td colspan="5">Carburetor
Oxidation catalyst
Secondary air injection</td><td colspan="5">Improved Carburetor
Improved oxidation catalyst
Secondary air injection</td><td colspan="3">Port fuel injection
Oxidation catalyst + Secondary air injection
Three-way catalyst (some models)</td></tr>
</table>

[a] Starting with Stage 4 no new two-stroke were sold in Taiwan, the Stage 4 & 5 technologies only apply to four-stroke engines

TABLE 5-2. DETAILS ON EVOLUTION OF CONTROL TECHNOLOGIES IN INDIA (IYER & BADAMI 2007)

ENGINE TYPE	CHARACTERISTICS	BHARAT STAGE I (2000)	BHARAT STAGE II (2005)	BHARAT STAGE III (2010)	FUTURE STANDARD-2015	FUTURE STANDARD -2025
Two-stroke engines	Technology	Improved engine and oxidation catalyst	Improved engine and improved oxidation catalyst	Air-assisted direct fuel injection and oxidation catalyst	Air-assisted direct fuel injection and improved oxidation catalyst	Battery electric
	Vehicle price (USD)	754	797	905	948	1034
	PM (g/km)	0.05	0.05	0.04	0.03	No tailpipe emissions
	NOx (g/km)	0.07	0.08	0.08	0.08	
	HC (g/km)	2.13	1.32	0.7	0.55	
	CO (g/km)	2.2	1.4	1	0.8	
	Fuel economy gasoline eq. (km/l)	45	45	59	59	150
Four-stroke engines	Technology	Improve engine with or without oxidation catalyst	Improved engine with improved oxidation catalyst	Port fuel injection with oxidation catalyst	Port fuel injection with three-way catalyst	Direct fuel injection with three-way catalyst
	Vehicle price (USD)	905	970	1121	1207	1293
	PM (g/km)	0.05	0.05	0.05	0.04	0.03
	NOx (g/km)	0.3	0.3	0.2	0.1	0.08
	HC (g/km)	0.7	0.7	0.56	0.45	0.36
	CO (g/km)	2.2	1.4	0.42	0.33	0.25
	Fuel economy gasoline eq. (km/l)	72	72	73	73	77

5.1.4 COMPLIANCE AND ENFORCEMENT PROGRAMS

Compliance and enforcement programs include all the government led programs put in place to ensure vehicle models are in compliance with new vehicle regarding emission certification and in-use emission standard limits to ensure compliance over time. The main programs are the type-approval process, the conformity of production and selective enforcement audit process and the vehicle recall program.

The *type-approval process*, or certification process as it is called in the US and Taiwan occurs prior to mass production and sale to the public. *Conformity* of production and new vehicle selective enforcement audit occur in the first few months of the vehicle model's availability on the market. A vehicle model *recall* can occur anytime within its official useful life.

The purpose of the *type-approval* is to show that the design is capable of meeting the standard.

The type-approval process is usually overseen by a government agency with relevant technical expertise, most often within the national environmental ministry or administration. Manufacturers are responsible for all testing performed during the type-approval process. Some manufacturers choose to invest in their own testing equipment; others contract the services of independent testing facilities.

The engine family is the basis for type-approval or certification. An engine family is defined by regulation and is composed of engines with the same engine and emission control characteristics. These characteristics include cylinder number and configuration, cooling system, and number of injectors within a displacement category. Type approval must be obtained for each engine family and each model year.

Test procedures require manufacturers perform exhaust emission testing and, if required, evaporative testing. The tests are performed on a representative pre-production vehicle for each engine family. The manufacturer selects the representative pre-production vehicle that would represent the worst-case scenario for emission within the engine family using their best engineering judgment. This is, for example, the vehicle with the largest displacement engine or with the lowest precious metal loading on the catalyst. In the US, this vehicle is referred to as an "Emission Data Vehicle". It is also best if this vehicle's features are as close to the expected production model as possible. This will reduce costly recalls later when vehicles are already in use.

Testing requirements vary by jurisdiction. In the US there are different requirements for on-highway and off-highway motorcycles. On-highway motorcycles above 50 cc must be tested at four specific points of accumulated distance. The first point is specified by regulation as the minimum test distance after emission stabilization. The last point is at half the official useful life. The second and third test points are at distances in between before and after specified periodic maintenance. Tests can use a dynamometer or a test track according to a procedure specified in the regulation. The emissions at the end of useful life must be estimated using statistical methods.

The test results are submitted to the oversight agency. If the emissions at the end of the motorcycle's useful life are below the standard limit values, requirements are met. The manufacturer then receives a certificate of conformity. If the requirements are not met, the manufacturer can upgrade engine and vehicle design for re-testing.

Periodic correlation tests are performed between manufacturers' test facilities, oversight agencies, and independent testing facilities to identify any systematic problems and ensure the reliability of results from different sources. There have been issues with fake certificates being issued for vehicles imported to the United States and routine inspection can minimize the risk of fraud. The oversight agency may choose to conduct factory inspections during motorcycle production to ensure that the manufacturer is building vehicles to the specifications approved in the type-approval process. This step is especially important during the production of the first generation of models subject to a new set of emission standards.

Conformity of Production and Selective Enforcement Audit is required to ensure that mass production implements the approved design Shortly after vehicles are made available to the public, manufacturers must demonstrate that the vehicles produced meet the requirements established under the type-approval process. In this mainly administrative step, the manufacturer must document production and quality management practices, including the testing they performed throughout production. If the oversight agency judges the documented practices are satisfactory, vehicle sales can continue. If not, the manufacturer must perform production upgrades and resubmit documentation for approval.

The oversight agency can choose to require the manufacturer to further test new engine or vehicle model emissions and to submit these results through the Selective Enforcement Audit (SEA) program. Engines and vehicles can either be pulled from the end of the factory assembly line or taken from the dealership for these selected enforcement audits. The testing can be done by the oversight agency or by the manufacturer following the agency's requirements. If the engines or vehicles fail to meet the standards, sales of that particular engine or vehicle model will be restricted until the manufacturer can demonstrate conformity with the standards. SEA allows the agency to identify, as early as possible, high emitting vehicle models so that vehicles sold are repaired and improvements are made at the production level.

Vehicle recall ensures the durability of the manufactured motorcycles. As with selective enforcement audits, the vehicle recall program allows for the identification and repair of systemic emission problems. This encourages manufacturers to be proactive in testing and quality assurance to avoid financial losses later during a specified warranty period. The oversight agency may select in-use vehicles for further emission testing anytime during the warranty, which is usually specified in terms of vehicle age and miles driven (e.g., 10 years/100,000 miles). These tests provide both the agency and the manufacturers with information on how the vehicles are performing in the real world. Typically this testing is triggered by data from an inspection and maintenance program. Data on warranty claims may also reveal that a specific engine family or vehicle model may be systematically failing to meet the standards. If the testing proves systematic failure, the oversight agency may issue a recall order to the manufacturer. The manufacturer must contact vehicle owners and must repair all the vehicles covered by the recall at its own expense. Manufacturers may also voluntarily issue recalls once a problem is identified. In general, recall programs have a broader scope than emission related issues and extend to safety and overall vehicle performance.

In Taiwan, for example, properly maintained motorcycles must meet standards; otherwise manufacturers must recall and repair them. A preliminary investigation tests emissions conformity among a selection of five motorcycles from each engine family. If these do not meet emission standards (or more than two tests from each engine family fail), a conformity test will ensue. Taiwan institutes a motorcycle recall when average emissions do not meet standards from ten samples in the same engine family.

5.2 MOTORCYCLE EMISSIONS IN-USE REQUIREMENTS

Motorcycle inspection and maintenance (I&M) are an important part of the framework to check that control systems are in working order. I&M is typically part of a larger emissions testing program covering cars and light trucks. Under inspection and maintenance programs, vehicles' emissions (and safety) are required to be inspected and tested at regular intervals, usually annually or bi-annually. The vehicles that fail to meet in-use standards must be repaired and retested. I&M programs thus create an incentive for vehicle owners to perform preventative maintenance to ensure their vehicles will pass inspection. This discussion focuses solely on the motorcycle components of I&M programs.

I&M programs can be centralized or decentralized. In a centralized system, only a few large facilities provide testing. Centralized stations are typically test-only stations that are operated by the government. In a decentralized system there are many smaller, often private facilities that provide both testing and repair services. Each structure has its advantages and disadvantages. Experiences with different testing designs are summarized in Table 5-3.

TABLE 5-3. I&M PROGRAM DESIGN CHOICES AND THEIR ADVANTAGES AND DISADVANTAGES (WALSH 2005)

DESIGN TYPE	DESCRIPTION	ADVANTAGES	DRAWBACKS
Centralized	Limited number of test only facilities	- Easier facility oversight for government - Potentially lower cost per test if large number of vehicles are tested in each facility	- Limited access to facilities for vehicle owners - Longer wait times, lost productivity, and vehicle idle emissions
Decentralized	Larger number of test and repair facilities	- Convenient access to facilities and to repair services for vehicle owners - Incentive for testing facilities to provide preventative maintenance to potential testing customers	- More challenging facility oversight for government (corruption, poor quality control) -Potentially higher cost per test if low number of vehicles are tested in each facility

Vehicle emission testing facilities can be public, private, or a hybrid arrangement. Hybrid testing can entail a mix of public and licensed private facilities in a decentralized structure or a private company contracted to operate test-only facilities in a centralized structure. If testing is provided by the private sector, it is important that contractor selection and facility licensing follow a rigorous and transparent process (Walsh 2005). Outsourcing of the testing or even the management of an I&M program requires continued government oversight to ensure the quality of the work performed. Transparency is key to public acceptance of I&M programs.

5.3 MOTORCYCLE FUEL ECONOMY STANDARDS

Fuel economy is an emerging regulatory issue in the motorcycle fleet, especially in the context of growing concerns about climate change and energy security. Although motorcycles tend to travel farther on a gallon (liter) of gasoline than passenger vehicles, further fuel economy gains can be achieved by optimizing engines and motorcycles. Reducing conventional pollutant emissions can reduce fuel consumption through improved combustion efficiency or the transition from two- to four-stroke engines.

Fuel economy standards are typical expressed in miles per gallon (km/liters) while the related measures of fuel consumption is measured in liters/100 kilometers. No matter what measure is selected it is important that fuel usage standards avoid the pitfalls cars have faced where vehicles are made more fuel-efficient as their fuel economy remains stagnant. This has been the case in the US where vehicle performance, engine size, and weight increased as vehicles were made increasingly more energy efficient without any meaningful reduction in fuel consumption.

Fuel economy certification is similar to that for air pollution emissions. Typically manufacturers are required to test representative pre-production models during the type approval process according to established test procedures that detail driving cycles. Oversight agencies may conduct independent testing to verify the data provided by manufacturers.

There are currently no in-use compliance programs for motorcycles (or cars). In general, the fuel economy of well-maintained vehicles is not anticipated to deteriorate and may even improve as wear reduces engine friction and tire rolling resistance. On the road, variable traffic conditions and road conditions, as well as driver behavior can

TABLE 5-4. MOTORCYCLE FUEL CONSUMPTION STANDARDS IN LITER PER 100 KILOMETER, BY ENGINE SIZE (GB16486-2008, GB15744-2008, LIN 2009)

ENGINE SIZE (cc)	CHINA TWO-WHEELER (L/100km)	CHINA THREE-WHEELER (L/100km)	TAIWAN TWO-WHEELER (L/100km)
≤50 (mopeds)	2.0	2.3	2.3
>50-100	2.3	3.3	2.7
≥100-125	2.5	3.8	2.8
≥125-150	2.5	3.8	2.8
≥150-250	2.9	4.3	4.0
≥250-400	3.4	5.1	4.0
≥400-650	5.2	7.8	5.5
≥650-1000	6.3	9.0	6.3
≥1000-1250	7.2	9.0	6.9
≥1250	8.0	9.0	6.9

contribute to high variability in fuel consumption in use. Poor maintenance can contribute to deterioration of fuel economy. Inspection and maintenance programs, discussed in Section 6.2, can help identify and repair malfunctioning motorcycles.

Taiwan has had fuel economy standards in place since 1987 and mainland China adopted standards in 2008. Table 5-4 summarizes the adopted fuel consumption limits for two- and three-wheelers in China and details the standards in force in Taiwan starting in 2009.

In India, manufacturers will begin voluntarily reporting fuel economy for motorcycles starting in spring of 2009. The fuel economy will be measured as per the emissions standards test procedure specified in rule 115 of the Central Motor Vehicle Rules (CMVR). It is expected that fuel economy standards will be proposed in late 2009 to take effect starting model year 2013.

Even with more publicly available standardized fuel economy information it will remain difficult to compare fuel consumption estimates in the major markets such as China and India. The main barrier to comparison is the difference in the testing methodology. There is also some indication that manufacturers may follow different strategies in accordance with customer preferences. In India, small two-stroke engines tend to be tuned to a lean air-fuel ratio to maximum efficiency, whereas small motorcycles in other countries tend to run rich to optimize power (Meszler 2007).

5.4 MOTORCYCLE FUEL AND LUBRICATING OIL QUALITY STANDARDS

The systems approach to vehicle emission control requires carefully matching emission limits with the corresponding fuel specifications. As discussed in previous sections, fuel quality affects the performance of many exhaust control after-treatment systems. Lubricating oil quality and usage rates mainly affect the emission performance of two-stroke engines. The following sections summarize current policies addressing fuel sulfur, metal and other additive contents as well as regulations of lubricating oil quality and use.

TABLE 5-5. CURRENT GASOLINE SULFUR CONTENT STANDARDS FOR SELECTED COUNTRIES AND REGIONS, 2007 (ICCT 2007a, PCFV 2007)

GASOLINE SULFUR CONTENT	COUNTRIES & REGIONS
≤ 10-15 ppm	Japan
> 10-15 and ≤ 50 ppm	European Union, South Korea, Taiwan, United States
> 50 and ≤ 150 ppm	China, India: Delhi, Mumbai, Kolkata, Chennai, Bengaluru, Hyderabad, Ahmedabad, Kapur, Pune, Surat, Agra; Singapore, Thailand
> 150 and ≤ 500 ppm	India (excluding 11 large cities), Vietnam
> 500 ppm	Bangladesh, Indonesia, Malaysia, Pakistan, The Philippines, Sri Lanka

5.4.1 SULFUR CONTENT OF FUEL

Many countries and regions regulate the sulfur content in the gasoline and diesel fuels available for sale. Sulfur limits, however, vary widely. Some of the world's lowest sulfur fuel is available in Japan, E.U., Taiwan, South Korea, and the U.S. But not all countries or regions with large motorcycle populations control high sulfur levels, leading to high motorcycle emissions. Table 5-5 includes current levels of sulfur in gasoline in selected countries.

As more countries move to lower sulfur fuels, there is strong evidence that the costs of this transition are outweighed by the public health and environmental benefit of cleaner fuels and vehicles. The full benefits of lower sulfur fuels can only be attained if they are implemented at the same time as emission standards for vehicles. Countries must couple emissions standards with fuel quality standards to fully enable cleaner vehicle technologies.

Figure 5-1 displays the estimated cost-benefit ratios from several analyses of proposed sulfur content reductions in diesel and gasoline coupled with tighter emission standard in the United States (light-duty, heavy-duty, and non-road vehicles), China (light and heavy-duty), and Mexico (light and heavy-duty). The analysis for China includes the costs and benefits of improving fuel quality and emission standards for motorcycles.

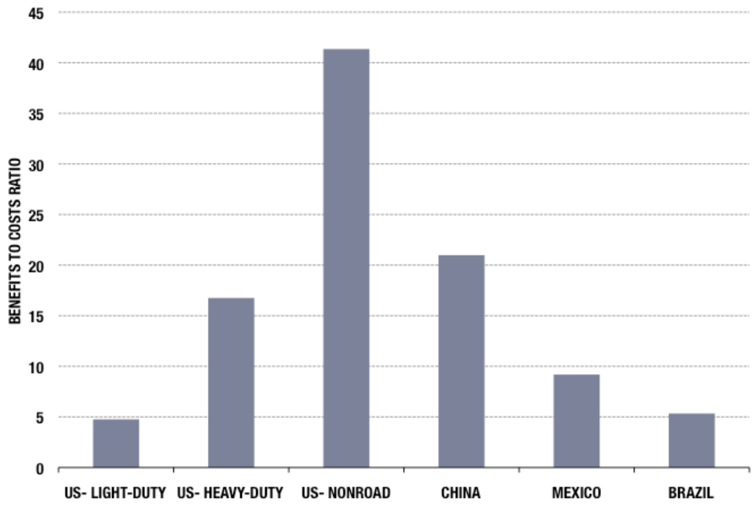


FIGURE 5-1. RATIO OF BENEFITS TO COSTS IN THE YEAR 2030 FOR SEVERAL RECENT ANALYSES (US EPA 1999, 2000, AND 2004; ICCT 2006; INE 2006

When transitioning to lower sulfur fuels, it is standard practice to make the fuel available ahead of the sale of vehicles designed to use the cleaner fuel to meet new emission standards. This allows potential fuel distribution issues to be resolved before the vehicles requiring the fuel are on the road. This also limits misfueling that may damage the vehicles' emission control systems.

Some countries, such as China and India, have elected to have cleaner fuels available in large metropolitan areas before they become available nationwide. The rationale behind this two-tiered implementation schedule benefits those areas where the burden of air pollution is the highest, while allowing fuel providers to ramp up their production or import cleaner fuels to meet nationwide demand. Unfortunately, in this approach, the risk of misfueling and damaging the emission control system is most probable for vehicles that frequently travel where lower sulfur fuel is unavailable.

5.4.2 FUEL METAL AND OTHER FUEL ADDITIVES CONTENT

Studies have shown a dramatic reduction in lead levels in blood since lead was phased-out of gasoline (ICCT 2001). However there are still countries, listed in Table 5-6, where lead continues to be used in all or part of the gasoline sold. In some cases, complete phase-out plans have yet to be agreed upon.

The continued use of lead will not only result in significant health impacts among the most vulnerable individuals, especially children under six years old, but also permanently damaging catalysts, precluding the use of advanced emission controls.

Methylcyclopentadienyl manganese tricarbonyl (MMT) – often used as an alternative to lead for fuel octane enhancement – is subject to strict limits or is banned in some countries. In Europe, the limits that will come into force in 2014 (2 milligrams/liter) are effective bans since these levels would not provide any significant increase in octane levels (ICCT 2008). In 2008, Beijing, China adopted a maximum limit of 6 mg/l MMT, while fuel providers in India and Indonesia volunteered not to use MMT as an octane booster (ICCT 2008).

5.4.3 LUBRICATING OIL QUALITY AND USAGE CONTROLS

In many countries the use of low smoke oil, also referred to as 2T oil, is required to be dispensed at service stations pre-mixed with gasoline to prevent the use of excessive amounts of poor quality lubricants. 2T oil specifications are provided by the Japanese Automotive Standards Organization as JASO FB and JASO FC, and by the American Petroleum Institute as API TC.

TABLE 5-6. STATUS OF LEADED FUEL USE IN THE WORLD (PCFV 2008)

STATUS	COUNTRIES
Leaded	Asia: Democratic People's Republic of Korea, Myanmar Middle East: Yemen
Dual System	Africa: Algeria, Morocco, Tunisia Asia: Afghanistan, Tajikistan, Uzbekistan Europe: Bosnia Herzegovina[a], Former Yugoslav Republic of Macedonia, Montenegro, Serbia[b] Middle East: Iraq

[a] Ban in 2010; [b] Ban planned for 2015-2020

Table 5-7 summarizes the regulations adopted in selected countries to control the use of lubricating oil for two-stroke engines. The experience with implementing lubricating oil regulations in India is provided in Case Study 3 below.

Policy frameworks matter when it comes to setting and enforcing environmental and energy standards. Without adequate verifiable test procedures, inspection, durability requirements, routine inspection, adequate oversight and coordination, it will be difficult, if not impossible, to realize the opportunities to improve motorcycles' emissions and fuel economy. A discussion of these opportunities follows in the next section.

TABLE 5-7. TWO-STROKE OIL QUALITY AND DISPENSING REQUIREMENTS FOR SELECTED COUNTRIES / REGIONS (ESMAP 2002, CAI ASIA 2004, BOAZ 2007)

COUNTRY/REGION	OIL	DISPENSING REQUIREMENTS	IMPLEMENTATION ISSUES
Bangladesh	2T oils meeting JASO FB or API TC specification Ban on mineral oil sales	None, 2T oil available in 60 ml packets	Availability of 2T oil
India	2T oils meeting JASO FC specification in 15 major cities	Dispense only pre-mixed oil and gasoline in large cities. Loose oil sale banned in some cities	No countrywide regulation on dispensing pre-mixed oil and gasoline
Pakistan	Ban on recycled oil sales	Allow oil sale only at gasoline dispensing facilities and not at other roadside locations	Adulteration of 2T oil

CASE STUDY 3. 2T OIL EXPERIENCE IN INDIA

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Indian policy with regards to lubricating oil has evolved in the last decade. In July 1998, the Supreme Court intervened in Delhi to mandate that meters be installed in the refueling stations to dispense pre-mixed lubricants and gasoline by December 1998. Supply and sale of loose 2T oil (not contained in sealed containers) were banned in refueling stations and service garages. Following this directive, the Union Ministry of Environment and Forests issued a notification titled, "2T oil Regulation and Supply and Distribution Order," in August 1998 that mandated the sale of 2T oils that conform to the American Petroleum Institute (API TC) and JASO FC grades in the national capital territory of India (Delhi, New Delhi and Delhi Cantonment). Thereafter, a few state governments enacted legislation regarding distribution, purchase and sale of 2T oil.

In November 2006, the Government of India extended the original 1998 Supreme Court order for Delhi to fifteen large cities including Agra, Ahmedabad, Bangalore, Chennai, Faridabad, Hyderabad, Jharia, Jodhpur, Kanpur, Kolkata, Lucknow, Mumbai, Patna, Pune, and Varanasi. A large part of the country still remains outside the scope of this order.

One of the barriers to further implementation has been the high cost of installation of pre-mix dispensers across the country. The pre-mix dispensers are either fully electronic or manual. The manual system can still be influenced at the operator and user's discretion. In Delhi, nearly 40 percent of the dispensers are estimated to be manual.

6. OPPORTUNITIES TO REDUCE MOTORCYCLE EMISSIONS AND ENERGY CONSUMPTION

Successful policy reform must be geared toward both conventional and next generation two- and three-wheeled vehicle technologies. Improving the performance and monitoring the use of conventional vehicles is key. Pushing cleaner and more fuel-efficient next generation technologies is also necessary.

The first policy priority is establishing emission standards and certifying new motorcycles equipped with both conventional and next generation technologies. This entails overseeing the activities of a handful of manufacturers, verifying that their products meet the most up-to-date national and local standards. Incentives can be employed to shift consumer preferences to cleaner models. The next crucial step is controlling in-use emissions. Controlling emissions from vehicles once they are on the road is often the most challenging part of a comprehensive emission control program. This requires dealing with the use and maintenance practices of each motorcycle owner, a necessary endeavor fraught with difficulties. The final step is advancing technological innovations to produce next generation two- and three-wheeled vehicles with a smaller energy and environmental footprint. The following sections will identify policies for each of these steps.

6.1 NEW VEHICLE POLICIES

6.1.1 EXHAUST EMISSION STANDARDS

Several developing nations and regions are implementing motorcycle emission standards. With motorcycle ownership on the rise, their adoption worldwide is necessary. Given that a limited number of motorcycle manufacturers export their production worldwide, there are large benefits to harmonizing regulatory standards, including reduced compliance costs for exporters and the opportunity for countries to leapfrog to the most stringent current standards.

In Asia, Taiwan was the first to adopt emissions standards and has remained a leader in implementing increasingly stringent norms. Thailand and China have adopted enhanced versions of the European air

TABLE 6-1. LATEST ADOPTED TWO-WHEELER WITH TWO- AND FOUR-STROKE ENGINE (MESZLER 2007)

COUNTRY/REGION	INDIA	EUROPEAN UNION[g]			TAIWAN	
Engine Size or Type	All	< 50 cc	50 – 150 cc	≥150 cc	<150 cc	≥150 cc
Effective Date	2010	2002	2006		2007	
CO (g/km)	1 [a]	1	2	2	2	2
HC + NOx (g/km)	1 [a]	1.2	-	-	-	-
HC (g/km)	-	-	0.8	0.3	0.8	0.3
NOx (g/km)	-	-	0.15	0.15	0.15	0.15
Driving Cycle	Indian Driving Cycle	ECE R47[c]	ECE R40 [d]	R40 + EUDC[e]	ECE R40	
Cold Start	Yes [b]	No	Yes	Yes	Yes	
Durability (km)	30,000	None	None		15,000	
Evaporative Emission Limit	None	None	None		2 g/ test[f]	

Notes: [a] Deterioration factor = 1.2; [b] Procedure does not require measurement at T=0; [c] United Nation Economic Commission for Europe Regulation 47 – mopeds; [d] United Nation Economic Commission for Europe Regulation 40 – motorcycles; [e] United Nation Economic Commission for Europe Regulation Extra-Urban Driving Cycle; [f] Determined by Sealed Housing for Evaporative Determination (SHED) test; [g] According to the European Commission Directive 2006/72/EC, manufacturers can also comply using the World Motorcycle Test Cycle. In that case the limit values are as follows: For maximum speed below 130 km/h, CO: 2.62 g/km, HC: 0.75 g/km, NO_x: 0.17 g/km. For maximum speed above or equal 130 km/h, CO: 2.62 g/km, HC: 0.33 g/km, NO_x: 0.22 g/km

TABLE 6-2. LATEST ADOPTED THREE-WHEELER WITH TWO- AND FOUR-STROKE ENGINE (MESZLER 2007)

Notes: [a] Deterioration factor = 1.2; [b] Deterioration factor = 1.1; [c] D

COUNTRY/REGION	INDIA		EUROPEAN UNION[g]			TAIWAN	
Engine Size or Type	Spark Ignited (SI)	Compression Ignited (CI)	<50 cc	>50 cc SI	>50 cc CI	<150 cc	≥150 cc
Effective Date	2010		2002	2003		2007	
CO (g/km)	1.25 [a]	0.5 [b]	3.5	7	2	2	2
HC + NOx (g/km)	1.25 [a]	0.5 [c]	1.2				
HC (g/km)				1.5	1	0.8	0.3
NOx (g/km)				0.4	0.65	0.15	0.15
PM (g/km)		0.05 [a]					
Driving Cycle	Indian Driving Cycle		ECE R47[e]	ECE R40[f]		ECE R40 [f]	
Cold Start	Yes [d]		No	No		Yes	
Durability (km)	30,000		None	None		15,000	
Evaporative Emissions Limit	None		None	None		2 g/test[g]	

eterioration factor = 1; [d] Procedure does not require measurement at T = 0; [e] United Nation Economic Commission for Europe Regulation 47 – mopeds; [f] United Nation Economic Commission for Europe Regulation 40 – motorcycles; [g] Determined by Sealed Housing for Evaporative Determination (SHED) test

quality standards program. India has developed its own unique set of norms. Tables 6-1 (two-wheeler standard) and 6-2 (three-wheeler standard) present the latest proposed or adopted standards in India, the EU and Taiwan. Mainland China and Thailand have either proposed to adopt or have recently adopted standards similar to Taiwan's standards.

Since each country/region follows different test procedures and driving cycles, standard emission levels are not directly comparable. The 2006 version of Euro standards, referred to as Euro 3, were one of the first attempts to narrow the gap between automobile and motorcycle standards. Taiwan's standards, in place since 2007, have similar emission limits as the Euro 3 program, but also include very important durability requirements. India's current and proposed standards are based on a unique Indian Driving Cycle.

As leaders in motorcycle emission control, the technology neutral performance standards in the EU, India, and Taiwan are discussed below. Technology-neutral standards offer the best opportunity to reduce motorcycle emissions throughout Asia and elsewhere. Refer to the Appendix for detailed history of the motorcycle air quality standards in each of these countries.

The *European Union* first adopted motorcycle standards in 1987. A trajectory of EU standards for four-stroke two-wheelers is presented in Figure 6-1. Since its inception, the EU's standards have been differentiated by motorcycle type, by engine size and, until 1999, by engine type. The latest three-wheelers European standards, also include separate spark-ignited and compression-ignited standards for three-wheelers, with more stringent limits for CO and HC but less stringent for NO_x and no PM emission limits. It is important to note that, to date, European standards have not included durability limits, cold start requirements or evaporative limits. These important enhancements were discussed in greater detail in the previous section.

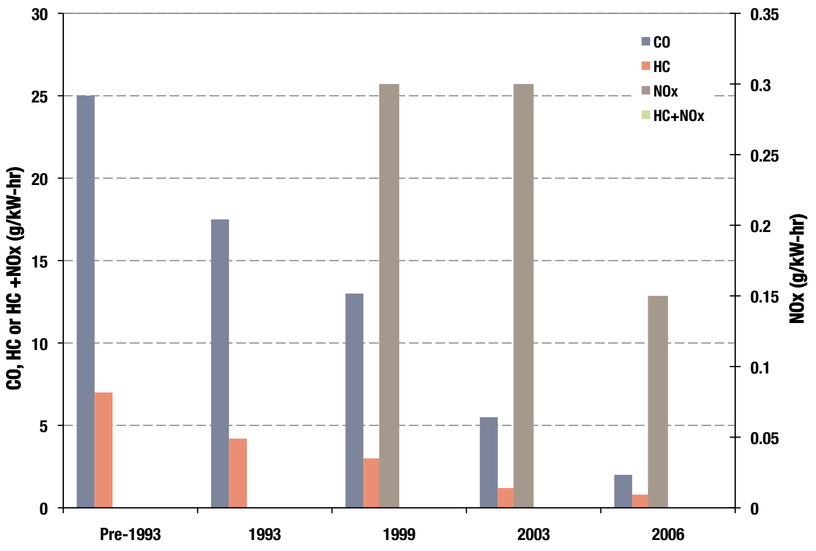


FIGURE 6-1. TRAJECTORY OF EU STANDARDS FOR A FOUR-STROKE

The global influence of European standards is significant. China, the largest motorcycle producer in the world, recently adopted standards similar to those in Europe. As motorcycles are a relatively small contributor to air pollution in much of Europe, enhancing the current program is a low priority. However, issues related to durability, defining the useful life of a vehicle, in-use compliance, and on-board diagnostics (OBD) are under consideration for future standards. The fact that European standards have the potential to determine the technology trajectory in regions where motorcycles are significant polluters makes incorporating these program improvements a necessary step in toward realizing opportunities to improve motorcycles worldwide.

Taiwan has long been the leader on motorcycle emission control regulations in Asia. With the highest motorcycle population density per square kilometer, their first regulation was adopted in 1988 and has been progressively tightened over the past two decades. Figure 6-2 details the trajectory of Taiwan's emission standards for four-stroke, two-wheeler motorcycles. The emission limits, based on the European ECE R40 cycle, have included durability requirements since 1991 and cold start requirements since 2002. The evaporative limit of 2 g/test was introduced in 1991.

The program in Taiwan did not distinguish between two and four-stroke engines until 2004, when more stringent limit values were adopted for HC+ NO_x emissions from two-stroke motorcycle under 700 cc (see Appendix A, Table A-4). This change virtually eliminated new two-stroke motorcycles in Taiwan for model year 2004 and beyond. Starting with model year 2007 the limit values have been harmonized with Euro 3. But the standards are considered more stringent as they include a 15,000-km durability requirement. China, along with its

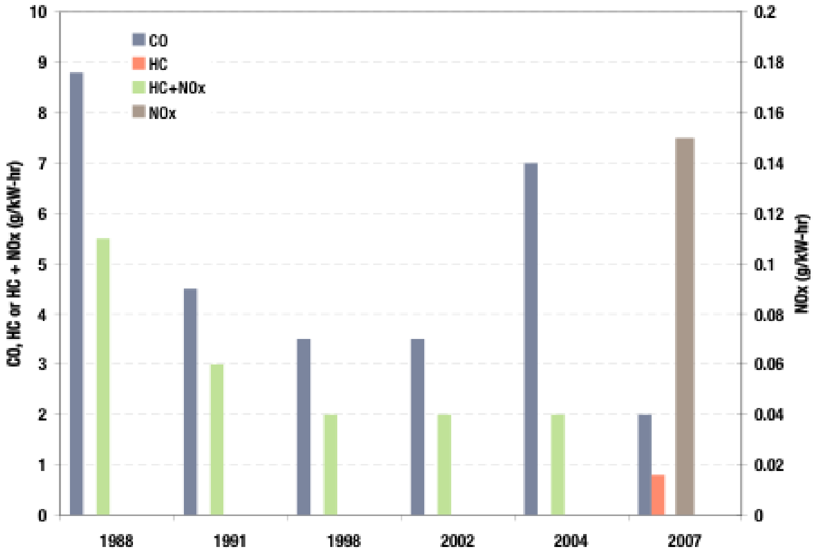


FIGURE 6-2. TRAJECTORY OF TAIWAN'S STANDARDS FOR A FOUR-STROKE 125 CC TWO-WHEELER (MESZLER 2007)

Euro 3 emission limits, has adopted a 30,000-km durability requirement and is using the sealed housing for evaporative determination (SHED) test to assess evaporative emissions.

In *India*, motorcycle regulations distinguish themselves by a unique test cycle, the Indian Driving Cycle, developed in the mid-1980s to represent Indian traffic and driving conditions. The Indian program applies the same limit values to two- and four-strokes and, unlike the latest standards around the globe, does not have separate limit values for HC and NO_x. Here, there is no differentiation by engine size. Since 2005, the Indian standards have a 30,000-km durability requirement and deterioration factors can be used to show that the motorcycles will maintain their emission performance over their useful life. The downward trend for Indian motorcycle emission standards is presented in Figure 6-3.

The Indian program includes standards for three-wheelers as they represent a significant share of this country's motorcycle population. The growing importance of diesel three-wheelers used for goods transport has led to specific compression-ignited (CI) engine standards for these vehicles in India. The CI engine standard is more stringent than the spark-ignition (SI) engine standard because it was set to be on par with Euro 3 standards for small passenger vehicles (Roychowdhury 2007). It also includes limit values for PM emissions. In contrast, the SI engine standards were set to be incrementally lower than the standard previous in force but are not set to be on par with small gasoline passenger vehicles (Roychowdhury 2007).

6.1.2 COMPLIANCE AND ENFORCEMENT OF STANDARDS

Compliance and enforcement programs are essential in ensuring that vehicles are built to meet the standards in force and continue to comply with the regulated exhaust limits throughout their useful life. Unfortunately, compliance and enforcement is often the weak link in many programs, with understaffed and underfunded oversight agencies. In Taiwan, for example, regulators attribute the success of their regulatory program to their "life cycle emission control" program (TEPA 2006). Figure 6-4 identifies the compliance and enforcement programs in place in Taiwan. This figure also documents at what point in the motorcycle life these programs take effect. The environmental protection administration, TEPA, oversees the certification, conformity of production, new vehicle selective enforcement audit and recall programs. The inspection and maintenance program, further described is

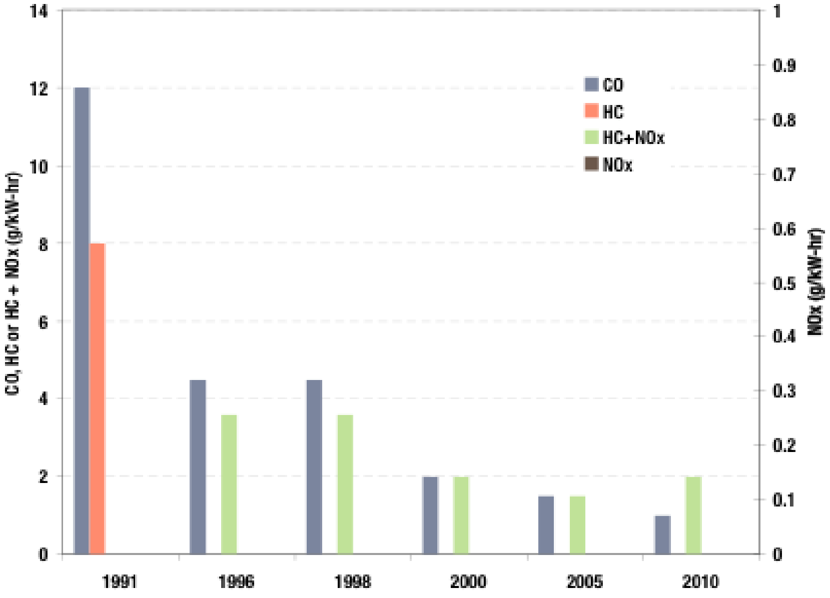


FIGURE 6-3. TRAJECTORY OF INDIA'S STANDARDS FOR A FOUR-STROKE 125 CC TWO-WHEELER (MESZLER 2007)

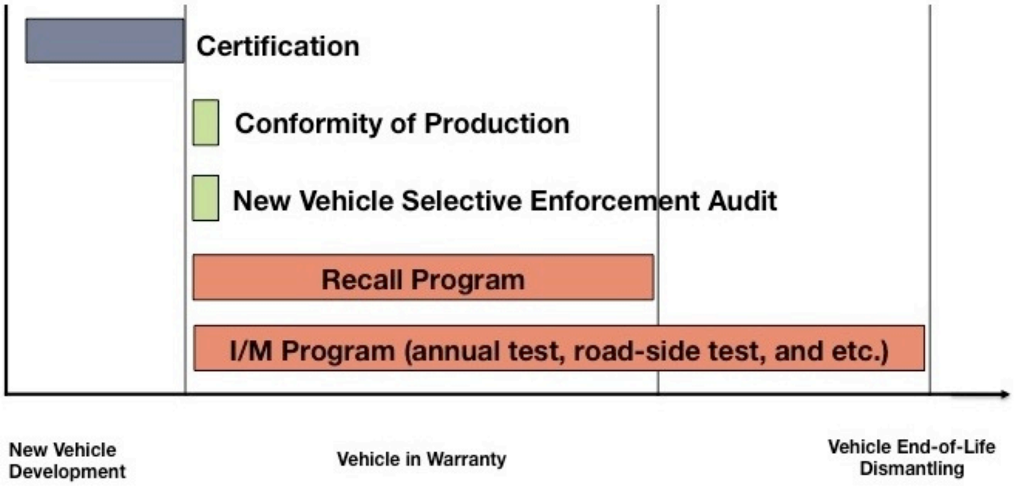


FIGURE 6-4. COMPLIANCE AND ENFORCEMENT PROGRAMS IN TAIWAN (TEPA 2006)

Section 6.2.1, is implemented in cooperation with local environmental agencies and law enforcement.

Each year, TEPA tests a number of engine family as part of their recall program. In 2008, ten engine families representing about 50 motorcycle models sold on the island were tested and all passed (Lin 2009). Regulators in Taiwan measure the effectiveness of their program by tracking the average emission of the vehicles tested in the various phases of the program. Over the years, the agency has seen a decrease in non-compliant vehicle model and in overall failure rates (TEPA 2006).

6.1.3 FUEL ECONOMY STANDARDS

There are few policy examples for advancing fuel economy standards on two- and three-wheeler fuel. The US, EU, and Japan do not currently regulate motorcycle fuel economy either. In these nations, cars and light trucks consume far more energy than motorcycles, so policymakers pay little attention to two-wheelers. Despite the lack of regulations, however, motorcycles are fully considered in fuel use inventories and included in climate change models.

Given their growing prevalence throughout Asia and in developing nations and regions, motorcycle fuel economy deserves greater attention. Other than Taiwan and Mainland China's regulations, no other Asian nation or region has adopted fuel economy standards (or greenhouse gas emission standards) for motorcycles. It is expected, that India, which has adopted a fuel economy-labeling program for motorcycle, will consider standards in the near future.

Taiwan has a fuel economy standard (km/liter) and Mainland China has a fuel consumption standard (liters/100 km). Both standards are tiered with limit values depending on engine size in cubic centimeters. Mainland China also has adopted standards for three-wheelers, which are less stringent than the two-wheeler fuel consumption limits, reflecting these vehicles larger load per engine size. Figure 6-5 presents the recently adopted standards in Mainland China, and the latest version of the standards in Taiwan converted to liters/100km that will be enforced in late 2009.

The fuel consumption test procedures used to demonstrate compliance with the standards in China are based on the fuel consumption

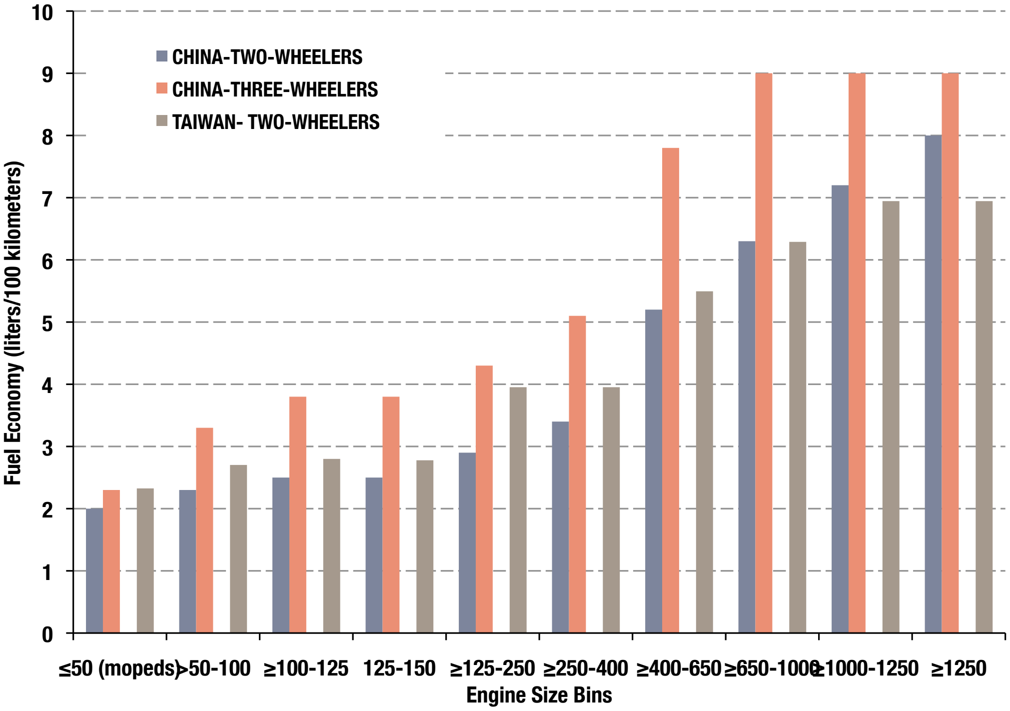


FIGURE 6-5. FUEL EFFICIENCY STANDARDS IN CHINA AND TAIWAN (EFFECTIVE 2009)
Note: two-wheeler standards in Taiwan and those in Mainland china are measured according to different test procedures and are not directly comparable

measurement methods described in the International Standards Organization (ISO) standards 7860 for motorcycles and 7859 for mopeds. Each model's fuel consumption is the weighted average of the results of a running mode test (ECE-4 and ECE-R40) and a constant speed test (speed varies by engine size category). According to testing performed at the Tianjin Motorcycle Center many of the motorcycles currently on the market may not comply with the proposed standards in some displacement categories (Wang 2006). It is therefore expected that the standards will improve the new vehicle fleet's overall performance.

In Taiwan, the fuel economy test is the weighted average of results on an urban driving cycle (ECE-15) and a constant speed test (50 km/hr for motorcycle and 40 km/h for mopeds).

Further research and policy development is expressly warranted to determine how best motorcycle fuel economy standards should be set, what the best measurement procedures are, whether standards and test procedures should differ from nation to nation or be harmonized, and how to enact enforcement requirements. Complementary fuel pricing policies should be considered to hasten the adoption of motorcycle fuel economy standards. Higher fuel prices (or taxes) create the conditions for public support of stringent, enforceable fuel economy standards.

6.1.4 ALTERNATIVE FUELS REQUIREMENTS

Different cities in various countries have experimented with alternative fuels in two- and three-wheelers as a means of reducing local pollution or moving to domestic energy resources. The success of alternative fuels in vehicle applications depends on local conditions and effective policymaking. The nature of regional pollution problems, consideration of fuel cycle emissions of domestic energy supplies, economic factors, adequate vehicle maintenance, full consideration of emission tradeoffs, and consistent policymaking efforts over the long term each play an important role.

Asian experiences with alternative fuel motorcycle programs have had mixed results. Some nations have been successful in ramping up ownership and use, but clearer goals and emission standard enforcement – akin to those applied to conventionally fueled motorcycles – are needed for alternative fuel motorcycles. Other nations have switched their support from one fuel to another, without making consistent progress. Merely requiring the use of alternative fuels while necessary is not sufficient to reduce emissions and fuel use.

India, for example, has substituted compressed natural gas (CNG) for conventional fuels for public transportation by court order. A 1998 Supreme Court of India directive ruled, as part of the ongoing public interest litigation on air pollution in Delhi, that the entire public transport bus fleet, along with the passenger three-wheeled vehicles and taxis, be converted to run on CNG by 2001. The objective was to reduce the alarming levels of particulate pollution in one of the most polluted cities of the world. The CNG program in Delhi is now fully established and there are more than 100,000 vehicles plying in the city, just over one-half are three-wheelers.

Electric three-wheelers tend to serve niche markets in India rather than reaching a mass market. Although they are commercially available from several major manufacturers, they have not attained large market acceptance. One specific niche application for electric three-wheelers is to transport visitors at the Taj Mahal in Agra, where the use of internal combustion vehicles is banned to avoid damaging World Heritage site (GTZ 2004).

In Katmandu, Nepal, alternative fuel policies have fluctuated in their support for electric motorcycles and LPG three wheelers. Still, pollution levels have continued to grow In the Katmandu valley. While new technologies have been introduced and operations improved, registration restrictions, variable fuel prices, high electricity rates, and import duties factor into Katmandu's alternative fuel motorcycle requirements, discussed in section 6.1.5 below.

Hybrid applications could extend to two and three-wheelers because these often operate in crowded urban areas in stop-and-go operation. Honda has developed a 50 cc hybrid scooter prototype that offers about a one-third reduction in fuel use and GHG emissions compared to similar 50 cc scooters (Honda, 2004). However, sales of two and three-wheeled vehicles in most markets are extremely price sensitive, so the extent of any potential market for hybrid technology may be quite limited.

Alternative fuels in motorcycle applications are very sensitive to local conditions. Cities currently embarking on programs to shift motorcycle fleets to alternative fuels will have to overcome technical, institutional, and market barriers for successful implementation and maximum emissions gains. Before governments get head long into selecting an alternative fuel, the better option is to adopt performance standards. This enables competition between viable alternatives and a greater likelihood that the outcome will deliver social benefits.

6.1.5 ON BOARD DIAGNOSTICS

On-board diagnostic (OBD) systems alert the vehicle driver about potential problems that can affect the emission performance of the vehicle. OBD requirements were first introduced in California for 1988 model year light-duty vehicles. This consisted of limited functional and circuit continuity checks of some vehicle engine components. Today, more thorough, although not comprehensive, OBD II requirements apply to light-duty vehicles and heavy-duty engines (but not yet motorcycles) throughout the US and Europe. These newer diagnostic systems monitor virtually every component and system that can affect emissions during normal driving, alerting the driver through a dashboard malfunction indicator light (MIL) and storing fault code information for repair technicians to access.

Like cars, motorcycles can also be equipped with OBD to help owners maintain clean vehicle operations and regulators enforce inspection and maintenance programs. OBD, an opportunity for improvement applicable to all motorcycles with electronic engine management, does not work with simplified carburetor fuel systems. A less-complex OBD I system (as opposed to the newer, more complex OBD II) is under consideration for motorcycles as a cost effective emission control technology in Europe (ACEM 2007). OBD requires equipment to decode recorded data, adding complexity in developing countries.

While technologically this provides a more advanced way to monitor motorcycle emissions, problems can arise with lack of standardization in terms of connectors, scan tools, and fault codes. This can result in many different manufacturer-specific designs in the field. Moreover, OBD can be further weakened if each manufacturer is left to define emission performance regarding how “bad” emissions have to be before they trigger a sensor and illuminate the “check engine” light. And when manufacturers are allowed to extinguish the MIL at their discretion, further emission control benefits are lost. OBD II has corrected many of these early failings of OBD I, but they come with extra cost in equipment and enforcement.

Driver education must accompany OBD system integration on motorcycles. The MIL is far too easy to ignore and to tamper with. Once new motorcycle owners realize that these indicator lights are useful to maintain overall vehicle operation and life, OBD usefulness increases. Sooner or later, faulty components adversely affect vehicle emissions and overall performance.

6.1.6 FISCAL POLICIES FOR CLEAN, EFFICIENT NEW MOTORCYCLES

In order to transition from conventional to cleaner technologies, governments often get involved to provide incentives for the manufacture, purchase, and use of clean, efficient new motorcycles. Such fiscal policies are complements to standards discussed previously. Financial policies support strategies to improve new vehicle and engine technologies, low-carbon alternative fuels development, and clean motorcycle retrofit programs. These can include favorable loans, financial incentives, and grants. Other tax mechanisms can be used to penalize or reward low-emission vehicle purchase and use. Examples of these fiscal strategies in Asian cities and countries are discussed below. Similar types of fiscal policies can apply to vehicles once they are in use.

Fiscal policies are more sustainable when developed to fit local conditions. Several specific examples follow. In the Philippines' San Fernando City, economic incentives drove the transition from two-stroke to four-stroke (less polluting) tricycles. Interest free loans have been made available for the purchase of four-stroke three-wheelers (Roychowdhury et al. 2006). In 2001, three-quarters of the city's 1,600 registered tricycles ran on two-stroke engines. But after a city council mandate to totally phase out the vehicles by 2004, and offers of interest-free loans for down-payments on four-stroke models, more than 400 four-stroke tricycles had replaced the older two-stroke models.

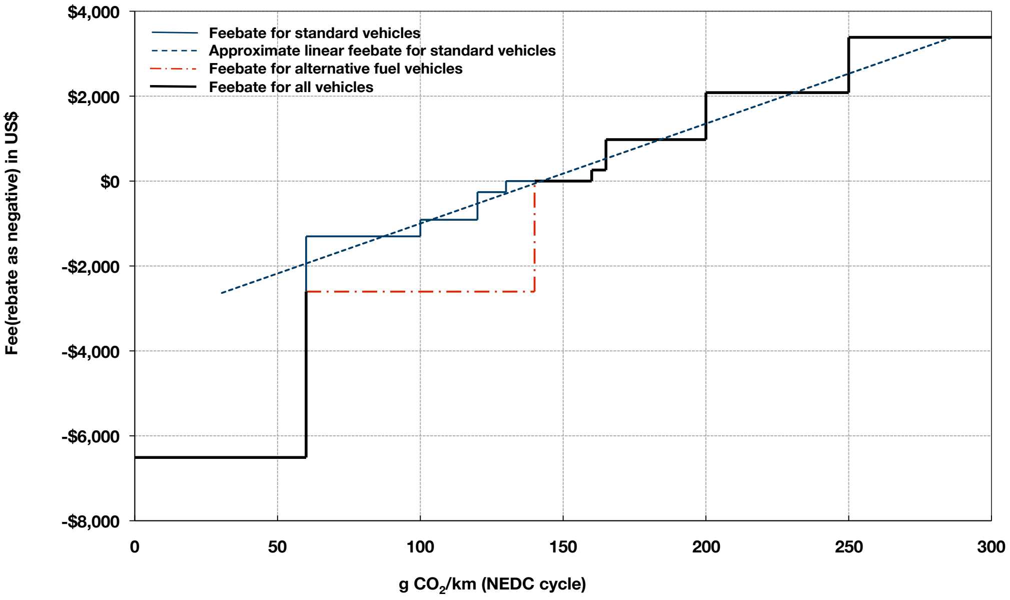
In 1999, the government of Katmandu in Nepal banned diesel ten-passenger three-wheelers (known locally as tempos). This ban followed a prior ban on new tempo registration in 1991 (IGES 2003). The diesel tempo ban led to a dramatic increase in electric or safa (clean) tempos operating in the city, which had replaced almost half of the diesel tempo fleet by 2002 (GTZ 2004). Starting in 1995, incentives such as reduced import duties were put in place to promote the purchase and use of electric tempos (GRI 1998). Electric three-wheelers operators are severely challenged by competition from gasoline and LPG three-wheelers. Safa tempos are more costly to operate than gasoline and LPG vehicles due to high electricity prices and high battery replacement costs (GTZ 2004). In addition, gasoline and LPG vehicles enjoy the same duty rates as electric vehicles (Kojima et al. 2000). As a result, many electric three-wheeler operators scrap their vehicle at the end of their batteries' useful life. Several programs are currently in place to build a more sustainable electric vehicle industry in Nepal (Boaz 2007).

Taiwan provides incentives for the purchase of low-emission motorcycles. To encourage the purchase of electric scooters, about $600 (US dollars) in incentive was provided during the 1990's and early 2000's. This project was subsequently discontinued and the sales of electric scooters plummeted.

In China, India, Taiwan, Thailand, and other Asian regions and nations, targeted policies to reduce the two-stroke motorcycle population are responsible for the decrease in production and sales of new two-stroke motorcycles. In Taiwan, for example, tighter emissions standards for two-strokes combined with financial incentives for the purchase of four-stroke motorcycles were adopted for model year 2004. Almost no new two-stroke motorcycles have been sold since model year 2004 (Chen & Lin 2007). Thailand uses taxation to accomplish similar goals. By charging a higher tax on two-stroke motorcycles than four-stroke models, consumers realize a tax reduction when they purchase of 4-stroke motorcycles (Kuson 2006).

Feebates are another incentive policy that can lead to continuous improvement in vehicle fuel economy. Unlike fuel economy standards, feebates do not run the risk of being set to high (increasing incremental costs and risking market rejection) or too low (where cost-effective technology goes unused). Feebates provide certain cost effective fuel economy improvements (Greene 2008). France has implemented a feebate program for automobiles that invokes significant fee and rebate amounts as shown in Figure 6-6.

FIGURE 6-6. FRANCE'S FEEBATE SCHEDULE FOR NEW AUTOMOBILES (ICCT, FORTHCOMING 2009)



6.2 IN USE VEHICLE POLICIES

Effective in-use programs can yield significant benefits because real world vehicle performance and use is what directly impacts the air people breathe, the fuel they burn, and greenhouse gases released into the atmosphere. Opportunities for improved motorcycle in-use control programs – inspection and maintenance, retrofit and engine replacement programs, usage restrictions, fuel standards, circulation fees, and road pricing – are discussed below. These in-use policies are not mutually exclusive. Together they are an important part of controlling two- and three-wheeler emissions and energy use in the future.

6.2.1 MOTORCYCLE INSPECTION AND MAINTENANCE PROGRAMS

Inspection and maintenance programs help ensure regulatory compliance during each vehicle's lifetime. They typically apply to air pollutant emissions and, sometimes, safety and noise.

I&M program designs vary regionally. Usually state or national governments require these programs and local government agencies implement them. Program design includes specifying in-use emission levels and test procedures, data collection and management requirements, and enforcement mechanisms.

In terms of program cost, it is recommended that vehicle owners pay the full cost of the program, including oversight and enforcement activities. This creates stable, long-term program operation (Walsh 2005). However, some countries subsidize their I&M programs. In Taiwan, for example, the government pays the entire test cost.

Annual testing is the most effective method to ensure that all the vehicles covered by an I&M program. Linking testing requirements to annual registration requirements is preferable (Walsh 2005). Given that many countries currently do not require annual registration or circulation (only registration when a vehicle is sold), systems using

TABLE 6-3. DESCRIPTION OF I&M PROGRAMS IN INDIA, TAIWAN, CHINA AND THAILAND (IYER 2007, CHEN & LIN 2007, WANGWONGWATANA 2007)

COUNTRY/REGION	STRUCTURE	REQUIREMENTS	FREQUENCY
India	Decentralized with mostly private test and repair facilities and some public test only facilities	All two- and three-wheelers	Every 6 months
Taiwan	Decentralized with mostly private test and repair facility and some public test only facilities	Motorcycles 3 years and older	Annually
Thailand	Decentralized with private test and repair facilities	Motorcycles 5 years and older	Annually

license plate stickers or I&M certificates can be useful in identifying vehicles that are in annual compliance with the in-use requirements.

Data management is a critical component of an I&M program. The large volume of data they generate must be readily available for enforcement and audits in order to evaluate actual program effectiveness. This requires a centralized computer database accessible to test providers, oversight agencies, and program enforcement agencies. The I&M database can be linked to vehicle registration data, where available, to generate test notifications. Table 6-3 summarizes motorcycle I&M program characteristics in those Asian countries with programs currently in place.

Emission standards must be established for vehicles based on their age. Current in-use I&M standards set emissions limits for CO (as a percentage of total exhaust) and HC (in parts per million, ppm). The amounts of CO and HC in the exhaust are basic indicators of engine and emission control performance. Table 6-4 details benchmarks for in-use

TABLE 6-4. IN-USE EMISSION STANDARDS IN INDIA, TAIWAN, CHINA, AND THAILAND (IYER 2007, CHEN & LIN 2007, WANGWONGWATANA 2007)

COUNTRY/REGION MOTORCYCLE TYPE		REGISTRATION OR MODEL YEAR				TEST METHOD
India – 2-stroke		Prior 2000 model year		2000 and later model year		
	CO (%)	≤4.5%		≤3.5%		Idle
	HC (ppm)	≤ 9,000 ppm		≤ 6,000 ppm		Idle
India – 4-stroke		Prior 2000 model year		2000 and later model year		
	CO (%)	≤4.5%		≤3.5%		
	HC (ppm)	≤9,000 ppm		≤ 4,500 ppm		
Taiwan		Prior January 2004		Jan 2004 and after		
	Certification level	Best	Marginal	Best	Marginal	
	CO (%)	≤3.5%	3.5%-4.5%	≤2.5%	2.5%-3.5%	Idle
	HC (ppm)	≤ 7,000 ppm	7,000-9,000 ppm	≤1,500 ppm	1,500-2,000 ppm	Idle
Thailand – 2-wheeler		Prior July 2006		July 2006 and after		
	CO (%)	≤4.5%		≤3.5%		Idle
	HC (ppm)	≤ 10,000 ppm		≤ 2,000 ppm		Idle
	White smoke opacity (%)	30%		30%		Max HP RPM
Thailand – 3-wheeler		All years				
	CO (%)	≤4.5%				Idle
	HC (ppm)	≤ 10,000 ppm				Idle
	White smoke opacity (%)	30%				Max HP RPM

standards in Taiwan, Thailand, and India. These limits or cut points were established taking into account the expected performance of engine and control technology over time, maintenance practices, and air quality goals. Limits tend to vary by registration date or model year, increasing in stringency for newer motorcycles.

In-use testing procedures generally require measurements taken during engine idle. This is far simpler than dynamic testing and uses low cost testing equipment and testing procedures. Unfortunately, however, testing at idle may not provide a reliable indication of actual emission performance. The correlation between idle emissions and actual mass emission rates have been shown to be directionally correct but not statistically significant (Iyer 2007). In contrast, new vehicles are typically certified at a range of engine speeds and loads, including idle. Special care must be used when idle testing to avoid sampling errors. Due to the variability in size and configuration of exhaust pipe, the sampling probe may not be fully inserted without the use of a leak-proof extension (Iyer 2007). It is also important that instruments be routinely calibrated and adjusted to ensure consistency.

Research is currently ongoing to improve I&M test procedures. Efforts are underway to implement test procedures that test under a range of operating conditions using low-cost loaded mode test equipment. Such equipment consists of a single or pair of rollers to drive the motorcycle through a combination of speeds, accelerations, decelerations, and idles, while remaining stationary. The Automotive Research Association of India (ARAI) has been working on a loaded mode test over a prescribed driving cycle for CO, HC, NO_x, and CO_2 (Iyer 2007).

Most I&M programs may also test the overall roadworthiness and safety of the motorcycle. Proper function of brakes, lights, and tires is checked. Some programs also verify that motorcycles meet mandated noise limits.

I&M is typically enforced along the roadside. Traffic police or other government agents verify possession of required documentation showing the motorcycle has passed its latest I&M test. Fines can be applied for non-compliance. Motorcycles can also be pulled over to perform testing on the curbside. Such roadside testing usually targets motorcycles with excessive visible smoke and is performed using mobile testing equipment.

Remote sensing using “hidden” measurement devices may be able to enhance enforcement, helping to identify motorcycles in violation of in-use standards. Remote sensing programs in Delhi and Pune, India indicate that data collection is more difficult for two- and three-wheelers than for four-wheel vehicles. Small exhaust volumes at variable heights are among the many technical issues that make sampling by remote sensing for motorcycles difficult.

The case study 4 focuses on the emission reductions, costs and cost effectiveness of Taiwan I&M program. This program is often described as a model for all motorcycle countries in Asia. It is however difficult to replicate, especially in larger regions, as this program is currently entirely subsidized by the government.

6.2.2 MOTORCYCLE RETROFIT AND ENGINE REPLACEMENT PROGRAMS

Motorcycle retrofits cover all in-use modifications made to a vehicle to upgrade one or several of its components. This

CASE STUDY 4. I&M PROGRAM COST EFFECTIVENESS IN TAIWAN

DATA PROVIDED BY YUNG HSUN CHEN, INDUSTRIAL TECHNOLOGY RESEARCH INSTITUTE (ITRI) (RETIRED)

The motorcycle I&M program in Taiwan was first implemented in 1996 in eight cities and was later expanded to cover all cities and counties by 1998. The number of testing facilities has grown from 187 stations, 67 of them publicly operated in 1996, to 2,252 in 2006. Today, only 16 of all stations are public, most of which are mobile, serving remote locations.

Originally, the Environmental Protection Agency (TEPA) managed the program throughout Taiwan. Oversight responsibilities were eventually transferred to local environmental protection bureaus. The oversight agencies certify testing equipment and test providers, check equipment calibration annually, and conduct all audit activities. All testing stations are connected through a networked computer system to a centralized database managed by TEPA. This data is also available to agents in the field using a handheld computer who can verify vehicle status by entering a license number. Roadside emission testing carried out by local environmental agencies target vehicle owners that evade annual I&M testing. It is estimated that about 66 percent of vehicle owners notified in 2006 complied with the testing requirement. Participation in 1996 at the program inception was about 45 percent and peaked in 2003 at 72 percent.

Figure 6-7 presents the Industrial Technology Research Institute's (ITRI) estimates of emissions reduced through the implementation of Taiwan's I&M program since its inception.

The government subsidizes the cost of the test. Motorcycle owners, therefore, do not pay to test their vehicles, but they must cover the cost of repairs if their vehicles do not pass. In 2006, about 2 percent of vehicles tested did not pass and their repair costs averaged US $7/motorcycle. Test stations receive US $2.50 per test performed from the government as well as revenue from repair service. The investment in I&M equipment and training is estimated at US $10,000 per facility and annual expenditures including labor costs and facility rent is estimated at US $7,000. On average, a station that performs 316 tests each month should break even on its investment. This break-even analysis does not include potential revenue from repair services.

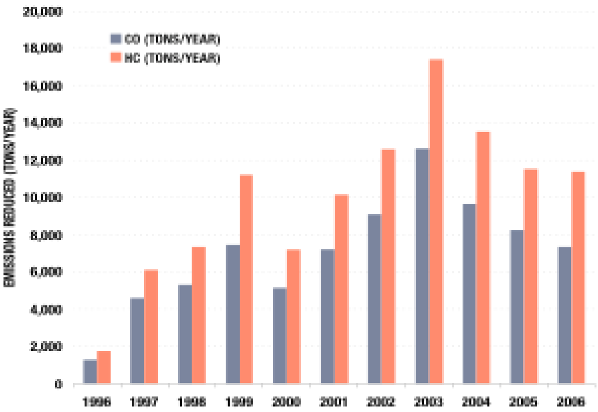


FIGURE 6-7. MOTORCYCLE I&M EMISSION REDUCTION ESTIMATES (CHEN & LIN 2007)

Government I&M expenditures include subsidies paid to station owners for test costs and funding of oversight activities by local environmental protection bureaus. In 2006, about US $14 million were disbursed in I&M station subsidies and US $6 million for government activities. Government expenditures averaged US $4 per tested motorcycle. The cost effectiveness of this government investment in 2006 was estimated at about US $2,600/ton CO and US $1,800/ton HC.

section focuses on retrofits aimed at reducing motorcycle emissions and fuel consumption by improving combustion and exhaust treatment or enabling the use of cleaner fuels. In theory, the emission control technologies that are standard in newer models can be applied to older motorcycles to improve their environmental performance. In practice, however, only those low-cost retrofits that are easily applicable to a broad range of motorcycle makes and models are made commercially available.

Other than the experience with alternative fuel retrofit on three-wheelers in India, there have been no wide-scale retrofit programs for motorcycles to date. The main barrier has been the lack of appropriate and cost effective retrofit technologies for older uncontrolled engines. This conclusion was reached in India in the late 1990s when two- and three-wheeler retrofits were first considered. India considered retrofitting older motorcycles by replacing the uncontrolled engine with a newer engine meeting at least the 1996 standards and adding an oxidation catalyst (Roychowdhury 2007).

Exhaust after-treatment technologies are most effective and durable when the pollutant levels in the engine exhaust are below a set level. After the engine swap, tests of retrofit oxidation catalysts achieved an estimated durability of 20,000 km and emissions reductions for HC of 40 percent and CO by 45 percent. Without the engine swap and tuning to the lowest emission setting possible, the retrofit oxidation catalyst would last 10,000 kilometers and reduce HC by 20 percent and CO by 25 percent (Roychowdhury 2007). At these durability levels, the retrofit catalyst would have to be replaced on an annual or biennial basis. Other concerns about retrofit catalytic converters in the late 1990s included high catalyst and exhaust tube temperatures burning drivers, the risk of catalyst poisoning from residual lead in older motorcycles that had used leaded fuel, and lower engine fuel efficiency from higher exhaust backpressure. While discussed in India, this program was never implemented due to uncertainties.

The results of a recent pilot project in Thailand show that engine replacement can be a viable option for the control of in-use emissions. The project involved replacing two-stroke engines in five three-wheelers with new and used four-stroke engines and installing better performing silencers (PCD 2007). Modifications were made to the four-stroke engines so that they would fit in the space allotted. Stress tests were performed to ensure that the heavier four-stroke engines did not compromise the structural safety of the three-wheelers. The upgraded three-wheeler had 12 percent better fuel economy in road testing (PCD 2007). However, because the installed four-stroke engines were much larger than the original two-stroke engines, laboratory testing yielded only slight improvements during driving cycle tests and decreased in fuel economy at steady speeds.

Table 6-5 summarizes motorcycle retrofit programs in India and the Philippines. Projects in both countries have targeted commercial motorcycles. This is because high levels of use in commercial application

TABLE 6-5. SUMMARY OF MOTORCYCLE RETROFIT PROGRAMS (IYER 2004, IYER 2008, ROYCHOWDHURY ET AL. 2006, WILSON 2006)

LOCATION	MOTORCYCLE TYPE	RETROFIT TECHNOLOGY	ESTIMATED REDUCTION	ESTIMATED COST (US $)	ESTIMATED PAYBACK
Delhi, Mumbai, Pune, India	Three-wheelers	CNG and LPG	CNG: CO: -17%, NOx:+34% LPG: CO:-22%, NOx:+25%	CNG: $450 LPG: $400	Not applicable
Manila, Vigan, Puerto Princesa, Philippines	Three-wheeler with 2-stroke engines (Kawasaki, Yamaha)	Direct injection	HC: - 89% CO: - 76% Oil use: - 50% Fuel use: - 35%	$300	Under 1 year based on fuel savings

The experience implementing two-stroke direct injection retrofit in the Philippines is discussed in more detail from the perspective of the retrofit manufacturer and marketer in Case Study 5. Retrofitting motorcycles is more involved that it may seem. In order to ensure that retrofit technologies provide real emission benefits, it is necessary for the retrofit kits be certified in a process similar to those applied to new vehicles. Certified retrofit components or kits should also meet durability standards, and their performance in-use should be verified periodically. An institutional framework for oversight of retrofit programs is needed to ensure standardized procedures. This is necessary to verify potential emission reductions and address technical issues as they arise during implementation. Retrofit installers should be certified as well to ensure that all installations are done according to the manufacturer and certification specifications.

Involving all the stakeholders in a retrofit project at the outset is also important. It allows not only early buy-in but also provides opportunities to discuss implementation issues before they can impede the project's success. The stakeholders in a retrofit project include at a minimum the vehicle owners and operators, the retrofit manufacturers, distributors and installers, the funding and oversight organization from both local and national government agencies.

CASE STUDY 5. IMPLEMENTING THE TWO-STROKE MOTORCYCLE RETROFIT PROJECT IN THE PHILIPPINES

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Carbureted two-stroke engines use an air/fuel mixture to force exhaust products from the engine, a process referred to as scavenging. During this process over 35 percent of the fuel escapes into the exhaust unburned, leading to high HC and CO emissions. Retrofitting motorcycles with direct-in cylinder (DI) fuel injection results in a more complete combustion of fuel, resulting in better fuel efficiency, more complete fuel combustion, and lower HC emissions. A DI fuel injection retrofit kit for two-stroke motorcycle engines has been developed. In tests, this two-stroke DI retrofit kit reduces carbon monoxide emissions by 76 percent, carbon dioxide emissions by 35 percent, and hydrocarbon emissions by 89 percent, compared to uncontrolled carbureted two-stroke engines. Carbon dioxide emission reductions translate into comparable 35 percent fuel use reductions. Oil use is also reduced by 50 percent. In comparison, replacing two-stroke engines with carbureted four-stroke engines have been found to increase carbon monoxide by 2 percent and only have a 20 percent reduction in fuel consumption compared to a carbureted two-stroke motorcycle.

At a cost of US$350, the DI retrofit kit payback is estimated at one year given annual fuel and oil savings of nearly $600. Given the simplicity of their construction, two-stroke engines can be cheaply repaired. Controlling their emissions with cost-effective retrofits can combine long engine life with reduced environmental impacts over motorcycles' lifetimes.

Pilot projects in the Philippines – home to 1.8 million two-stroke motorcycles – have focused on the cities of Vigan (population 150,000/tricycle population 3,000), Puerto Princesa (population 129,500/ tricycle population 4,000) and Boracay (population 12,000/ tricycle population 200). DI retrofit has been tested over 200,000 kilometers (~12,000 hours) of driving in the Philippines on over 100+ pre-production vehicles. A self-financing social venture includes key partners: Local Government Units, Office of the Mayor, Tricycle Owners and Drivers Associations, commercial partnerships (Orbital Engine, Synerject, RT Technologies, and Ropali), and organizational partnerships (US EPA, Colorado State University, and CAI-Asia). A National micro-finance package through CAI-ASIA plays a key role in widespread awareness-raising activities.

Key components of the retrofit are brought in from outside the country while core components are manufactured regionally. The goal is 'tipping point' that involves retrofitting 1,200 – 1,500 units/month with an annual removal of unburned HC (90 percent per kit) and CO (76 percent per kit), as detailed in Table 6-7. Other retrofit projects are being explored in Asian countries such as India, Sri Lanka, China and Thailand.

TABLE 6-6. EVALUATION OF ENVIROFIT PROJECT BENEFITS BY PROJECT SCALE (ENVIROFIT, CASE STUDY 5)

METRIC	PILOT PROJECT COMPLETION Q2 2009	TIPPING POINT ENVIROFIT SUSTAINABLE	WIDESPREAD IMPLEMENTATION NATIONAL EXPANSION
Cumulative number of retrofits	3000 taxis	15000 taxis	500,000 taxis
Tons of Carbon Dioxide Eliminated	3000 tons	11,700 tons	720,000 tons
Liters of fuel saved	1,440,000 liters	5,600,000 liters	346,000,000 liters
Automobile equivalents of pollution eliminated	150,000	750,000	20,000,000
Dollars infused into local economy	$1,410,000	$2,500,000	$188,000,000
Local jobs created	15 – 20 jobs	90-100 jobs	500+ jobs

6.2.3 TWO- AND THREE-WHEELER USE RESTRICTIONS

Motorcycle usage restrictions prohibit all, or some types of, motorcycles (e.g. two-stroke motorcycles, motorcycles older than 10 years) from operating on certain roads or within certain parts of a city. Use restrictions are most common in the congested city center. Decisions on road usage and restrictions are usually under the purview of city regulators.

Use restrictions are intended not only to reduce emissions in densely populated areas, but also to reduce traffic congestion, accidents, noise, and other societal problems. In Guangzhou, China, motorcycle gangs created public safety problems leading to a ban on all motorcycles from the city center (Yardley 2007). Several large cities, including Jakarta and Lahore, have issued similar bans on motorcycle operation in the central business district, limiting motorcycle use to suburbs and rural areas (Roychowdhury et al. 2006). Chinese cities' motorcycle bans came on the heels of limiting new motorcycle registrations in the late 1990s. By 2000, 37 cities were no longer issuing new registrations and 21 additional cities had limited the number of new registrations allowed (Roychowdhury et al. 2006). Lahore in Pakistan is implementing a ban on two-stroke three-wheelers in the city's major arteries. Table 6-8 provides additional details on several current and proposed motorcycle bans throughout Asia.

A number of usage restrictions have focused on commercial three wheelers powered with two-stroke engines. Usage restriction proposals are often met with significant opposition from owners and operators. Equity concerns often arise when such

TABLE 6-7. SELECTED CURRENT AND PROPOSED MOTORCYCLE RESTRICTION PROGRAMS (ROYCHOWDHURY ET AL. 2006, YARDLEY 2007)

LOCATION	MOTORCYCLE TYPE	PROGRAM DETAILS
Dhaka, Bangladesh	Two-stroke three wheelers	Progressive ban from city: pre-1994 phased-out by January 2002, all remaining phased-out by January 2003
Guangzhou, China	All motorcycles and electric bicycles	Ban from entire city and suburban areas since January 2007
Jakarta, Indonesia	Two-wheelers	Restricted lane use proposed to be extended to peak hour ban
Katmandu, Nepal	Diesel three-wheelers	Ban from city since 1999
Lahore, Pakistan	Two-stroke three-wheelers	Ban from majors road to be progressively extended to entire city by December 2007
San Fernando, Philippines	Two-stroke three-wheelers	1970's models ban since 2003, 1980's since 2004
Taipei, Taiwan	Motorcycles above 550cc	Ban from urban districts

programs are announced, as most commercial motorcycle operators' limited incomes depend heavily on operating in city centers. In Dhaka, for example, workshops were held with affected stakeholders, including drivers, owners, and service providers to develop rehabilitation plans.

Complementary measures, such as enhanced transportation services, can make bans easier to bear. Dhaka's 50,000 phased-out three wheelers were eventually replaced by: 10,000 CNG and gasoline three wheelers, 1,000 minibuses, 370 buses, 6,000 taxicabs (up from 3,000), and 670 human powered vehicles (Roychowdhury et al. 2006). Many three-wheeler phase-out programs are adopted with complementary incentive policies to assist operators in purchasing new and cleaner vehicles.

Banning some or all motorcycles is perceived as a lower-cost option to adopting and enforcing emissions standards, retrofit, and other programs. However, the long-term costs and benefits of bans are unclear. The key to assessing them requires understanding how and at what cost motorcycle trips are replaced. Costs and benefits would be different if motorcycle trips were replaced by walking, biking, public transportation or by private car trips. It is also unclear that removing two- and three-wheelers will, over the long-term, alleviate congestion in city centers, especially if they are replaced with cars that occupy more road space. Broad motorcycle bans also limit the use of fuel-efficient and zero emission electric motorcycles. This results in a missed opportunity for controlling emission and fuel use from transportation sources in urban centers.

Vehicle bans can have unintended consequences. They can lead to the export of a large number of low cost two-stroke motorcycles. In the poorest countries, in Sub-Saharan Africa for example, used vehicles imports of all types are growing rapidly. Those with the lowest income strive to purchase an imported motorcycle, regardless of its environmental or safety drawbacks.

It might be more useful to adopt a performance standards to give vehicle owners compliance options, including vehicle phase out, replacement with a conventional or an alternative fuel vehicle, or vehicle retrofit. Performance standards could be tightened over time to ensure continued reductions in motorcycle fuel-cycle emissions. Driver and maintenance staff

TEXT BOX 6-2. SHOULD TWO-STROKES BE BANNED?

Cities throughout Asia struggling to control air pollution from motorcycles, older vehicles have not been allowed to operate unless then switch to clean fuels. As a result, many two-stroke engine motorcycles have been effectively banned. These decisions have often been very controversial. On the one hand, the environmental benefits are evident. Reduced two-stoke motorcycle operation provides a significant and immediate reduction in air pollution and exposure. In Dhaka, PM_{10} levels were reduced by 31 percent and $PM_{2.5}$ by 41 percent the week after the phase-out (Roychowdhury et al. 2006). On the other hand, the overall costs of outright bans are often not accurately calculated. Phasing-out owned vehicles has many negative socio-economic impacts ranging from loss of revenue for owners and operators to reduced mobility for low-income customers to social unrest. Enforcement of bans requires significant manpower and societal impacts. And deciding what to do with the banned vehicles bears costs in terms of local disposal or transferring impacts to others who import banned motorcycles.

Bans are only successful if they ultimately lead to the adoption of alternatives that provide real and permanent emission reductions. It is important to evaluate whether similar emission benefits at equal or lower cost could be obtained through financial incentives, performance standards, or other technology fixes, such direct injection retrofits, engine upgrades, and/or the addition of after-treatment technology.

retraining programs could be provided if new skills are needed to handle and maintain an improved motorcycle fleet. Finally, enhanced public transportation options are necessary to ensure adequate levels of service to meet all mobility needs when motorcycle use is restricted.

6.2.5 FINANCIAL INCENTIVES FOR IN-USE MOTORCYCLE PERFORMANCE

Different nations use different financial tools to advance motorcycle performance and moderate use. Low interest or interest-free loans, incentives, and grants for the purchase of the lower-emitting motorcycle retrofit kits and electronic road pricing are two examples.

In Singapore, one of the first nations to adopt an electronic road pricing system in 1975 after Hong Kong, motorcycles are subject to tolls along with cars and trucks. The concession made is that motorcycles count as one-half of a vehicle unit and are subject to lower charges than cars. Road pricing, which is now in force in London and elsewhere worldwide, is a policy that has found to be effective at changing vehicle use patterns. Drivers consider charges when deciding when and how best to travel in areas with road pricing in effect. Transport for London estimates that the city's congestion pricing program has reduced carbon dioxide emissions by 20 percent.

In Taiwan, a payment of about $60 (US Dollars) was offered for giving up a motorcycle that is over a decade old (Chuang 2001). Such incentives for owners to trade in their older, deteriorated vehicles are gaining popularity. They are also known as "vehicle scrappage" programs. Scrappage programs may have some environmental benefits if scrapped vehicles are destroyed and are replaced by lower emission models.

6.3 NEXT GENERATION TECHNOLOGY POLICIES

There have been policies that target increasing the market share of next generation technologies for transportation. For example, the California Zero Emission Vehicles (ZEV) required the seven largest automotive companies in California to "make available for sale" an increasing number of vehicles with zero tailpipe emissions. California's latest revision in 2008 requires automakers to produce a total of 7,500 fuel cell vehicles or 12,500 battery electric vehicles (or some combination thereof) between 2012 and 2014, along with 58,000 plug-in hybrids, placing more emphasis on plug-in hybrid electric technologies than other innovations. However California's ZEV mandates do not apply to motorcycles. As is the case with emission standards in general (discussed earlier), motorcycles do not comprise a large or growing share of vehicles in the US and most developed countries. For this reason, two-wheelers are not the focus of increasingly stringent regulations on vehicle emissions.

In China, however, this is not the case. The prevalence of e-bikes has resulted from a confluence of circumstances that could spur the use of these advanced motorcycle technologies in other Asian countries. E-bike technology – specifically motors and batteries – improved significantly during the late 1990's. Simple technology, a vast supplier base, and weak intellectual property protection made it easier for e-bike makers to enter the industry, increasing competition and driving prices down. Improved economic conditions in developing countries meant that household incomes rose considerably. This translated into a greater share of disposable incomes devoted to transportation. As e-bike prices decreased, gasoline prices rose and electricity prices in rural areas dropped, making e-bikes more economically competitive with alternatives like gasoline-powered scooters and bus.

National and local government policy in China, has motivated by energy and air quality issues, created favorable conditions for e-bike growth. Banning gasoline-powered motorcycles in large city centers eliminated the prime competitor to e-bikes. Changes in urban form and suburbanization increased trip length and congestion, making bicycles and buses less attractive travel options. Recently, there have been efforts to close the loopholes in the national e-bike standards. A proposal has been made to define an electric motorcycle as a two-wheeler with speed higher than 50km/h or a three-wheelers weighing less than 400kg. An electric moped would be defined as a two-wheeler with speed between 20 and 50km/hr or a three-wheeler with speed less than 50km/hr. Electric bicycle are vehicles with speed below 20 km/hr. These standards that limit the size and speed of larger e-bikes are expected to address some of the road sharing conflicts with bicycles, motorcycles, and four-wheelers.

The advent of zero emission motorcycles could extend beyond China. Much of Asia could eventually benefit from these cleaner technologies. The last section summarizes findings and presents recommendations for reducing motorcycle emissions and fuel use. Asian nations, regions, and cities have several opportunities to better control motorcycle emissions and energy consumption. These apply to both new motorcycles and vehicles once they are in use. Both performance standards and their enforcement mechanisms is key, so too are fiscal measures that complement and reinforce standards. Whether policymakers are focused on controlling conventional motorcycle technologies, have an eye toward next generation technologies, or are trying to manage their motorcycle fleets in use, there are opportunities to reduce emissions and fuel use in the growing number of two- and three-wheeled vehicles and there are places to turn to for guidance and support.

7. FINDINGS AND RECOMMENDATIONS

7.1 SUMMARY OF FINDINGS

Emissions from two- and three-wheelers are a very large and growing problem in many countries in Asia, and increasingly in Latin America and Africa. Two-stroke engines are in great part responsible for motorcycles' disproportionate air quality impact. And these engines are also highly ineficient when it comes to fuel use – with up to 40 percent of the fuel and much of the oil escaping from the exhaust unburned. Motorcycle exhaust is packed with oxides of nitrogen, oxides of sulfur, hydrocarbons and fine particles – all toxic contributors to air pollution and detrimental to public health. Poor fuel quality is a confounding issue that factors into high pollutant emissions from motorcycles in Asia and elsewhere.

Asian countries and regions have begun to implement a combination of policies to reduce motorcycle emissions and increase customer preference for more fuel-efficient four-stroke motorcycles. These policies have lead to a rapid decline of new two-stroke motorcycle sales. This trend is apparent in China, India, Taiwan, and Thailand.

Despite progress, an average two- or four-stroke motorcycle can emit more pollution than a car with the most up-to-date emission control technology. These and other issues such as noise and public safety have led to increasing restrictions even bans of motorcycle use in some cities.

There are however significant opportunities to improve motorcycles. The technologies developed to clean up passenger cars, including fuel injection and catalytic converters, are being adapted to more and more motorcycle applications. All the major motorcycle countries such as China, India, and the EU have developed unique regulatory systems with requirements that are not directly comparable. The recommendations below highlight opportunities for further reduction in motorcycle emissions and fuel use in these various programs.

Although motorcycles are among the most fuel-efficient road transportation modes, gains in fuel economy are still possible. Following the leadership of in China, fuel efficiency requirements should be adopted and further developed for two- and three-wheeled vehicles. When consumers move to larger and often less efficient motorcycles, as is being witnessed in many motorcycle countries, fuel economy standards can ensure that this trend does not result in significant erosion of fleet fuel efficiency. Fuel economy would also benefit if separate emission standards for NO_x and HC were adopted. This is currently prevented by concerns over tradeoffs between NO_x and fuel use.

Three-wheelers mainly used in commercial applications warrant specific targeted strategies. Emissions standards for three-wheelers are lagging behind both two-wheelers and their direct competitors, cars. In particular, the rise of diesel three-wheelers for freight transport and passenger transport is problematic. Opportunities to improve new three-wheeler emission controls include emission standards aligned with passenger vehicles and differentiated by fuel type, as in the Euro 3 program. For the in-use mainly two-stroke fleet, retrofits, replacements and alternative fuel have all shown promise. These in-use programs must rely on clear performance standards and transparent certification procedures. Financial incentives such as low to no cost loans and grants are important complementary policies.

7.2 RECOMMENDATIONS

In countries where motorcycles are a major contributor to air pollution problems, a comprehensive plan is needed to effectively and efficiently control these vehicles. This plan should include:

- A platform for world harmonization of motorcycle emission standards that accelerates the use of proven, cost-effective, advanced technologies
- A parallel policy effort, with coordinated strategies, to reduce motorcycle fuel use and carbon emissions
- Emission standards for new motorcycles with durability requirements that reflect real world useful life, cold start testing, and limits on evaporative emissions
- A thorough compliance program to enforce adopted emission standards
- Routine enforcement activities, such as vehicle recall systems that minimize the risk of fraud and ensure that manufacturers are building motorcycles to required specification is important, especially

during the production of first-generation of models subject to revised emissions standards

- Emissions standards coupled with fuel quality standards to fully enable cleaner vehicle technologies
- Standards for lubricating oil quality for two-stroke motorcycles and premix dispensing facilities to prevent inappropriate dosage
- Strategies to address in-use motorcycle emissions, including in-use emission standards, retrofit and vehicle programs, usage restrictions, and inspection and maintenance programs
- Analysis that takes local factors into account and directs appropriate strategies to promote the use of alternative fuels

7.2.1 POLICIES FOR NEW MOTORCYCLES AND THEIR FUELS

Emission standards should lead to the adoption of the best available control technologies in new motorcycles. The latest EU standards for motorcycles, Euro 3, are the first attempt to set motorcycle emission levels that require advanced technology similar to technology used in passenger cars. This sets a good example for other regions. Still, the Euro program is currently lacking some essential features including durability requirements.

Emission standards can be designed and enhanced with additional requirements that help ensure emission limits will be met throughout the motorcycle's useful life. Nations and regions, including China, Taiwan and Thailand that have adopted or are planning to adopt standards with emission levels similar to Euro 3 have for example enhanced them with durability requirements. Recommended enhancements include setting durability standards and/or deterioration factors, requiring cold start emission testing, and including evaporative emission limits and test procedures. The recommended emission standard design features include HC and NO_x emission limits (both individually and combined) to adequately control large motorcycle emissions. Some of these features are included in the programs in place in China, India, Taiwan, and Thailand.

With major motorcycle manufacturing countries meeting stringent standards, other countries, especially nations that are primarily motorcycle importers, should consider leapfrogging to the most stringent standards. A larger market would only reduce the incremental cost of technologies required to meet enhanced emission levels. Questions regarding the design of these next-generation motorcycle emission standards merit further research. India, China, Thailand, countries with substantial motorcycle populations, will have to think about the next five-year horizon. So while Europe may not have the compulsion to move on a fast track to the next stage of emission controls, Asian nations will likely have to tackle this on their own.

Harmonization of test procedures can further facilitate the dissemination of regulatory enhancements. The World Motorcycle Test Cycle developed by the United Nations Economic Commission for Europe (UNECE) was designed to represent a global average of driving patterns and will be the test cycle for the European type approval starting in 2008. Amendments to the test cycle to better represent conditions in regions with smaller displacement engines and low traffic speeds were submitted by India and were adopted by UNECE in 2008. Countries and regions can adopt this cycle with or without the approved amendments as part of their regulatory programs. India may adopt this cycle after 2010. In the meantime India can further improve its current test procedures by improving its durability limits and including cold start emissions.

Compliance programs are a critical piece of regulatory efforts for motorcycles. To ensure that new motorcycles are able to meet prescribed emissions levels over their full useful life, manufacturer-directed programs should contain the following elements:

- Type-approval (certification) process for each motorcycle and engine model before mass production
- Conformity of production demonstration shortly after production has begun;
- Manufacturer-backed warranty against individual failures valid throughout the vehicle useful life
- Selective enforcement audits shortly after production has begun
- Recall investigation during the warranty period and recall order if a substantial number of failures are found

Durability requirements are gradually being extended in regulatory programs but they are still significantly shorter than actual useful life. It is recommended that durability requirements be revised to reflect real world motorcycle useful life. Moreover, the need exists to strengthen technical capacity for vehicle certification in motorcycle manufacturing countries. If the certification agency has the capacity to test emission control durability, then these requirement can be enforced.

Fuel quality is an important piece of the puzzle in solving air quality problems attributed to motorcycles, as well as other motor vehicles. Using poor quality fuel and overuse of two-stroke lubricating oil significantly reduces motorcycle emission performance. All gasoline should be unleaded and low in sulfur and phosphorus, especially if motorcycles are equipped with after treatment technologies. Low-smoke or 2T lubricating oil dispensed pre-mixed with gasoline at service stations is the preferred option for two-stroke engines to avoid the overuse of poor quality oil and excessive smoke emissions (HC and PM).

In the future, *on-board diagnostic (OBD) systems* and remote sensing technology may facilitate the control of in-use emissions. But these automated systems can be expensive and they also require sophisticated equipment and training in order to diagnose the particular emission failure. Vehicle owners and operators, moreover, must be educated so that they repair problems once they are alerted.

Advanced technologies such as hybrid and electric motorcycles and alternative fuels, including natural gas and LPG, may be able to provide cost effective emission reductions if local conditions are conducive. Incentives and other in-use control measures should be used to encourage the adoption of these fuels and technologies when they can provide environmental and societal benefits. Special safeguards should be included to assure that electric vehicles do not result in increased lead emissions from batteries throughout their lifecycle, during manufacture, use, and disposal.

In order to improve the environmental performance of e-bikes, policies should focus on reducing lead emissions associated with e-bike use. Stricter standards are needed to guide domestic lead production and recycling industry and limit lead contamination in the local environment. Further consolidation of the lead production and clean battery manufacturing is necessary to facilitate the adoption of enforceable environmental standards.

Incentives offer a way to help implement advanced technologies and create demand for next generation motorcycles and fuels. Without financial policies, the status quo usually continues unabated until regulations change the economic equation. The benefit of an incentive program can more directly affect behavioral change by encouraging early adoption of new technologies.

7.2.2 POLICIES FOR MOTORCYCLES IN USE

In-use control measures focus on reducing emissions from vehicles on the road. These measures can consist of three major strategies. Inspection and maintenance programs under which vehicles are required to be tested and inspected at regular intervals and repaired to meet adopted in-use emission standards. Second, retrofit and replacement programs focus on upgrading motorcycles with improved emission control equipment, newer engines, or by replacing old vehicles with newer and cleaner motorcycles. Lastly, vehicle use restriction measures ban or limit motorcycle activities in all or part of a city.

Inspection and maintenance (I&M) programs for motorcycles can be a useful in-use control measure in countries and cities where two- and three-wheelers are the main sources of transportation-related air pollution. In most cases, a centralized structure is preferred as it offers fewer opportunities for fraud and corruption. It is also preferable that vehicle owners cover all program costs, including enforcement costs, to ensure financial sustainability. A transparent process, consistent government oversight, and effective roadside enforcement are important features of successful I&M programs. The program in Taiwan identifies opportunities for improved management of motorcycles. However, it is a decentralized program that is highly subsidized by the government.

Retrofits or replacements should be performed with certified retrofit kits or replacement engines meeting adopted in-use emission and durability standards. Replacement vehicles should meet new vehicle emission standards. Complementary policies such as low to no interest loans, incentives and grants for the purchase of the cleanest retrofit kit or replacement engine/vehicle can significantly improve a program's success. Most programs to date have targeted three-wheelers because their high usage rate allows quicker payback of capital cost through fuel cost savings.

Vehicle restrictions may not always lead to the adoption of alternatives that will provide real and permanent emission reductions in all the important pollutant categories. It is worthwhile to evaluate whether similar emission benefits at equal or lower cost could be obtained through other programs, including vehicle replacements, retrofits, engine upgrades, and/or the addition of after-treatment technology.

Fiscal policies, taxes, and user fees are necessary to affect beneficial changes in motorcycle use. These tools are often used to complement standards when the market does not immediately react to regulations. At times fiscal policies are used as a stand-alone means to trigger technological changes.

7.3 CONCLUSIONS

There are more knowledge gaps when it comes to motorcycles than with other passenger vehicles. Cars and light trucks have been the focus of environmental and energy regulation and fiscal policy for decades in the US, EU, and other developed nations. This is not the case with two-wheelers, and especially three-wheeled vehicles. There are extensive knowledge gaps in dealing effectively with the growing motorcycle population in the developing world. Research is needed for effective policymaking to determine the next steps for global leaders concerned with local and global pollution levels and energy consumption patterns, not to mention also road safety and dangerous noise levels.

The most important pollution issue confronting motorcycles is what the next stage of norms will be. Looking beyond Euro 3 and Bharat III in India, how should future emission standards be designed?

As the share of motorcycles in cities, regions, and nations' fleets grows throughout Asia and the rest of the developing world, policymakers must develop, test, implement, and enforce an array of strategies to minimize the unintended negative societal consequences attributed to these pervasive motorized vehicles. Without appropriate regulations and incentives, business-as-usual trends will continue, creating mounting problems. Sound policies, over time, can reverse these trends and create a future where two- and three-wheeled motorized vehicles offer sustainable mobility to a growing portion of the world's population.

8. REFERENCES

Assosiasi Industri Sepeda Motor Indonesia (AISI). *Statistic*. http://www.aisi.or.id/statistic.html. Accessed November 2008.

Association des Constructeurs Européens d'Automobiles (ACEA). 2001. *ACEA Position on Metal Based Fuel Additives*. Informal Document No. 15. 43rd Working Party on Pollution and Energy (GRPE). Geneva, Switzerland.

Association des Constructeurs Européens de Motorcycles (ACEM). 2007. *ACEM Yearbook 2007 - Facts and Figures on PTWs in Europe*. Brussels, Belgium.

Badan Pusat Statistik (BPS). 2006. *Transportation Statistics*. http://www.bps.go.id/sector/transpor/index.html. Accessed August 2007.

Bajaj Auto (Bajaj). 2007. *Presence*. http://www.bajajauto.com/1024/globalbajaj/presence.asp. Accessed August 2007.

Boaz, A. 2007. *Environmentally Sustainable Transport (EST) in South Asia*. Asian Mayors' Policy Dialogue for Promotion of EST in Cities. Kyoto, Japan.

Cardekho. 2008. *Advertised Fuel Economy*. http://www.cardekho.com/. Accessed October 2008.

Chen, Y. and Lin, R. 2007. *Inspection and Maintenance and Other Programs in Taiwan*. Motorcycle Emission Control: Vietnamese and International Experience Workshop. Hanoi, Vietnam.

Cherry, C. 2006. *Implications of Electric Bicycle Use in China: Analysis of Costs and Benefits*. UC Berkeley Center for Future Urban Transport-Volvo Summer Workshop. Berkeley, CA, USA.

Chuang, Jeff, S.C. 2001. *Taiwan Regulatory Experience*. Asian Vehicle Emission Control Conference. Bangkok, Thailand.

Clean Air Initiative for Asian Cities (CAI-Asia). 2004. *Fake 2T Oil Sold in Inner City of Lahore*. http://www.cleanairnet.org/caiasia/1412/article-58961.html. Accessed May 2007.

Deutsche Gesellschaft für Technische Zusammernarbeit (GTZ). 2004. *Sustainable Transport: A Sourcebook for Policy-Makers in Developing Cities Module 4c: Two and Three-Wheelers*. GTZ. Eschborn, Germany.

DWS. 2007. *Latest Car Prices in India*. http://www.dancewithshadows.com/auto_price_list.asp. Accessed August 2007.

DWS. 2008. *Advertised Fuel Economy.* http://www.dancewithshadows.com/. Accessed October 2008

Energy Sector Management Assistance Programme (ESMAP). 2002. *Bangladesh: Reducing Emissions from Baby-Taxis in Dhaka.* Washington, DC, USA.

ESP. 2004. *New Delhi Remote Sensing Pilot Demonstration – An On-road Characterization for the In-use emissions of Delhi's Motor Vehicle Fleet through Remote Sensing Devices (RSD).* India.

Foreign Economic Cooperation (FEC). 2007. *Motorcycle Output Surpasses 20 Million Units.* http://fec2.mofcom.gov.cn/aarticle/theoryresearch/200703/20070304449782.html. Accessed August 2007.

Giridharadas, A. 2008. Four Wheels for the Masses: The $2,500 Car. *The New York Times.* January 8, 2008. New York, NY.

Global Resources Institute (GRI).1998. *Promoting Electric Vehicles in the Developing World.* http://www.grilink.org/ev.htm. Accessed August 2007.

Gong, H. 2008. Personal communications.

Greene, D.L., 2008. *Feebates: Complements or Replacements for Standards?* California Air Resources Board Symposium, April 21, http://www.arb.ca.gov/cc/ccms/meetings/042108/4_21_feebates_0_greene.pdf

HeroHonda. 2007. *Key Milestones of Hero Honda.* http://www.herohonda.com/co_milestones.htm. Accessed August 2007.

Instituto Nacional de Ecologia (INE). 2006. *Estudio de evaluación socioeconómica del proyecto integral de calidad de combustibles–Draft.* Prepared in collaboration with PEMEX and SERMANAT. México D.F., México.

International Council on Clean Transportation (ICCT). 2001.*Bellagio Memorandum on Motor Vehicle Policy- Principles for Vehicles and Fuels in Response to Global Environmental and Health Imperatives.* Bellagio, Italy.

International Council on Clean Transportation (ICCT). 2004. *Status Report Concerning the Use of MMT in Gasoline.* San Francisco, CA, USA.

International Council on Clean Transportation (ICCT). 2006. *Cost Benefit Analysis of Reduced Sulfur Fuels in China.* International Council on Clean Transportation. San Francisco, California, USA.

International Council on Clean Transportation (ICCT). 2007a. Personal communications with ICCT participants.

International Council on Clean Transportation (ICCT). 2007b. *Passenger Vehicle Greenhouse Gas and Fuel Economy Standards: A Global Update.* Washington, DC, USA.

International Council on Clean Transportation (ICCT). 2008. *Methylcyclopentadienyl Manganese Tricarbonyl (MMT): A Science and Policy Review.* San Francisco, CA, USA.

International Council on Clean Transportation (ICCT). 2009. *Fiscal Policies for Passenger Vehicle* CO_2 *Reduction: A Global Review*, forthcoming.

Institute for Global Environmental Strategies (IGES). 2003. Introduction of Electric Three-Wheelers in Kathmandu, Nepal. IGES. Kitakyushu, Japan.

International Road Federation (IRF). 2007. *World Road Statistics 2006- Data 1999 to 2004.* IRF. Geneva, Switzerland.

Iyer, N.V. 2003. Role of the Three-Wheeled Vehicle in Urban Transportation in South Asia. *Smart Urban Transport.* Australia.

Iyer, N.V. 2004. *Managing Two and Three-Wheeler Emissions.* National Workshop on the Improvement of Urban Air Quality of Pakistan. Lahore, Pakistan.

Iyer, N.V. 2006. *Pathways of Emission Control Technologies for Small Two-Wheelers: Past, Present, and Future.* Better Air Quality 2006. Yogyakarta, Indonesia.

Iyer, N.V. and Badami, M. 2007. Two-wheeler Motor Vehicle Technology in India: Evolution, Prospects and Issues. *Energy Policy.* Vol. 35 pp. 4319-4331.

Iyer, N.V. 2007. *Management of In-Use Motorcycle Emissions- The Indian Experience.* Motorcycle Emission Control: Vietnamese and International Experience Workshop. Hanoi, Vietnam.

Iyer, N.V. 2008. Personal communication.

Japan Automobile Manufacturers Association (JAMA). 2007. *Motor Vehicles Statistics of Japan 2006.* JAMA. Tokyo, Japan.

Kojima, M. Brandon, C., and Shat, J. 2000. *Improving Urban Air Quality in South Asia by Reducing Emissions of Two-Stroke Engine Vehicles.* World Bank. Washington, DC, USA.

Kuson, M. 2006. *The Management of Motorcycles in Thailand.* Better Air Quality 2006. Yogyakarta, Indonesia.

Landrigan, P., Nordberg, M., Lucchini, R., Nordberg, G., Grandjean, P., Iregren, A. and Alessio, L. 2006. *Declaration of Brescia on Prevention of Neurotoxicity of Metals*. International Workshop on Neurotoxic Metals: Lead, Mercury and Manganese Brescia, Italy.

Le, A. T. 2007. *Urban Pollution Caused by Transportation and Motorcycles- Emissions Control Solutions for Major Cities*. Motorcycle Emission Control: Vietnamese and International Experience Workshop. Hanoi, Vietnam.

Leong, S.T., Muttamara, S., and Laortanakul. 2002. Influence of Benzene Emission from Motorcycles on Bangkok Air Quality. *Atmospheric Environment*. Vol. 36, pp. 651-661.

Lin, Rui Rung. 2009. Personal communication.

Lung, S.C., Mao, I., Liu, L.S. 2007. Residents' Particle Exposures in Six Different Communities in Taiwan. *Science of the Total Environment*. Vol. 377, pp. 81-92.

Meszler, D. 2007. *Air Emissions Issues Related to Two- and Three-Wheeler Motorcycles*. MES. Maryland, USA.

Mohan, D. 2006. Road Traffic Injuries and Fatalities in India- A Modern Epidemic. *Indian Journal of Medical Research.*Vol. 123, pp. 1-4.

Motorcycle Ten (MCTEN). 2008. http://www.motorcycle-ten.com/PremiereIssue/MotorcycleClubs/MotorcyclePhilippinesFederation/tabid/110/Default.aspx. Accessed November 2008.

National Statistical Office Thailand (NSO). 2000. *Number of Vehicles Registered Under Motor Car Act by Type 1998-1999.* The Department of Land transport, Ministry of Transport and Communications. Bangkok, Thailand.

Nguyen, H. A. 2008. Personal communication.

Partnership for Clean Fuels and Vehicles (PCFV). 2007. *Asia-Pacific Sulfur Levels in Diesel Fuel.* http://www.unep.org/pcfv/PDF/Asia-PacificSulphurMatrixJul05-2.pdf. Accessed May 2007.

Partnership for Clean Fuels and Vehicles (PCFV). 2008. *Leaded Gasoline Phase-out.* http://www.unep.org/pcfv/resources/leaded.asp. Accessed November 2008.

Pollution Control Department (PCD). 2007. *The Study on the Possibility of Replacing Two-Stroke Engines with Four-Stoke Engines and Installing Silencers in Tuk Tuk Vehicles.* Ministry of Natural Resources and Environment. Bangkok, Thailand.

Ramanathan, V.2007 Global Warming and Dangerous Climate Change: Buying Time with Black Carbon Reduction. Scripps Institution of Oceanography. La Jolla, CA, USA.

Roychowdhury, A., Chattopadhyaya, V., Shah, C., and Chandola, P. 2006. *The Leapfrog Factor-Clearing the Air in Asian Cities*. Centre for Science and Environment (CSE). New Delhi, India.

Roychowdhury, A. 2007. Personal Communication.

Saksena, S., Luong, P.V., Quan, D.D., Nhat, P.T, et al. 2006. Commuter's exposure to Particulate Matter and Carbon Monoxide in Hanoi, Vietnam-A Pilot Study. *East-West Center Working Paper.* No. 64.

Saksena, S., Prasad, R.K., Shankar, R. 2007. Daily Exposure to Air Pollutants in Indoor, Outdoor, and In-Vehicle Micro-environments: A Pilot Study in Delhi. *Indoor and Built Environment*. Vol. 16, No. 1, pp.39-46.

Society of Indian Automobile Manufacturers (SIAM). 2007. *Automobile Production Trends*. http://www.siamindia.com/scripts/production-trend.aspx. Accessed August 2007

Sperling, D. and Gordon, D. 2009. *Two Billion Cars: Driving Toward Sustainability*. Oxford University Press. New York, NY, USA.

Sperling, D. and Salon, D. 2002. *Transportation in Developing Countries: An Overview of Greenhouse Gas Reduction Strategies.* Pew Center on Global Climate Change. Arlington, VA, USA.

Suksod, J. 2001. *Automotive Emission in Thailand*. Reduction of Emissions from 2&3-Wheelers. Hanoi, Vietnam.

Thailand Automotive Institute (TAI). 2008. *Motorcycle Product.* http://www.thaiauto.or.th/Records/eng/MOTORCYCLE_PRODUCTION_Eng.asp. Accessed November 2008.

Taiwan Environmental Protection Administration (TEPA). 2006. *Motorcycle Emission Control In Taiwan*. Presentation to ICCT. Taipei, Taiwan.

Tso, C. and Chang, S. 2003. A Viable Niche Market- Fuel Cell Scooters in Taiwan. *International Journal of Hydrogen Energy*. Vol. 29, pp. 757-762.

United States Environmental Protection Agency (US EPA). 1999. *Regulatory Impact Analysis: Control of air pollution from new motor vehicles: Tier 2 motor vehicle emissions standards and gasoline sulfur control requirements.* Washington, D.C.

United States Environmental Protection Agency (US EPA). 2000. *Regulatory Impact Analysis: Heavy-duty engine and vehicle standards and highway diesel fuel sulfur control requirements.* Washington, D.C.

United States Environmental Protection Agency (US EPA). 2004. *Final Regulatory Analysis: Control of Emissions from Nonroad Diesel Engines*. EPA420-R-04-007 pg. 672. Washington, D.C.

United States Environmental Protection Agency (US EPA). 2005. *Six Common Air Pollutants*. http://www.epa.gov/air/urbanair/6poll.html. Accessed December 2005.

United States Environmental Protection Agency (US EPA). 2006. *An Introduction to Indoor Air Quality: Volatile Organic Compounds (VOCs).* http://www.epa.gov/iaq/voc.html#Health%20Effects. Accessed October 2006.

United States Environmental Protection Agency (US EPA). 2007a. *Integrated Risk Information System (IRIS*. http://www.epa.gov/iris/index.html. Accessed August 2007.

United States Environmental Protection Agency (US EPA). US EPA 2007b. *Lead in Paint, Dust and Soil*. http://www.epa.gov/lead/pubs/leadinfo.htm. Accessed May 2007.

Walsh, M. 2005. *Motor Vehicle Inspection and Maintenance*. http://walshcarlines.com/pdf/SIAT2005%20IM.pdf. Accessed August 2007.

Walsh, M. 2006. *Alternative Octane Boosters and the Impact on Vehicle Emissions and Public Health*. http://walshcarlines.com/pdf/Gasoline%20Additives%20BAQ%202006%20Final.pdf. Accessed August 2007.

Wang, J., Chiang, W., Shu, J. 2000. The Prospects- Fuel Cell Motorcycle in Taiwan. *Journal of Power Sources*. Vol. 86, pp. 151-157.

Wang, Q. 2006. *Development Trend of Chinese Emission Standards*. Presentation to ICCT. Beijing, China.

Wang, Q. 2008. Personal communication.

Wangwongwatana, S. 2007. *Motorcycles' Emission Control in Thailand.* Motorcycle Emission Control: Vietnamese and International Experience Workshop. Hanoi, Vietnam.

Ward's. 2007. 2007 Model Car US Specifications and Prices. Ward's Automotive Group.

Weinert, J., Ma Z.D., Cherry C. 2006. The Transition to Electric Bikes in China: History and Key Factors for Rapid Growth. *Journal of Transportation Special Issue: Motorization in Asia*. pp.26.

Willson, B. 2006. *New Solutions to Global Challeng*es. Better Air Quality 2006. Yogyakarta, Indonesia.

World Health Organization. 2004. *World Report on Road Traffic Injury Prevention.* Geneva, Switzerland.

World Health Organization. 2005. *Health Effects of Transport-Related Air Pollution.* Copenhagen, Denmark.

World Resources Institute. 2007. *Sustainable Urban Transport in Asia: Making the Vision a Reality*. CAI-Asia Program.

Yardley, J. 2007. Uneasily, China hits a Milestone of Prosperity. *International Herald Tribune*. January 15, 2007.

APPENDIX A

MOTORCYCLE EMISSION STANDARDS AND PROGRAMS IN DIFFERENT COUNTRIES

The tables that follow detail emission standards in China (Table A-1), India (Table A-2), Japan (Table A-3), Taiwan (Table A-4), Thailand (Table A-5), EU Two-Stroke (Table A-6), EU Four-Stroke (Table A-7), California (Table A-8), and the US Federal Standards (Table A-9).

SELECTED REGULATORY PROGRAMS EXHAUST EMISSIONS STANDARDS IN DIFFERENT COUNTRIES

TABLE A-1. CHINA EXHAUST EMISSION STANDARDS

Year Began	Engine Size (cc)	CO (g/km)	HC (g/km)	NO_x (g/km)	HC+ NO_x (g/km)	PM (g/km)	Driving Cycle	Cold Start	Durability (km)
Two-Wheeler with Two-Stroke Engine									
2003	<50 cc (moped)	6			3		ECE R47	No	6,000 [1]
	≥50 cc	8	4	0.1			ECE R40	No	6,000 [1]
2004	≥50 cc	5.5	1.2	0.3			ECE R40	No	10,000 [1]
2005	<50 cc (moped)	1			1.2		ECE R47	No	10,000 [1]
Two-Wheeler with Four-Stroke Engine									
2003	<50 cc (moped)	6			3		ECE R47	No	6,000 [1]
	≥50 cc	13	3	0.3			ECE R40	No	6,000 [1]
2004	≥50 cc	5.5	1.2	0.3			ECE R40	No	10,000 [1]
2005	<50 cc (moped)	1			1.2		ECE R47	No	10,000 [1]
2008	< 50 cc	1			1.2		ECE R47	Yes	10,000
	50-150 cc	2	0.8	0.15			ECE R40	Yes	18,000 [2] 30,000 [3]
	≥ 150 cc	2	0.3	0.15			ECE R40 +EUDC	Yes	18,000 [2] 30,000 [3]
Three-Wheeler with Two-Stroke Engine									
2003	< 50 cc (moped)	12			6		ECE R47	No	6,000 [1]
2003	≥50cc	12	6	0.15			ECE R40	No	6,000 [1]
2004	≥50cc	7	1.5	0.4			ECE R40	No	10,000 [1]
2005	< 50 cc (moped)	3.5			1.2		ECE R47	No	10,000 [1]
2008	< 50 cc (moped	3.5			1.2		ECE R47	Yes	10,000
	≥ 50cc	4	1	0.25			ECE R40	Yes	12,000 [4] 18,000 [2] 30,000 [3]
Three-Wheeler with Four-Stroke Engine									
2003	< 50 cc (moped)	12			6		ECE R47	No	6,000 [1]
2003	≥50cc	19.5	4.5	0.45			ECE R40	No	6,000 [1]
2005	< 50 cc (moped)	3.5			1.2		ECE R47	No	10,000 [1]
2005	≥50cc	7	1.5	0.4			ECE R40	No	10,000 [1]
2008	< 50 cc (moped)	3.5			1.2		ECE R47	Yes	
	≥50cc	4	1	0.25			ECE R40	Yes	12,000 [4] 18,000 [2] 30,000 [3]

Notes: [1] If installed with emission control device; [2] Maximum speed under 130 km/h and displacement above 150cc; [3] Maximum speed equal to or above 130 km/h and displacement above 150cc;
[4] Displacement between 50 and 150 cc; Moped: Maximum speed under or equal to 50 km/h and displacement under or equal to 50 cc

TABLE A-2. INDIA EXHAUST EMISSION STANDARDS

Year Began	Engine Size (cc)	CO (g/km)	HC (g/km)	NO$_x$ (g/km)	HC+ NO$_x$ (g/km)	PM (g/km)	Driving Cycle	Cold Start	Durability (km)
Two-Wheeler with Two- and Four-Stroke Engine									
1991	All	12-30	8-12				IDC	No	None
1996		4.5			3.6		IDC	No	None
1998		4.5			3.6		IDC	No	None
2000		2			2		IDC	No	None
2005		1.5*			1.5*		IDC	Yes	30,000
2010		1*			1*		IDC	Yes	30,000
Three-Wheeler with Two- and Four-Stroke Engine									
1991	All	14.3			20		IDC	No	None
1996	All	6.75			5.4		IDC	No	None
1998	All	6.75			5.4		IDC	No	None
2000	All	4			2		IDC	No	None
2005	Spark	2.25*			2*		IDC	Yes	30,000
	Comp.	1**			0.85***	0.1*	IDC	Yes	30,000
2010	Spark	1.25*			1.25*		IDC	Yes	30,000
	Comp.	0.5**			0.5***	0.05*	IDC	Yes	30,000

Notes: * Deterioration factor of 1.2 applies to this standard; ** Deterioration factor of 1.1 applies to this standard; *** Deterioration factor of 1 applies to this standard

TABLE A-3. JAPAN EXHAUST EMISSION STANDARDS

Year Began	Engine Size (cc)	CO (g/km)	HC (g/km)	NO$_x$ (g/km)	HC+ NO$_x$ (g/km)	PM (g/km)	Driving Cycle	Cold Start	Durability (km)
Two- and Three- Wheeler with Two-Stroke Engine									
1998	to 50 cc	8	3	0.1	n/a	n/a	ISO 6460	No	6,000
	126-250 cc	8	3	0.1					12,000
1999	51-125 cc	8	3	0.1					8,000
	251 cc+	8	3	0.1					12,000
2006	to 50 cc	2	0.5	0.15				Yes	6,000
	126-250 cc	2	0.5	0.15					24,000
2007	51-125 cc	2	0.5	0.15					8,000
	251 cc+	2	0.3	0.15					24,000
Two- and Three- Wheeler with Four-stroke Engine									
1998	to 50 cc	13	2	0.3	n/a	n/a	ISO 6460	No	6,000
	126-250 cc	13	2	0.3					12,000
1999	51-125 cc	13	2	0.3					8,000
	251 cc+	13	2	0.3					12,000
2006	to 50 cc	2	0.5	0.15				Yes	6,000
	126-250 cc	2	0.5	0.15					24,000
2007	51-125 cc	2	0.5	0.15					8,000
	251 cc+	2	0.3	0.15					24,000

TABLE A-4. **TAIWAN EXHAUST EMISSION STANDARDS**

Year Began	Engine Size (cc)	CO (g/km)	HC (g/km)	NO$_x$ (g/km)	HC+ NO$_x$ (g/km)	PM (g/km)	Driving Cycle	Cold Start	Durability (km)
Two- and Three- Wheeler with Two-Stroke Engine									
1988	All	8.8			5.5		ECE R40	No	None
1991	All	4.5			3.0		ECE R40	No	6,000
1998	All	3.5			2		ECE R40	No	15,000
2002	<700 cc	3.5			2		ECE R40	No	15,000
	≥700 cc	10			2.5		ECE R40	Yes	15,000
2004	<700 cc	7			1		ECE R40	Yes	15,000
2007	<150 cc	2	0.8	0.15			ECE R40	Yes	15,000
	≥150 cc	2	0.3	0.15			ECE R40	Yes	15,000
Two- and Three-Wheeler with Four-Stroke Engine									
1988	All	8.8			5.5		ECE R40	No	None
1991	All	4.5			3.0		ECE R40	No	6,000
1998	All	3.5			2		ECE R40	No	15,000
2002	<700 cc	3.5			2		ECE R40	No	15,000
	≥700 cc	10			2.5		ECE R40	Yes	15,000
2004	<700 cc	7			2		ECE R40	Yes	15,000
2007	<150 cc	2	0.8	0.15			ECE R40	Yes	15,000
	≥150 cc	2	0.3	0.15			ECE R40	Yes	15,000

TABLE A-5. **THAILAND EXHAUST EMISSION STANDARDS**

Year Began	Engine Size (cc)	CO (g/km)	HC (g/km)	NO$_x$ (g/km)	HC+ NO$_x$ (g/km)	PM (g/km)	Driving Cycle	Cold Start	Durability (Km)
Two- and Three-Wheeler with Two-Stroke Engine									
1993	All	16-40	10-15				ECE R40	No	None
1995	All	12.8-32	8-12				ECE R40	No	None
Two-Wheeler and Three-Wheeler with Four-Stroke Engine									
1993	25-50	7-10					ECE R40	No	None
1995	17.5-35	4.2-6					ECE R40	No	None
Two- and Three-Wheeler with Two- and Four-Stroke Engine									
1997	All	13	5				ECE R40	No	None
1999-2001	All*	4.5			3		ECE R40	No	12,000
2003-2004	All Evap.≤ 2g/test	3.5			2		ECE R40	No	12,000
	All Evap. > 2 and ≤ 6 g/test	3.5			1.8		ECE R40	No	12,000
2008-2009	<150 cc Evap.≤ 2g/test	2	0.8	0.15			R40 + EUDC	Yes	
	<150 cc Evap. > 2 and ≤ 6 g/test	2	0.6	0.15			R40 + EUDC	Yes	
	>150 cc Evap.≤ 2g/test	2	0.3	0.15			R40 + EUDC	Yes	
	>150 cc Evap. > 2 and ≤ 6 g/test	2	0.1	0.15			R40 + EUDC	Yes	

Note: * Evaporative emissions ≤ 2 g/test for engine 150 cc and greater

TABLE A-6. EUROPEAN UNION EMISSION STANDARDS: TWO-STROKE

Year Began	Engine Size (cc)	CO (g/km)	HC (g/km)	NO_x (g/km)	HC+ NO_x (g/km)	PM (g/km)	Driving Cycle	Cold Start	Durability (km)
Two- Wheeler with Two-Stroke Engine									
Pre-1999	< 50 cc	8	5				ECE R47	No	None
1999		6			3		ECE R47	No	None
2002		1			1.2		ECE R47	No	None
Pre-1993	>50 cc	16-40	10-15				ECE R40	No	None
1993		12.8-32	8-12				ECE R40	No	None
1999		8	4	0.1			ECE R40	No	None
2003	50-150 cc	5.5	1.2	0.3			ECE R40	No	None
2006		2	0.8	0.15			ECE R40	Yes	None
2003	150 + cc	5.5	1	0.3			ECE R40	No	None
2006		2	0.3	0.15			R40 + EUDC	Yes	None
Three-Wheeler with Two-Stroke Engine									
Pre-1999	< 50 cc	15	10				ECE R47	No	None
1999		12			6		ECE R47	No	None
2002		3.5			1.2		ECE R47	No	None
Pre-1993	>50 cc	16-40	10-15				ECE R40	No	None
1993		12.8-32	8-12				ECE R40	No	None
1999		12	6	0.15			ECE R40	No	None
2003	> 50cc Spark	7	1.5	0.4			ECE R40	No	None
	> 50cc Comp.	2	1	0.65			ECE R40	No	None

TABLE A-7. EUROPEAN UNION EMISSION STANDARDS: FOUR-STROKE

Year Began	Engine Size (cc)	CO (g/km)	HC (g/km)	NO_x (g/km)	HC+ NO_x (g/km)	PM (g/km)	Driving Cycle	Cold Start	Durability (km)
Two- Wheeler with Four-Stroke Engine									
Pre-1999	< 50 cc	8	5				ECE R47	No	None
1999		6			3		ECE R47	No	None
2002		1			1.2		ECE R47	No	None
Pre-1993	>50 cc	25-50	7-10				ECE R40	No	None
1993		17.5-35	4.2-6				ECE R40	No	None
1999		13	3	0.3			ECE R40	No	None
2003	50-150 cc	5.5	1.2	0.3			ECE R40	No	None
2006		2	0.8	0.15			ECE R40	Yes	None
2003	150 + cc	5.5	1	0.3			ECE R40	No	None
2006		2	0.3	0.15			R40 + EUDC	Yes	None
Three-Wheeler with Four-Stroke Engine									
Pre-1999	< 50 cc	15	10				ECE R47	No	None
1999		12			6		ECE R47	No	None
2002		3.5			1.2		ECE R47	No	None
Pre-1993	>50 cc	16-40	10-15				ECE R40	No	None
1993		12.8-32	8-12				ECE R40	No	None
1999		19.5	4.5	0.45			ECE R40	No	None
2003	> 50 cc Spark	7	1.5	0.4			ECE R40	No	None
	> 50 cc Comp.	2	1	0.65			ECE R40	No	None

TABLE A-8. CALIFORNIA, UNITED STATES EMISSION STANDARDS

Year Began	Engine Size (cc)	CO (g/km)	HC (g/km)	NO_x (g/km)	HC+ NO_x (g/km)	PM (g/km)	Driving Cycle	Cold Start	Durability (km)
Two- and Three-Wheeler with Two-and Four-Stroke Engine									
1978	50-169	17	5				Modified FTP-75	Yes	12,000
	170-279	17	5-6.7				FTP-75	Yes	18,000
	280-749	17	6.7-14				FTP-75	Yes	30,000
	≥750	17	14				FTP-75	Yes	30,000
1980	50-169	17	5				Modified FTP-75	Yes	12,000
	170-279	17	5				FTP-75	Yes	18,000
	≥ 280	17	5				FTP-75	Yes	30,000
1982	50-169	12	1				Modified FTP-75	Yes	12,000
	170-279	12	1				FTP-75	Yes	18,000
	≥ 280	12	2.5				FTP-75	Yes	30,000
1985	≥ 280	12	1.4				FTP-75	Yes	30,000
1988	280-699	12	1				FTP-75	Yes	30,000
	≥700	12	1.4				FTP-75	Yes	30,000
2004	≥ 280	12			1.4		FTP-75	Yes	30,000
2008	≥ 280	12			0.8		FTP-75	Yes	30,000

TABLE A-9. UNITED STATES EMISSION STANDARDS

Year Began	Engine Size (cc)	CO (g/km)	HC (g/km)	NO_x (g/km)	HC+ NO_x (g/km)	PM (g/km)	Driving Cycle	Cold Start	Durability (km)
1980	50-169	12	5				Modified FTP-75	Yes	12,000
	170-279	12	5				FTP-75	Yes	18,000
	≥ 280	12	5				FTP-75	Yes	30,000
2006	<50	12	1				Modified FTP-75	Yes	6,000
	50-169	12	1				Modified FTP-75	Yes	12,000
	170-279	12	1				FTP-75	Yes	18,000
	≥ 280	12			1.4		FTP-75	Yes	30,000
2010	≥ 280	12			0.8		FTP-75	Yes	30,000