A Technical Assessment of Emissions and Fuel Consumption Reduction Potential from Two and Three Wheelers in India

Prepared for the International Council on Clean Tranportation (ICCT)

by Narayan V. Iyer

August, 2012

A Technical Assessment of Emissions and Fuel Consumption Reduction Potential from Two and Three Wheelers in India

Prepared for the International Council on Clean Transportation

by

Narayan V. Iyer
Consultant

Disclaimer: This document does not necessarily represent the views of the ICCT, or of the organizations or government agencies with which ICCT participants are affiliated. Primary research for this report was conducted during the second half of 2011. While it is believed that the information presented here continues to reflect current conditions, changes may have occurred since 2011 that are not incorporated into this document. Any and all errors are the sole responsibility of the author.

Acknowledgement: The author would like to sincerely thank Fanta Kamakaté, Anup Bandivadekar and Francisco Posada for their thoughtful comments. Thanks to Mr K.K.Gandhi, Technical Director of SIAM and Mr M.N.Muralikrishna, Adviser Technical of TVS Motors, both for providing the views of the vehicle manufacturers regarding future plans for emission control and fuel efficiency improvement. Also, thanks to Mr T.M.Balaraman of Hero Moto Corp for providing insights into the UNECE and EEC activities related to two and three-wheelers.

Citation: Iyer N.V., (2012). *A Technical Assessment of Emissions and Fuel Consumption Reduction Potential from Two and Three Wheelers in India*. Prepared for: the International Council on Clean Transportation. Washington, DC.

TABLE OF CONTENTS

1. INTRODUCTION

The motorcycles sales in India have been growing in the past few years at double-digit rates, and recently surpassed one million vehicles a month mark. With annual sales five times that of passenger car sales, motorcycles continue to dominate the on-road passenger vehicle fleet and petrol consumption. Three wheelers in India are expected to surpass half a million in sales in financial year 2010-2011. These three wheelers play a critical role in providing point-to-point as well as feeder service in all urban and semi-urban areas. Given the importance of two and three wheelers in improving personal mobility in India, careful attention must be paid to the possibility of reducing emissions and fuel consumption from these vehicles.

In 2007, the ICCT published an initial assessment of technologies to control air pollution from motorcycles[1], which was followed by a broader report on opportunities to reduce emissions and fuel use from two wheelers[2]. These reports have set the stage for detailed country specific assessment of technology and policy opportunities for realizing on-road emission reduction from two and three wheelers.

This report makes a broad assessment of the engine technology changes and after-treatment systems being employed by Indian manufacturers of two and three-wheelers to meet the prevalent emission standards (Bharat Stage III) for a range of fuels such as petrol (all two-wheelers), diesel, CNG and LPG (three-wheelers), followed by an assessment of the technical options available to reduce emissions to meet the proposed Euro 4/5/6 equivalent limit values in the respective years of their likely adoption and implementation in India.

It also includes a review of the possible technical options that may be available over the coming decade to reduce fuel consumption of two and three wheelers such as improved engines and other sub-systems, control system optimization etc., and an estimation of fuel consumption reductions possible through these technical options.

The report also examines the technical options to address important – and hitherto neglected areas of - durability requirements, cold start emissions, evaporative emissions, and on-board diagnostic systems along with an assessment of the cost impact of measures and the likely challenges for their introduction and effective implementation.

Finally, the report gives certain policy recommendations for improving the in-use vehicle testing and compliance program as also to improve fuel and lubricant quality to enable further reductions in emissions and fuel consumption of two and three-wheelers.

---

[1] www.theicct.org/2007/07/moto-emissions-initial-assessment/

[2] www.theicct.org/2009/10/managing-motorcycles/

2. THE INDIAN TWO AND THREE-WHEELER MARKET

2.1 MARKET PROFILE OF TWO-WHEELERS

2.1.1 DOMESTIC AND EXPORT MARKET SIZE

It is now a well-known fact that powered two-wheeled vehicles occupy a leading position in the personal transportation sector both in the urban and rural areas in India. It is not surprising that the production and sales of two-wheelers have been surpassing those of passenger cars by nearly a factor of 5 consistently for the last several years. Two-wheelers have been forming over 75% of annual domestic sales of all vehicles for the last many years (Figure 1).

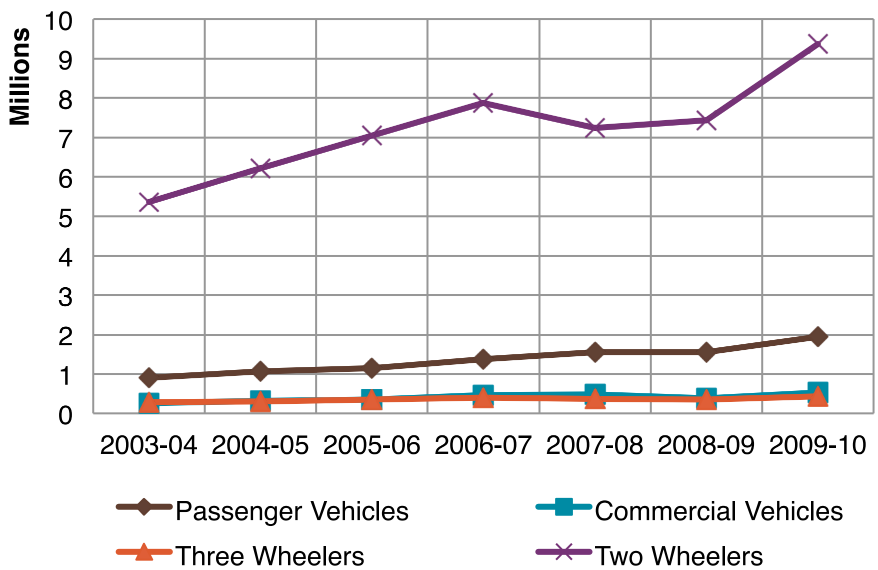


Figure 1. Annual Domestic Sales of Different Categories of Vehicles (*SIAM 2011*)

The number of powered two-wheelers produced in India in the last fiscal year 2010-2011 has crossed 10 million vehicles, with exports accounting for up to 10% of total production numbers (Figure 2).

According to Bajaj Auto Ltd, one of the major Indian two and three-wheeler manufacturers, major export markets are in Africa, Central America, and South Asia – mainly Bangladesh and Sri Lanka, where they have dominant market shares while some exports are also made to a few South East Asian countries.

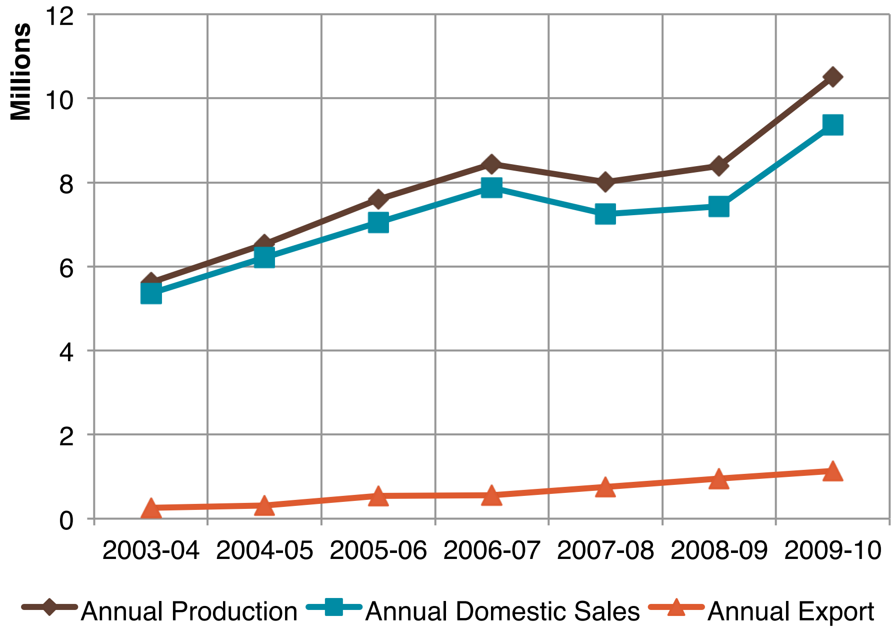


Figure 2. Annual Production, Domestic Sales and Exports of 2-Wheelers (*SIAM 2011*)

2.1.2 TYPES OF TWO-WHEELERS

The Indian market has three basic types of powered two-wheelers, namely mopeds, scooters and motorcycles. There are two other categories called the "Scooterette" and the "Step-through". Of these, the "Step-through" category has almost disappeared from the market. The main distinguishing features of these vehicles are described below.

Mopeds: The mopeds are usually powered by small single cylinder air-cooled 2-stroke petrol engines of less than 60 cc displacement. They use a fixed belt or chain transmission, or a combination of chain and belt transmission. Some models use an automatically variable two-speed belt transmission that helps to provide a higher wheel torque during starting and low speeds and lower torque for cruising. Mopeds use larger wheels, usually greater than 14". These vehicles use low-cost cycle parts for handle bars, brakes etc. The electric power required to operate the horn and lights is derived from a flywheel mounted magneto. Most of the mopeds either do not have, or, have low-capacity batteries. They do not have self-starting arrangements and are provided with pedals for starting the engine as well as to serve as footrests. Mopeds thus are the least-cost powered two-wheelers available in the market. Because of their inherent simplicity, low price and ease of maintenance, these vehicles are preferred by persons belonging to the lower income group, students and aged persons, small merchants, particularly in the small towns and rural

areas. The simplicity and low cost are also the reasons for the continued preference of 2-stroke engines for this class of vehicles.

Scooters: Scooters are characterized by the engine and the fuel tank mounted under the driver's seat, ample legroom in the form of a foot-platform between the seat and the handle bar and using small wheels, usually smaller than 12". The engine, usually of 100 to 150 cc displacement, is an integrated power unit that includes the clutch, gearbox and final transmission, which drives the rear wheel either directly or through a chain/belt transmission. Most current models of scooters are powered by single cylinder air-cooled 4-stroke petrol engines. While many scooters have a manual shift gearbox, some others use the automatic variable ratio belt transmission similar to the one used on mopeds. The body of the vehicle is covered with attractively shaped metal or plastic claddings, which cover the engine and the fuel tank fully and also provide a leg-guard in the front, extending from the foot-platform to the handle bar. The construction of the body is either a monocoque – such as the original Vespa and the later Bajaj - or made of a tubular space frame and plastic and/or metal claddings. The scooter was the most preferred two-wheeler in India until a few years ago when motorcycles overtook them. The vehicle was considered as a family vehicle that was convenient because it could carry two persons and a child quite easily. It was, and continues to be, preferred by ladies who find it difficult to ride a motorcycle because of the type of attire they wear.

Scooterettes: This vehicle is a combination of the moped and the scooter. Its body shape is like that of the scooters but it uses power units, including the transmission, similar to those of the mopeds. It is essentially a low-cost, low-power scooter. They are mostly classified along with scooters.

Step-throughs: This is a combination of a motorcycle and a moped. It uses power units similar to those on mopeds but of higher capacities - say up to 80 cc displacement and use wheels larger than 14". A major difference with respect to the motorcycle is the absence of the fuel tank in front of the rider thereby providing an open space similar to that of the moped. This type of vehicle continues to be extremely popular in many South-East-Asian countries. It is no longer sold in the Indian market.

Motorcycles: Motorcycles perhaps do not need a detailed description since their constructional features are almost universal. They are constructed of metal frames; use an integrated power unit consisting of the engine, clutch, and gearbox and a final chain transmission to the rear wheel. The fuel tank, usually attractively designed, is located right in front of the rider and above the engine. Motorcycles use wheels of 16” to 17” size. Practically all current models of motorcycles in India are powered by single cylinder, air cooled 4-stroke petrol engines.

2.1.3 BRIEF HISTORICAL PERSPECTIVE AND MARKET SHARES OF DIFFERENT CATEGORIES

Over a decade ago, the ‘powered two-wheeler’ market in India was dominated by “scooters”. Bajaj Auto Ltd. enjoyed the lion’s share of the market due to the high popularity of the rugged and reliable ‘all-metal-body’ scooter. The Bajaj scooter was a derivative of the popular ‘Vespa’ manufactured by the Italian Piaggio. Bajaj was manufacturing these vehicles under licence from Piaggio.

Following a partial liberalization of the economy in the 1980s, major Japanese two-wheeler companies – Honda, Yamaha and Suzuki – and, Piaggio from Italy (whose collaboration with Bajaj had ended), set up joint ventures to produce their state-of-the art two-wheelers, most of which were small motorcycles. Honda had set up two different ventures through one of which – Kinetic Engineering - they introduced their immensely popular ‘Lead’ scooter powered by a 100 cc 2-stroke engine and a belt driven variable transmission. The ‘Lead’ – rechristened ‘Kinetic Honda’ – was popular mainly because of its modern looks, superior comfort, easy riding – even sari-clad women were quite comfortable using it. From their joint ventures in India Yamaha (Escorts) and Suzuki (TVS) introduced 100 cc 2-stroke motorcycles, which started to get more and more acceptable to the market, which was, until then, more familiar with the scooter. Honda’s second venture with the Hero Motors group brought sub 100 cc 4-stroke with fuel efficiency better than that of 2-strokes. The success on sales compelled competitors to introduce more fuel-efficient 4-stroke motorcycles.

Another important factor that led to the introduction of 4-stroke motorcycles was the enforcement of progressively stringent exhaust emission standards. While it was necessary to use an oxidation catalytic converter to reduce the high 2-stroke hydrocarbon emissions to meet the mass emission standards, the 4-strokes were able to meet the standards by simple tuning and lean calibration. Bajaj Auto – the traditional scooter maker – also introduced 4-stroke motorcycles produced under licence from Kawasaki. As can be seen from Figure 3 motorcycles have dominated the growth of the powered two-wheeler market during the last decade.

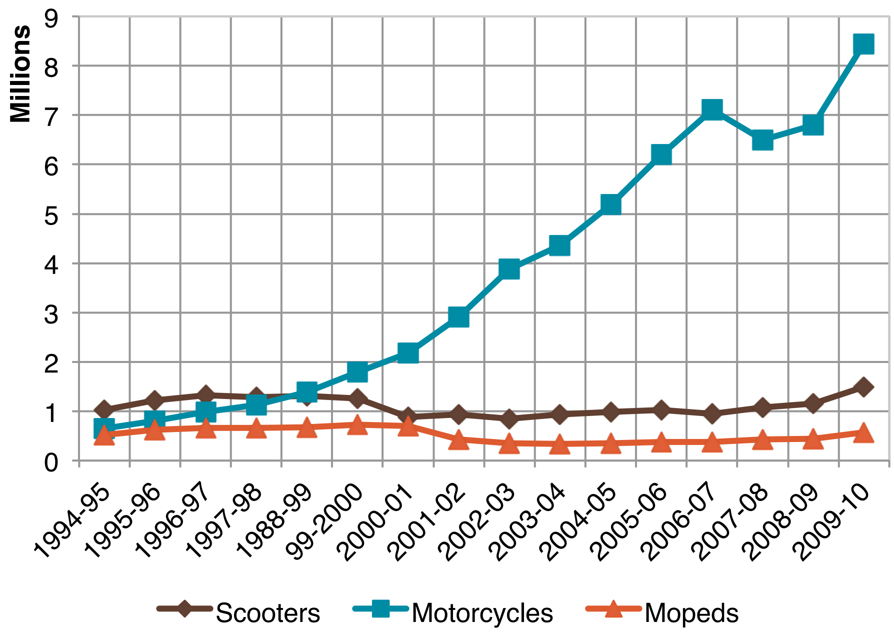


Figure 3: Growth in two-wheeler production over the last 15 years *(ACMA 2011*)

In comparison, the production of scooters registered a decline in spite of the fact that new models representing the state-of-the-art were introduced in the market. The next round of liberalization of the economy led Honda to set up its wholly owned subsidiary. On account of their agreement with Hero for the manufacture and sale of motorcycles, Honda entered the market with a 4-stroke scooter in spite of the fact that the scooter market share was getting drastically eroded by the 4-stroke motorcycles. Honda's superior technology, however, helped to re-establish the popularity of scooters with the market showing a remarkable recovery. Thanks to the 4-stroke engine, the Honda scooter was inherently more fuel-efficient than the older models powered by 2-stroke engines. It must, however, be noted that the relative shares of scooters and mopeds in the total two-wheelers market continued to be relatively low due to the scorching pace of growth of the motorcycle market. Figure 4 shows the per cent share of scooters, mopeds and motorcycles in the total production of all 2-wheelers over the last decade and a half. It is seen that the share of motorcycles has steadied during the last five years and the share of scooters is registering a growth.

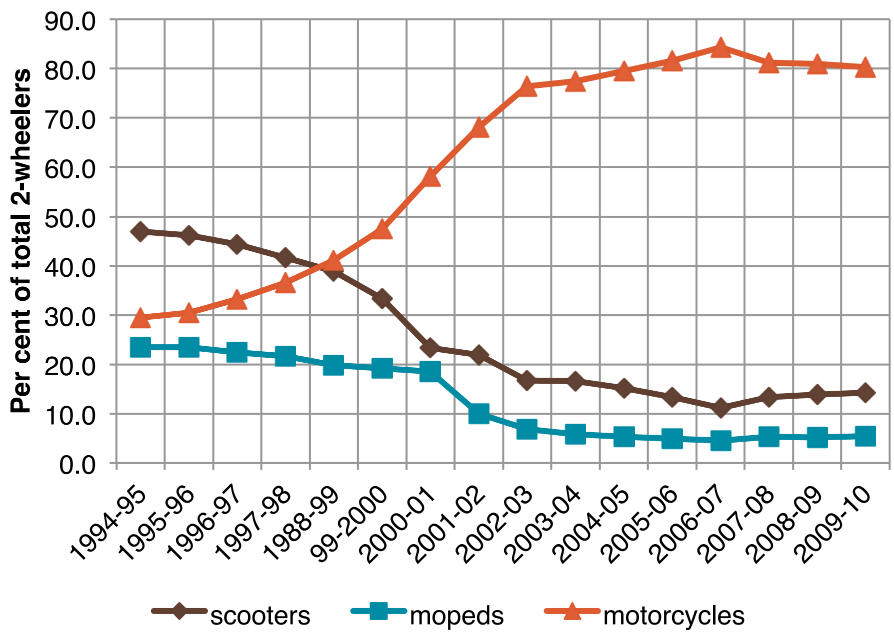


Figure 4. Per Cent Share of Different Categories of Two-Wheelers over 15 Years (*ACMA 2011*)

It will be seen from Figure 5 – which shows the 'Year-on-Year' growth rate (in per cent terms) for the three categories of vehicles that the rate of growth of scooters and mopeds had become negative during a few years beginning from the year 2000. The growth rates of these two categories seem to have recovered in subsequent years and are now almost comparable to that of motorcycles, albeit the fact that the former two are from a relatively low base line.

The story of mopeds is quite different from that of scooters. Mopeds were primarily introduced in the early 1980s – mostly after the first round of economic liberalization – by two manufacturers. One was TVS Motors located in the state of Tamil Nadu in the south of India and the other was Kinetic Engineering Ltd located in the western state of Maharashtra. Majestic Auto, a member of the Hero group, located in the north of India, also sold some numbers in the northern cities. All these companies had introduced locally developed models that were primarily powered by small 50 – 60 cc 2-stroke engines and used belt driven fixed or variable transmission.

The mopeds were popular during the period when the main alternative 2-wheeler was the scooter. It seems that the availability of several other models of 2-wheelers, particularly the fuel efficient 4-stroke motorcycles, and the progressive improvement in the economic status of the customers led to a gradual reduction in the market share of mopeds.

Currently the main, and perhaps the only, manufacturer of mopeds is TVS Motors and the market also seems to be mainly confined to the southern states. The moped models also do not seem to have undergone many changes and continue to use the 2-stroke engine.

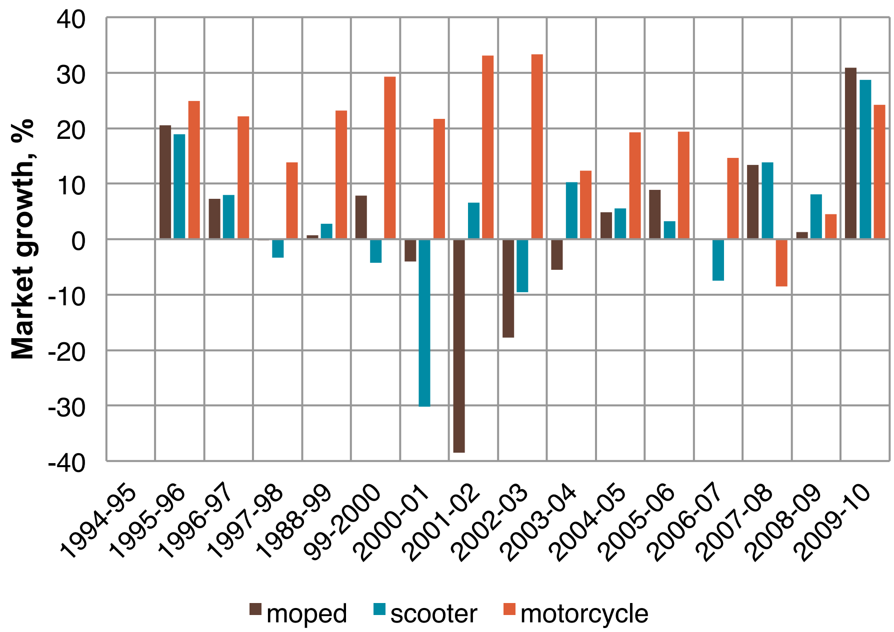


Figure 5: Year-on-Year Growth Rates of Different Categories of Two-Wheelers

The decline in the market share of mopeds was sought to be compensated by the introduction of the "scooterette" which seemed to have appealed to a section of users due to its scooter-like appearance and comfort and availability at a lower price. TVS is the leading manufacturer of the scooterette in addition to mopeds.

2.1.4 TECHNICAL CLASSIFICATION OF TWO-WHEELERS

In order to analyse the market profiles in terms of broad specifications of the two-wheelers sold in the country, a classification evolved by 'Society of Indian Automobile Manufacturers (SIAM) (Table 1) (*SIAM 2011*) has been used which is based on the wheel size and engine capacity. Motorcycles are divided into three classes based on the range of engine displacements, basic price points and certain features. These classes are identified in the market as "Entry Level" or "Commuter Standard", "Executive" or "Commuter Deluxe" and "Premium" or "Sports" classes. These terms are used loosely in the market and do not represent any official classification. Scooters are divided into two classes.

Table 1: Classification of Two-Wheelers Followed by SIAM

S. No	Description	Wheel size	Engine cc	Market class#
A1	Scooterettes	<12”	<75 cc	none
A2	Scooter	<12”	>75 and <125	none
A3	Scooter	<12”	>125 and <250	none
B1	Motorcycle/step-through	>12”	<75 cc	none
B2	Motorcycle	>12”	>75 and <125	Entry/Commuter Standard
B3	Motorcycle	>12”	>125 and <250	Executive/Commuter Deluxe
B4	Motorcycle	>12”	>250	Premium/Sports
C	Mopeds *	>12”	<75 cc	none

*Fixed Transmission. # Not used by SIAM

Figure 6 shows the relative market shares of different categories of two-wheelers during the fiscal year 2009-2010. In this chart, ‘scooters’ include both engine capacity ranges namely >75 and <125 cc and >125 and <250 cc due to the very small number of scooters in the >125 and <250 cc category.

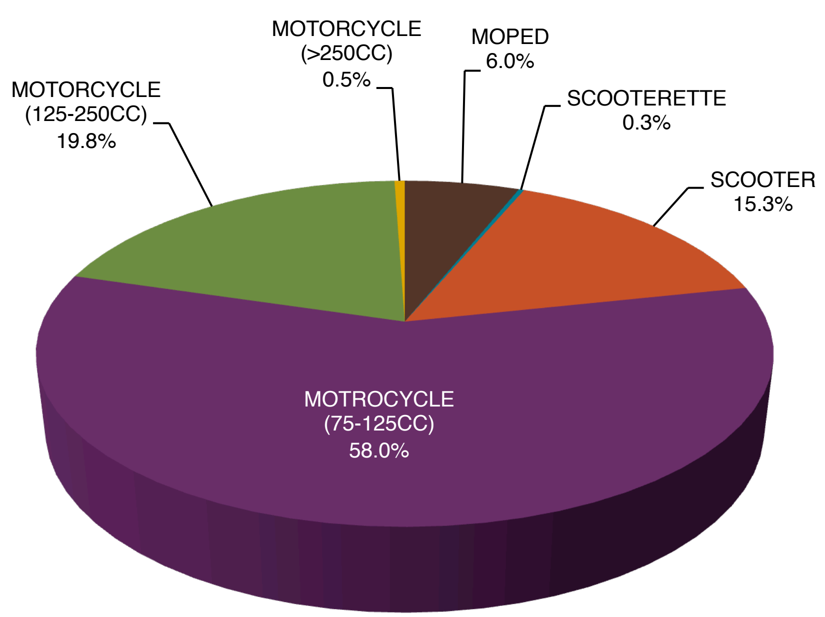


Figure 6: Market Shares of Different Categories of Two-Wheelers during 2009-2010 (*SIAM 2011*)

On account of their low volumes, the "Step-through" category has been considered along with motorcycles. It is seen that the motorcycles category with engine capacities ranging from 75-125 cc has the largest market share (58%) among two-wheelers. Motorcycles category with engine capacities between 125 cc to 250 cc has the second largest market share (nearly 20%). Scooters (all engine capacities together) have the third largest share of the market (around 15%). Mopeds continue to have a relatively small but significant market share of 6%.

2.1.5 MAJOR MANUFACTURERS OF TWO-WHEELERS

There are six major manufacturers currently manufacturing two-wheelers in India. These include, roughly in the order of their market shares, Hero Honda Motors Ltd (HHML) (now Hero Motocorp), Bajaj Auto Ltd (BAL), TVS Motor Company Ltd (TVS), Honda Motorcycle and Scooter India Pvt Ltd (HMSI), Yamaha Motor India Ltd (YMIL), Suzuki Motorcycles India Pvt Ltd (SMIL), and Mahindra and Mahindra Ltd (M&M). HHML manufactures mostly motorcycles and a smaller number of scooters. TVS manufactures a wide range of two-wheelers such as mopeds, scooterettes, scooters and motorcycles. It had a joint venture with Suzuki of Japan until a few years ago. Suzuki now has its own wholly owned subsidiary SMIL, as do Yamaha (YMIL) and Honda (HMSI). HMSI, until recently, was manufacturing only scooters (due to an on-going agreement with Hero Honda) now has a range of motorcycles in the market. YMIL and SMIL manufacture mainly motorcycles, though SMIL does have a small presence in the scooter segment also. Bajaj Auto has been the leading manufacturer of scooters but has now ceased the production of scooters and has emerged as a major manufacturer of motorcycles. In addition to several products of its own design, it also has a licence agreement with Kawasaki of Japan for certain high-end motorcycles, such as the Ninja. Mahindra & Mahindra is the latest entry into the market after having taken over Kinetic Engineering Ltd and it currently manufactures only scooters.

In addition to the above, certain niche market manufacturers/distributors operate in the Indian market such as Enfield India, Harley Davidson, Hyosung, Ducati and KTM, with the last mentioned having a stake from BAL. Among these, Enfield India, one of the oldest motorcycle manufacturers in the country, has complete production facilities in India. Others either import fully built units or partially carry out local assembly. These niche market manufacturers and their products have not been taken into account in the present report due to their very small volumes and very high costs, some of which exceed those of mid-size cars and are considered only as recreational products.

2.1.6 MANUFACTURERS' MARKET SHARES OF DIFFERENT CLASSES OF TWO-WHEELERS

Scooters: Figure 7 shows the per cent market shares of scooters among different manufacturers. Honda Motorcycle and Scooters India has the major share of (over 51%) followed by TVS Motors (about 19%). Suzuki Motorcycle India and Mahindra have achieved significant shares (nearly 10% and 5%, respectively). Bajaj Auto is insignificant since it has stopped making scooters.

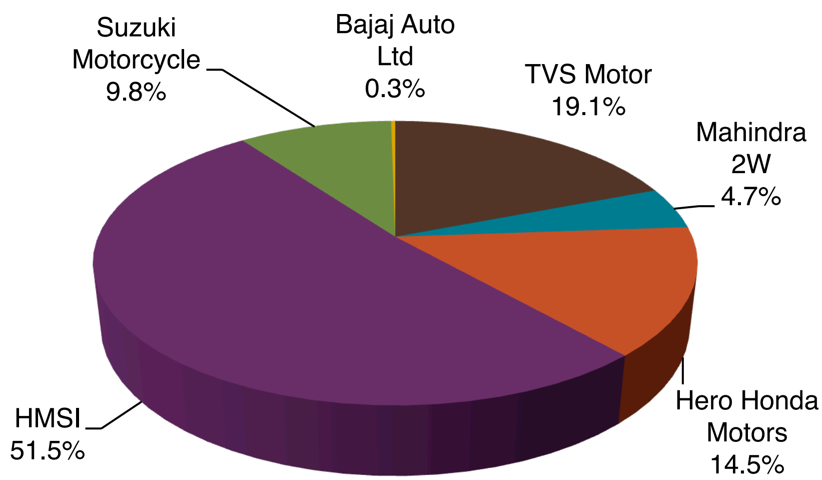


Figure 7. Market Shares of Different Manufacturers of Scooters during 2009-2010 (*SIAM 2011*)

Motorcycles: Figures 8 and 9 are similar charts showing the relative market shares of motorcycles of 75-125 cc category and 125-250 cc category respectively. Hero Honda Motors has the dominant share of nearly 75% of this category, followed by Bajaj Auto in the second place with around 17% share. On the other hand, Bajaj Auto dominates the 125-250 cc category with a 45% share with the second position occupied by HMSI with a 23% share. Hero Honda has a relatively small share of around 13%. This category of vehicles has a significant presence of other manufacturers such as Suzuki Motors, India Yamaha Motor and TVS Motors.

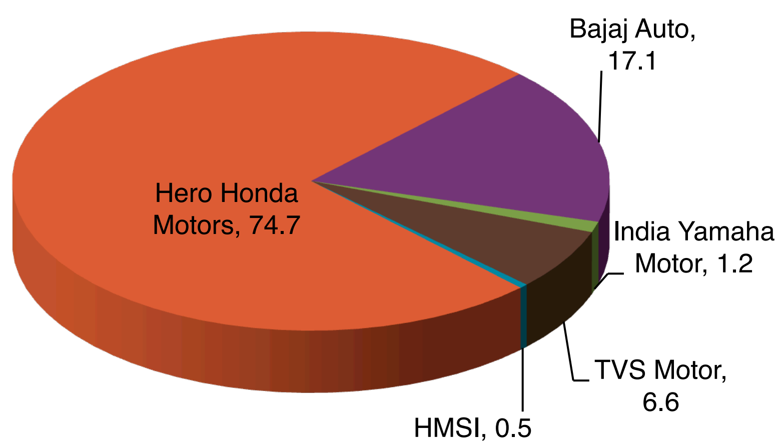


Figure 8. Market Shares of Motorcycle Manufacturers (75-125 cc) 2009-201 (*SIAM 2011*)

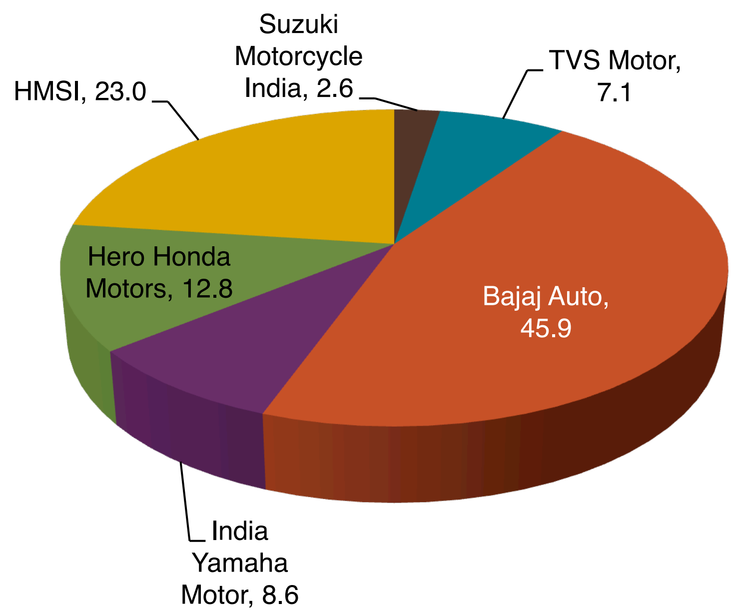


Figure 9. Market Shares of Different Manufacturers of Motorcycles (125-250 cc) during 2009-2010 *(SIAM 2011)*

2.1.7 OVERALL MARKET SHARES OF MANUFACTURERS

The overall market shares across all categories of vehicles, in terms of actual numbers sold in the domestic market during the fiscal year 2009-2010 are given in Annex I *(SIAM 2011)***.**

2.1.8 PRINCIPAL CHARACTERISTICS OF TWO-WHEELERS

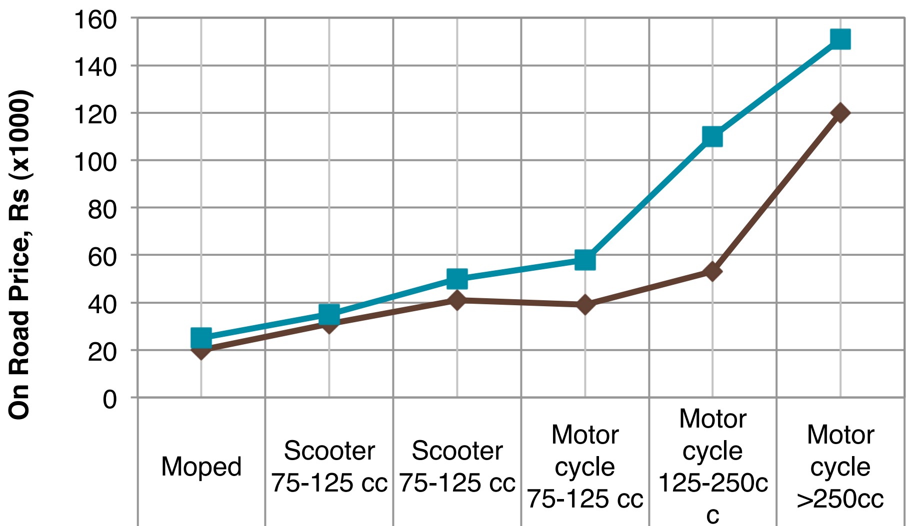
The overall profile of vehicle characteristics of the large variety of products being sold in the market in terms of engine capacity, maximum power and vehicle kerb weight is summarized in Table 2.

Table 2: Summary of Main Characteristics of Two-Wheelers Sold in the Market

Segment	Kerb Weight, kg	Engine Capacity, cc	Max Power, kW	Price, Rs (x1000)
Moped	65-75	70	2.61-3.5	20-25
Scooterette	78	70-72	3.5	31-35
Scooter 75-125 cc	95-115	88-125	3.7-6.4	41-50
Motorcycle 75-125 cc	108-125	94-125	5.4-8.7	39-58
Motorcycle 125-250 cc	108-137	149-249	9.6-13.1	53-110
Motorcycle >250 cc	180-190	346-499	14.7-20.2	120-151

2.1.9 PRICES OF TWO-WHEELERS

The prices of 2-wheelers vary a great deal from category to category and, within the categories, among models. Often manufacturers offer model variants with different extra features such as disk brakes, self-starters, alloy wheels etc. The prices included in the present analysis are those of the basic models offered by each manufacturer. The prices have been taken from a popular magazine (*Bike India 2011*). The ranges of prices (figures rounded off to the nearest thousand Rupees) – on road Pune (Maharashtra) – are depicted in Figure 10. It is seen that the range of prices of motorcycles of 75-125 cc category – the highest selling category – is very wide with prices varying from Rs 39,000 to Rs 58,000. The price range is wider in the motorcycles of 125-250 cc category. The variations largely arise from the additional features offered by the manufacturers. The prices are also influenced by the company policies and market strategies.



	Moped	Scooter 75-125 cc	Scooter 75-125 cc	Motor cycle 75-125 cc	Motor cycle 125-250c c	Motor cycle >250cc
MIN	20	31	41	39	53	120
MAX	25	35	50	58	110	151

Figure 10. Ranges of Prices of 2-Wheelers - Pune (*Bike India 2011*)

2.1.10 PREDICTIONS ON FUTURE GROWTH OF 2-WHEELER MARKET

As can be seen from the preceding sections, the two-wheeler sector, particularly the motorcycle segment, has been registering a remarkable growth thus becoming a subject of significant interest to investors. This sector, therefore, also attracts the attention of market researchers. Reproduced below are excerpts from a research study of future growth of two-wheeler market. The full text can be seen from the link provided in the reference (*India Automotive 2010*)

"Motorcycles as a segment have grown at a CAGR (Compound Annual Growth Rate) of 17.4% during the last 16 years, while the other two-wheelers (scooters, mopeds) have been virtually stagnant, growing at a meagre CAGR of 1.8%. In India, the share of motorcycles in the two-wheeler market has risen from 30% to 80% in the last decade and a half, during which period annual sales of motorcycles in the country have grown by a multiple of 13. In the near future, volume growth is expected to persist, though percentage growth is likely to decline slightly on the back of a substantially increased base.

The key drivers of demand are the households earning Rs 300,000 to 500,000 per annum. As income rises on the back of rapid economic growth, many households are moving from two-wheelers to small cars. However, such is the pyramid that an even higher number from lower income categories are moving in to motorcycle ownership. So, yes, the motorcycle segment is addressing a key demographic sweet spot, which will fuel the demand for years to come.

The overall penetration of two-wheelers in India is of the order of 28% of all households. In the urban segment, the penetration is of the order of 45%, whereas in the rural segment, the penetration is only about 12% of the households. Clearly, the big drive in future will come from the rural segment.

As many as 11 million urban households and 4.4 million rural households have annual household incomes in the Rs 300,000-500,000 category. The next category consists of 25 million urban and 23 million rural households. At least a quarter of these (11-12 million) will likely move into the two-wheeler purchasing segment during the next five-ten years.

At present as many as 72% of the bikes are in the entry segment (defined as 75 to 125 cc), and 27% are in the executive segment (defined as 125-250 cc). Only 1% of the bikes are in the premium segment, which is expected to continue being a niche segment and its share is not expected to grow beyond 2-2.5% over the next decade. However, that implies that it will be a market of about 200,000 to 250,000 annual units, which is substantial and attractive. (As a comparison, the declining Japanese market currently consumes only about 350,000 motorcycles annually in the above-250 cc category, having fallen sharply over the past few years).(India Automotive 2010)"

2.2 MARKET PROFILE OF THREE-WHEELERS

2.2.1 DOMESTIC AND EXPORT MARKET SIZE

Three-Wheeled vehicles of various types form a very important part of the transportation system in India. They are used as “Intermediate Public Transport (IPT)” in most cities plying either as flag-down taxis or operating from point to point on fixed routes like omnibuses. Some of them also operate from city borders to small towns and villages in the outskirts to ferry passengers. A large number of them are designed as goods carriers and operate as intra-city goods transport vehicles. They are particularly preferred for moving relatively low weights – up to 500kg.

There are several reasons for the popularity of three-wheeled vehicles. In addition to the low initial and running costs, the other major reason is the ability of the vehicle to be maneuvered into small spaces on narrow streets, which are characteristic of most of the cities and towns in the region. They occupy small parking space and they are easy and cheap to maintain. From the users' perspective, they offer a flexible and reliable service that is cheaper than a four-wheeled taxi but is faster and more dependable than a city bus. Another driving force for their increasing popularity is the opportunity they provide to a large number of people to seek self-employment, not to mention the added employment opportunities created by the repair and maintenance services. It is estimated that each three-wheeler provides livelihood to at least two families in India *(Iyer 2003)*.

Their predominant role in the transport sector can be seen from Figure 11, which shows that, over the last few years, the sales numbers of three-wheelers (all categories together) have almost been matching the sales numbers of all other commercial vehicles taken together. The commercial vehicles referred to above include light and heavy passenger and goods vehicles such as buses, trucks, light trucks, minibuses etc.

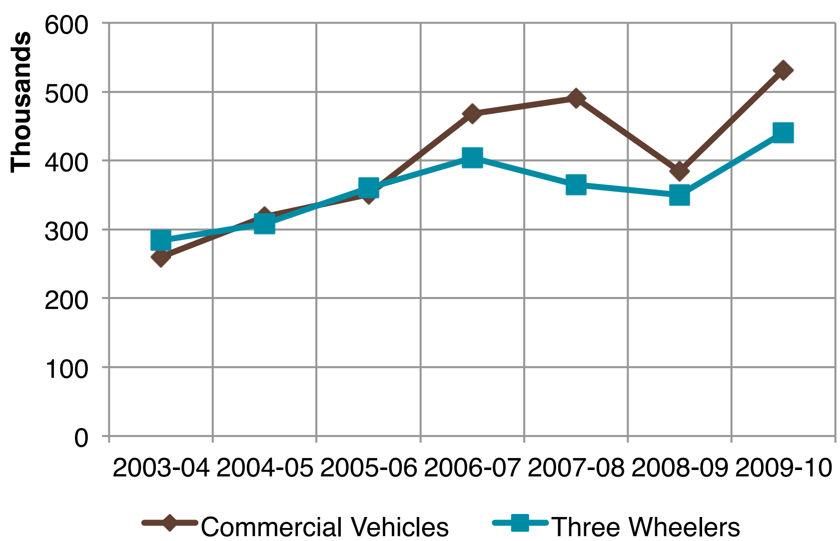


Figure 11. Annual Domestic Sales of Commercial Vehicles and 3-Wheelers (*SIAM 2011*)

The three-wheeler has been gaining in popularity over the years as can be seen from the growth of annual production in the last fifteen years shown in Figure 12**.** The annual production increased three-fold in the last decade. The 3-wheeler growth rate has been keeping pace with the rapidly growing 2-wheeler market maintaining a 5 to 7 per cent proportion of the latter over the years.

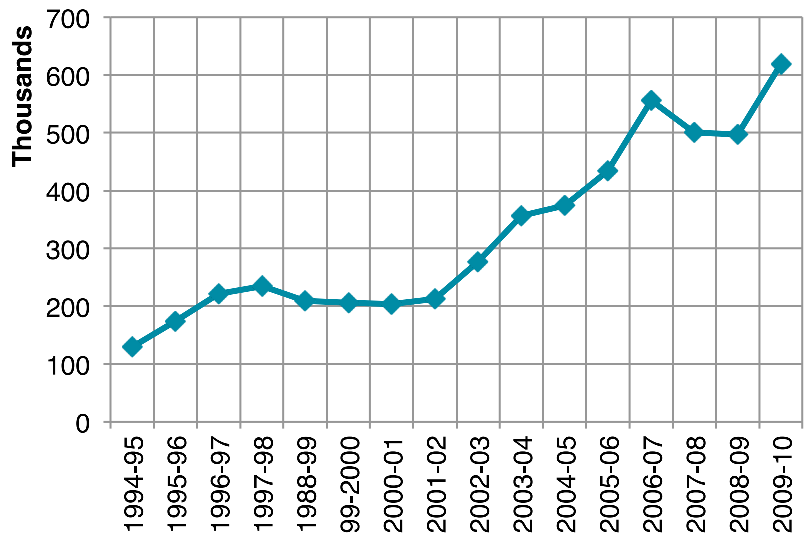


Figure 12. Annual Production of 3-Wheelers in India in the Last 15 Years (*ACMA 2011*)

A large number of 3-wheelers produced in India are exported. The steady growth of exports and domestic sales over the years is shown in Figure13**.** From just below 20% of domestic sales, exports currently constitute nearly 30% of domestic sales.

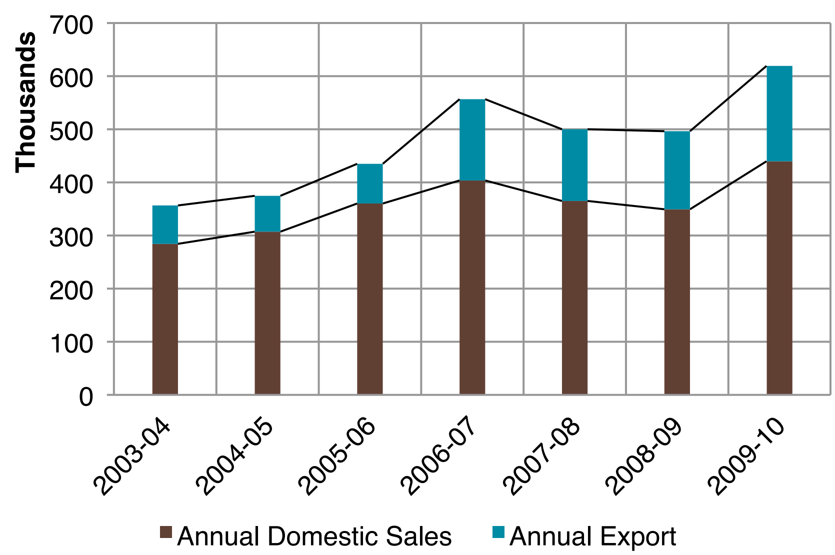


Figure 13. Domestic Sales and Exports of 3-Wheelers (*SIAM 2011*)

2.2.2 TYPES OF THREE-WHEELERS

Three-wheeled vehicles in India can be broadly divided into two categories – the passenger carriers and the goods carriers. Passenger carriers are of two types, one is the compact 4 persons carrier (3 passengers plus the driver) called the auto-rickshaw and the 7 persons carrier (6 passengers plus driver) – often called the Tempo. These two basic platforms also have corresponding goods versions.

2.2.2.1 PASSENGER CARRIERS

The Auto-Rickshaw

A majority of three-wheeled vehicles used in India are designed to carry three passengers in addition to the driver and are called auto-rickshaws. In most of the larger cities these vehicles operate as ‘flag-down’ taxis for which they are equipped with tariff meters approved by the local authorities. The ‘auto-rickshaw’ is constructed in the simplest possible manner to minimize its cost, weight and fuel consumption. Its design is considered to be the most optimum in terms of material inputs and operating efficiency for performing the intended task at the least cost. The chassis and body are made of pressed steel and include a bench seat each for the driver and the passengers. A hood made out of fabric is provided to protect the occupants from rain and sun. A windshield protects the front but the sides are usually open. The vehicle is steered by a handle bar exactly like one in a scooter. The picture to the right is that of the Bajaj RE 205 CNG auto-rickshaw (illustration: Courtesy of Bajaj Auto Ltd).

The Six-Seat Rickshaw or the Tempo

Another type of three-wheeled vehicle that typically carries six passengers has been growing in popularity in recent years. These vehicles are powered by small, single cylinder diesel engines and operate on fixed routes more or less like the omnibus, often providing a competition to the latter. This vehicle is made of a tubular frame with a sheet metal body mounted on it. This vehicle is also provided with a hood made of fabric and has no doors either in the driver or in the passenger compartments. It has two bench seats facing each other for the passengers and one bench seat in the front for the driver and one more passenger. However, government regulations do not permit a passenger to use that seat and the vehicle continues to be referred to as the ‘six-seat-rickshaw’ or ‘tempo’. The vehicle is provided with a steering wheel like those in four-wheeled vehicles.

2.2.2.2 GOODS CARRIERS

Variants of the basic three-wheelers that are provided with a goods tray, or built like a delivery van, are quite popular for intra-city movement of small merchandize like vegetables, bread, kitchen gas cylinders etc. Most of these vehicles have a payload capacity of half to one tonne. These vehicles basically use a steel frame chassis with a goods tray mounted on it. The front of the vehicle where the driver sits is usually the same as in the corresponding passenger version. Most of these are open on the sides though, recently certain models with doors in the driver's compartment have been introduced. All the three-wheelers usually have maximum speed in the region of 50 to 55 km/h. The picture to the right is that of the Bajaj GC Max goods vehicle (illustration: Courtesy of Bajaj Auto Ltd) .

2.2.3 BRIEF HISTORICAL PERSPECTIVES

Three-wheelers were brought into India by the company that preceded Bajaj Auto Ltd., recognizing their potential as a useful mode of passenger and goods carriers. The inspiration came from Piaggio's Ape' car with whom BAL already had a licence agreement to manufacture and sell two and three-wheelers in India. The present shape of the vehicle is a result of progressive evolution over the years to meet the requirements of the users. For instance, the original Italian design was of the "Front Engine" type, which had a single cylinder air-cooled 2-stroke engine under the driver's seat and had a hooded compartment for the passengers behind the driver. In a subsequent development, BAL introduced a "Rear Engine" model that had the engine mounted below the passenger compartment giving relief from heat, noise and smoke both to driver and passengers. The overall comfort level of the vehicle also improved due to the use of independent suspension with shock absorbers. The varieties of goods carriers simply emerged from the original Italian design.

The original 2-stroke petrol engine was only of 150 cc displacement and was not found adequate for the goods carrier application. This resulted in the development of a diesel version. A single cylinder diesel engine, basically used for industrial applications, was tuned to be adopted as an automotive engine. This engine enabled an increase in the payload capacity while giving a lower running cost due the lower price of diesel fuel and the inherently superior fuel efficiency of the diesel engine. The diesel passenger carriers did not seem to find much favour in the auto-rickshaw market perhaps due to unacceptable noise and vibrations.

A larger three-wheeler that could take six passengers in addition to the driver was introduced by a government owned company called Scooters India Ltd. In some regions of India, this vehicle is called 'Tempo' or 'Tum Tum'. Though the six passenger vehicle was available with a petrol engine, its diesel version became popular both for passenger and goods carriers due to the relatively low price of diesel. Other manufacturers such as Force Motors (formerly Bajaj Tempo), Mahindra & Mahindra and later on Atul Auto introduced similar vehicles in the market.

2.2.4 CLASSIFICATION OF THREE-WHEELERS AS PER USAGE

Based on their usage, SIAM has evolved a classification system of three-wheelers mainly for consolidation of statistical data. This is shown in Table 3.

Table 3: Classification of Three-Wheelers Followed by SIAM

Designation	Maximum Mass, tonne	Number of Seats Including Driver
A1 Passenger Carrier	< 1	< 4
A2 Passenger Carrier	≤ 1.5	≥ 4 seats <7
B1 Goods Carrier	≤ 1	-
B2 Others	-	-

2.2.5 MARKET SHARES OF DIFFERENT CATEGORIES OF THREE-WHEELERS

The relative shares of different categories of 3-wheelers, based on the domestic sales for the fiscal year 2009-2010 are shown in Figure14 which indicates that passenger vehicles category of <4 persons (including the driver) occupies the largest market share – close to 80 per cent of the total sales of 3-wheelers. The sub-one-tonne goods carrier is a distant second having a share of 17 per cent. It can seen from Figure 15 that the sale of goods carriers – both <1 tonne and 'others' types taken together - is declining over the last few years whereas the sale of passenger carriers– taking both 4-seat and 7-seat types together is increasing thereby bringing about an overall growth of the three-wheeler market.

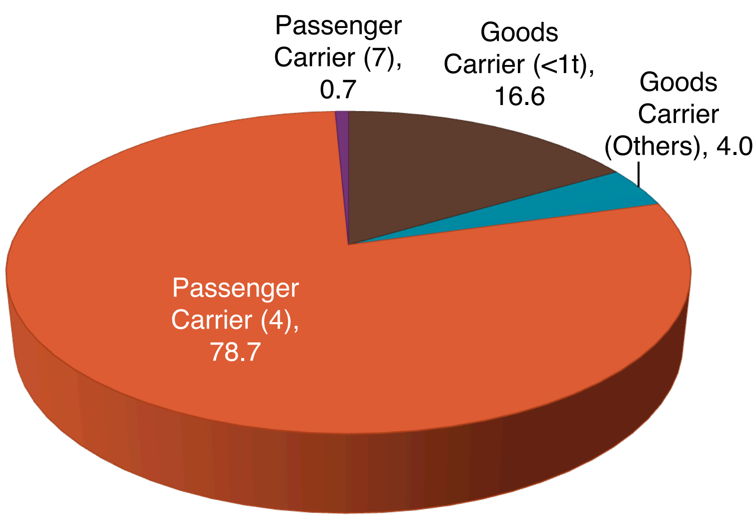


Figure 14. Per Cent Share of Different Categories of 3-Wheelers (*SIAM 2011*). Based on domestic sales for fiscal year 2009-2010

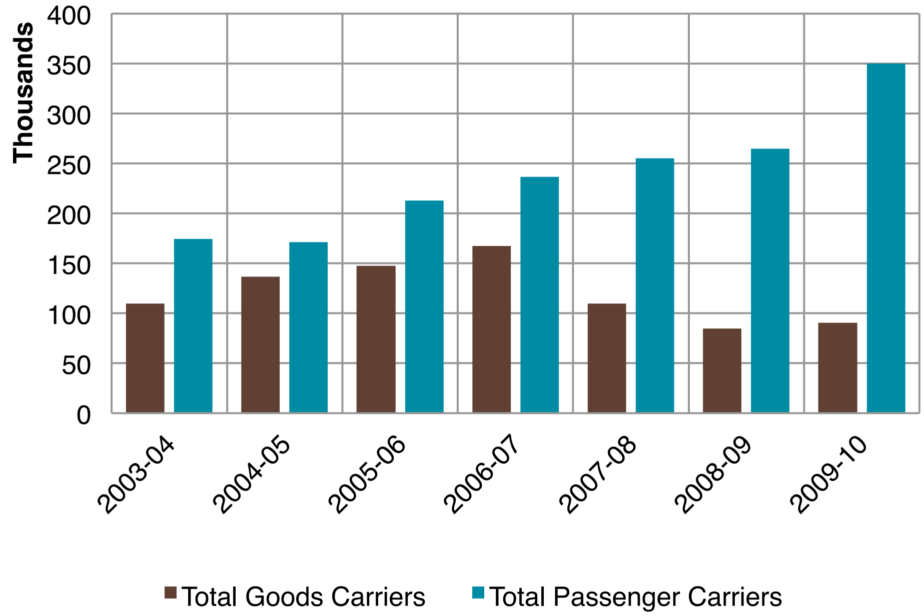


Figure 15. Changing Annual Sales of Passenger and Goods 3-Wheelers (*SIAM 2011*)

2.2.6 MAJOR MANUFACTURERS OF THREE-WHEELERS

There are seven major manufacturers of three-wheelers in India. Bajaj Auto is the pioneer among them and is credited with bringing the 'auto-rickshaw' concept into India. Several other manufacturers have now entered the market and have started manufacturing a range of three-wheeled vehicles that include passenger and goods vehicles, powered by either diesel, petrol, CNG or LPG. The major ones among them are Piaggio Vehicles Pvt. Ltd. and Mahindra and Mahindra. The most recent entrant is TVS Motors, which has introduced the <4seat auto-rickshaw in select markets.

2.2.7 MANUFACTURERS' MARKET SHARES OF DIFFERENT CATEGORIES OF THREE-WHEELERS

The overall market shares of various manufacturers, considering all three-wheelers together, are shown in Figure 16. Bajaj Auto, which enjoyed the number one position until a few years ago, seems to have conceded it to Piaggio, which has now (in the fiscal year 2009-2010) a marginally higher share (41%) compared to Bajaj Auto (40%).

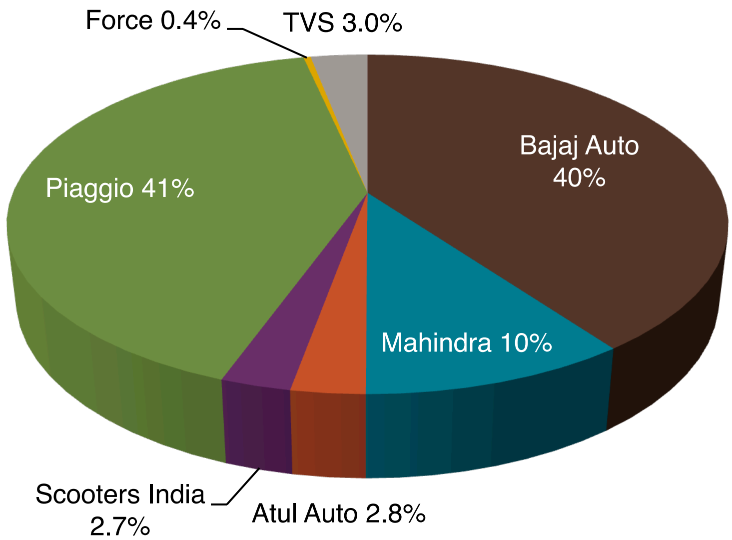


Figure 16. Market Shares of Different Manufacturers for All Types of 3-Wheelers (*SIAM 2011*)

Table 4: Sales of Different Categories of 3-Wheelers of Different Manufacturers Based on Sales Figures of Fiscal Year 2009-2010 *(SIAM 2011)*

Manufacturer	Pass, <1t, <4 seats	Pass, <1.5t, 4<seats <7	Goods <1t	Goods (Others)	Total
Bajaj Auto	1,64,493		11,534		1,76,027
Mahindra	30,243	198		13,997	44,438
Atul Auto	4,986		7,302		12,288
Scooters India	3,018	2,709	3,412	2,580	11,719
Piaggio	1,30,138		50,659		1,80,797
Force Motors	152	325		1,222	1,699
TVS	13,400				13,400
Total	3,46,430	3,232	72,907	17,799	4,40,368

The types of products currently being manufactured by the seven companies vary considerably, summarized in Table 4**.** The category of passenger 3-wheelers of <4 persons has products from every manufacturer. This is also the largest category accounting for nearly 78 per cent of the total sale of all 3-wheelers. The goods vehicles segment of less than 1 tonne category is the second largest with about 16 per cent share. Among the manufacturers, Bajaj Auto and Piaggio occupy the top two positions. Figure 17 shows the market shares of different manufacturers in the passenger vehicle category. The <4 persons category is dominated by Bajaj and Piaggio products. The next category of 4 to 7 passengers, which is just about 1 per cent in sales of the <4 seat category, is dominated by Scooters India. The market shares of manufacturers of goods three-wheelers are shown in Figure 18. The goods 3-wheelers category itself is just about one-fourth the size of the passenger category and is dominated by Piaggio and Mahindra respectively.

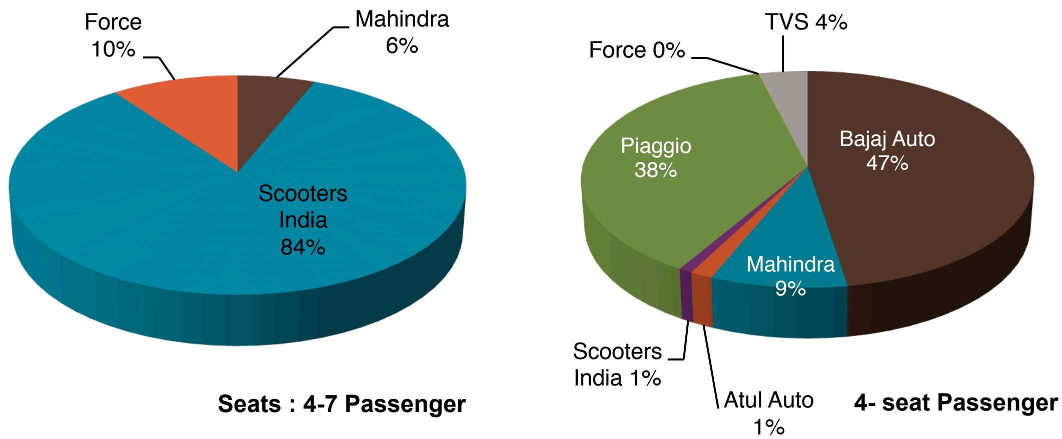


Figure 17: Market Shares of Different Manufacturers in the Passenger Categories, <4 seat and between 4 and 7 seats (*SIAM 2011*)

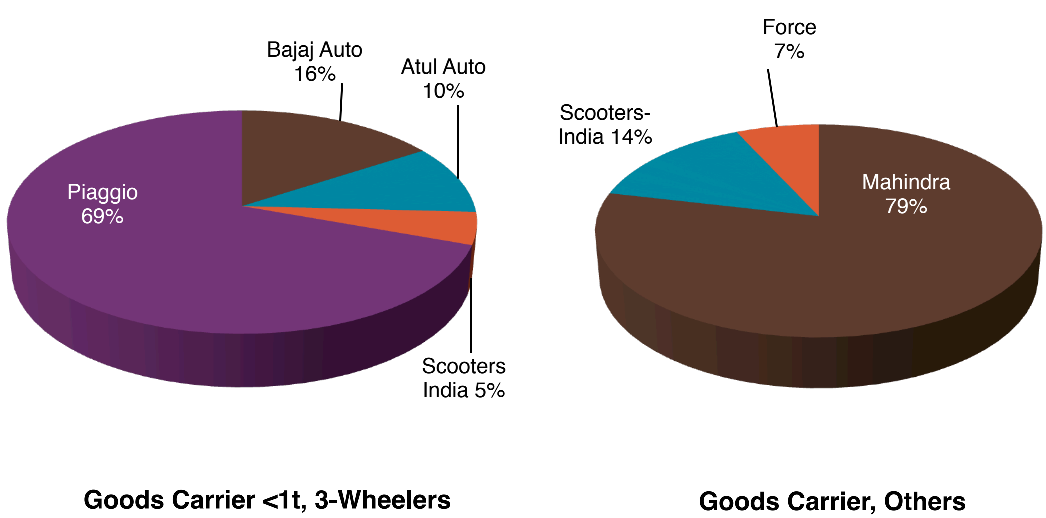


Figure 18. Market Shares of Different Manufacturers in the Goods Categories of <One tonne and others (*SIAM 2011*)

2.2.8 FUELS USED IN THREE-WHEELERS

Different models of three-wheelers using petrol or diesel are manufactured and sold in the domestic and overseas markets. In addition, there are variants that can run on CNG or LPG. The passenger auto-rickshaws of <4 persons category, until recently, were almost entirely powered by petrol engines. The arrival of diesel-powered versions in this category has slowly changed the market shares, which is now almost equally divided between diesel and petrol. Most of the goods carriers are powered by diesel engines. The vehicles designed to run on CNG or LPG are basically derived from the petrol versions. These are not conversions of diesel engines unlike in the commercial vehicles sector. The distribution of vehicles of different categories as per the fuel used is shown in Figure 19.

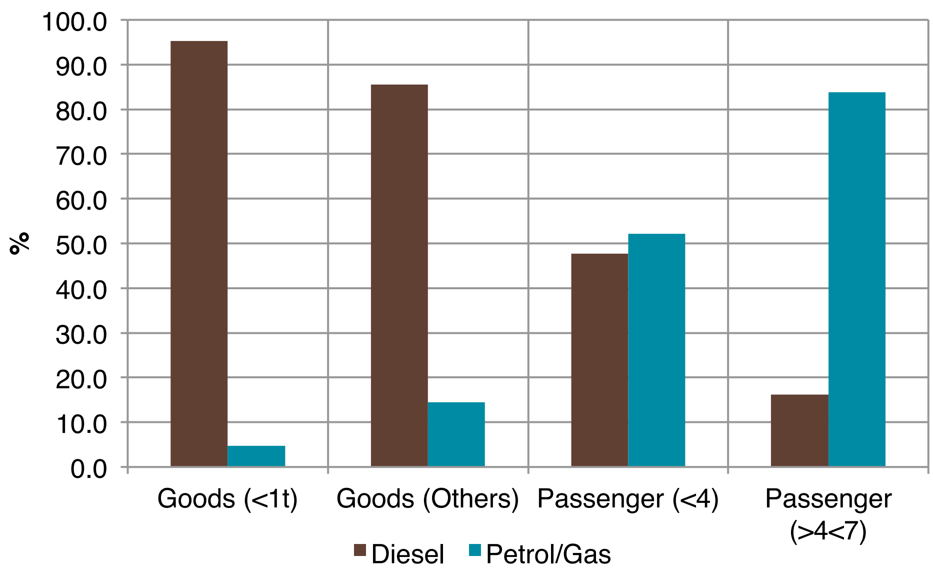


Figure 19: Relative Proportions of Diesel and Petrol/ Gas in Different Categories (*SIAM 2011*)

Since separate sales figures for CNG and LPG vehicles are not readily available, and since most CNG and LPG vehicles are basically conversions of original petrol vehicles, in the diagram in Figure 19 the CNG and LPG fuels have been shown as alternatives to petrol vehicles. It is seen that the use of diesel engines is predominant in both of the goods vehicles categories namely <1 tonne and ‘others’. In the <4 persons passenger category, however, diesel and petrol versions are present in almost equal in proportions.

The auto-rickshaw segment of the <4 persons type perhaps accounts for practically all the CNG and LPG three-wheeled vehicles initially resulting from regulatory directives from the Supreme Court in Delhi (See BOX 1).

BOX 1 INTRODUCTION OF CNG IN DELHI AUTO-RICKSHAWS

Use of CNG in three-wheelers started as a result of directives from the Supreme Court of India to curb the high level of pollution faced by the city of Delhi. The Court had directed the replacement of all the petrol three-wheelers, registered before the year 1991(which, at that time, were almost entirely powered by 2-stroke petrol engines), by those running on 'clean fuels'. Though the court order did not specify CNG as the clean fuel to be used, the choice was obvious considering that Delhi already had a CNG pipeline running close to it, and the court had also ordered the augmentation of the CNG vehicle filling facilities. The implementation of the programme started in the year 2000 when Bajaj Auto Ltd., the dominant manufacturer of auto-rickshaws, introduced their indigenously developed 4-stroke CNG auto-rickshaw. Subsequently, several private enterprises came up with retro-fit kits to convert 2-stroke petrol engines to operate on CNG. More recently, Bajaj Auto has also added the 2-stroke CNG version to its range of 3-wheelers.

2.2.9 TECHNICAL CHARACTERISTICS OF POWER UNITS USED ON THREE-WHEELERS

The engine in most of these vehicles is located in a compartment behind the passenger seat. The basic petrol engine is quite similar to that used in two-wheeled scooters except for the differences in the gearbox and transmission. The latter includes a differential to drive the two rear wheels through two propeller shafts.

The diesel versions also use single cylinder engines of less than 500 cc displacement. The limitation on engine displacement comes from a provision in the Motor Vehicles Rules according to which, many rules meant for two-wheelers apply to three-wheelers only if the latter has an engine of less than 500 cc. If this engine size is exceeded, rules for four-wheeler rules apply.

Most of the petrol driven auto-rickshaws and their goods carrier variants are provided with a long lever by the side of the driver's seat for manual cranking of the engine. More recent versions of auto-rickshaws, particularly those powered by diesel engines and the goods carrier versions are provided with self-starters.

The petrol and CNG/LPG engines used in the three-wheelers can be either 2-stroke or 4-stroke. Data on relative proportions of 2-stroke and 4-stroke engines are not available. Anecdotal information suggests that more than nearly 70 per cent of the petrol vehicles are powered by 2-stroke engines. Typical specifications of these engines are summarized in Table 5 for Bajaj Auto and Table 6 for Piaggio. TVS has entered the three-wheeler market recently and seems to have only one 4-stroke forced air-cooled SI engine of 200 cc displacement developing 5.5 kW at 5000rpm (*TVS 2011*). It will be seen from the specifications given in the tables that all the engines, both diesel and petrol, are of single cylinder type.

Bajaj Auto Engines Bajaj Auto has all possible varieties of engines namely 2-stroke petrol, CNG and LPG (the latter two not included in Table 5), 4-stroke petrol, CNG and LPG and a 4-stroke diesel. These combinations derive from three basic engines, a 2-stroke 145 cc engine, a 4-stroke 175 cc engine and a 415 cc diesel engine. The 2-stroke engine is a derivative of the period when Bajaj had a licence from Piaggio and has, since then, undergone several changes to improve fuel efficiency and reduce emissions. The 4-stroke version was developed through in-house R&D efforts. Bajaj is also the only manufacturer to have introduced a 'Direct Injection' 2-stroke engine. The diesel engine is an indirect injection engine of Kubota (Japan) design with a Kubota patented "three-vortex" combustion chamber that is claimed to reduce PM emissions.

Table 5: Specifications of 3-Wheelers Produced by Bajaj Auto *(Bajaj 2011)*

Description	Petrol	Petrol	Petrol	CNG	LPG	Diesel
Fuel Control	Direct Injection	Carburettor	Carburettor	Regulators	Regulators	Indirect Injection
Engine Type	2-stroke forced air cooled, SI *	2-stroke forced air cooled, SI*	4-stroke forced air cooled SI*	4-stroke forced air cooled SI*	4-stroke forced air cooled SI*	4-stroke air cooled CI#
Displacement, cc	145.5	145.5	173.5	173.5	173.5	416.6
Compression Ratio	11.0 ± 1.0:1	10.0 ± 0.7:1	9.0 ± 1.0:1	9.0 ± 1.0:1	9.0 ±1.0:1	24.0 ±1.01
Max Power, kW @ rpm	6.8 kW@ 5000 rpm	5.2 kW @ 5000 rpm	6.0 kW @5000 rpm	4.8 kW @5500 rpm	5.7 kW @5500 rpm	5.0 kW@ 3000 rpm
Max Torque, Nm @ rpm	14.91 Nm @3500rpm	12.17 Nm @ 3500rpm	11.5 Nm @ 4000rpm	9.3 Nm @ 2500rpm	11.5Nm @3500 rpm	18.7 Nm @ 2200 (±200) rpm

*Spark Ignition. #Compression Ignition

Piaggio Engines Piaggio's basic engine is a 395 cc diesel that powers most of its 3-wheelers, which are also available as CNG and LPG variants. There is also a 436 cc diesel to power goods vehicles of larger payloads. Piaggio has recently announced a new "Ape´City" engine that is a 4-stroke spark ignition engine of 275 cc displacement with three variants that can respectively run on petrol, CNG or LPG. The manufacturer claims that this engine is BS III compliant and does not require a catalytic converter except for the LPG variant. The engine is air-cooled but is provided with an oil cooler, having two valves with an overhead camshaft and delivers power outputs of 7.07 kW (4400 rpm) with petrol, 4.99 kW (3800 rpm) with CNG and 5.4 kW (4000 rpm) with LPG respectively. This appears to be the most powerful spark ignition engine for 3-wheelers so far in the Indian market.

Table 6: Specifications of 3-Wheelers Produced by Piaggio *(Piaggio 2011)*

Description	Diesel	CNG	LPG	Cargo BSII	Cargo BSIII
Fuel Control	Direct Injection	Regulators	Regulators	Direct Injection	Direct Injection
Engine Type	Single cylinder, 4-stroke, diesel	Single cylinder forced air cooled with oil cooler	Single cylinder forced air cooled with oil cooler	Single cylinder, 4-stroke, diesel	Single cylinder, 4-stroke, diesel
Displacement, cc	395	395	395	395	436
Compression Ratio	8.5:1	8.5:1	8.5:1	18.1:1	19;1
Max Power, kW @ rpm	6.0 @3600rpm	5.65 @3200rpm	6.75 @3200rpm	5.55 @3600rpm	5.52@ 3600rpm
Max Torque, Nm @ rpm	-	18.78 Nm @2000 rpm	23.39 Nm @2000 rpm	-	18Nm @2400 rpm
Fuel consumption, km/l	36 ± 4	-	-	-	36 ± 4

2.2.10 RANGES OF PRICES OF 3-WHEELERS

Typical on-road prices (inclusive of levies and taxes) of the vehicles in India vary from Rs 70,000/- for a 2-stroke gasoline engine version to over Rs1,00,000/- for one using a 4-stroke Natural Gas engine.

3. INDIAN EMISSION STANDARDS FOR TWO AND THREE-WHEELERS AND TECHNOLOGIES – PROGRESSION, CURRENT AND FUTURE

This section is divided into two parts. The first one deals with the existing Indian emission standards and the technology solutions being adopted to meet these standards. The second deals with the likely progression of emission standards over the next ten-year time frame – standards that will become applicable from the years 2015 and 2020 respectively - and the potential technologies to meet these standards. This part also includes an assessment of the government moves on progression of emission standards and our own proposals. The second section also addresses the status of the standards and test procedures under the Worldwide Harmonization of Technical Regulations undertaken by the UNECE and India's obligation to transpose the Global Technical Regulation No 2 (GTR2) into the Indian national standards.

3.1 PROGRESSION OF INDIAN EMISSION STANDARDS AND TECHNOLOGIES ADOPTED

The first set of mass emission standards for two and three-wheeled vehicles were introduced in the year 1991. These were based on the Indian Driving Cycle (IDC). As can be seen from Figure 20 and Figure 21, the limits prescribed were quite lax and could be met by most of the vehicles by suitable tuning up of the engine. However, the limits were significantly tightened up in the year 1996, which required optimization of basic design parameters of the engine. The year 2000 saw a further major tightening up and requirement of the use of catalysts, particularly for the 2-stroke engines. This stage also led to the introduction of several 4-stroke engine powered vehicles. The year 2005 emission standards enforced very stringent limits that required major efforts by way of improvement and optimization of the basic engine as well as the after-treatment systems.

3.2 CURRENT INDIAN EMISSION STANDARDS AND TECHNOLOGIES ADOPTED

The emission standards that are currently prevalent have been effective from April1, 2010. Table 7 summarizes the emission standards effective from the year 2005 and the prevailing ones implemented from April1, 2010. It is seen that the current limits represent a 33% reduction for both CO and HC+NOx over the previous standards. If the Deterioration Factor (DF) is taken into account, the actual limits to be complied with at the time of Type Approval would be 0.83 g/km for both CO and HC+NOx. In case of three-wheelers, the limit values for CO and HC+NOx are 25 per cent higher than those for two-wheelers. The approach of fixing higher emission limits for three-wheelers is based on the premise that three-wheelers are essentially derivatives of two-wheelers and, due to their construction and transmission systems, tend to face more severe operation when driven through the driving cycle. This practice is also used in the EU. However, in case of diesel-powered vehicles, the emission limit values are common to two and three-wheelers, are lower than those for spark ignition engine vehicles (though there are limits specified for diesel two-wheelers, such two-wheelers are rather rare) and also include limit values for PM emissions.

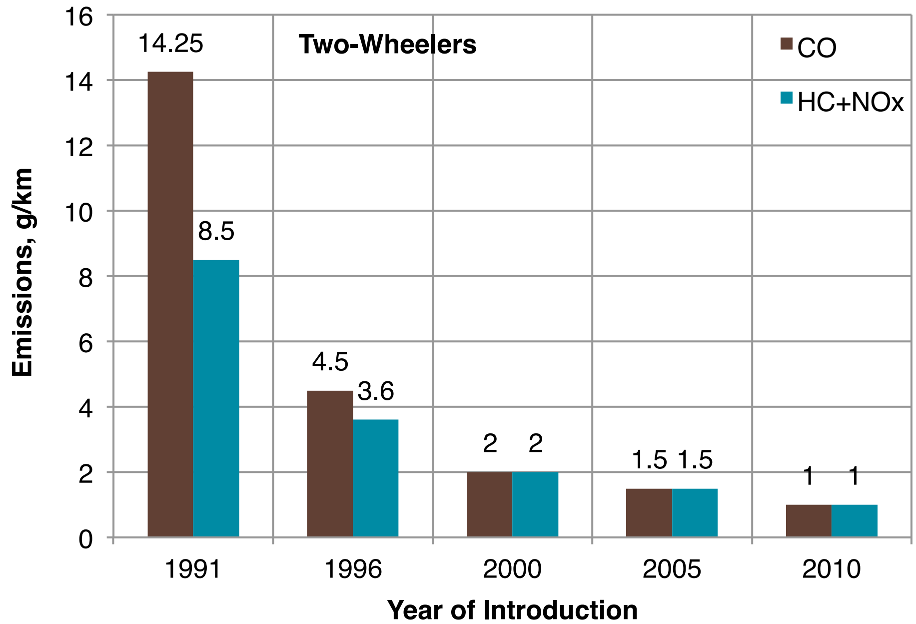


Figure 20. Progression of Indian Mass Emission Standards for 2-Wheelers

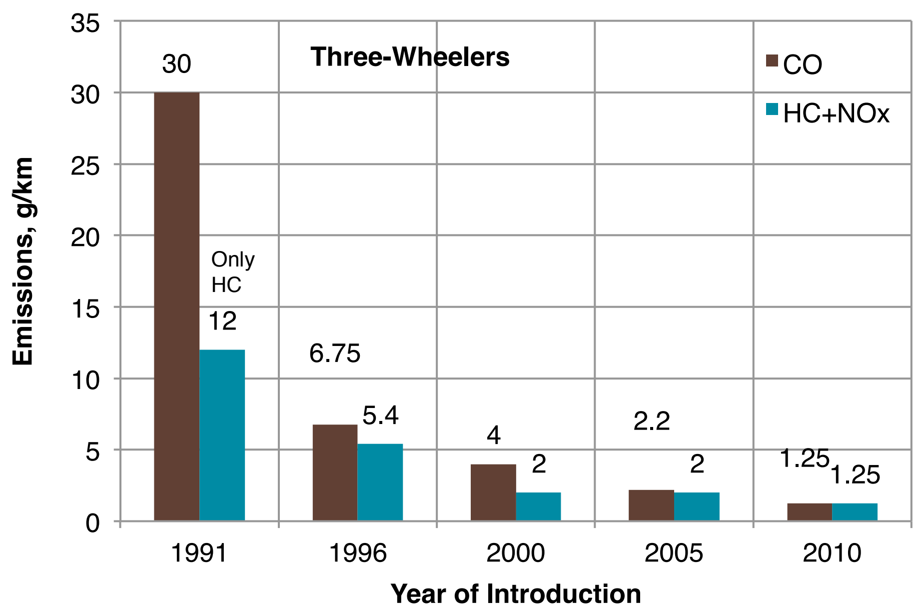


Figure 21. Progression of Indian Mass Emission Standards for 3-Wheelers (only Spark Ignition Engines)

Table 7: Currently Prevailing Indian Emission Standards for 2 and 3-wheelers

2 or 4 Stroke	2 or 3 Wheeler		Emissions Standards, g/km			Drive Cycle	Durability	
SI or CI		Stage	CO	HC+NOx	PM		km	DF
2&4	2	2005	1.50	1.50	-	IDC	30000	1.2
2&4	2	2010	1.00	1.00	-	IDC	30000	1.2
2&4 SI	3	2005	2.25	2.00	-	IDC	30000	1.2
2&4 SI	3	2010	1.25	1.25	-	IDC	30000	1.2
2&4 CI	2&3	2005	1.00	0.85	0.10	IDC	30000	1.1
2&4 CI	2&3	2010	0.50	0.50	0.05	IDC	30000	1.1

The main technology solutions adopted by the vehicle manufacturers to meet these emission standards included substitution of 2-stroke engines with 4-stroke engines. Other solutions for both 2-stroke and 4-stroke powered vehicles, included design improvements, optimizing the air-fuel ratio and ignition timing and use of after-treatment devices, mostly oxidation catalytic converters. In case of compression ignition engines the primary approach consisted of optimization of injection parameters and recalibration. These are described in some more detail in the following sections. Also described are some innovative solutions adopted by certain manufacturers based on the patents obtained by them.

3.2.1 SUBSTITUTE TWO-STROKE ENGINE WITH FOUR-STROKE ENGINES

Two-Wheelers: The shift from 2-stroke to 4-stroke had begun around the year 2000 along with the introduction of new emission limit values. This process gained further momentum in the years 2005 and 2010**.** The shift is attributed not only to the need to meet the emission standards but also to changing market preferences – from predominantly two-stroke-powered metal-bodied scooters to fuel efficient four-stroke motorcycles. As a result, the two-stroke engines have all but been eliminated from the Indian market. A small number of two-stroke engines are still used in a few models of mopeds and scooterettes. All other vehicles – scooters and motorcycles of all capacities are powered by single cylinder 4-stroke engines. With reference to the data on domestic sales of various categories of vehicles, it will be seen that the relative share of 2-stroke engines is around 6% of the total powered two-wheelers sales in the country.

Three-Wheelers: At the time, around 1999 to 2001, when the shift from 2-stroke to 4-stroke on two-wheelers was already going on, Bajaj Auto was still the largest manufacturer of petrol operated ‘auto-rickshaws’ using the 2-stroke petrol engine. However, on the lines of the two-wheelers, Bajaj developed a 4-stroke engine for its three-wheelers also and launched an ambitious programme to stop production of the two-stroke engine. Unfortunately, the four-stroke ‘auto-rickshaw’ did not receive a favourable response from the market. Bajaj, therefore, had to restart the production of the popular “RE 2-stroke” (Rear Engine) auto-rickshaw. The reasons for the poor market acceptance of the 4-stroke engine auto-rickshaw were attributed to differences between the profiles of two-wheeler and three-wheeler customers. While the former is a private user of the vehicle, the latter buys the vehicle to earn a living from the vehicle. He would take the risk of investing in a new type of vehicle, with which he is not familiar, and at a higher price too, only if he is assured of a net benefit.

Even though converting a motorcycle or a scooter to 4-stroke brought clear benefits in terms of fuel economy, the 4-stroke three-wheeler did not show the same level of benefit. It is also possible that the customer expectations were set rather too high based on the large difference in fuel efficiency of 2-stroke motorcycle and 4-stroke motorcycle. Even though the basic engine was as fuel efficient as that used on two-wheelers, the final mileage in terms of km/l was not attractive enough. The mileage of the 2-stroke three-wheeler, for example, was reported to be 27 to 29 km/l in actual city running conditions *(GTZ 2009*). The four-stroke was expected to give a mileage of 30 to 31 km/l. While this amounts to an average improvement of around 10% in fuel efficiency, the lower and upper limits of the difference could be as low as 3% and as high as 15%. Some differences also come up due the driving practices, the traffic condition etc. Another factor that was unfavourable to the 4-stroke three-wheeler is related to the cost and complexity of maintenance. The 2-stroke engine is simple in construction with fewer moving parts that wear out and need to be repaired or replaced. The 4-stroke engine, on the other hand, has many more parts and hence is more expensive to maintain. This experience led Bajaj to continue with the 2-stroke engines as the main engine for its auto-rickshaws though 4-stroke engines continued to get accepted in a few markets.

It must be pointed out that Bajaj had, during the same period, started developing the CNG versions for which it used the 4-stroke auto-rickshaw platform. The new auto-rickshaws that were used to replace the pre-1991 ones in Delhi as per the Supreme Court order had 4-stroke CNG engines. Also, the CNG auto-rickshaws that were supplied in Mumbai and Surat were also based on 4-stroke engines.

3.2.2 REDUCING ENGINE-OUT EMISSIONS – TWO AND THREE-WHEELERS

Even though the use of after-treatment systems is now quite prevalent, the first effort of the engine designer is to bring down engine-out emissions through various design improvements and performance optimization techniques. These include improvements in the carburettor to achieve a better control of the air-fuel ratios, optimizing ignition timings to get the best performance at different operating regimes of the engine. Most of the details of the actual improvements carried out remain proprietary to the respective manufacturers. One of the generic types of improvement is the use of leaner air-fuel mixtures, which is described below.

3.2.3 SOLUTIONS FOR 2-STROKE ENGINES

One of the important technical solutions for 2-stroke engines was the use of lean air-fuel mixtures, along with other improvements in order to reduce the emission of HC and CO. These engines have inherently very low NOx emissions. Since the 2-stroke engines used on two-wheeler scooters and three-wheeler auto-rickshaws are similar in their designs, the design improvement approaches for the two 2-stroke engines were quite similar. These efforts included re-designed ports and exhaust system improvements to achieve more effective scavenging and reduced mixture short-circuiting, improved carburetion, higher compression ratios, electronic ignition, combustion chamber re-design and spark-plug re-location to reduce knocking on account of the higher compression ratios, and piston re-design to minimize crevice volumes and friction losses, etc *(Kojima 2000).* The above mentioned approach was primarily aimed at reducing the 'engine out' emissions which was the only way to meet the 1996 emission standards due to the non-availability of unleaded petrol which precluded the use of catalytic after-treatment. Since these approaches constitute the basics of engine design and performance optimization, they continue to be explored to meet the more stringent emission standards thereby minimizing the use of after-treatment systems.

3.2.4 LEAN AIR-FUEL MIXTURES FOR 4-STROKE ENGINES

As a result of a demand for good fuel efficiency even at the cost of performance from the customers, manufacturers have been tuning their engines for lean air-fuel mixtures, which, in addition to improving the fuel efficiency, lead to a desirable reduction in the emission of Carbon Monoxide (CO) and Unburned Hydrocarbon (HC). The adverse impact of using lean air-fuel mixture ratios is that it leads to an increase in the emission of Oxides of Nitrogen (NOx). So far, this has not been a matter of great concern to the Indian manufacturers since the Indian emission standards for two-wheelers prescribe a composite limit for HC+NOx in addition to a limit for CO. Since the HC emissions of 4-stroke engines are inherently lower than those of 2-stroke engines, they are able to meet the composite HC+NOx limit even if the NOx emission is on the higher side. Wherever required, oxidation catalytic converter was used to control CO and HC emissions.

3.2.5 NOVEL PATENTED SOLUTIONS FOR FOUR-STROKE ENGINES

(a) Digital Twin Spark Ignition System (the DTSi system)

This is a patented development of Bajaj Auto Ltd and is described in the Indian Patent Number IN195904, "Internal Combustion Engine with Improved Combustion Characteristics" *(Bajaj Patent (1)2002)*. The system basically consists of the use of a second spark plug in the combustion chamber of a 4-stroke engine that could lead to a more efficient burning of lean air-fuel mixtures. The use of two spark plugs is not new to the automotive technology *(Pundir 2010*). The patent is granted on the basis of a claim pertaining to the method of fixing two spark plugs diametrically opposite to each other in the combustion chamber of small engines of cylinder bore between 45 mm to 70 mm with two valves. It is claimed that, with this arrangement the combustion is completed in a comparatively shorter duration of time leading to reduction in emission and improved fuel consumption while maintaining the predetermined level of performance. This reduced time of achieving near complete combustion permits use of less amount of fuel air mixture or lean mixture without affecting the performance, especially at part throttle condition.

Bajaj Auto has been using this technology on several of their models with name "DTSi" system that seems to have been well accepted in the market. It appears from the claim made in the patent application that the system does make it possible to use lean air-fuel mixtures more efficiently. This can be seen from the results shown in Table 8.

Table 8: Performance Improvements Achieved with the Twin Spark Plug system *(Bajaj Patent (1) 2002)*.

Parameter	Units	Single Spark Plug	Twin Spark Plug	Per Cent Improvement
CO Emission	g/km	1	0.6	40% reduction
HC Emission	g/km	0.7	0.5	28% reduction
NOx Emission	g/km	0.5	0.5	No change
Fuel Consumption	Km/l	55	62	12.8% reduction
Maximum Power	PS	11.7	12.5	6.8% increase

It is seen that significant reduction in CO and HC emissions – 40% and 28% respectively – have been achieved by the use of the DTSi technique. A commensurate decrease in fuel consumption of 12.8% has been claimed. However, the emission of NOx remains unaffected.

The 'DTSi' technology is used in 'Discover 150 cc', the 'Pulsar 150', 'Pulsar180' and 'Pulsar 220 cc' models and the 'Avenger 220 cc' models. While it is not possible for other manufacturers to use this patented technology, the invention does go to show that scope for improving the performance of the basic engine to reduce 'engine out' emissions and improve fuel economy through various innovative techniques does exist.

(b) Automatic Ignition Advance with Respect to Speed and Load

This is another patented development of Bajaj Auto that is described in the Indian Patent No IN208578 "An Improved Ignition System for 2 or 3 Wheeled Vehicles" *(Bajaj Patent (2) 2003)*. The patent has been granted for an improved ignition system for 2- or 3-wheeled vehicles that makes use of a magnetic throttle position sensor to sense the load of the engine. The engine speed is sensed via the magnetic pulsar coil, which sends signals to the spark plug thus varying the ignition timing to optimum levels as per speed and load of the engine.

3.2.6 DESIGN AND OPTIMIZATION OF ENGINE PERFORMANCE

A search of Indian patents did not reveal any other patents granted for technical solutions similar to the two patents described above. While Bajaj Auto has obtained a patent for the above system, in the absence of any information in the public domain, it is not known whether other manufacturers employ similar optimization techniques on their models. However, it is not possible to deny the fact that other manufacturers, especially those with strong research and development capabilities of their overseas parent companies, might be making use of systems that achieve the same objective. It is, however, certain that all manufacturers employ various design improvement and optimization techniques, whether patentable or not, to meet the emission standards and provide a good fuel economy to satisfy the customer demand.

3.2.7 OXIDATION TYPE CATALYTIC CONVERTERS

Improvements in engine design and optimization of performance characteristics of 2-stroke engines were not sufficient to reduce the CO and HC+NOx emission to meet with the limits enforced from the year 2000. This necessitated the use of oxidation catalytic converters to bring about further reduction in CO and HC emissions. These engines, both for two and three-wheelers, continued to use simple carburettors that did not enable an accurate control of the air-fuel ratio required for efficient operation of the catalytic converter. As such, these catalytic converters operated at an estimated conversion efficiency of around 50% on an average *(Palke 1999)*.

Some of the four-stroke engines, in spite of the use of lean air-fuel ratios, required the use of oxidation catalytic converters to meet the year 2000 and the year 2005 emission standards. Three-Way Catalytic Converters (TWC) have not come into use so far on Indian 2-wheeled vehicles, partly since they have not been found necessary, and partly because they require an accurate control on air-fuel ratios, which can be achieved only with an electronic fuel injection or an electronic carburettor along with a closed loop system using an oxygen sensor as in passenger cars.

3.2.8 SECONDARY AIR INJECTION

Introduction of controlled quantities of secondary air in the exhaust helps to increase the supply of oxygen in the exhaust stream thereby helping to reduce the emissions of CO and HC *(Palke 1999)*. Experimental results on a 125 cc 4-stroke two-wheeler engine presented by Sud-Chemie in Table 9 show that CO as well as HC+NOx emissions reduced significantly *(Sud-Chemie 2008)*.

Table 9: Effect of Secondary Air Injection on Emissions of a 4-Stroke Engine (*Sud-Chemi, 2008*)

Condition	CO, g/km	HC+NOx, g/km
Without after-treatment	1.97	0.53
With oxidation catalytic converter,	1.47	0.42
With oxidation catalytic converter and secondary air injection	0.213	0.23

However, the use of Secondary Air Injection (SAI) is not very prevalent in Indian two-wheelers on account of the fact that most of these engines, as said before, use lean air-fuel ratios, which provides the extra oxygen in the exhaust stream.

3.2.9 TECHNOLOGIES FOR THREE-WHEELERS USING COMPRESSION IGNITION ENGINES

The basic approach to meet the emission standards for diesel-powered three-wheelers has been one of optimization of injection parameters and tuning and finer calibration of the engine.

Except for the Bajaj three-wheeler, which uses the Kubota indirect injection engine with a patented three-vortex combustion chamber, the other models use direct injection engines that are more amenable to control of emissions. None of the diesel engine models use automatic fuel injection timing control, catalytic converters or exhaust gas recirculation (EGR).

3.3 FURTHER PROGRESSION OF INDIAN EMISSION STANDARDS

The Indian regulations related to safety and emissions of motor vehicles draw heavily upon the concerned EU Directives. For instance, the emission standards for four-wheeled vehicles have been following more or less fully the corresponding EU Directives, except for a few changes to suit the unique Indian conditions and a time lag.

However, the emission standards for two and three-wheelers have been following an independent progression. The reason for this is the fact that the EU regulations for two and three-wheelers were very lax when the Indian emission standards were getting formulated. This refers to the period of 1996-2000. The driving cycle and the emission limit values for two and three-wheelers continued to be unique from the early stages until the present time. In this context, proposal like those of the EU for the "L" category of vehicles *(EU 2010)* are unlikely to be adopted in India. In fact, the progression of emission standards is likely to be influenced by local needs to improve ambient air quality, which would likely be conductive to adopting the UNECE Global Technical regulations for 2- and 3-wheelerls. Indeed, as shown later, India is obliged to transpose the GTR into its own regulations within a reasonable time frame.

3.3.1 INFLUENCE OF UNECE GLOBAL TECHNICAL REGULATION ON PROGRESSION OF EMISSION STANDARDS

Under the "1998 Agreement" concerning the establishing of "Global Technical Regulations (GTR) for Wheeled Vehicles", the Contracting Parties of the UNECE (United Nations Economic Commission for Europe) have established the Global Technical Regulation No2 (GTR2) pertaining to the emission of gaseous pollutants and fuel consumption and the related measurement procedures for two-wheeled motorcycles *(UNECE 2005).* The GTR2 has two main components, one related to the measurement procedures and the other related to emission limit values. In order to represent the world-wide on-road motorcycle operation a new drive cycle, referred to as the "World Harmonized Motorcycle Test Cycle (WMTC), has been developed along with detailed test procedures for measurement of emissions. In a subsequent development, emission limit values for two-wheeled vehicles to be adopted by the member countries have been given. These aspects have been described in some more detail in the following sections. Since India is a member of the United Nations and is a signatory to the "1998 Agreement", it is obliged to adopt the GTR2 into its own regulations. In view of its importance in the future Indian emission regulations for two-wheeled vehicles, the following sections provide some more details of the GTR2.

3.3.1.1 WORLD HARMONIZED MOTORCYCLE TEST CYCLE (WMTC)

With a view to ensure that the test procedure is representative of worldwide on-road vehicle operation, the development of the WMTC took note of the then prevailing ECE regulation, the EU directives, the Japanese regulations and the US regulations for two-wheelers. As pointed out by India, the worldwide drive cycle proposed did not take into account the Indian Driving Cycle (IDC) and did not reflect the drive pattern prevailing in India. As a result, and considering the large size of the Indian 2-wheeler market, it was decided to prepare a new proposal based on data on Indian traffic patterns to be provided by India and an analysis by a group of experts from TUV (Germany), JASIC (Japan) and IMMA (*UNECE 2008*). Based on the analysis of the Indian data, it was decided to carry out certain modifications to the original proposal to overcome the problems of cycle traceability faced by some of the Indian vehicles, The details of the finally adopted cycles are given in Annex I.

3.3.1.2 NEW CLASSIFICATION OF TWO-WHEELERS AS PER GTR 2

In order to take into account the extremely diverse driving patterns and vehicle designs throughout the world, the GTR2 classifies the motorcycles into three main classes, which are further divided into sub-classes. The main features of the classifications are described in Table 10. The classifications are based on engine displacement (cm^3) and maximum speed (V_{max}) of the vehicle. For an easy understanding, the vehicle classifications are shown in a diagrammatic form in Figure 22.

Table 10: Classification of Motorcycles in GTR2

Class	Sub-class	Description	Driving Cycle
Class 1	-	50 cm^3<engine capacity <150 cm^3 and v_{max} <50 km/h or Engine capacity <150 cm^3 and 50 km/h v_{max} <100 km/h	Part 1, reduced speed in cold condition, followed by part 1 reduced speed in hot condition.
Class 2	Sub-class 2-1	Engine capacity < 150 cm^3 and 100 km/h ≤ v_{max} < 115 km/h or Engine capacity ≥150 cm^3 and v_{max} < 115 km/h	Part1 in cold condition, followed by part 2, reduced speed, in hot condition
	Sub-class 2-2	115 km/h ≤ v_{max} < 130 km/h	Part 1 in cold condition, followed by part 2 in hot condition
Class 3	Sub-class 3-1	130 ≤ v_{max} < 140 km/h	Part1 in cold condition, followed by part 2 in hot condition, followed by part 3 , reduced speed in hot condition
	Sub-class 3-2	V_{max} ≥ 140 km/h	Part1 in cold condition, followed by part 2 in hot condition, followed by part 3 , in hot condition

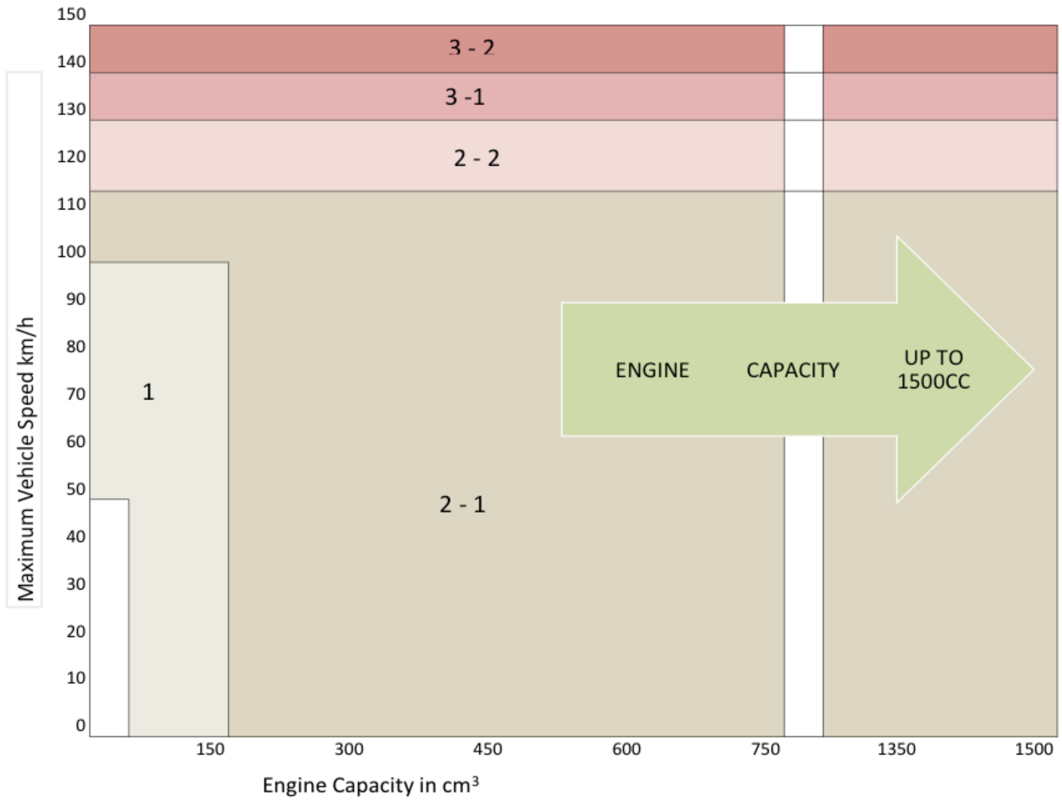


Figure 22. Diagrammatic Representation of Vehicle Classes Given in GTR2

3.3.1.3 NEW DRIVING CYCLES AND WEIGHTING FACTORS FOR TWO-WHEELERS AS PER GTR 2

The "World Motorcycle Test Cycle (WMTC)" itself consists of three parts, each with two variants – one normal and the other with reduced speed (Refer to Annex I). It also specifies whether the test has to be done with cold start or hot start. The details of the parts of the test cycles to be followed for testing vehicles falling into each of the sub-classes are also given in Table 10 The GTR2 specifies the weighting factors to be used to determine the final emission and fuel consumption values.

3.3.1.4 EMISSION LIMIT VALUES IN GTR 2

An important development that will influence the progression of emission standards is India's obligation to transpose the test cycles, procedures and emission limit values finalized by the UNECE under the GTR2. India has been actively participating, as a 'Contracting Party', in the deliberations of the World Forum for Harmonization of Vehicle Regulations, Working Party on Pollution and Energy (GRPE), which led to the development of GTR2 *(UNECE 2005).* Contracting Parties of the UNECE 1998 agreement are required to transpose the GTR2 into their own country's regulations (See BOX 2).

India also participated in the test programme to develop correlations that led to the finalization of proposals for limits to be transposed by the member countries into their own regulations. Based on India's submission and correlation results, the 'Informal Group on WMTC' in its report *(UNECE 2008)* has noted that "a difference in national / regional legislation exists concerning NOx and HC. In some cases the limits are separated, sometimes combined. "The reason for separated limits may be a focus on NOx controlling countries like India, focusing more on fuel consumption and CO_2 emissions prefer a combined limit value. USA also follows a combined HC+NOx" *(UNECE 2008)*. The draft text of Amendment 2 to GTR2 on the introduction of performance requirements was approved by GRPE in January 2011*(UNECE 2011(1))*. Based on the submissions by various countries the Working Party on Pollution and Energy (GRPE) approved of a set of limits for pollutant emissions called the "principal limits." These are given in Table 11. It is stated in the GTR2 document (*UNECE 2011(2))* that the limit values set out in Table 11 represent the most stringent national or regional emission limits applied by a Contracting Party at the time of adoption of the last amendments to this GTR. It is the intent that the GTR would be amended to update these limit values at such time that new more stringent standards are adopted through national or regional legislation, in order to represent those new limit values.

Table 11: Principal Emission Limit Values for 2-Wheelers Approved by GRPE

Vehicle class	**CO** Class1 and Class2	**CO** Class3	**HC** Class1 and Class2	**HC** Class3	**NOx** Class1 and Class2	**NOx** Class3
Limit values, L_A in mg/km	2200	2620	450	270	160	220

The GRPE also approved of three alternative emission limits of stringency proposed by the Contracting Parties. It is observed that there can be several reasons for the introduction of alternative emission limit values. Some of these are

- Different environmental priorities for different gaseous pollutants, CO_2 and energy/fuel conservation, or cost-benefit situation;
- Diverse traffic situation or special vehicles (performance, classification);
- Separated or combined limits for HC and NOx;
- Different reference fuels because of the market fuel situation.

BOX 2. OBLIGATION OF A CONTRACTING PARTY REGARDING ADOPTION OF GTRs INTO ITS OWN COUNTRY'S REGULATIONS (EXCERPTED FROM ECE/TRANS/132 dated 25 June, 1998)
http://www.unece.org/trans/main/wp29/wp29wgs/wp29gen/wp29glob.html

ARTICLE 7

ADOPTION, AND NOTIFICATION OF APPLICATION,

OF ESTABLISHED GLOBAL TECHNICAL REGULATIONS

7.1. A Contracting Party that votes in favour of establishing a global technical regulation under Article 6 of this Agreement shall be obligated to submit the technical Regulation to the process used by that Contracting Party to adopt such a technical Regulation into its own laws or regulations and shall seek to make a final decision expeditiously.

7.2. A Contracting Party that adopts an established global technical regulation into its own laws or regulations shall notify the Secretary-General in writing of the date on which it will begin applying that regulation. The notification shall be provided within 60 days after its decision to adopt the Regulation. If the established global technical regulation contains more than one level of stringency or performance, the notification shall specify which of those levels of stringency or performance is selected by the Contracting Party.

7.3. A Contracting Party that is specified in paragraph 7.1. of this Article and that decides not to adopt the established global technical regulation into its own laws or regulations, shall notify the Secretary-General in writing of its decision and the basis for its decision. The notification shall be provided within sixty (60) days after its decision.

7.4. A Contracting Party that is specified in paragraph 7.1. of this Article and that has not, by the end of the one-year period after the date of the establishment of the Regulation in the Global Registry, either adopted that technical regulation or decided not to adopt the Regulation into its own laws or regulations, shall provide a report on the status of the Regulation in its domestic process. A status report shall be submitted for each subsequent one-year period if neither of those actions has been taken by the end of that period.

Since the 'Principal Emission Limit Values' represent the most stringent limits currently applied in national or regional legislation with the test procedures set out in the GTR2, vehicles complying with the principal emission limits are deemed to comply with the alternative requirements. Contracting Parties may opt to accept motorcycles complying with one or more of these alternative performance requirements in addition to the motorcycles complying with principal requirements. These emission limit values are given in Table 12.

Table 12: Alternative Emission Limit Values for 2-Wheelers Approved by GRPE

Alternative performance requirement A					
	CO	CO	HC+NOx	HC+NOx	HC+NOx
Vehicle class	Class1 and Class 2.1	Class 2.2 and Class 3	Class1 and Class 2.1	Class 2.2	Class 3
Limit values, L_A in mg/km	1870	2620	1080	920	550
Alternative performance requirement B					
	CO	HC	HC+NOx		
Vehicle class	All	Class1 and Class 2	Class 3		
Limit values, L_A in mg/km	12000	1000	800		
Alternative performance requirement C					
	CO	HC	HC	NOx	NOx
Vehicle class	All	Class1 and 2	Class 3	Class1 and 2	Class 3
Limit values, L_A in mg/km	2620	750	330	170	220

The GRPE report states, "When a Contracting Party transposes this global technical regulation in a manner that includes any of the specified alternative performance requirements, the national or regional legislation should ensure that a motorcycle that complies with the Principal Performance requirements in this GTR2 will satisfy the national or regional legislation. This will give some planning reliability for manufacturers. Compliance with the principal or alternative performance requirements, as opted for by the Contracting Party, will be determined by the national or regional certification or type approval authority".

3.3.1.5 TRANSPOSING THE GTR2 LIMITS AND TEST PROCEDURES INTO INDIAN REGULATIONS

The "Alternative Performance Requirements A" given in Table 12 were proposed by India based on their own requirements and results of tests on motorcycles falling into Class 1 and Class 2.1 of GTR2. Composite HC+NOx limits were proposed as the Indian vehicles are tuned for better fuel consumption. Tighter NOx limits would lead to higher fuel consumption resulting from a need to shift to richer than currently used air-fuel ratios for efficient functioning of three-way catalytic converters. Class 2.2 and Class 3 motorcycles are basically performance vehicles and hence the WMTC norms were acceptable to India (except clubbing HC & NOx together).

3.3.1.6 DRAFT INDIAN REGULATIONS REGARDING GTR2

With a view to transpose the relevant parts of GTR2 into its own legislative requirements, the Ministry of Road Transport and Highways (MoRTH), Government of India, has issued a draft notification *(MoRTH 2010).* This draft gives a set of emission limit values for different classes of two-wheelers as per the "Alternative A" of GTR 2 (Table 12). The vehicle classifications and test procedures are also as per the GTR2.

The draft rules are open to the public for a period of sixty days from the date of its publication for raising their objections or making any comments. [3] It has been the experience that it takes much longer than the sixty days period before the final notification, with modification if required, is published. The relevant contents of the draft notification are summarized in Table 13.

3.3.1.7 GTR2 DOES NOT COVER DURABILITY REQUIREMENTS

GTR2 has not addressed the issue of 'Durability Requirements' and/or useful life provisions as these are considered to be "outside the scope of this GTR 2". Accordingly, the GTR says that "Contracting Parties may specify durability requirements and/or useful life provisions in their national or regional legislation in relation to the emission limits set out in the GTR2.

Table 13: Emission Limit Values as per GTR2 notified as a draft

Category	2 or 4 stroke SI or CI	2W/3W	Stage	Emissions Standards (g/km) CO	HC+NOx	PM	Drive cycle	Durability
Class 1+2.1	2&4(SI)	2	2011	1.87*	1.08*	none	WMTC	*DF included
Class 2.2	2&4(SI)	2	2011	2.62*	0.92*		WMTC	*DF included
Class 3.1	2&4(SI)	2	2011	2.62*	0.55*		WMTC	*DF included
Class 3.2	2&4(SI)	2	2011	2.62*	0.55*		WMTC	*DF included

Vehicle classification used by the Ministry of Road Transport and Highways in its Notification No GSR 103E dated 31st December 2010:

Category	Engine capacity	Speed range
Class1	50< cc <150	V_{max} < 50 km/h Or
	>150	50 < V_{max}< 100 km/h
Class 2.1	cc <150	100 < V_{max} < 115 Or
	cc >150	V_{max} < 115 km/h
Class 2.2	any	115 < V_{max} < 130 km/h
Class 3.1	any	130 < V_{max} < 140 km/h
Class 3.2	any	V_{max} > 140 km/h

3.3.1.8 EXPECTATIONS OF GTR2 FOR PROGRESSION OF EMISSION STANDARDS

As mentioned before, the requirements of different regions of the world have been taken into account in the GTR. In addition to a few major regions of the world, special consideration has been given to India by GRPE considering that "India is one of the biggest markets for motorized two wheelers in the world" *(UNECE 2007).* However, considering that India will continue to participate in the UNECE proceedings in the coming years too, it will necessarily have to move towards more stringent emission standards. Observations of the GRPE in this regard are given in BOX 3 *(UNECE 2011)*

[3] Even though the sixty day period is long over, as of now (December 2011), there is no indication from any authoritative sources regarding the finalization and formal introduction of the GTR2 as an alternative.

BOX 3. OBSERVATIONS OF GRPE REGARDING NEED TO INTRODUCE MORE STRINGENT STANDARDS

It is the intent that GTR2 would be amended to update the Principal Emission limits at such time when new more stringent limits are adopted through national or regional legislation. It may also become necessary to amend the alternative emission limits due to such developments in countries opting for alternatives. It is also expected that different Contracting Parties will start applying principal emission limits at different dates considering the lead time required for implementing stricter norms. It may also become necessary to induct the earlier Principal Emission limit as one of the alternatives.

3.3.2 CURRENT INDIAN SITUATION REGARDING PROGRESSION OF EMISSION STANDARDS

The prevalent emission limit values (Bharat Stage III) got enforced a little over a year ago (April1, 2010). The draft notification transposing the GTR2 has been done only a year ago (31st December 2010). According to ARAI, which plays a leading role in the formulation of emission standards, discussions on this issue have not yet started *(Marathe 2011).* Going by the past experience of the process of formulating and notifying emission and other regulations in India, it may be a few years before this process is initiated.

3.3.3 VIEWS OF VEHICLE MANUFACTURERS ON EMISSION STANDARDS PROGRESSION

According to a feedback received from the Society of Indian Automobile Manufacturers SIAM *(Gandhi 2011),* the next stage of emission regulation (BS IV) will be scheduled for introduction by the year 2015. As far as the industry is concerned, it would be ready at that stage to switch over to the GTR 2 regulation and the WMTC test procedure. Being an active member of IMMA (International Motorcycle Manufacturers Association) and also an active participant in the UNECE meetings, SIAM mentions that the manufacturers are aware of the global developments and expect the progression of Indian emission standards to be in line with the global trends. The manufacturers are having internal deliberations to formulate proposals for the limit values and hope to finalize them by end of this year. In addition, they have committed to the government to introduce evaporative emission controls from 2015. For the next stage of emission regulation (BS V) to be scheduled for introduction in the year 2020, they propose to review the position around 2017, taking into consideration new technologies available by that time.

Regarding the progression of emission standards for three-wheelers, SIAM feels that this category of vehicles does not have parallels in other countries and as such there are no references available for India to consider while planning for future norms. Besides, since WMTC does not cover three wheelers, it feels that a new test cycle may have to be developed. The manufacturers are having internal discussions to evolve an emissions road map for three-wheelers.

3.3.4. APPROACH TO ARRIVE AT FUTURE EMISSION STANDARDS PROPOSALS

In an ideal situation, the limit values of pollutant emissions from a particular category of vehicles are derived from an estimation of the contribution of that category of vehicles to the ambient air pollution and the reduction required for achieving acceptable air quality. This is followed by a detailed study of the possible technology options available to achieve the desired reduction in emissions. The final decisions are made based on the cost of adopting the known and potential control technologies and a cost-benefit analysis. Fixing emission standards for different categories of vehicles in India have, so far, not adopted such an approach. This is mostly due to the non-availability of reliable data related to ambient air quality, source apportionment and cost-benefit analysis.

There is also an absence of any specific indication from any authoritative sources regarding the likely future course of emission standards for two and three-wheelers. As a result, certain probable scenarios have been considered here which are based on an assumption that the GTR2 will be the underlying regulation for future emission standards for two and three-wheelers. Three different scenarios have been considered for arriving at a final proposal.

3.3.5 PROBABLE SCENARIOS REGARDING PROGRESSION OF EMISSION STANDARDS.

Scenario 1: The government may mandate the GTR2 standards and procedures from the year 2015 without any option to use the IDC. This is based on the views of the manufacturers mentioned previously. The implementation of this scenario will amount to practically no change from the present situation since the emission limits will be as per Alternative A (proposed and adopted as an alternative by India), which essentially represent an equivalence with GTR2 cycle of the present emission levels with the IDC. In the absence of any road map, either from the government authorities or from the industry for years beyond 2010 this scenario does not contain any proposals for years beyond 2015.

Scenario 2: The government, in addition to mandating the GTR2, may tighten the emission limit values from the year 2015. This is based on the views of certain other stakeholders. No specific limit values have been proposed assuming that, as per the present practice, these will be proposed by an Expert Committee and finalized in consultation with the vehicle manufacturers and other stakeholders. Going by the past experience, this is most likely to be the approach of the Indian authorities. It seems the industry is also working on its own proposals, which may be on the lines of this scenario. The industry has indicated that the durability norm of 30,000km will continue to apply even though, it has been taken care of by incorporating Deterioration Factors into the GTR2 emission limit values. The industry has also indicated that fuel with a maximum sulphur content of 150ppm will have to be made available throughout the country *(Singh 2011).*

Scenario 3: This scenario differs from Scenario 2 in that, it proposes specific emission limit values not only for the year 2015 but goes on to propose limit values for the year 2020 also on the lines of the proposals of the EU for ‘L’ category vehicles *(EU 2010)*, but taking into account the Indian situation with regard to the market demands for low cost and good fuel efficiency, the preferred vehicle models etc. This scenario is discussed in greater detail in the following sections.

3.3.5.1 SCENARIO 3: DEVELOPMENT OF EMISSION STANDARDS PROPOSALS AS PER GTR2 AND ON THE LINES OF EU PROPOSALS

In this scenario, it is assumed that the progression of emission standards would follow broadly the progression proposed by the EU. In order to develop the emission limits for this scenario, a comparison was first made of the classification of vehicles and the corresponding emission limit values given in the GTR2 and the classification finalized by the EU, which has several sub-classes within the overall classification of the former. While the Indian draft notification seems to have directly adopted the classification given in the GTR2, the EU sub-classification includes a wide variety of vehicles starting with a pedal assisted moped to a heavy-duty quadricycle with different provisions. The existing Indian emission regulations, on the other hand, are uniformly applicable to all two-wheeled vehicles though it seems to have incorporated the GTR2 classifications along with the 'Alternative A' emission limits. From the comparison, it seems that practically all the two-wheelers currently being manufactured and sold in India would fall into one class namely "L3e – Motorcycle". This is shown in Table 14 *(EU 2010).* The Motorcycle class L3e is further sub-divided into three sub-classes as shown in Table 15.

Table 14: Classification of L Category of Vehicles in the European Union

Category	Vehicle type	No of Wheels	Max speed (Km/h)	ICE Max capacity, (cc)	ICE Max Power (kW)	Electric Motor (kW)	Max Unit Mass (kg)	Status in India
L1e	Moped	2	45	50		4		DNE
L2e	Three-wheeled moped	3	45	50(SI)	4(other ICE)	4		DNE
L3e	Motorcycle	2	>45	>50				Most Common
L4e	Motor cycle with side car	2	>45	>50				Special case
L5e	Motor tricycle	3 symmetrical	>45	>50				DNE
L6e	Light Quadri cycle	4	45	50(SI)	4(other ICE)	4	350	DNE
L7e	Heavy Quadri cycle	4			15	15	400(Passengers) 550 (goods)	Under discussion

ICE: Internal Combustion Engine; cc: Cubic Capacity of Engine. DNE: Does Not Exist.
SI: Spark Ignition

Table15: Sub-classification of Motorcycles in the European Union

L3e-A1	**2-wheel motorcycle Low performance**	***Engine 50 < Vd < 125 cc *Vmax > 45 km/h *4 < Pmax. cont < 11 kW *power/weight <0.1 kW/kg**
L3e-A2	2-wheel motorcycle Medium performance	*Engine Vd > 50 cc *Vmax > 45 km/h *4< Pmax.cont ≤ 35 kW *power/weight ≤0.2 kW/kg
L3e-A3	2-wheel motorcycle High performance	Any other L3e category Motorcycle

A comparison has been made of the emission norms finalized by the EU for the motorcycle classes – from the present Euro 3 to the future Euro 5 - with the corresponding norms for Indian two-wheelers, which, as mentioned before, include possibly the entire range of two-wheeled vehicles in the market. These are shown in Table16.

Table16: Current and Future Emission Norms for Motorcycles in the EU and India

Propulsion Class	Indian Equivalent	Euro Level	Drive Cycle	Imp. Year	CO (g/km)	THC (g/km)	NOx (g/km)	HC+NOx (g/km)	DF
PI, Vmax <130 km/h	Most current 2wheelers	Euro 3	WMTC	2006	2.62	0.75	0.17	-	-
		Euro4	WMTC	2015	1.97	0.56	0.13	-	-
		Euro5	WMTC	2018	1.14	0.38	0.07	-	-
PI,Vmax ≥130 km/h	A few current 2Wheelers	Euro 3	WMTC	2006	2.62	0.33	0.22	-	-
		Euro4	WMTC	2015	1.97	0.25	0.17	-	-
		Euro5	WMTC	2018	1.14	0.17	0.09	-	-
Indian Norms	All 2-wheelers	BSIII	IDC	2010	1.0			1.0	1.2
		BSIII alt	WMTC	2011					
Class1	50< cc <150	V_{max} < 50 km/h Or			1.87			1.08	Include-ed in norm
	> 150 cc	50< V_{max} < 100 km/h			1.87			1.08	
Class 2.1	< 150 cc	100 < V_{max} < 115 Or			1.87			1.08	
	> 150 cc	V_{max} < 115 km/h			1.87			1.08	
Class 2.2	any	115 < V_{max} < 130 km/h			2.62			0.92	
Class 3.1	any	130 < V_{max} < 140 km/h			2.62			0.55	
Class 3.2	any	V_{max} > 140 km/h			2.62			0.55	

To create the scenario for a possible progression of Indian emission norms comparable to that in the EU, it was decided to follow the same per cent reduction of limit values for each pollutant from one stage to the next as adopted in the EU progression. It is found that the Euro limit for Euro 4 for all pollutants, namely CO, HC and NOx are approximately 25 per cent lower than the limits of Euro 3. Similarly, the reduction from Euro 4 to Euro 5 varies from 32 to 47 per cent depending upon the pollutant and the class of the vehicle. The details can be seen in Table 17.

Table 17: Progressive Per Cent Reduction of Emissions Limits in EU

Euro Level	Propulsion Class	Year	CO		THC		NOx		HC+NOx	
			g/km	(%) reduction*	g/km	(%) reduction	g/km	(%) reduction	g/km	(%) reduction
Euro 3	PI, V_{max} < 130 km/h	2006	2.62	0	0.75	0	0.17	0	0.92	0
Euro 4		2015	1.97	25	0.56	25	0.13	24	0.69	25
Euro 5		2018	1.14	42	0.38	32	0.07	46	0.45	35
Euro 3	PI, V_{max} ≥ 130 km/h	2006	2.62	0	0.33	0	0.22	0	0.55	0
Euro 4		2015	1.97	25	0.25	24	0.17	23	0.42	24
Euro 5		2018	1.14	42	0.17	32	0.09	47	0.26	38

Drive Cycle WMTC in all cases. * Per cent reduction over previous limit

3.3.5.2 PROPOSED POLLUTANT EMISSION LIMIT VALUES FOR TWO-WHEELERS (SCENARIO 3)

Based on the above observations a progression of emission limits for India was visualized. For CO, a 25% reduction was assumed from BS III to BS IV, as is the case in the EU progression. For the next stage from BS IV to BS V, a CO reduction of 40% was assumed. Similarly, for HC+NOx, a 25% reduction from BS III to BS IV and, a 35% reduction from BSIV to BS V were assumed. It may be noted that the composite limit for HC+NOx has been retained as done in the GTR 2 due to the emphasis in India on fuel efficiency. As is customary in India, a period of five years has been proposed between consecutive levels to give enough time to the manufacturers to gear up with new technology developments that may be required. Based on the above, the progression of new Indian emission limits could thus be as shown in Table 18. An important aspect of this proposal is that the emission limit values will be entirely based on the WMTC cycle, vehicle classifications and test procedures and that the IDC will no longer be used.

Table 18: Suggested Emission Limits Progression in India- 2-Wheelers

Vehicle Class	Engine Capacity Range	Max speed ranges	CO, g/km			HC+NOx, g/km		
			2010 (BSIII) Existing	2015 (BS IV) Proposed	2020 (BSV) Proposed	2010 (BSIII) Existing	2015 (BS IV) Proposed	2020 (BSV) Proposed
Class 1	50 < cc <150	V_{max} < 50km/h	1.87	1.40	0.84	1.08	0.81	0.53
	> 150 cc	50 < V_{max}<100 km/h	1.87	1.40	0.84	1.08	0.81	0.53
Class 2.1	< 150 cc	100 < V_{max} < 115	1.87	1.40	0.84	1.08	0.81	0.53
	> 150 cc	V_{max}<115 km/h	1.87	1.40	0.84	1.08	0.81	0.53
Class 2.2	any	115 <V_{max} <130 km/h	2.62	1.97	1.18	0.92	0.69	0.45
Class 3.1	any	130 < V_{max} <140 km/h	2.62	1.97	1.18	0.55	0.41	0.27
Class 3.2	any	V_{max} >140km/h	2.62	1.97	1.18	0.55	0.41	0.27

3.3.6 PROGRESSION OF EMISSION LIMIT VALUES FOR THREE-WHEELERS AND TWO-WHEELERS POWERED BY COMPRESSION IGNITION ENGINES

The suggested progression of emission limit values for two-wheelers for the coming decade up to the year 2020 were worked out based on the need to transpose the GTR2 into the country's regulations and generally following the progression followed in the EU proposals. In case of three-wheeled vehicles, it is proposed to apply broadly the same per cent reductions to the prevailing emission limit values as per BSIII limits *(MoRTH 2009)*. The limit values so decided are summarized in Table 19. Diesel powered two-wheelers continue to be retained in the proposals. As mentioned before, Indian emission standards for 3-wheelers powered by Compression Ignition (CI) engines are also applicable to 2-wheelers powered by CI engines. Two-wheelers using CI engines do exist in the market but in negligible volumes. The driving cycle and the DFs have also been retained without any changes.

Table 19: Suggested Emission Limits Progression in India – 3- Wheelers

Categ.	2 or 4Stroke	2 or 3 wheeler	Stage	Emission Standards, (g/km)			Drive cycle	Durability	
				CO	HC+NOx	PM		Test, km	DF
All	2&4 SI	3	2010	1.25	1.25		IDC	30000	1.2
	2&4 SI	3	2015	0.94	0.94		IDC	30000	1.2
	2&4 SI	3	2020	0.66	0.66		IDC	30000	1.2
	2&4 CI	2&3	2010	0.50	0.50	0.05	IDC	30000	1.1
	2&4 CI	2&3	2015	0.38	0.38	0.038	IDC	30000	1.1
	2&4 CI	2&3	2020	0.26	0.26	0.025	IDC	30000	1.1

4. POSSIBLE SOLUTIONS TO MEET THE EMISSION STANDARDS IN VARIOUS SCENARIOS

In this section, a review has been made of the possible technological solutions that may be employed to meet the emission standards proposed in the three scenarios. Scenario 1 considers mandating of the GTR2 regulation, which is currently notified as an alternative. Scenario 2 assumes a tightening of the GTR2 emission limits but without assigning any specific numbers. Both of these scenarios do not have clear proposals for years beyond 2015. The technology review of both Scenarios 1 and 2 is, therefore, largely of a general nature. The technology review of Scenario 3 is more detailed since it recommends specific limit values for the pollutant emissions for the years 2015 and 2020. This review includes a study of the potential of known technologies as well as that of certain emerging technologies to meet the proposed limit values

4.1 SCENARIO 1: POSSIBLE SOLUTIONS TO MEET DRAFT NOTIFICATION MANDATED FROM YEAR 2015

The current emission standards for two and three-wheelers do not require the measurement of emission immediately from the first start of the vehicle during the 'Type 1' test. Though, "cold start" is a part of the WMTC for various categories of vehicles, it is unlikely to cause any major concern to the manufacturers since the present emission limit values have been derived from correlation studies between the Indian Driving Cycle and the WMTC. This may thus be the simplest of the scenarios from the point of view of the manufacturers. However, this does not imply that all the models produced by all the manufacturers will automatically be able to meet these standards. Little or marginal developmental work may be required to comply with the GTR2 standards on a consistent basis. However, according to the Indian industry, the significant differences between GTR2 and IDC driving cycles in terms of acceleration and deceleration values would require considerable re-optimization work in order to meet the GTR2 limits. This would include reducing engine out emissions and optimizing the after-treatment systems. The industry also feels constrained due to the lack of base line data of Indian vehicles with the GTR2 cycles *(Singh 2011).* Requirement of further tuning and recalibration of the fuel-air introduction system and improvements in after-treatment in many cases cannot be ruled out. Since no separate limits for NOx are proposed in the GTR2, the lean air-fuel ratio calibration of the engines will most likely continue to meet the HC+NOx limits and deliver a good fuel economy as well. This also indicates that, in this scenario, the conventional carburettors with oxidation catalytic converters will continue even after the year 2015, though more and more of models might start using fuel injection. It is not known whether any manufacturers have opted for the GTR2 option ever since the publication of the draft notification making it available as the alternative to the existing standard. It will be necessary to gain practical experience with the new standards and test procedures before any conclusion could be drawn regarding the technical solutions that may be required to meet the standards on a consistent basis on all production vehicles.

4.2 SCENARIO 2: POSSIBLE SOLUTIONS TO MEET TIGHTENED LIMIT VALUES WITH WMTC

The scenario most likely to be emerging in India is Scenario 2. The possibility is also shared by the manufacturers. The most likely continuation of the combined HC+NOx limit over the years on account of the fuel economy impact of independent NOx emission control may be a great advantage. However, whether conventional carburettors are able to meet the tighter standards or other alternative systems such as fuel injection systems or electronic carburettors are required will depend upon the extent of tightening up of the limits. A personal communication from SIAM *(Gandhi 2011)* anticipates the introduction of a larger number of models using fuel injection, though this may be restricted to certain higher end models with relatively higher capacity engines. A few models with fuel injection have already been introduced in the market.[4] According to SIAM, the vehicles with fuel injection introduced so far have been well received by the users. Vehicles with lower displacement engines may continue with the carburettors albeit vastly improved. High system cost is a major barrier to a more widespread use of fuel injection. Increased volumes could perhaps help to bring down the prices. Regarding further progression of standards beyond 2015, manufacturers will start assessing the requirements and the technologies available around the year 2017.

Manufacturers of catalytic converters feel that the first impact of mandatory emission limit values tighter than the current “Alternative Limits” is the need to meet the cold start requirement of the GTR2 consistently on all models. This may necessitate the use of improved catalytic converters that can aid a quick warm up of the engine exhaust such as the ‘close coupled’ or the ‘start-up catalysts’. An improved insulation of the exhaust system of the vehicle may also be resorted to. Both of these solutions will have a cost impact. *(Dias 2011).* According to SIAM, most current BS III compliant models use oxidation catalytic converters and more efficient catalyst systems using multiple catalysts/hot tubes, with new formulations (for higher efficiency and durability) are under development. In addition to this, in some cases, it may be necessary to introduce fuel injection and three-way catalysts (TWC) to meet the more stringent emission limit values. It will, however, be necessary to find new solutions to minimize the loss of fuel efficiency arising out of the necessity to switch from the current lean air-fuel ratio to the ‘stoichiometric’ for efficient functioning of the TWC. SIAM sees this as a major challenge.

4.3 SCENARIO 3: POSSIBLE SOLUTIONS TO MEET THE PROPOSED NEW EMISSION STANDARDS

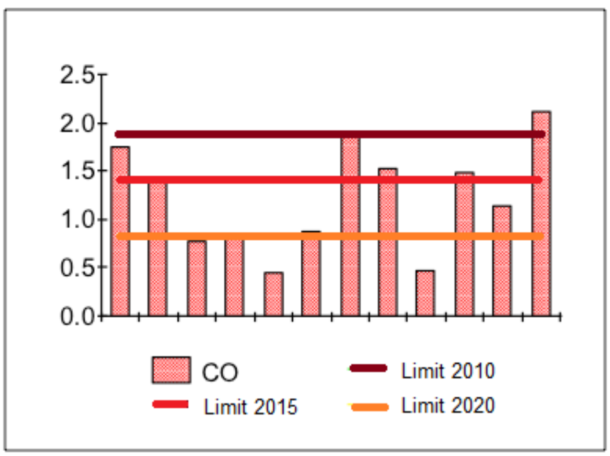
Many of the observations by the manufacturers of vehicles and catalytic converters and other stakeholders in relation to Scenario 2 are applicable to a part of Scenario 3 as well, namely meeting the proposed emission standards. The proposals for introduction from the year 2015 in both of the scenarios are similar except that Scenario 2 did not put up any specific values whereas specific limit values have been proposed in Scenario 3 not only for the year 2015 but also for the year 2020. A more detailed assessment of the possibility of meeting the 2015 (BS IV) and 2020 (BS V) limit values proposed in Scenario 3 is presented in the following section.

[4] Refer to Section 5.3 for more descriptions of fuel injection vehicles already in the Indian market.

4.3.1 ESTABLISHING COMPLIANCE LEVEL OF PRESENT TWO-WHEELERS TO PROPOSED BS IV AND BS V LIMIT VALUES

A detailed analysis has been attempted to ascertain the compliance level of existing BS III compliant vehicles to meet the proposed BSIV standards using the 'Best Available Technology' approach.

An assessment of the possibility of meeting the proposed emission limits was examined by analysing the correlation data generated on Indian vehicles during the formulation of the emission limit values for the GTR2. It may be noted that similar correlation tests were carried out by other major participating countries also such Japan, USA, and the EU *(UNECE 2008)*. In the correlation exercise described in details in the GRPE document referred to above, a total of 18 vehicles of Indian origin were tested using both of the test cycles, namely BS II (which was the standard prevalent in India when the tests were done) and WMTC respectively. Another four vehicles were tested in a subsequent phase, which are not considered here. Out of the eighteen vehicles, sixteen vehicles fell into the Classes 1 and 2 - 1 for which the GTR 2 (and proposed Indian) limits values are the same. Out of these sixteen vehicles, three vehicles showed abnormally high values and were discarded as outliers. The analysis was finally carried out on thirteen vehicles. The CO and HC+NOx values of these vehicles are plotted in Figures 23A and 23B.



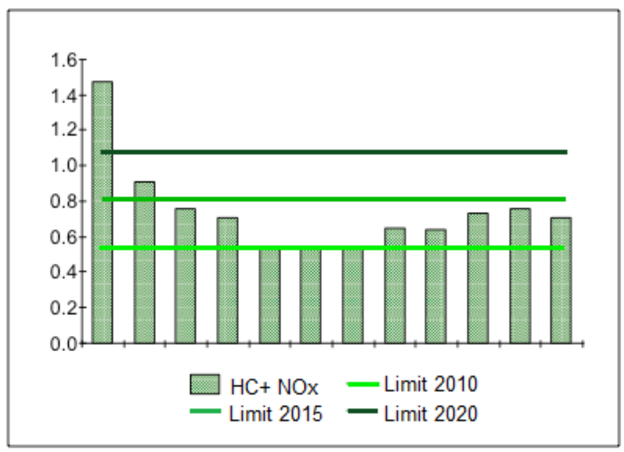


Figure 23A. CO Emissions of Indian Vehicles Tested for WMTC Correlation

Figure 23B. HC+NOx Emissions of Indian Vehicles Tested for WMTC Correlation

While the main purpose for which the data was originally generated was to establish a correlation between the WMTC and the IDC cycles by testing all the vehicles using both the IDC and the WMTC cycles, only the emission data obtained using the WMTC cycle has been used here to get an assessment of the level of compliance that these vehicles achieve with respect to the proposed limits. All the tested vehicles belonged to the BS II level, though the exact compliance levels were not ascertained. The emission limit values proposed in Scenario3 (Ref Table 19) for the years 2015 and 2020 respectively were compared with the emission test results obtained using the WMTC cycle. It is seen that the per cent of vehicles that comply with the respective emission limits goes down as the limits get tighter. The levels of compliance for CO and HC+NOx are summarized in Table 20.

Table 20: Percentage of Vehicles Complying with the GTR 2 Indian Limits

Year	2010	2015	2020
CO limit, (g/km)	1.87	1.4	0.84
% Compliance	92	54	31
HC+NOx limit, (g/km)	1.08	0.81	0.53
% Compliance	92	77	0

Even though the tested vehicles were of the BS II level, nearly over 90 per cent of these seem to comply with the GTR 2 limit, which is an alternative to the BS III (2010, existing limits) level. Since the number of vehicles on which tests have been done is rather small, it may not be correct to conclude that the stringency of the GTR 2 emission limit values may be questionable. The per cent of vehicles complying with the next two levels of limits, namely BS IV (2015) and BS V (2020), is rather low. It appears from the above that meeting the suggested BS IV limits may be possible for several vehicle models through incremental technical solutions, which may be termed as the 'Best Available Technology', such as improved carburettor, improved catalytic converters - both efficacy and location – and optimization of ignition timing etc. The fact that not a single vehicle was able to meet the HC+NOx limit of the BS V level in the above analysis indicates that recourse to major developments in technology to minimize HC and NOx emissions will be called for.

4.3.2 MEETING THE PROPOSED 2015 (BS IV) EMISSION STANDARDS – THREE-WHEELERS

Unlike in the case of two-wheelers, there is no data available for three-wheelers in public domain that could be analysed to understand the compliance levels of existing three-wheeled vehicles with respect to the various suggested emission limit values. However, the conclusions drawn in respect of two-wheeler engines could be considered as generally applicable to three-wheeler engines also. A different approach will be required in case of diesel-powered vehicles.

5. AN ASSESSMENT OF VARIOUS TECHNOLOGY OPTIONS TO REDUCE EMISSIONS TO THE PROPOSED 2020 (BS V) LEVELS

This section includes a more detailed assessment of the various technology solutions that may be available to meet the 2020 (BS V) emission limit values. It may be appreciated that each basic vehicle model would require a unique technical solution to meet the given standards. Some of the solutions may be already "known" in terms of the basic approach and may be deployed with incremental improvements and changes. Some others may be termed as "potential" which are technically well established but are not yet introduced in series production due to several constraints of complexity, cost etc. Yet others may be termed as "Emerging" as they are at various stages of development mostly in the laboratories.

In addition to describing the current level of development of the technology options, this section also includes a review of the solutions adopted in the European Union countries to meet the applicable standards there and a discussion on the possibility and challenges of adopting technologies well established on larger engines. An assessment of the Indian situation is also included.

5.1 REVIEW OF KNOWN TECHNOLOGIES

5.1.1 TWO-STROKE ENGINE POWERED 2 AND 3-WHEELERS

As mentioned previously, nearly 94 per cent of the two-wheelers currently manufactured and sold in India are powered by four-stroke engines. The picture was just the opposite during the nineties when the enforcement of emission standards started. It must, however, be noted that the proportion of 2-stroke engines in three-wheelers continues to be high. The emission standards introduced in the year 2000 were among the most stringent in the world at that time and led to the use of oxidation catalytic converters on all 2-stroke engines and an increasing switch to 4-stroke engines. It may be noted that the 2-stroke engine two-wheelers that continue to be in production still use optimization techniques supported by oxidation catalytic converters. It is very likely that over the next ten years, some of these may shift to 4-stroke engines with oxidation catalytic converters or may adopt simple fuel injection or electronic carburettor. The likely scenario will strongly depend upon the cost of the two options since the vehicles – the so called mopeds – and many three-wheelers that continue to use 2-stroke engines - are among simplest forms of vehicles and cater to an extremely price sensitive market.

5.1.2 FOUR-STROKE ENGINE POWERED 2 AND 3-WHEELERS:

A majority of two-wheelers is now powered by 4-stroke engines, which have inherently low HC emissions but high NOx emissions. Some of these might shift to port fuel injection and some may use, in addition, an oxidation catalytic converter to meet the HC+NOx limit values. Some models may be shifted to port fuel injection along with a three-way catalytic converter supported by an oxygen sensor in a closed loop system. Some low-end models might use the electronic carburettor. As mentioned before, it will be a challenging task to maintain the fuel efficiency at the current level, leave alone improving it over the current level.

5.1.3 PM EMISSION CONTROL FROM 2-STROKE ENGINES:

Some of the extensive studies recently carried out on PM emissions from two-stroke engines have observed that the oil and fuel quality have considerable influence on the particulate emissions, which are mainly oil condensates *(Cromas 2004, Sakai 1999.)*. Use of synthetic or semi-synthetic lubricating oils in lower proportions with respect to the fuel can reduce PM emissions. It has also been shown that the oxidation catalytic converters that are now invariably used on all 2-stroke engines also help to reduce the PM emission very significantly *(Palke 1999)*.

Two-stroke engines in which air-assisted fuel injection is applied are equipped with a separate pump to supply the lubricating oil. This cuts the proportion of oil-to-fuel by half – from 1:50 recommended for carburetted engines to 1:100. Recent research on the emission of PM from 2-stroke engines equipped with air-assisted fuel injection showed that the particulate mass decreased significantly when the oil-to-fuel ratio was decreased from 1:50 to 1:100. Further reduction of the oil-fuel ratio to 1:400, a rate of oil consumption equal to that of 4-stroke engines, the reduction of PM occurred more slowly. This indicated the predominance of combustion generated PM over the oil derived PM. This shows that the application of air-assisted fuel injection can help to reduce PM emissions to the levels of four-stroke engines (*Cromas 2004).*

Other studies have shown that, engine technology influences nanoparticle emissions by mixture preparation, mixture tuning, oil consumption, post-oxidation, quality and condition and temperature of the catalyst *(Czerwinski 2006).* The study concludes that, since particulate emission of the 2-stroke engines consists mainly of lube oil condensates, the minimization of oil consumption stays always an important goal *(Rijkeboer 2005)*.

While there is no limit specified in the Indian legislation at present to control the PM emissions from 2-stroke engines for two and three-wheelers, an order requiring the sale only of 'Low Smoke' 2-stroke lubricating oils conforming to JASO FC 'smoke index' rating is already in existence with salutary results *(MoEF 1996, MoEF 2006).*

5.1.4 DEVELOPMENTS IN CATALYTIC CONVERTERS: (FOR 2-STROKE AND 4-STROKE ENGINES)

Two and Three-Wheelers have been traditionally using metallic substrates for catalytic converters due to their easy canning and substrate robustness required to meet the rather arduous operating conditions of the two-wheeler. Manufacturers of catalytic converters have been keeping pace with the increasing stringency of the emission limit values and have developed substrates that can achieve superior conversion efficiency with a minimum of back pressure and lower cost. EMITEC, a leading supplier of metallic substrates has developed high cell density metallic substrates with turbulent structures that improve dramatically the conversion efficiency of the catalytic converter which can play an important part in the future optimization of the entire exhaust system to meet future stringent emission standards *(Pace 2009)***.** The application of the turbulent structure catalysts is expected to reduce the cost of a 40x60 100cpsi unit by nearly US $3 (Rs 135 estimated in the year 2008)) resulting from the use of a 15 per cent lower volume leading to a reduction in the cost of the substrate, the precious metals and coating *(Dias 2008, Jayat 2009)*.

5.1.5 SECONDARY AIR INJECTION: (FOR 2-STROKE AND 4-STROKE ENGINES)

Secondary air injection is employed to reduce the CO emission, and to a smaller extent, HC in the exhaust. Usually, passive reed valve system is used *(Archer 2001)*. Negative pressure pulses in the exhaust are used to draw fresh filtered air into the exhaust system. Secondary air injection is often used in conjunction with catalytic converters.

Passive reed valve systems are not well suited to 2-stroke engines. This is because the scavenging of the exhaust gases from a 2-stroke engine is dependent upon the exhaust negative pressure pulses. Drawing fresh air into the system may adversely affect the scavenging process. Besides, due to the loss of fresh air-fuel charge through the exhaust port, the 2-stroke engines may mostly contain a certain amount of excess air and further addition through the secondary air injection may not be of any use.

5.1.6 APPLYING TECHNOLOGIES OF LARGE ENGINES TO SMALL TWO-WHEELER ENGINES

To meet the suggested 2020 emission limits, technologies currently being used on motorcycles of larger engine capacities – say 500 cc and above – and on light duty vehicles and passenger cars may need to be considered for adoption on Indian motorcycles using engines of small capacities – in the range of 75 cc to 150 cc – which, as seen in the section on “Indian two and three-wheeler market”, is the range of engine capacities with a predominant share of the Indian market. Even though a gradual change in market preference is taking place towards higher engine capacities, this shift is from engines up to 125 cc to those up to 150 cc, which is not a large difference. From the point of view of applying technical solutions for emission control, these “higher” capacities will continue to remain “small”. In the absence of model wise sales figures, if the number of models of different engine capacities of all manufacturers together is considered, it will be seen that nearly 55% of the models are of 2-wheelers (including all categories of vehicles) powered by engines of less than 125 cc. Another 15% are with engines from 125 to 150 cc, bringing the total share of models with engines of less than 150 cc to nearly 70 per cent of the total. It is difficult to imagine a strong shift towards engines of high capacities in the ten-year time frame envisaged for the introduction of BS V level of limits.

It is evident that the challenges involved in adopting advanced technologies, such as fuel injection and electronic engine management will remain high despite the change towards relatively higher capacity engines. Some of the important challenges arise from the fundamental differences in the characteristics of the engines used in cars and motorcycles, the differences in the shape and structure of the vehicles themselves and costs of emission control systems.

5.1.6.1 CHALLENGES FOR APPLYING TECHNOLOGIES OF LARGE ENGINES TO SMALL ENGINES

Higher Specific Power and Maximum Speeds: Even though both cars and motorcycles use 4-stroke engines, the ones used on motorcycles are more stressed than those used in cars. This would be evident from a comparison of the specific power outputs of the engines. While a typical motorcycle engine, of say 100 to 125 cc capacity, would produce an average of 65 kW of power output per litre of capacity, a car of 1000 to 1200 cc capacity would produce, on an average, around 50 kW of output per litre, which is three-fourths of that of motorcycles. The higher power output comes mostly from higher maximum power speeds (engine speed at which maximum power is produced) of motorcycles – ranging from 7500 rpm to 9000 rpm compared to typically 4000 to 5000 rpm of car engines. An additional consideration for small motorcycles is that almost all of them have air-cooling system whereas almost all cars are liquid cooled.

Different Body Structure and Lack of Space: As regards the differences in the vehicle structure, the most important aspect is related to the installation of the after-treatment devices. The available space for emission control devices is much less in motorcycles, compared to passenger cars. After-treatment systems are required to be installed in the exhaust line, which is often very close to the rider's body. The available space is not enough to fit larger catalysts, or fit them close to the engine exhaust to allow quicker warm up. The Meszler study instituted by ICCT *(Meszler 2007)* observes that, "small (single cylinder) motorcycle engines are significantly more sensitive to exhaust back pressure than are larger automobile engines. This sensitivity affects not only emissions, but power and driveability as well. As a result, catalyst flow restriction must be minimized, so that a small motorcycle catalyst is typically constrained to a cell density of 100 cells per square inch (CPSI) -- as compared to the 400-1200 CPSI catalyst designs commonly used in current four-wheel applications."

More Demanding Test Drive Cycle: The report of the study on possible new measures concerning motorcycle emissions done on behalf of the European Commission *(Ntziachristos 2009)* observes that, "the motorcycle type approval cycle is a much more demanding cycle, compared to the passenger car one". This observation is based on a comparison of the engine frequency of operation of a motorcycle engine over the passenger car and the WMTC driving cycles in the cited reference where it is shown that the frequency of operation is towards higher speed and load in the latter case.

Although there is no data on Indian vehicles on this aspect, the statement would be largely applicable to the Indian situation also.

Higher Cost Relative to Vehicle Cost: A third important aspect is related to the cost of the technology as a fraction of the total cost of the vehicle. For example, to quote Meszler *(2007)* again, "a $100 catalyst investment represents only one-half of one per cent of the cost of a $20,000 vehicle. However, many motorcycles sold in the Asian market have retail costs of $1,000 or less, so that the same $100 catalyst would represent a 10 per cent surcharge". It may be noted that the actual cost of a catalytic converter for two and three-wheelers may not be as high as $100 as assumed by Meszler. However, even if a cost of $35 is assumed, it still forms a 3.5 per cent of the vehicle cost, which is much higher than that for the car,

Efforts to adopt the emission control technologies well established for four-wheelers into two and three-wheelers have to face several constraints mentioned above. This situation is perhaps the reason for the emission limit values for small two and three-wheelers being less stringent than those for passenger cars. However, the significant pollutant contribution by the rapidly increasing numbers of two and three-wheelers in the Indian market cannot be ignored and strong efforts will need to be initiated to overcome the constraints.

5.1.7 THE TECHNOLOGY PROGRESSION IN EUROPE:

A look at the two-three-wheeler technology evolution in Europe when the emission standards progressed from Euro 1 to Euro 3 would be helpful in assessing the possible technology solutions that may be adopted by the Indian industry to meet the proposed future emission standards. According to Ntziachristos et al. *(2009)*, reducing the 'engine-out" emissions by improving the fuel delivery was the primary approach for European motorcycles. This involved a switchover from carburettors to fuel injection on both 2-stroke and 4-stroke engines. Emphasis was also placed on optimizing the combustion chamber design, optimization of ignition and valve timing (in case of 4-stroke engines) and the gas-exchange process. In case of 2-stroke engines, improved scavenging to minimize the air-fuel mixture loss was also an important approach. A gradual shift from 2-stroke to 4-stroke engines was also considered as an important solution.

After-treatment devices started playing an important role, partly at Euro 1 level but mainly at Euro 2 level. Euro 2 for mopeds was basically reached by the use of oxidation catalyst to all models, sometimes assisted by secondary air injection to promote the oxidation of HC in the exhaust. Oxidation catalysts were also used on some small 4-stroke engines of <1500 cc. For those models that already used 4-stroke engines at the Euro 2 level, further emission control was achieved by using three way catalysts with the closed loop lambda control system. Progression from Euro 2 to Euro 3 level was achieved using more efficient catalysts and the replacement of carburettors by fuel injection systems to almost all motorcycle models.

5.2 REVIEW OF POTENTIAL TECHNOLOGIES – FUEL INJECTION

A precise control of the air-fuel ratio, a good mixture preparation and complete combustion of the fuel are the basic requirements for improved engine performance, reduced emissions and superior fuel efficiency. Historically the air-fuel mixture management of all types of spark-ignited engines – cars as well as motorcycles - was done using the carburettor. However, the need to bring about significant reduction in emissions brought with it the need for a more precise air-fuel mixture control that the conventional carburettor could not provide. This led to the development of the throttle body injection (TBI) with a single injector, which was followed by the superior Multi Point Fuel Injection (MPFI) system using a separate injector for each cylinder. The advent of fuel injection brought with it the electronically controlled engine management system also opening up avenues for more precise control of several engine parameters.

While electronically managed fuel injection has become the norm for four-wheelers almost throughout the world, small two and three-wheelers continue to rely upon the conventional carburettor. Requirement of low cost and simplicity and the absence of stringent emission standards ensured the continued use of the carburettor, particularly for the small sized vehicles. Use of fuel injection in motorcycles started with relatively large engine sizes since adapting the four-wheeler technology was relatively easy and cost was not a major consideration. The introduction of progressively stringent emission standards in various countries such as Taiwan, Thailand and India in Asia and the European Union, led to increasing efforts to develop fuel injection systems that were relatively simple and cheap and could be adapted without much difficulty on small engines.

While relatively simpler systems have been developed, the costs of these systems remain high firstly due to low volumes and use of components originally meant for four-wheelers with features not required on two-wheelers. As a result, systems that are dedicated to small engines are also being explored and it seems almost certain that fuel injection may completely replace the conventional carburettor in the coming years.

In the section below, various fuel injection options available for small 2-stroke and 4-stroke engines are discussed with respect to their relative characteristics. Some of the recent efforts to reduce the cost of the fuel injection system are also included. Also described are developments of electronic carburettors, which can perform many of the functions that the fuel injection system does. Also included is a brief description of the promising advanced combustion systems such as charge stratification and controlled auto ignition.

5.2.1 FUEL INJECTION SYSTEMS FOR TWO-STROKE ENGINES

There are primarily two types of fuel injection systems that can be used on small 2-stroke engines: the 'Air Assisted Direct Injection' and the 'High Pressure Direct Injection'.

5.2.1.1 AIR ASSISTED DIRECT INJECTION:

Air assisted direct injection, developed by the Orbital Engine Company, Australia, based on their Orbital Combustion Process, is among the most widely used fuel injection systems suitable for 2-stroke engines. The system was originally developed for marine engines and was later adapted to small two-wheelers. Italian two-wheeler manufacturers Aprilia introduced the system on their 50 cc "DITECH" scooter in the year 2000. Compressed air at a low pressure of around 7bar is supplied by a crankshaft driven pump to the air-fuel rail, which consists of a fuel injector and a direct injector. The fuel injector controls the fuel dosage by injecting precise quantities into the direct inject interface. The direct injector is controlled by an Electronic Control Unit (ECU) and mixes the petrol from the fuel injector with the compressed air and uses the force of the air/fuel charge to atomize the fuel particles as it enters the combustion chamber. The Sauter Mean Diameter (SMD) of the particles is typically 7μm. The fuel injector functions due to the difference in pressure between the petrol it contains and the compressed air circuit. In addition to the above, the system also consists of an electronic oil pump to inject the optimum oil quantity for engine lubrication. In the conventional carburettor system, the lubricant is either supplied in a pre-mixed form in the fuel tank itself or injected by means of a pump into the air-fuel stream. With these practices, it is not possible to restrict the oil quantity in an optimum fashion, thereby leading to smoke (PM) emission. The ECU also controls the ignition timing thereby making it possible to vary it to the most optimum values for different operating conditions.

The injection of fuel charge into the engine cylinder takes place after the exhaust port is closed, thus essentially eliminating the fuel-air mixture short-circuiting. This injection system also allows the stratified charge operation at idle, low and part loads, thereby allowing the engine to run on lean air-fuel mixtures to obtain reduction in emissions of CO and HC and improvement in fuel efficiency. Fuel efficiency benefits of up to 25 to 30%, have been reported *(Govindarajan 2005).* Archer et al. have reported a fuel efficiency benefit of up to 40% (*Archer 2001).* Due to the reduced knock sensitivity, engines with air-assisted fuel injection can operate with higher compression ratios. While the injection process itself helps to bring down the emission levels significantly, meeting the future limits proposed for BS IV and BS V may require the use of catalytic converters over and above the fuel injection system. The availability of the ECU control makes it possible to control the air-fuel ratios more precisely thereby achieving a much higher efficiency of the catalytic converter than that achieved on engines using carburettors.

5.2.1.2 HIGH PRESSURE DIRECT INJECTION:

As against the air-assisted fuel injection, the high-pressure direct injection does not allow a good atomization of the fuel, with the SMD of the particles being between 15 to 30 μm. The other drawbacks are the need to use higher injection pressures (20 to 100bar). Problems also arise since the fuel metering is done directly by the direct injector by varying the opening duration.

5.2.2 FUEL INJECTION OPTIONS FOR FOUR-STROKE ENGINES

There are three main systems that could be used on 4-stroke engines: 'Port Fuel Injection', 'Direct Injection' and 'Air Assisted Direct Injection'.

5.2.2.1 PORT FUEL INJECTION

The basic 4-stroke engines used in Indian two-wheelers are designed to be highly fuel efficient to meet the market demand. Since they make use of lean air-fuel mixtures, they also produce low levels of CO and HC emissions, often meeting the emission standards without the use of any after-treatment system. Slightly poor performance such as inadequate transient response and poor driveability prove to be the adverse aspects of this approach. Consistency of the carburettor performance in terms of fuel delivery becomes an important requirement. Use of electronic fuel injection, such as Port Fuel Injection, can help to improve the consistency of fuel delivery that can improve transient response. However, since the basic combustion process remains the same as with the carburettor, the gains in fuel efficiency and emissions would be limited *(Leighton 2003)***.** The benefits in fuel efficiency and emissions of CO and HC, albeit limited, arise out of the fact that the fuel injection system employs a fully mapped fuel delivery and spark timing and reduced wall wetting by injecting the fuel directly into the back of the intake valve. Since fuel metering is done electronically, this fuel injection system makes it possible to improve the conversion efficiency of oxidation catalytic converters and also makes it possible to use the three-way catalytic converter which requires an accurate control on the air-fuel ratios.

Port fuel injection is used on many two-wheelers in Europe, Taiwan and Japan. Two-wheelers in these countries are designed more for performance such as high acceleration and maximum speed but not so much for fuel economy. The use of port fuel injection helps to deliver a better fuel efficiency while maintaining the performance characteristics. Leighton *(2003)* reports that port fuel injection applied to a Taiwanese San Yang 150 cc scooter resulted in a 10% gain in power output and a 20% reduction in fuel consumption. CO reduced by 20% and HC+NOx by 70%.

5.2.2.2 DIRECT INJECTION IN 4-STROKE ENGINES

Use of direct injection as against Port Fuel Injection, allows the introduction of stratified combustion system, which has a good potential to improve fuel efficiency. Gains in fuel efficiency can also come from the possibility of reducing engine pumping work by operating a more open throttle at part loads, allowing a further optimization of the valve train timing and allowing the use of higher compression ratios due to the reduced knock sensitivity. Reduced wall wetting is another reason for the reduction of exhaust emissions. Four-stroke direct injection systems, however, are not in production, though they have been used in passenger cars. A major consideration is that the cost of the direct injection system, as a fraction of the vehicle cost, may be too high.

5.2.2.3 AIR-ASSISTED DIRECT INJECTION IN 4-STROKE ENGINES

Air Assisted Direct Injection system referred to earlier has been commercially applied to a range of 2-stroke engines, from 50 to 500 cc/cylinder displacements. Certain developments have taken place to adopt air-assisted fuel injection on small 4-stroke engines, ranging from small motorcycle engines through to multi-cylinder automotive applications *(Cathcart 2004).* The researchers of the above study believed that many of the specific challenges related to the application of DI to small displacement motorcycle engines can be addressed with an air-assist DI combustion system. Using the experimental results of an air-assisted DI system, the authors carried out a prediction of fuel consumption and emissions of a 125 cc 4-stroke over the ECE 40 drive cycle. To reflect the trade-off between fuel efficiency and NOx emissions, the predictions were done in two calibrations – one for minimum NOx emissions and the other for minimum fuel consumption.

The predicted results of the drive cycle simulations showed a 10% fuel economy improvement for the low NOx calibration compared to the stoichiometric baseline with the carburetted engine. The corresponding engine out NOx emissions level was less than 0.1 g/km. This result indicates the possibility of avoiding the use of after-treatment systems. For the low fuel consumption calibration a 17% improvement in fuel economy was obtained compared to the baseline engine. The engine-out NOx emissions in this case were approximately 0.46 g/km for the ECE40 drive cycle simulation.

5.3 TWO AND THREE-WHEELERS USING FUEL INJECTION ALREADY IN THE MARKET

Although use of fuel injection in small engines is still considered as an upcoming technology for small vehicles, a few models using it have already been introduced in the market. These include a three-wheeler and several motorcycles of mostly higher engine capacities. The description below includes an announcement by Honda regarding the development of a Programmed Fuel Injection system suitable for their very small engine of 50 cc displacement. This is considered as an important development since Honda has a large share of the two-wheeler market in India and in many other countries in the Asian region.

5.3.1 BAJAJ AUTO'S RE GDI LAUNCH – INDIA'S FIRST DIRECT INJECTION TWO-STROKE ENGINE

Bajaj Auto launched a new variant of its auto-rickshaw, in Mangalore (*Bajaj 2011*)*.* The new petrol-engine RE-GDI three-wheeler incorporates gasoline direct injection (GDI) technology, which, according to Bajaj, allows the vehicle to achieve very low emissions figures, making it cleaner than auto-rickshaws that run on LPG or CNG. In addition to being more eco-friendly than regular petrol engines, the RE-GDI also delivers up to 33% better fuel efficiency, hence reducing running costs for operators. The new auto-rickshaw is priced at Rs 92,000 and a deluxe version at Rs 1.17 lakh, 'on the road' (lakh=100,000). According to Duret (*2011*), the Bajaj RE-GDI is the only three-wheeler in the world with a DI 2-stroke *(Bajaj 2011).* As per report published in the newspapers, Bajaj claims a fuel efficiency of 44km/l in addition to a reduction of 50 per cent in CO, and a 25 per cent reduction in hydrocarbon and oxides of nitrogen *(Business Line 2007)*. From the specifications of the 2-stroke DI engine (Ref Table 5) it is seen that the DI system enables the 145 cc 2-stroke engine to deliver 30 per cent more power output than the carburetted version. Its power output is nearly 13 per cent higher than that of the four-stroke carburetted model. On the whole, the 2-stroke DI seems to be a very promising technology not only to meet the future emission limits but also improve fuel efficiency.

5.3.2 BAJAJ AUTO'S MOTORCYCLE

Bajaj Auto had introduced the Bajaj Pulsar 220 model using a fuel injection system. However, it was later withdrawn *(India Automotive 2011*) and replaced by a carburetted version.

5.3.3 HONDA'S PGM-FI FUEL INJECTION SYSTEM FOR SMALL 4-STROKE ENGINES

On October 2003, Honda Motor Co., Ltd. announced that it had developed the world's first electronically controlled fuel injection system (Honda Programmed Fuel Injection, or 'PGM-FI') for use in 4-stroke, 50 cc engines *(Honda 2003)***.**

This system was claimed to offer superb starting along with improved fuel economy and cleaner emissions. The company had announced that all Honda scooters for sale in Japan would be scheduled for conversion to PGM-FI by 2007, and the majority of models for sale worldwide will be equipped with PGM-FI by 2010.

Approximately 7% better fuel economy in 30km/h steady speed test mode, and approximately 10% better fuel economy in a test mode designed to simulate actual city driving conditions has been claimed. Emissions of CO and HC reduced to half the level stipulated in the Japanese government regulations.

The PGM-FI system has been developed for the European 50 cc mopeds. A control on costs has been achieved by reducing the number of parts from 15 used in conventional PGM units on larger models to just 8. This has been achieved by combining some of the functional components and integrating the sensing functions.

In order to provide minute injection volumes required by the 50 cc engine, and achieving a fine atomization of the injected fuel, a new two-hole injection nozzle has been developed. The new injector uses an optimized internal flow-path shape to achieve the world's highest level of atomization.

5.3.4 HONDA MOTORCYCLES & SCOOTERS INDIA: CBR250R

Honda Motorcycle & Scooter India, which is a wholly owned Indian subsidiary of Honda recently launched its much-awaited CBR250R motorcycle in India *(Zigwheels 2011***)**. While larger motorcycle models using fuel injection have been sold in India, albeit in negligible numbers, the CBR 250R perhaps comes closest to the generally popular models in India. The vehicle is powered by a 25BHP single cylinder 249 cc DOHC engine with, in addition to PGM-FI fuel injection, 4-valves and liquid cooling. This is perhaps the first motorcycle in the Indian market with a 250 cc engine.

5.3.5 HONDA MOTORCYCLE & SCOOTERS INDIA: CBF STUNNER

Honda Motorcycle and Scooters India Ltd has also introduced a fuel-injected version of its model CBF Stunner. The engine capacity and the power output are respectively 125 cc and 8.7 kW and are the same as those of the carburetted version. The company claims that the fuel efficiency is 65 km/h. This claim seems to be borne out by the Bike India test report *(2011), which* shows a figure of 66.6 km/l compared 60 km/l of the carburetted version. The vehicle, most probably for the first time in India, has featured a malfunction indicator lamp. It also claims, without any details, that the emission levels are one-tenth of the BS II standards *(HMSI 2011).*

5.3.6 TVS MOTOR: APACHE RTR 160

TVS Motor Company had showcased the fuel-injected version of its best-selling motorcycle the Apache RTR 160 in the 2008 auto expo *(Zigwheels 2011)***.** The capacity of the fuel-injected version is retained at 160 cc. The power output and torque are also not much different from the carburetted version. While the company does not make any claims regarding the fuel efficiency of the motorcycle, the figures of the road test reports published by "Bike India" magazine *(2011)* indicate that the fuel efficiency of the fuel injected version is 55 km/h compared to 50km/h of the carburetted version, an improvement of 10%.

5.3.7 HERO HONDA: GLAMOUR

Hero Honda has also introduced a fuel-injected version of their model 'Glamour'. The vehicle is powered by a 125 cc, 4-stroke engine with a maximum power output of 6.7 kW. The specifications of the carburetted version are the same. The declared fuel efficiency of the carburetted and the fuel-injected versions are 81.1 km/l and 85.8km/l respectively, which show a 5.8% improvement in fuel efficiency with fuel injection. The 'Bike India' road test figures show values of 72.74 km/l for the original version and 80.75 for the fuel-injected version, thus showing an improvement of over 11%.

5.4 SUMMARY OF THE TECHNOLOGY PROGRESSION IN INDIA – SO FAR AND IN THE FUTURE

The progression of technical solutions applied to Indian vehicles to meet the currently prevalent emission standards –the BSIII introduced in the year 2010 - and the expected progression in the years 2015 and 2020, proposed in this report, are given in a summarized form in Table 21.

Table 21: Technology Progression for Two-Wheelers from the year 2010 to 2020 according to Scenario 3

Year of Introduction,	Emission Standard Scenario 3	2-stroke	4-stroke
2010 (Current)	BS III	*Engine Optimization + Oxidation Catalytic Converter – on all models	* Engine Optimization – variable ignition timing (some models only), + Oxidation Catalytic Converter (with a few possible exceptions)+ Secondary Air Injection (a few models) * A few high end models with Port Fuel Injection with a Closed Loop System + Three-Way Catalytic Converters
2015 (Scenario 3)	BS IV	*Improved Oxidation Catalytic Converter- on all models * A few models with Air Assisted Direct Injection with improved catalytic converter (some models) * A few models with electronic carburettor	* Further Engine Optimization - wider use of variable ignition timing + Improved Catalytic Converter – Close Coupled Catalyst / Start-up Catalyst / Quick Warm-up Catalyst, Exhaust Insulation (double exhaust pipes) – all on selected models, * A few models with Port Fuel Injection * A few models with electronic carburettor
2020 (Scenario 3)	BS V	*Replace with improved 4-stroke engines (some models) *Air-Assisted Direct Injection (some models) with oxidation catalytic converter *Electronic carburettor	*Most models with Port Fuel Injection with oxidation catalytic converter * Some models with Closed Loop System + Three-Way Catalytic Converter *Some high end models with Gasoline Direct Injection

5.5 COST ESTIMATES OF THE TECHNICAL SOLUTIONS

Information on costs in the Indian context is hard to get. Estimates of overall costs of the injection systems are given in some of the research publications some of which are given here.

5.5.1 COST ESTIMATES FROM LITERATURE

Ravenhill et al. One of these is the paper on the Pulse Count Injection (PCI) *(Ravenhill et al. 2009*) (More details of the PCI system in Section 5.6.3) The authors claim that the cost of the PCI system would be expected to be $40 - $60, which is approximately half the price of $100 - $200, of the conventional Pulse Width Modulation (PWM) systems. The comparative cost of a sophisticated carburettor is quoted as $20 - $30.

Franz Winkler et al. The paper by Franz Winkler et al. (*2005*) gives certain relative cost estimates vis-à-vis those of the carburettor. These are apparently based on the actual costs of the systems in the market. Though the paper was published in the year 2005, it may be presumed that the relative differences in the costs may still be holding good. The costs estimated are summarized in Table 22.

Table 22: Relative Costs of Different Fuel Introduction Systems for 2-Stroke Engines (*Winkler et al., 2005)*

System Description	System costs, % of standard carburettor 2-stroke engine	Estimated Cost (US $) Assuming Carburettor Cost to be US $30
High pressure Direct Injection (HPDI)	200%	60
Air- assisted DI with piston compressor	150-170%	45 - 51
Air assisted DI (electronic air and fuel injection)	160-170%	48 - 51
Semi Direct Injection	140-160%	42 - 48
Electronic carburettor	120-140%	36 - 42

The Meszler Report ICCT had instituted a study on the air emission related issues of two and three-wheelers *(Meszler 2007)***.** In their report, Meszler have estimated the cost-effectiveness of various technical solutions applied to 2-stroke and 4-stroke two-wheelers. Some of the important costs assumed are summarized in Table 23.

Table 23: Estimated Costs of Various Emission Control Systems (*Meszler, 2007*)

System	Cost (US $)
Two-Stroke Oxidation Catalyst System	34
Two-stroke oxidation catalyst system with secondary pulse air injection	46
Direct Injection (small motorcycles)	42
Four-stroke secondary air systems	26
secondary air and oxidation catalyst system	61
Three-Way Catalyst for Four-Stroke Engines	39
Fuel Injection for Four-Stroke Engines without catalyst	111
Fuel Injection for Four-Stroke Engines with catalyst	166

5.5.2 COST ESTIMATES USED IN THE EUROPEAN STUDY

Cost estimates have been reported in the European study on possible new measures concerning motorcycle emissions *(Ntziachristos 2009)*. However, in their report Meszler *(2007)* states that "without exception, technology cost estimates reported by the European Union average 4-8 times higher than average costs reported by other researchers. While some differences are to be expected given the generally larger displacement motorcycles marketed in Europe, the reported estimates are significantly larger than estimates reported by U.S. researchers for large displacement motorcycles". As a result of this observation and finding that the costs assumed by Meszler seemed to be closer to the values quoted by other researchers, it was decided not to include the EU values in our assessment.

5.5.3 COST ESTIMATES BY EXPERTS

Since there is still no market for two and three-wheeler fuel injection systems in India, it is difficult to get realistic cost estimates. However, broad views of certain experts who are closely connected with the developments of fuel injection systems have been obtained. These are summarized below:

S. Govindarajan (UCAL) The cost will depend on the volumes. For a production volume of 1 million units and above for 4 stroke FI system the cost may be anywhere between US $70 to $90 depending on the scope of supply and features required *(Govindarajan 2011).*

Steven Ahern, Orbital "Across the industry the target delta cost for a 1 cylinder PI system is around US$50, with people wanting this a little lower for India (~US$40). Current systems are probably closer to the US$80 to $100 range"(*Ahern 2011*).

5.5.4 ESTIMATE OF COST BASED ON AVAILABLE INFORMATION

It would appear from the above that the cost of a four-stroke port fuel injection system without a catalyst could be taken as approximately US $85, which would be an average of the prices indicated by the experts. Accordingly, the costs indicated by Meszler for the various systems may be a little on the high side. The costs estimated based on the figures given by Winkler et al. appear to be on the lower side since these are for 2-stroke engines.

Assuming a current exchange rate of Indian Rs 45 to a Dollar, the figure of US$ 85 would translate to Rs 3,825/-. Assuming a mark-up of 50 per cent from the manufacturer to the end customer (taking into account the levies and taxes, dealer margins, profits, etc.), the additional price of the motorcycle would be Rs 5,737/- [5]. In an earlier section mention was made of the motorcycles using fuel injection introduced by various Indian manufacturers. From their specifications, it appears that these models with fuel injection may be variants of original models using the conventional carburettor. The differences in the 'on-the-road prices' ex Pune (that is inclusive of all taxes, insurance, and others) between the original and fuel-injected versions are shown in Table 24. The prices have been taken from the Bike India magazine *(2011).*

[5] While the Rupee/USD exchange rate remained stable for a long time, the current rate (December 2011) is around Rs 53 to a US Dollar. It is believed that this may be a transitional phase.

Table 24: Comparative characteristics and on the road prices of variants of motorcycles using carburettors and fuel injection *(Bike India 2011)*.

Model Name (all 4-stroke models)	Engine Capacity cc	Max Power, kW	On Road Price, Rs	Difference in Price, Rs
Hero Honda Glamour	125	6.7	55,431	
Hero Honda Glamour F1	125	6.7	66,121	10,690
TVS Apache RTR	159.7	11.3	69,521	
TVS Apache RTR EFI	159.7	11.7	78,348	8,827
HMSI Stunner CBF	124.7	8.25	59,357	
HMSI Stunner CBF FI	124.7	8.82	75,709	16,352

The data in Table 24 shows that the incremental cost of incorporating fuel injection system are well within the additional prices being charged for these vehicles. It must, however, be considered that the increased price may not only be covering the cost of the fuel injection system but also other features which might be on offer.

5.5.5 SUMMARY OF COST ESTIMATES OF VARIOUS TECHNOLOGY OPTIONS

All the information from different sources described above has been summarized to get a picture of the costs of various technology options. These have been summarized in Table 25. These cost estimates may be treated only as indicative of the relative costs. The actual costs may differ quite significantly from these values.

Table 25: Summary of Cost-Estimates of Various Technology Options

System	**Cost (US $)**		
Source	Meszler	Winkler	Author*
2-Stroke oxidation catalyst system	34	-	-
2-stroke oxidation catalyst with secondary pulse air-injection	46	-	-
2-stroke air assisted direct injection	42	45 – 51	-
2-stroke high pressure direct injection 2-stroke	-	60	-
2-stroke electronic carburettor	-	36 - 42	-
4-stroke secondary air systems	26	-	-
4-stroke secondary air and oxidation catalyst system	61	-	-
4-stroke three-way catalyst	39	-	-
4-stroke fuel injection without catalyst	111	-	85
4-stroke fuel injection with catalyst	166	-	-

* Estimates based on experts' views and differences in market prices of similar motorcycle models with and without fuel injection.

5.6.1 SYNERJECT SYSTEMS

'Synerject Systems Integration' is a major supplier of fuel injection systems and components. Since high cost is one of the barriers in the widespread use of fuel injection systems in small two and three-wheelers, Synerject recommend several cost reduction strategies for both the air assisted direct injection for 2-stroke engines and port fuel injection for 4-stroke engines. The recommended steps include minimizing the functionality of the components to meet the small engine requirement only. Components used on cars are designed for several functions, which are not required on small two and three-wheelers. It recommends the redesign of key system specific components such as the ECU and fuel pump to reduce cost and complexity *(Archer 2001*)**.**

5.6.2 YAMAHA MOTOR

Yamaha Motor Company has reported the development of an electronically controlled fuel injection system that is ideal for small, motorcycles, cost-efficient, compact, and saves electric power consumption, while maintaining accuracy *(Nakamura 2003)***.** The reduction in cost was achieved primarily by reducing the number of sensors. Highly accurate methods were developed for the measurement of intake air mass, detection of acceleration, distinction of engine stroke, and estimation of atmospheric pressure without using a throttle position sensor, cam-timing sensor, and barometric sensor. An injector in-tank fuel pump module was developed to achieve compactness, which is half the volume of the conventional injector, and reduces electric power consumption. The fuel pump, fuel pressure regulator, fuel filter, and fuel level gauge were integrated into one compact form and were located inside the fuel tank so as not to interfere with other layouts. The fuel pump is designed to consume one third (1.7Ampere at 12 Volt) of the power consumed by the conventional one. These systems have already been installed on a Taiwan made four-stroke 125 cc scooter, which is already in the market.

5.6.3 SCION-SPRAYS'S LOW COST ELECTRONIC FUEL INJECTION (PCI)

Scion-Sprays Ltd, UK, has developed a novel engine management system called the Pulse Count Injection (PCI) system, which is designed from the outset specifically for low cost small engines for motorcycles and utility applications *(Ravenhill 2009).* According to the company, "the PCI is based around an injector that operates as a positive displacement pump. The piston in the injector oscillates at high frequency, typically 700Hz. Each time a piston oscillation occurs a fixed volume of fuel is delivered from the injector to the engine. This action is performed a controlled number of times every engine cycle with the number of pulses injected being dependent on engine load and speed." By virtue of this unique method of controlling the fuel flow, the injector itself performs the functions of the conventional pump, pressure regulator and injector-metering device. It can also serve as feedback sensor. This allows the whole system to be consolidated and miniaturized.

The design of PCI has been done with the objective of minimizing parts count and reducing overall cost, specifically for the small engine market. This was achieved by integrating as many parts as possible into one unit. For instance, the temperature sensors, pressure sensor and throttle position sensor were incorporated on the PCB directly thereby reducing the cost of the system. This not only obviates the need for additional wiring and harnesses with connectors but it also eliminates sources of failure through water and dirt ingress into connectors. The authors claim that the cost of the PCI system would be expected to be $40 - $60, which is approximately half the price of $100 - $200, of the conventional Pulse Width Modulation (PWM) systems. The comparative cost of a sophisticated carburettor is quoted as $20 - $30.The PCI is also capable of providing diagnostic feedback.

5.6.4 DELL'ORTO ELECTRONIC CARBURETTOR

Dell'Orto is a major supplier of carburettors for two and three-wheelers *(Colombo 2010).* They have proposed a system, which includes an electro-actuated carburettor, in which "the air-fuel ratio setting is achieved by means of a control electro-valve. Oxygen sensor feedback signal is used to keep the air-fuel ratio in a narrow window, close to the stoichiometric conditions, thus enhancing the efficiency of the catalytic exhaust after-treatment. Apart from carburation management the system also integrates a fully digital timing ignition control. The fuelling and ignition management control is performed by the ECU according to several input signals. The oxygen sensor feed-back control is used also during the transient operation of the emission test cycle, improving the catalyst performance".

The key advantages claimed are "the compact, highly integrated contactless throttle position sensor, the closed coupled unheated oxygen sensor feedback, the small and fast electro-valve and the battery-less, low-cost ECU". One of the most important features of the development, which would be particularly important for India, is that The 'Closed Loop Control' of the electronic carburation system technology can be easily integrated into existing vehicles with a limited development cost, without any vehicle, engine or electrical system modification.

A feature that is important for the low-cost mopeds is that the system can work out of power from the flywheel magneto. As such, the engine can run even if the battery is low and also if the sensors or the electro-valve are, for any reason, out of service. This can be an interesting feature for the mopeds in India that still use carburettors. Many models of mopeds are not fitted with a battery and work on the electricity produced by a flywheel magneto.

5.6.5 ARAI ELECTRONIC CARBURETTOR

A proposal to explore the potential of electronic carburettors was mooted by the ARAI *(Karle 2003)***.** The proposal made use of a solenoid valve in the air bleed circuit of the carburettor to control the fuel flow and, as a result, the air-fuel ratio. An electronic control unit controlled the functioning of the valve. A prototype of the system was optimized for performance on a 150 cc 4-stroke scooter engine complying with the year 2000 standards. The baseline CO and HC emissions of the engine increased with the electronic carburettor due to the fact that the air-fuel ratio was now getting maintained at near stoichiometric level compared to the lean ratio of the original engine. However, the conversion efficiency of the catalytic converters vastly improved due to the better control of the air-fuel ratio. As per the results of tests on the vehicle on the Indian Driving Cycle, the conversion efficiency of the catalysts increased from 49 and 46 per cent for CO and HC respectively with the conventional carburettor to 82 to 84 per cent respectively with the electronic carburettor.

5.7 EMERGING NEW TECHNOLOGIES FOR SMALL ENGINES

The challenges posed by the increasing pressure in different parts of the world to bring about drastic reduction in emissions from small engines are leading researchers to look for advanced solutions that have not been explored in the past. The researchers seem to be targeting the large Asian markets like India, which use a large number of small 4-stroke engines and where low cost is a prime consideration.

The primary goal of their research work is to improve the basic combustion process to bring down the "engine out" emissions and improve fuel efficiency. Overcoming the major deficiencies of the two-stroke engine is also an important target area of research. The effectiveness of new approaches has been established through prototype tests in the laboratories and may reach the series production level in the coming years.

5.7.1 EMERGING TECHNOLOGIES FOR 2-STROKE ENGINES

Described in the following sections is the important development work being carried out by leading institutions like Graz University of Technology (GUT) in Austria on low-pressure direct injection, Honda R&D in Japan on stratified charge auto-ignition, and Institut Français du Pétrole (IFP) in France on controlled auto-ignition.

5.7.1.1 GRAZ UNIVERSITY OF TECHNOLOGY (GUT) – THE LOW PRESSURE DIRECT INJECTION SYSTEM

Based on its earlier successful development of a 50 cc 2-stroke low-pressure (5 bar) direct injection system, GUT has reported the results of a demonstrator engine of 250 cc. *(Oswald 2010).* As is well known, loop scavenged two-stroke engines with external mixture preparation suffer from high HC emissions, leading to poor efficiency. Utilizing an electronic fuel metering and a proper position of the fuel injector in a standard two-stroke engine has a high potential to reduce the scavenge losses at both full load and part load operation. The Low Pressure Direct Injection (LPDI) system demonstrated by GUT is capable of effecting two different mixture preparation systems. The fuel can either be directly applied to the cylinder or can be injected into the crankcase for homogenously scavenged engine operation. The demonstrator LPDI combustion process has been shown to achieve the two goals of high engine power and low engine-out emissions, while providing a significantly increased fuel economy and very long catalyst endurance at the same time. The above results show that the LPDI technology developed by GUT, which is of a simple mechanical design equipped with a low cost injection system, could be a good alternative to expensive four-stroke engines, particularly in the Indian situation where high efficiency and very low emissions at low costs are of special interest.

5.7.1.2 NEW CONCEPT OF 2-STROKE GASOLINE ENGINE FROM HONDA R&D COMPANY – STRATIFIED CHARGE AUTO-IGNITION

Honda R&D Company has developed and tested a new two-stroke gasoline engine utilizing stratified-charge auto-ignition *(Nishida 2009).* The concept aimed at overcoming the traditional problems of 2-stroke engine, namely mixture short-circuiting and irregular combustion. Overcoming these defects can help to take advantage of the excellent torque and mechanical efficiency thereby obtaining a good fuel economy. Mixture short-circuiting can be overcome by using direct fuel injection. The countermeasures for irregular combustion include homogeneous-charge auto-ignition (HCAI) combustion and stratified-charge spark-ignition combustion. Since HCAI has not been practically successful, the researchers developed another auto-ignition method which they refer to as the 'Stratified-Charge Auto-ignition (SCAI). The engine concept was to switch the combustion mode according to the engine operating load and speed, as shown in Table 26.

Table 26: Different Combustion Modes for Different Operating Conditions

Operating Condition	Combustion Mode
High Load	Homogeneous Charge Spark Ignition
Mid-to-Low Load Range	Homogeneous Charge Auto Ignition
Low Load Low Speed Range	Stratified Charge Auto Ignition
Idling	Stratified Charge Spark Ignition

The experimental engine was of 250 cc liquid cooled single cylinder 2-stroke gasoline. It was provided with a direct fuel injection system to control the stratification of mixture formation and an exhaust valve system to control the internal EGR rate and a combustion chamber design that induces proper temperature distribution of the in-cylinder gas by promoting stratification of the scavenging flow. Experimental results showed that switching the combustion modes as per the concept made it possible to realize a two-stroke engine that was completely free from irregular combustion. This led to the specific torque of the experimental engine to increase by 1.7 times thus allowing a downsizing of 30% compared to the base engine. The results were compared with those of a 125 cc 4-stroke engine, which showed that the fuel economy under the ECE 40 mode improved by 8% over the 125 cc 4-stroke while the improvement was 20% when compared to a downsized engine that had the same output as the base 4-stroke engine. The HC and NOx emissions were also reduced by 15% and 80% respectively compared to the base 4-stroke engine of 125 cc.

5.7.1.3 INSTITUT FRANCAIS DU PETROLE (IFP) – CONTROLLED AUTO-IGNITION

Pierre Duret of IFP School (Institut Français du Petrole) observes that “for a small engine as used in 2 and 3 wheelers in India, in terms of fuel economy (and low CO2) the best engine is obviously a Direct Injection (DI) 2-stroke engine” (*Duret 2011*). A disadvantage of the 4-stroke engine is that, as the displacement becomes small the friction losses become higher and higher compared to 2-stroke engines. For engines below 20-25 kW, the advantage is in favour of the DI 2-stroke.

Very low levels of emissions can be achieved from gasoline 4-stroke with stoichiometric operation and a 3-way catalyst. The same levels in HC and CO can be obtained from a DI 2-stroke with an oxidation catalytic converter. In fact, the CO emissions can be even lower because of the lean exhaust conditions with an oxidation catalyst. Even if NOx emission is inherently low from a 2-stroke DI engine, ultra-low levels of NOx can be reached by using Controlled Auto Ignition (CAI) or Active Thermo Atmosphere Combustion (ATAC). IFP has carried out several experiments on two-wheeler and automobile engines to obtain part load CAI combustion in 2-stroke DI engines. CAI combustion is preferable to charge stratification as the latter produces higher NOx and PM emissions. According to Ishibashi *(2000),* two-stroke engines should be one of the most suitable subjects for applying auto-ignition combustion considering that their particular gas exchanging state often induces auto-ignition at part throttle operation. Systems such as CAI have a high potential but are still under development. More intense research efforts in these fields may make these solutions suitable for mass production.

Duret cites some examples to illustrate the fuel economy/emissions advantage of DI 2-stroke for small engines. End of 2007, the Taiwanese EPA audited 85 motorcycles. The “Top 14” were selected to determine the green motorcycle rating by ranking the vehicle HC+NOx emissions, the CO emissions and the fuel economy capability. It was the DI 2-stroke that achieved this best Taiwan Green Motorcycle ranking. The French EPA made a study in 2005 of several 50 cc scooters in the market and the DI 2-stroke was, on an average 35 % better in fuel economy than the 4-stroke models.

5.7.2 EMERGING TECHNOLOGIES FOR 4-STROKE ENGINES

This section mainly deals with the development of Stratified Charge Combustion being developed by Yamaha in Japan.

5.7.2.1 YAMAHA’S STRATIFIED CHARGE COMBUSTION WITH EGR TO IMPROVE FUEL EFFICIENCY AND REDUCED NO_X

Yamaha has recently reported the results of a study on a single cylinder 400 cc four-stroke motorcycle engine to improve the fuel efficiency and reduce NOx emissions *(Takasu 2008*). The engine was equipped with a low pressure (0.8MPa) – Direct Injection system to achieve a lean stratified combustion with good stability. The experiments showed that the stratified charge combustion could lead to improvement in fuel efficiency more than the homogeneous combustion. However, it also led to an increase in NOx emissions. The use of Exhaust Gas Recirculation (EGR) helped to reduce NOx emissions. The work reported in the paper confirms that the Direct Injection system is needed to take advantage of EGR for getting the combined benefit of better fuel efficiency and reduced NOx emission.

5.8 CONCLUSIONS ON THE POTENTIAL AND EMERGING TECHNOLOGY OPTIONS TO REDUCE EMISSIONS

It is seen from the foregoing that there seems to be a great amount of effort going on to progressively reduce emissions and improve fuel efficiency. The prominent technologies to reduce engine out emissions include air assisted direct injection for 2-stroke engines and port fuel injection for 4-stroke engines. Electronic carburettor seems to be emerging as a strong contender and so is the Pulse Count Injection (PCI). Efforts are also going on to reduce the costs of these systems so that they become more affordable to the buyers of the low cost motorcycles. Catalytic after-treatment will continue to remain an important component of the emission control strategy. While most vehicles currently use oxidation catalytic converters, the technologies of fuel injection, electronic carburettor and PCI will help to improve the efficiency of these oxidation catalysts and also permit the efficient use the three-way catalytic converters. With a judicious combination of technologies to reduce engine out emissions and after-treatment devices, it seems highly probable that it will be possible to meet the proposed emission standards for the proposed BSIV and BSV levels effectively and at reasonable costs. The extent of fuel efficiency gains may be limited compared to those obtained on vehicles in Europe, Japan and Taiwan due to the fact that the basic engines in India are designed for a customer-forced high fuel efficiency. Marginal improvements would, however, be possible. It is also seen that leading motorcycle manufacturers in India have started developing advanced fuel injection systems. This experience should help them to carry out further improvements to meet the proposed BS IV and BS V standards. A few fuel injection versions of 4-stroke motorcycles have been introduced in the market. The difference between the market prices of these models and those of their original versions (assuming that the difference essentially represents the incremental cost of the fuel injection system) when compared with the approximate costs of the fuel injection systems, show that the former are higher than the incremental price of the fuel injection systems. A major southward impact on the prices can also be expected when the volumes grow.

Several new areas of research are now being explored to improve the basic performance of the small engine and overcome its deficiencies. These researches are primarily focused on improving combustion through charge stratification and a combination of controlled auto-ignition and spark ignition. It seems highly probable that some of these innovations may reach the volume production stage in the coming years.

6. TECHNICAL MEASURES OTHER THAN THE MASS EMISSION STANDARD

Fixing exhaust mass emission standards that force the development and adoption of new technological solutions is not only an effective but also an essential measure to minimize the pollutant contributions of 2 and 3-wheeled vehicles to ambient air. Evaporative emission is another important source of hydrocarbon emissions that needs to be controlled.

While these measures mainly help to control emissions from new vehicles, with progressive usage, vehicle emissions tend to increase thereby negating the emission control achieved by the adoption of new technological measures. It is, therefore, necessary to institute effective measures to ensure that the deterioration of pollutant emissions over the useful life of the vehicle is kept at the minimum possible level. These include specifying durability requirements for pollutant emissions and enforcement of several regulatory measures for effective management of vehicles in-use.

6.1 INTRODUCTION OF EVAPORATIVE EMISSION STANDARDS

Evaporative emissions arise from breathing losses directly from the fuel tank and through the open bowl of the carburettor. Fuel permeation is another cause of evaporative losses. The mechanisms of evaporative emissions include "Diurnal Emissions" due to the daily variation of ambient temperature and "Hot Soak Emissions" due to the warmed up fuel after the engine is switched off. In addition, there are "Running Losses" due to the warming up of the fuel during the running of the vehicle.

A proposal to introduce standards for evaporative emissions for two and three-wheeled vehicles, on the lines of those prevalent in Taiwan, has been under the active consideration of the government for many years. The introduction was, however, deferred on account of the difficulty expressed by the industry in achieving the desired level of performance of the control devices. One of the major differences between a passenger car and the two-wheeler pertains to the fuel supply system. Passenger cars mostly have the fuel tank located at a level lower than the carburettor or fuel injection system to which the fuel is supplied by means of an electrically driven pump. In most of small two-wheelers, the fuel tank is above the level of the carburettor, which receives the fuel supply by gravity feed. There is no electrically driven pump. Previous industry submissions indicated that this led to difficulties in the proper functioning of the evaporative emission control systems. As mentioned before, the industry has agreed to the introduction of the evaporative emission control to coincide with the introduction of the next stage of emission standards in the year 2015. *(Gandhi 2011).* It would be appropriate to recommend a limit of 2g/test for India on the lines of the existing regulations in Taiwan, Thailand and the California Air Resources Board. Compliance to this limit is required to be established by carrying out tests using the 'SHED' (Sealed Housing for Evaporative Determination) method.

In the EU study of possible new measures concerning motorcycle emissions, it is observed that fuel injection results in lower evaporative emissions due to its sealed construction, compared to the open bowl of the carburettor. For its evaluation, the referred study had assumed that all motorcycle types emitted about 1.2-1.3 kg HC/year/vehicle *(Ntziachristos 2009)* . The new experimental information shows that this is rather true for large motorcycles equipped with carburettor. The introduction of fuel injection has already significantly reduced evaporation emissions by ~60%.

6.2 IMPROVED DURABILITY REQUIREMENTS

The term 'durability' essentially implies that the engine should continue to function at its optimal level throughout its useful life subject to use of recommended fuels and lubricants and periodic maintenance as recommended by the manufacturer. However, despite these precautions, a certain deterioration of vehicle performance over a period of time is inevitable due to normal wear and tear of the moving engine parts and the build-up of undesirable deposits on critical engine parts. Good lubrication and usage practices can only minimize the wear and tear and deposit build-up but cannot eliminate them altogether. This unavoidable situation leads to progressive deterioration of engine performance, reflected by loss of power, increase in fuel consumption and increase in emission.

A more important durability concern is the progressive deterioration of after-treatment devices, such as the catalytic converters, installed in the vehicle to reduce emissions. There are two main mechanisms of catalyst deterioration; one is due to thermal degradation and the other due to chemical poisoning. Thermal degradation takes place since the catalysts are subjected to high temperatures during their functioning arising from exothermic reactions. Chemical poisoning results from exposure of the catalysts to various chemicals contained in the fuel and the lubricant. Some of the chemicals cause irreversible damage to the catalyst, for example the well known lead compounds (tetraethyllead - TEL) added to petrol to increase its Octane Number. Of course, the use of TEL is now banned in most of the countries. It has not been used for more than a decade in India. Deterioration of the catalyst leads to a permanent damage with a serious adverse impact on emissions. The increase in emissions due to the deterioration of the catalyst could be greater than that caused by normal engine wear. Besides, a damaged or malfunctioning catalyst cannot be noticed by the vehicle user, except where the vehicle is equipped with the OBD (On Board Diagnostics), since there is no apparent deterioration of engine power or fuel efficiency. It is, therefore, essential that the design of the catalytic converter in terms of its size, noble metal loading etc., ensures that it lasts through the normal life of the vehicle. The above considerations underline the importance of building in the durability requirement as an important measure for controlling vehicular emissions. From a regulatory point of view this is ensured by requiring the manufacturer to demonstrate the durability through actual testing or by applying the specified Deterioration Factor (DF) to the emission limit values at the time of Type Approval and subsequent production conformity checks. The concept of Deterioration Factor (DF) is to provide a compensation for the expected deterioration of emission performance over a reasonable lifetime of the vehicle. Vehicle emissions should preferably deteriorate very little over vehicle life, if the concept of a DF based on a lifetime deterioration of 10% or 20% is used.

6.2.1 EU DURABILITY REQUIREMENTS

While evaluating the proposal to enhance the durability mileage, the EU study *(EU 2010) observes* that "the disadvantage of the system is that the manufacturer carries the full burden of guaranteeing that the vehicles fulfill the durability requirements, which means increased compliance costs and longer development programmes. This may thus lead to an increase in the time to market of new products. An additional disadvantage of moving from no durability requirements at present (in Europe) to high mileages may lead to initially uncompetitive products, as extending the mileage in durability testing is costly and time-consuming. This may result in manufacturers requiring more time to bring new products to the market, and the additional cost may be transferred to the consumer. It is clear from the above that any move to increase the present durability requirements will need to be carefully evaluated for its cost-effectiveness and possible adverse impacts on the industry.

Notwithstanding the above, the final report of the EU study on new measures *(Ntziachristos 2009)* observes that "Regulations for durability need to be introduced to effectively control emissions over the useful life of the vehicle. It is today very difficult to estimate the current degradation level of motorcycles but there is evidence that certain models may emit much beyond the emission limits at relatively short mileage after their type-approval". The report, however, laments that there has been no solid information on what is the actual degradation of motorcycles. However, it quotes and analyses the results of two specific studies.

6.2.1.1 THE HONDA STUDY

The first study concerns a Honda motorcycle, which was tested to examine its durability distance by its manufacturer *(Akamatsu 2004)*. A commercially available motorcycle equipped with a water-cooled, in-line 4 cylinder engine of 1100 cc displacement was used for this research The test motorcycle was equipped with an electronically controlled fuel injection system for fuel supply and an oxygen sensor for the feedback control. The exhaust system also consisted of a metal-body 3-way catalyst and the secondary air induction device.

The results of this test (Figure 24) show that over 30000 km the degradation of HC and CO emission is of the same order of magnitude (20-25%). The degradation of NOx is marginal. It is concluded from the above study that powered two-wheelers put a large strain on after-treatment *(Ntziachristos 2009).*

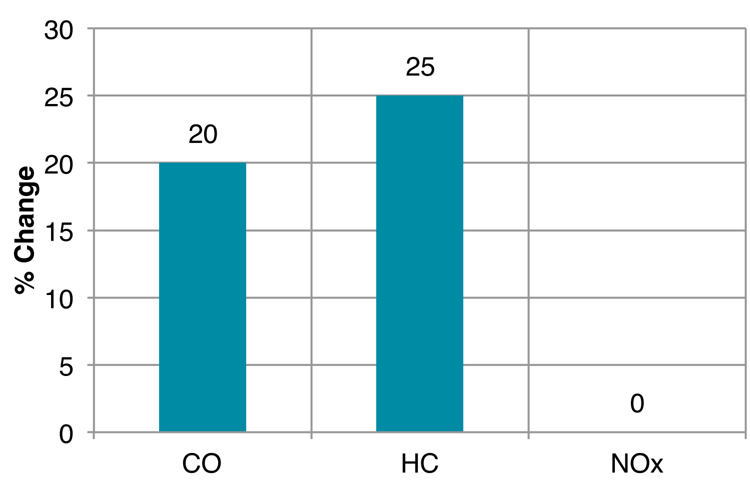


Figure 24: Results on durability from an 1100 cc Honda Motorcycle. Per Cent Increase in Emissions after 30,000km Test on Honda 1100 cc Motorcycle *(Akamatsu 2004)*

6.2.1.2 THE AECC STUDY

The second study quoted in the report referred above concerns the 2008 AECC (Association for Emissions Control by Catalyst) programme which, in addition to measuring the emission level of several Euro 3 motorcycles, also examined the degradation performance of a motorcycle by a far-east manufacturer *(Favre 2009).* The durability test was done on a Euro 3 compliant motorcycle powered by a 500 cc single cylinder engine provided with a closed loop electronic fuel injection, secondary air injection and a catalytic converter. Mileage accumulation was carried out using pump grade 95 RON gasoline. Periodic emissions tests performed at start, 2,000 km, 5,000 km, 10,000 km, 15,000 km and 20,000 km. respectively.

The results of this exercise are distinctly different than results from the Honda study described before. CO emissions exceed the emission standard already after 2000 km of driving. NOx exceed the emission standard after 5000 km of driving and continue to increase over the whole distance (20000 km). In fact, NOx emissions at 20,000 km are more than three times higher than at the beginning of the testing.

Both of the above studies have been performed on technically advanced motorcycles equipped with closed loop fuel injection system and had engines of capacities five to ten times of those of the average Indian motorcycles

Taiwan has been stipulating durability requirements for two-wheelers. The current requirement for all categories of vehicles is 15,000 km *(Taiwan EPA 2007*), which is likely to be revised in stages along with the introduction of OBD also *(Chen 2011).*

It follows from the above that it is necessary to carry out systematic studies in India on the actual durability of emissions to ascertain that the deterioration factors specified are truly representative of the real world conditions. Based on the outcome of the study, a decision can be made about enhancing the durability mileage. The present Indian durability mileage of 30,000 km is among the highest as far as two and three-wheelers are concerned. It cannot, however, be denied that this is very low compared to the mileages prescribed for four-wheeled vehicles. It would, therefore, be appropriate for the above study to explore the possibility of enhancing the durability mileage, say up to 50,000 km.

6.2.2 CURRENT INDIAN DURABILITY REQUIREMENTS

The currently prevailing emission regulations in India for two and three-wheelers provide an option to carry out an ageing test through the stipulated mileage of 30,000km *(MoRTH 2003)* [6]. In case of the option of WMTC cycle and emission limit values for GTR2, the requirements of DF have been built in the mass emission standards *(MoRTH 2010).* According to this provision, a mileage accumulation test is required to be carried out either on the road, test track or chassis dynamometer. Three different test cycles, A, B and C are specified respectively for three classes of vehicles, namely up to 75 cc, between 75 to 250 cc and above 250 cc. For the three-wheelers, cycle A is specified. The cycle consists of eleven laps, with specified speeds for each class. At least five mass emission tests must be carried out, including the first and the last,

[6] Note: This provision remains unchanged in the subsequent notifications namely GSR 84E for BSIII standards.

during the course of the mileage accumulation. The Deterioration Factor (DF) is determined by using a linear function to determine the mass emission values at 2500km and 30000km and dividing the latter with the former. The DF so calculated is used for all engines of the same family. The details of this procedure are given in the TAP document issued by ARAI on behalf of the MoRTH *(CMVR 2011)*.

However, to the best knowledge of the author, no single vehicle has been submitted for the full-scale durability test. The alternative of demonstrating compliance with a lower emission limit value to the extent of the specified Deterioration Factor (DF) seems to be preferred by the manufacturers. The observed emission value of each pollutant, multiplied by the DF, is expected to be within the concerned emission limit value. In effect, this provision amounts to a tightening up of the emission standards.

The author of this report was closely associated with a large number of durability tests that were carried out by the manufacturers in association with the ARAI. The test procedures were derived from the corresponding Taiwan procedures with certain changes in lap speeds to suit the Indian conditions. The findings of this study influenced the proposals for the Deterioration Factors, which are now specified in the emission regulation as alternatives to the full-scale test. Unfortunately, none of the details of the tests and the results are available in public domain.

6.3 MANAGEMENT OF IN-USE VEHICLES

It is expected that the performance of the vehicle both in terms of its characteristics and emissions remains at an optimum level throughout its working life. Though it may be the primary responsibility of the vehicle user to ensure that the vehicle is used and maintained as per the manufacturers' recommendations, it is the responsibility of the manufacturers to ensure that the vehicle is designed for optimum performance throughout a reasonable life. It is also necessary for the authorities to evolve regulations and mechanisms to ensure that the vehicles in use are indeed operating up to their optimum levels. This is usually achieved by a suitable combination of following measures:

- Conformity of Production
- Periodic Inspection of In-use vehicles
- In-use Conformity Testing
- On Board Diagnostics

The status of the above measures in the Indian regulations with particular reference to two and three-wheelers is discussed in this section.

6.3.1 CONFORMITY OF PRODUCTION:

Although this is strictly not a part of the use phase of the vehicle, it has an important impact on the performance of the vehicles during its lifetime. The 'Conformity of Production' – "COP" – system takes care of the need to exercise a control on the vehicle during its mass production phase. The system ensures that the emission performance of the vehicles leaving the manufacturer's premises is consistently maintained in all the production. While the manufacturer may have in-house quality assurance systems, it is necessary to carry out periodic audits by way of full-fledged mass emission tests on sample vehicles. India has a well-defined COP system in place that clearly specifies the detailed administrative procedures *(CMVR 2011).* The Ministry of Road Transport and Highways is the nodal agency for implementation of emission legislation in both its aspects of Type Approval and Conformity of Production.

The nodal agency receives advice on all matters pertaining to the implementation of Emission Legislation in general, and particularly on formulation, monitoring and controlling the policy and actions for Type Approval and Conformity of Production Testing System and Procedures.

Table 27 gives the COP frequency and sample requirements for two and three-wheelers complying with the BSII and BSIII standards. It is seen that the frequency of COP testing is higher for higher volumes of production.

Table 27: Bharat Stage II & Bharat Stage III - COP frequency and samples For 2 & 3 wheelers

Sr Number	Type of Vehicle	Annual Production/ Import		COP frequency
		Exceeding	Up to	
1	Two-wheeler and three wheeler	250 per 6 months	10000 per year	Once every year
2	Two-wheeler	10000 per year	150000 per 6 months	Once every 6 months
3	Two-wheeler	150000 per 6 months	------	Once every 3 months
4	Three-wheeler	10000 per year	75000 per 6 months	Once every 6 months
5	Three-wheeler	75000 per 6 months	-------	Once every 3 months

The testing agencies that are authorized by the government to carry out the Type Approval tests are also responsible for carrying out the physical activity of COP. This involves obtaining a record from the manufacturers about the production volume of the models Type Approved by them, taking random samples of the vehicle from the production lot and subjecting them to the tests as per the laid down procedure. The results of the tests are then passed on to the MoRTH. In case of a failure of the COP tests, the manufacturer is asked to cease production of the concerned model until the nodal agency gives a decision in the matter. There are several conditional options for re-testing usually involving a larger number of sample vehicles and a statistical analysis of the results. In case of failure even after the re-tests, the manufacturer is advised to take corrective action on the vehicle model already sent into the market including a positive recall, if necessary.

It is the experience of the author that the COP procedure is followed quite efficaciously ensuring that all new vehicles comply with the applicable emission standards.

6.3.2 PERIODIC INSPECTION OF VEHICLES

Mandatory periodic vehicle inspection is necessary to ensure that vehicles are properly maintained and they continue to perform optimally in terms of emissions and fuel efficiency. There are several reasons that lead to a rapid deterioration of engine performance over and above the natural deterioration discussed previously in the section on durability. Abuse of the vehicle and neglecting preventive maintenance and use of improper fuels and lubricants are among the main causes for this.

Abuse and Lack of Periodic Maintenance: While the root cause of deterioration of performance may be the inferior quality of the product itself, more often it may be the result of abuse by the customer such as overloading and aggressive driving. Deterioration of emission performance can also be accelerated by missing out on periodic maintenance of the vehicle as recommended by the manufacturer.

Use of Wrong Fuel: Chances of deliberate use of inferior fuel may not be high since most of the two-wheeler users buy petrol from pumps. However, the possibility of the pump fuel being adulterated cannot be ruled out. The subject of adulteration is too vast requiring an independent discussion and, therefore, is not considered in the present report. Besides, much has been discussed and written about this problem that afflicts the entire road transport and petroleum fuels sector.

Use of Wrong or Inferior Lubricating oils: Considering its important role in the smooth functioning of the engine, use of lubricating oil of grade and quality lower than that specified can compromise protection of the engine from wear and tear and corrosion. Users, basically to save on running costs, may be tempted to use cheap inferior oils, which are made from filtered used crankcase oil and do not contain the required additives. There may also be users who are ignorant or are negligent about the importance of using proper oils and leave the choice of oil to the garage, which carries out oil change or servicing.

For a long time, when most of the two and three-wheelers were powered mainly by 2-stroke engines, a severe problem of smoke emission was faced not only due to the use of inferior quality of lubricating oils but also the use of excessive quantities. The latter problem mainly came from a mistaken view among users of vehicles that a higher quantity of oil would lead to a better engine protection *(Badami 2006).* The problem was addressed to a great extent by the introduction of two regulations; one requiring the compulsory supply of 2-stroke lubricant that is pre-mixed with the fuel in all major cities and the other a countrywide mandate requiring the oil to meet the JASO FC 'Smoke Index' requirement *(MoEF 1996)*, *(MoEF 2006).* Lubricating oils with high smoke emission also lead to undesirable deposits in the exhaust system, spark plug and the combustion chamber with adverse effects on emission performance and faster deterioration of catalytic converters.

The problem arising from improper lubricating oils is common to 4-stroke engines also. In addition, lubricating oils for air-cooled 4-stroke engines are specially formulated to conform to JASO MA specification that ensures protection against high temperature operation and clutch slipping. Use of crankcase oils meant for passenger cars can have adverse impact, particularly on fuel efficiency.

6.3.2.1 PRESENT SYSTEM OF PERIODIC VEHICLE INSPECTION IN INDIA

Most countries have instituted a system of subjecting, (preferably) all the vehicles to undergo a periodic inspection for emissions. In some European countries it is a part of the roadworthiness inspection. The test used for this inspection is quite simple, mostly involving a check for CO and HC concentrations in the exhaust at the idling speed. Since the exhaust concentrations of CO and HC at idling cannot give an accurate idea of the emission performance of the vehicle under actual operating conditions, only pass-fail criteria are used to determine the roadworthiness of the vehicle.[7] In India a periodic emission inspection system exists and is known as the PUC – the "Pollution-Under-Control" system.[8] Regulations are in existence for the emission limit values at idle speeds for different categories of vehicles *(MoRTH 2004).* These are summarized in Table 28.

Table 28: Idle Emission Limits for Two and Three-Wheelers driven by petrol/CNG/LPG

Sr No	Vehicle Type	CO %	*HC ppm
1	2&3-Wheelers, (2/4Stroke) Vehicle manufactured on and before 31/03/00	4.5	9000
2	2&3-Wheelers, (2Stroke) Vehicle manufactured after 31/03/00	3.5	6000
3	2&3-Wheelers, (4Stroke) Vehicle manufactured after 31/03/00	3.5	4500

* Normal Hexane Equivalent
The Idling emission standards for vehicle when operating on Compressed Natural Gas (CNG) shall contain Non-Methane Hydrocarbon (NMHC) in place of hydrocarbon (HC) and shall be estimated by the following formula, NMHC = 0.3 x HC, where HC = Total hydrocarbon measured as n-Hexane equivalent.
Similarly idling emission standards for vehicles when operating on Liquefied Petroleum Gas (LPG) shall contain Reactive Hydrocarbon (RHC) and shall be estimated by the following formula, RHC = 0.5 x HC, where HC = Total hydrocarbon measured as n-Hexane equivalent.

The PUC system consists of a large number of independent testing centres mostly in private sector. (Typically, a city like Delhi would have ~400 centres). Many of these consist of a car or a van equipped with the test equipment parked on roadsides. The emission inspection of all two-wheelers every six months is mandatory throughout the country. The vehicle owner is required to carry a 'PUC' certificate whenever he uses the vehicle. Though there are provisions in the law to carry out surprise roadside inspection checks, these are rarely carried out.

---

[7] In most countries, the Periodic Vehicle Inspection also includes checks for safety related parameters such as brakes, lights, horns, etc.

[8] The present Indian system does not include the inspection of safety related parameters for all types of private vehicle such as passenger cars, motorcycles etc. Only an 'Annual Fitness Test" is mandatory for all types of commercial vehicles. Three-wheelers registered for commercial purposes are also required to undergo this annual inspection.

Much has been discussed and written about the shortcomings of the PUC system in India. Some of the important shortcomings include slack enforcement, lack of adequate oversight on the functioning of the test centre, a general lack of professionalism, and lack of public credibility. While these are issues related to the administration of the system, a more important aspect is the ability of the idle tests, assuming they are performed properly, to distinguish between a polluting and a non-polluting vehicle. The present test is based on simple pass-fail criteria with high probability of errors of omission and commission. In view of this limitation of 'idle speed' tests, experts believe that the only sure way of identifying a polluting vehicle is by performing a full-scale mass emission test –like the IM240 in the USA.[9]

6.3.2.2 ARAI LOADED MODE TEST

In this connection, mention must be made of an interesting development carried out by ARAI of a simple loaded mode test suitable for two-wheelers *(Iyer 2007).* The system has recently been granted an Indian Patent 248221 dated 28 June 2011 and is titled: 'Test Set up and Method for Estimating Mass Emissions of In-Use Two Wheelers'. The system consists of a simple chassis dynamometer made up of rollers and flywheels which is adequate to simulate the running of a two-wheeler. A four-gas analyser normally used for the PUC centre is used to analyse raw exhaust gas. The system consists of a Driving Cycle Display and a PC with software for estimating the mass emissions as per in-built algorithms. A schematic view of the system is given in Figure 25.

A speed based signature is developed to estimate mass emissions from raw continuous data after extensive trials on 2-wheelers. Several vehicles have been tested using this set up with encouraging results. The mass emission results obtained on the new system were compared with the mass emission results of the same vehicles tested on the full-scale chassis dynamometer as per the Type Approval procedure. The correlation graphs for CO an HC are shown in Figure 26 *(Marathe M. 2011).*

The figure shows a very good correlation between the values of CO and HC measured by the two methods. The use of this system could certainly give a far better estimate of the emission level of the in-use vehicle. The Committee appointed by the government to formulate the auto fuel policy had strongly recommended further development of this system and to adapt it to the in-use vehicle inspection system instead of using only the idle emission testing *(Mashelkar 2002).* However, no major efforts seem to have gone in that direction. ARAI also does not seem to have pursued further development of the very useful concept.

According to the personal conversation with the ARAI researcher who had conceptualized and developed this system *(Marathe M. 2011),* the system needs to be tried on wider scale by installing a few more setups at select sites, and systematic experience gained under competent supervision. The proving of the system could be accomplished in 6 to 8 months after which it can be introduced on a regular basis. Since this test would be more expensive than the idle

[9] IM240**:** (Inspection/Maintenance) is a shortened version of the Federal Test Procedure (FTP). It is a loaded-mode transient dynamometer test, which measures the mass of emissions collected over a 240 second, two mile driving cycle.

emission test, the validity of the certificate could be enhanced to 1 or 2 years from the current six months.

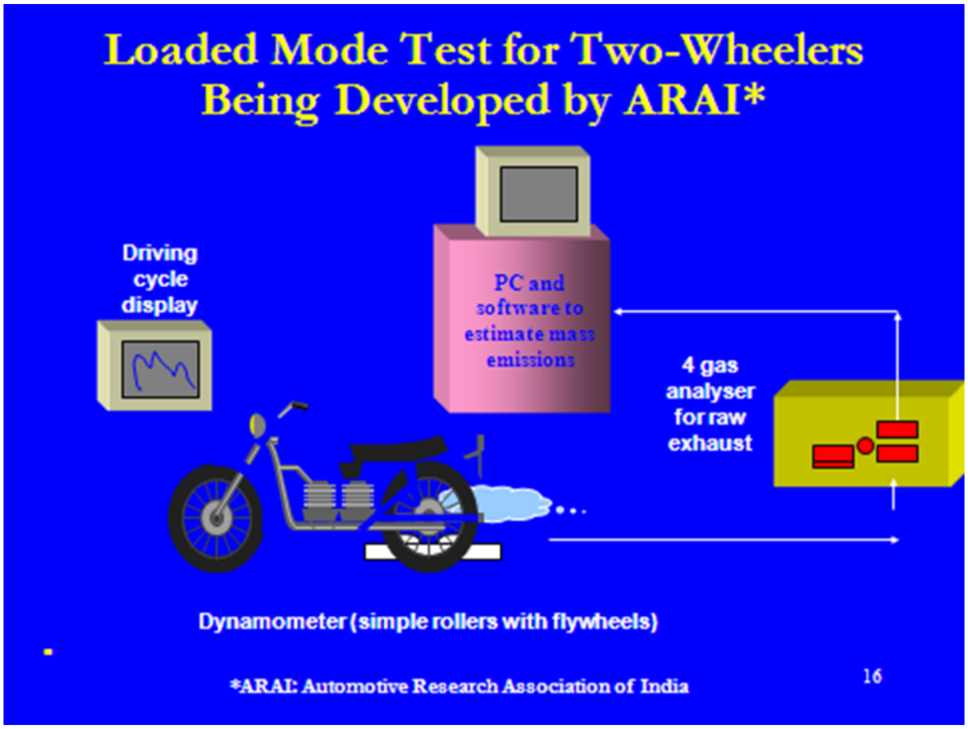


Figure 25: A Schematic Set Up of the Simple Loaded Mode Emission Testing System Developed by ARAI (Courtesy: Automotive Research Association of India)

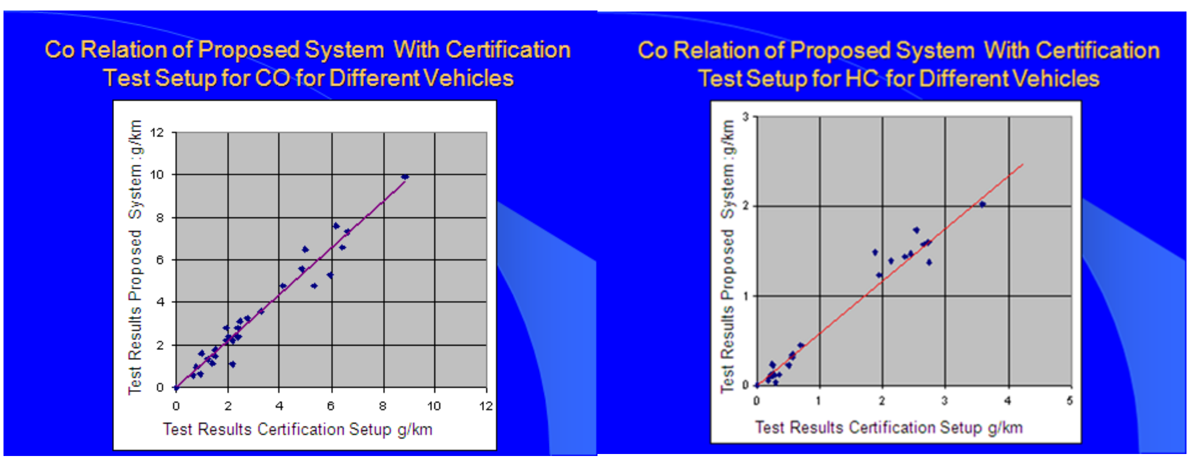


Figure 26: Correlation between the emissions of CO and HC measured on the loaded mode test and the certification testing (Courtesy: Automotive Research Association of India)

6.3.3 IN-USE CONFORMITY TESTING

"In-use conformity testing" (IUC), wherever practised, is established to ensure that the emissions of a vehicle in the real world are kept below the standards for certification. It is conducted by randomly selecting a small sample of vehicles from the road and performing the full type approval test. According to experts *(Ntziachristos 2006)* an in-use compliance programme has a preventive rather than a direct effect. The enforcement of the in-use conformity testing programme compels the vehicle manufacturers to take precautionary measures for compliance. The EU proposal to introduce the in-use conformity testing will be preceded by a comprehensive study latest by January 2016. The study will decide the categories and sub-categories for which it will be made applicable. As per the EU programme *(EU 2010)*

> *"IUC exhaust and/or evaporative emissions could be tested and analysed on in-use vehicles. For this purpose a representative number of vehicles should be selected to perform IUC testing. This representative sample would then be tested under vehicle-emission laboratory conditions and employing testing methods similar to the accurate and advanced methods used to test new vehicles in type-approval demonstration testing.*
>
> *"Ultimately, if a high number of vehicles in the sample failed to comply with the exhaust and/or evaporative emission limits, the vehicle manufacturer could be obliged to recall the vehicles in the field to correct the root cause of the failure. The burden of conducting this type of test would be borne mainly by the vehicle manufacturers and the national authorities. Using IUC testing as instrument to keep vehicle emissions under type-approval limits would be scrutinised. This policy option could be part of the integral approach towards environmental measures to guarantee that the emission performance of a vehicle degrades over vehicle life only up to the defined levels".*

There is no denying the fact that it is necessary to institute regulatory measures to ensure that emissions of vehicles in use do not deteriorate beyond a certain acceptable level. However, there does not seem to be any move towards introducing in-use compliance testing in India for any category of vehicle. A primary barrier to such implementation is the need to build an infrastructure and create an administrative set up that will be required to enforce this regulation. The existing facilities for type approval are almost fully occupied due to the extensive amount of testing for COP which, unlike in Europe, is required to be entirely done by the independent testing agencies like ARAI. Introduction of the in-use compliance testing will require substantial enhancement of the testing facilities.

6.3.4 ON BOARD DIAGNOSTICS (OBD)

According to the EU proposal *(EU 2010)*

> *"On-board diagnostics" is a monitoring system able to identify the likely area of component or system malfunctioning, storing diagnostic trouble codes and environmental information in a computer memory, reporting these upon the request of a generic scan tool and warning the driver of severe functional safety and/or environmental concerns through illumination of the malfunction indicator light on the instrument panel".*

The system will ensue that the driver of a vehicle is informed in case an emission related component suddenly fails or degrades drastically, leading to an inordinate increase in emissions, so that he can take necessary corrective action and ensure that the vehicle is restored to its original condition.

On Board Diagnostic system regulation for four-wheeled vehicles in India has been notified along with the BS IV standards (enforced from April1, 2010) for four-wheelers, which include all M1 and M2 vehicles with less than 3500 Gross Vehicle Weight (GVW), using gasoline and diesel fuelled engines and N1 category vehicles powered by diesel engines. Other vehicles such as N1 vehicles using LPG and CNG and all other vehicles with greater than 3500 GVW will have to be equipped with OBD from April1, 2013.

BS IV standard for four-wheelers has been in force in select larger cities (Delhi, Mumbai, Kolkata, Chennai, Bangalore, Hyderabad, Ahmedabad, Pune, Surat, Kanpur and Agra) from April 1, 2010. The implementation of OBD is to take place in two phases, the "OBD I" which has been done from April 1, 2010 and "OBD II" from April 1, 2013. The "OBD I" is required to have 'the capability of identifying the likely area of malfunction by means of fault codes stored in computer memory' as per procedure laid down (*CMVR 2011*). The items to be monitored by the OBD I on vehicles with positive ignition are oxygen sensor, secondary air injection system, coolant temperature, EGR (if provided), emission control systems/components, circuit continuity for all emission related power train components and distance travelled since malfunction indicator lamp came on. 'OBD II' will, in addition, have to monitor catalyst, misfire, fuel system and fuel tank leakage. For OBD II, the notification also gives the threshold levels of increase in emissions of CO, HC, NOx and PM beyond which the indication must come on.

Application of OBD on two-wheelers that still use carburettors and catalytic converters without any air-fuel ratio control may not serve much useful purpose. It is observed by Ntziachristos et al. *(2006)* that OBD without monitoring the catalyst performance is not very effective. It is, therefore, suggested that introduction of OBD for two and three-wheelers could start with the proposed introduction of BS IV in 2015. Initially it could be made mandatory for all vehicles that use fuel injection or any other electronic control of air-fuel ratio and a catalytic converter using a closed loop control with an oxygen sensor.

It is interesting to note that HMSI, a major motorcycle manufacturer, has introduced a malfunction indicator on model "CBF Stunner PGM FI" powered by a 125 cc 4-stroke engine that uses programmed fuel injection (*HMSI 2011*). This could set the trend in the market ahead of any formal regulation that makes the OBD mandatory for two-wheelers.

6.3.5 SYSTEM USED IN TAIWAN

In addition to being in the forefront of emission control and fuel efficiency regulations for two and three-wheelers, Taiwan has also in place an effective “Life Cycle Emission Control Programme” *(Kamakaté 2009)*. The ‘Environmental Protection Administration of Taiwan (TEPA)’ oversees the entire programme, which, in addition to certification and conformity of production consists of a “new vehicle selective enforcement audit and recall programme”. This involves tests on a certain number of new vehicles taken from the market. Each year, TEPA tests a number of engine family as part of their recall programme. In 2008, ten engine families representing about 50 motorcycle models sold on the island were tested and all passed.

6.3.6 SUMMARY OF SOLUTIONS AND OPTIONS FOR MANAGEMENT OF IN-USE VEHICLES

Several technical and administrative aspects of the measures to manage emissions from in-use vehicles have been discussed in the foregoing sections. The solutions discussed, their current status and recommendations concerning the solution are summarized in Table 29.

From the analysis of the current status of measures already in existence and those that could be considered for implementation, it appears that revamping the PUC system and introduction of the loaded mode test should be taken up on priority. In fact, the loaded mode test may be found adequate even for the in-use conformity (IUC) test, instead of the full mass emission test, thereby making the IUC process faster and more cost-effective. A decision on in-use compliance (IUC) test may be taken after a detailed study. In fact, a more effective loaded mode test and a revamped PUC system may obviate the need to introduce the IUC. The Taiwan experience in this area can add useful inputs while finalizing a similar programme for India.

OBD is unlikely to be useful and effective on vehicles using carburettors. Its introduction may be considered along with the proposed 2015 BS IV emission standards by which time there may be a larger proportion of 2- and 3-wheelers using electronically managed fuel injection systems.

Table 29: A comparative assessment of in-use vehicle emission management solutions

Measure	Current Status	Recommended action
Conformity of Production (COP)	Working satisfactorily	No action required at present
Periodic Inspection (PUC)	Unsatisfactory test method and Poor implementation	Revamp the PUC system (for all vehicles) Finalize the loaded mode test for 2-wheelers and develop it as a regular method of periodic inspection with reduced frequency
In –Use Compliance test IUC	Does not exist for any category of vehicle	A comprehensive study to determine the practical feasibility and the effectiveness Finalize a detailed proposal based on above
On Board Diagnostics OBD	OBD I introduced on four-wheelers from 2010 OBD II in 2013	Consider introducing mandatory requirement on 2-wheelers using fuel injection

6.4 RETROFITTING AND SCRAPPING OF OLD VEHICLES

6.4.1 RETROFITTING

Retrofitting old in-use vehicles with components used in alternative or later technologies is one of the recommended measures to reduce emissions and improve fuel efficiency. Retrofitting catalytic converters on older generation petrol cars and diesel particulate filters on older model vehicles have been successfully carried out in some countries. However, other than the mandated retrofitting of CNG or LPG kits on old auto-rickshaws in Delhi, there have not been any truly successful retrofit programmes for two and three-wheelers in India or in any other country.

The second notable programme reported by GTZ *(2009)* w*as* pursued by 'Envirofit', a not-for-profit organization, in the Indian city of Pune that involved retrofitting old two-stroke engine auto-rickshaws with a 'Direct Injection (DI)' kit in place of the original carburettor. The kit was developed by Envirofit using the DI technology of Orbital Engine Corporation, Australia *(Envirofit 2008)*. According to the GTZ report and a more recent communication from Tim Bauer *(2011)*, the actual results obtained during normal operation of three auto-rickshaws for a period of six months have showed a 35% reduction in fuel consumption, a 54% reduction in oil consumption, a 61% reduction in CO and a 74% reduction in HC+NOx. The programme conducted by 'Envirofit' on tricycles in the Philippines showed similar improvement in fuel efficiency and reduction in CO, Hydrocarbon and NOx emissions.

The main reasons for the low acceptability of retrofit programmes, particularly in the two and three-wheelers sector are the relatively high costs of the replacement parts and the difficult availability of cheap finances to fund the retrofitting programme.

The Delhi programme was successful since it was based on a strict mandate from the Supreme Court of India and was supported by financial incentives by the local Delhi government. Retrofit programmes for auto-rickshaws, mostly using LPG, have been carried out in other Indian cities also, although on a smaller scale, than the Delhi CNG programme. These programmes are being implemented as per the directives of the Supreme Court to various state authorities of selected cities.

6.4.2 SCRAPPING/REPLACING

There are no regulations in India for scrapping of old vehicles that are no more fit for use on road and/or the cost of repairing/upgrading them is prohibitive. The Motor Vehicles Act, however, has a provision that gives the government powers to fix age limits for commercial vehicles. Barring a few exceptions in selected cities and for specific categories of vehicles, this power has never been used to enforce age limits for all commercial vehicles, mainly due to resistance from the stakeholders who are adversely affected. Auto-rickshaw is a commercial vehicle and the government is empowered to fix age-limits for them.

The CNG/LPG retrofit programmes for three-wheelers in different cities are often combined with mandates for the scrapping of old vehicles. For instance, the Supreme Court directive that brought about the large scale introduction of CNG auto-rickshaws consisted of a clear mandate that said, "all pre-1990 (model year) autos (auto-rickshaws) and taxis to be replaced by new ones running on clean fuels effective March 2000." The rules and systems instituted by the Delhi state government to implement the court directive allowed the owner of the pre-1990 auto-rickshaw either to sell it outside the National Capital Territory or scrap it. The government also arranged for financial incentives such as sales tax exemption and interest subsidy on loans. As a result of the above measures, most owners preferred to scrap their vehicles as it gave them an opportunity to get a brand new vehicle under the existing operating permit.

Two other factors that contributed to the success of the Delhi CNG auto-rickshaw programme are the rapid building up of the CNG dispensing infrastructure and the ready availability of superior technology vehicles which, in addition to operating on CNG, were four-stroke and were laced with other features such as self-starter.

The programme of converting existing auto-rickshaws to operate on LPG in some other cities also accompanied by mandates by which the old vehicle of certain vintage – e.g., pre-1991 model year – will not be allowed to ply if they are not converted to operate on LPG by a stipulated date. The programmes in these cities have not achieved as spectacular results as the one in Delhi due to the poor availability of LPG dispensing pumps and absence of attractive incentives.

6.4.3 CONCLUSIONS REGARDING RETROFITTING/SCRAPPING

It would be evident from the above that while it would be beneficial from the points of view of emission and fuel efficiency improvement to enforce regulations that fix age limits for auto-rickshaws and mandate conversion to cleaner fuels such as CNG/LPG, it would be necessary to take several supporting actions such as ensuring adequate supply of the gas and access to attractive financial incentives. Retrofitting solutions for two-wheelers would be far more complex to implement.

7. TECHNICAL SOLUTIONS TO REDUCE FUEL CONSUMPTION

This section deals with the subject of fuel efficiency improvement of vehicles powered by spark ignition engines. In the report on light vehicle fuel economy improvement *(EEA 2007)* it is stated that "improvements to spark ignition engine efficiency have the potential to improve the fuel economy by up to 25 per cent". Engine efficiency can be improved by increasing the thermodynamic cycle efficiency, reducing pumping and throttling loss during normal driving, and reducing internal friction losses from moving parts.

It is stated that "many engine technologies can simultaneously affect two or all three of the above parameters, and combinations of multiple technologies can have substantial overlap in their fuel economy impacts". Many of these technologies have been gainfully deployed on four-wheeled vehicles and some of these may still be in the development phase. However, due to constraints of space, complexity and cost, only a few of these can be practically applied to small two and three-wheelers.

Several of the technical solutions that have been described in the section on pollutant emission control options bring about basic improvements in the engine thermodynamic efficiency by influencing the gas exchange and combustion characteristics. These are described in the following sections with specific reference to fuel efficiency.

7.1 TWO-STROKE ENGINE POWERED VEHICLES:

7.1.1 IMPROVING THE SCAVENGING EFFICIENCY OF 2-STROKE ENGINES

The improvement in the basic efficiency of the engine is measured in terms of 'brake specific fuel consumption - bsfc - in g/kWh. The bsfc values reported by Winkler et al. *(2005)* using different types of fuel introduction systems are summarized in Table 30: It is seen that the high pressure direct injection gives the lowest bsfc both at wide open throttle (WOT) as well as at part load. However, the cost of this system is the highest among the various options considered.

Table 30: Fuel efficiency (bsfc, g/kWh) and Relative Costs of Different Fuel Introduction Systems for 2-Stroke Engines *(Winkler 2005)*

System	WOT bsfc (g/kWh)	Part load (20km/h) bsfc (g/kWh)	System costs, % of standard carburettor 2-stroke engine
High pressure Direct Injection (HPDI)	250-390	450	200%
Air- assisted DI with piston compressor	350-360	550	150-170%
Air assisted DI (electronic air and fuel injection)	290-390	Not available	160-170%
Semi Direct Injection	350-450	700	140-160%
Electronic carburettor	350-450	600	120-140%

7.1.2 AIR ASSISTED DIRECT FUEL INJECTION FOR 2-STROKE ENGINES

In their paper Archer et al. *(2001)* report a 50% improvement in fuel efficiency over the carburetted version on a small two-wheeler of below 50 cc engine capacity. Govindarajan reports a fuel efficiency benefit of 25 to 30% over carburetted engines *(Govindarajan 2005)*. Leighton et al. *(2003)***,** based on their predicted results on IDC test procedure, indicate fuel efficiency improvement of 33 to 40% over the base engine depending upon the type of the vehicle namely scooter, CVT scooter or motorcycle. Though the two-wheelers considered by Leighton et al. meet the year 2000 (BSI) standards, it can be presumed that the per cent improvements by the use of air assisted fuel injection may still be achievable, albeit to a smaller extent. This assumption is based on the premise that the engines continue to use the conventional carburettor and that most of the reduction in emissions was obtained using the oxidation catalytic converter and not due to changes in the engine design to reduce 'engine out' emissions. On the other hand, the air-assisted fuel injection brings about a basic change in the fuel air mixture control, scavenging loss and the combustion process itself. Use of air-assisted fuel injection, therefore, seems to be best available solution to improve the fuel efficiency of the 2-stroke engine powered two-wheelers.

Results of a programme taken up by Envirofit *(2008)* to retrofit a Direct Injection Kit (based on the patented Orbital Air Assisted Direct Injection) developed by them on 2-stroke auto-rickshaws in Pune, Maharashtra also indicate the extent of emission and fuel efficiency benefit that could be obtained from DI compared to the conventional carburettor. As already reported in section 6.4.1, in addition to a significant reduction in emissions, preliminary results showed that fuel efficiency in km/l improved by 36 per cent. Lubricating oil consumption was reduced to half the original value.

7.2 FOUR-STROKE ENGINE POWERED TWO-WHEELERS.

7.2.1 PORT FUEL INJECTION

In this report the port fuel injection was considered as the best solution for 4-stroke powered vehicles to meet the future emission standards proposed for the years 2015 and 2020. The estimates of the fuel efficiency benefits, however, do not show this as the best solution for improving the fuel efficiency of the vehicles. Govindarajan *(2005)* quotes Honda's claim of 6% improvement in fuel efficiency of their four-stroke models in actual driving conditions. In a test programme on three different scooter models tested with different driving cycles, Archer et al. *(2001)* found a 20% saving in fuel consumption with the port injection system relative to the baseline carburetted 4-stroke engine. The baseline scooter, however, appeared to have had a high fuel consumption than their Indian counterparts. The relevant part of the test results given in the paper are summarized in Table 31.

It is seen that port fuel injection has shown a 25% improvement in fuel efficiency over the carburetted version. It must, however, be noted that the fuel efficiency of the base line version is inferior to the fuel efficiency of scooters currently being sold in the Indian market. The average fuel efficiency of typical scooters powered by 125 cc 4-stroke engines is 41km/l as per the road test results published by Bike India *(2011).* This may lead to the conclusion that no specific improvement in fuel efficiency may be obtainable by switching over to port fuel injection on 4-stroke engine powered vehicles. Leighton et al. *(2003)* based on their predicted results on IDC test procedure indicate fuel efficiency improvement of approximately 3 to 8.5% over the baseline vehicles depending upon the type of the vehicle namely scooter, CVT scooter or motorcycle.

Table 31: Emission and Fuel Economy of a 4-Stroke Engine Scooter with Carburettor and Port Fuel Injection (IDC Tests) *(Archer 2001*)

Model	Fuel System	HC (g/km)	CO (g/km)	NOx (g/km)	HC+NOx (g/km)	Fuel Economy Km/l
Large 4S (150 – 200 cc)	Carburettor (baseline)	0.90	9.59	0.1	1.00	32.0
	Port Fuel Injection	0.56	1.21	0.22	0.78	40.0

7.2.2 HONDA PROGRAMMED FUEL INJECTION, OR 'PGM-FI'

This introduction by Honda has already been described in the section on emission control technologies as a major breakthrough towards advanced emission control on small engines. In the context of fuel efficiency improvements of small two wheelers, it is worth noting that Honda claims approximately 7% better fuel economy in 30km/h steady speed test mode, and approximately 10% better fuel economy in a test mode designed to simulate actual city driving conditions.

7.2.3 EXPERT VIEWS ON PORT FUEL INJECTION

Many experts also agree that the fuel economy gains with port fuel injection on current Indian 4-stroke two-wheelers would be marginal. Ahern *(2011)* feels that around 10% fuel efficiency gain was perhaps achievable on earlier Indian models of two-wheelers – those meeting the year 2000 (BS I) emission limit values. However compared to typical Indian 2-wheelers which has lower BMEP and has carburettor calibrated lean for fuel economy, the fuel efficiency gain might only be 2 to 4%, making it harder to justify the additional cost of the Electronic Management System (EMS) system. Duleep *(2011)* wonders whether the measured fuel efficiency on a new vehicle with port fuel injection will show significant improvement over a modern carburettor with an acceleration enrichment pump. It might, however, help the stability of emissions and fuel efficiency with vehicle age. Govindarajan *(2011)* also believes that the port fuel injection on four-stroke engines may not give any fuel efficiency benefit. Pundir *(2011)* believes that fuel efficiency benefit of 4 to 10% may be realized by using port fuel injection on 4-stroke engine powered two-wheelers arising from a more precise control of the air-fuel ratios required to meet the future tighter emission regulations. Marathe *(2011)* agrees with Pundir saying that with fuel injection one could expect a better control on fuelling thus reducing the variability in mass production. It may not have any significant effect on fuel consumption since the Indian designs are already so much optimized. However, variability could still be improved. Main point will be cost, which will decide the future. David Raney *(2011)* also feels that port fuel injection has not yet seen significant/high volume penetration on smaller more fuel efficient products such as scooters or machines less than 250 cc engine displacement primarily due to cost. He, however, feels that "without government fuel economy requirements or a standardized test procedure in place historically in the U.S., manufacturers have lacked the pressure point to build more fuel efficiency into their product."

7.2.4 PERFORMANCE OF 4-STROKE MODELS WITH FUEL INJECTION ALREADY IN THE INDIAN MARKET

We have seen before that certain models of 4-stroke engine powered motorcycles have been introduced featuring fuel injection. Table 32 gives the fuel efficiency of these models compared with their original carburetted versions.

Table 32: Comparative characteristics and fuel efficiency (km/l) of variants of Indian motorcycles using carburettors and fuel injection

Model Name (all 4-stroke models)	Engine Capacity (cc)	Declared Fuel Efficiency (IDC) (Km/l)	Difference Between Carb and FI Versions (%)	Reported Fuel Efficiency (on road) (Km/l)	Difference Between Carb and FI Versions (%)
Hero Honda Glamour	125	81.1		72.74	
Hero Honda Glamour F1	125	85.8	+5.8%	80.75	+11%
TVS Apache RTR	159.7	60.1		50	
TVS Apache RTR EFI	159.7	Not available	Not available	55	+10%
HMSI Stunner CBF	124.7	70.3		61	
HMSI Stunner CBF FI	124.7	70.9	+0.85%	66.6	+9.2%

The data regarding the 'reported' on-road fuel efficiency in Table 32 was obtained from information published by Bike India *(2011).* These values are based on actual on road testing done by the magazine staff and are more representative of the fuel economy the customer is likely to get in real terms. The values of 'declared' fuel efficiency are based on those determined during the Type Approval test done by the authorized testing laboratory such as the ARAI. Based on the data supplied by the manufacturers these values are published by SIAM on their website *(SIAM 2011).* The 'declared' values are meant to guide the consumers by providing comparative data of different models of different manufacturers on a common basis. As can be seen, the 'declared' values seem to be higher than the reported values.

It is seen that the fuel efficiency improvement due to the incorporation of fuel injection varies within a wide range with a minimum of less than 1% to about 6%. Quite interestingly, the fuel efficiency improvement based on the 'reported' values seem to be higher – from 9 to 11% - and are also more consistent among the various models.

7.2.5 PROSPECTS OF USING GASOLINE DIRECT INJECTION ON TWO-WHEELERS

Direct gasoline injection is the generic term applied to worldwide development in “jet directed”, “wall directed” or “air directed” mixture formation systems. Mitsubishi were the first to commercialize this technology and register the name “Gasoline Direct Injection - GDI”. In this engine, petrol is injected directly into the cylinder with precise timing by operating in two modes – Ultra Lean Combustion mode and High Output mode. The GDI engine management system provides for very lean mixture at low loads and rich mixture for full load and suitable mixture enrichment for transient operation. GDI system achieves complete combustion even at air-fuel ratios of up to ultra-lean level of 40:1. The engine is capable of using higher compression ratios, up to 12.5:1.Govindarajan *(2005)* reports fuel efficiency improvement of nearly 20%.

Although GDI has so far been developed mainly for larger passenger car engines, Orbital has been working on using the system on a single cylinder motorcycle engine. Their testing has shown that the technology is transferable to smaller engines too *(Leighton 2003).* Orbital’s prediction using a simulation of the likely results over the IDC test cycle show fuel efficiency improvements ranging from 13% to 16% depending upon whether the vehicle is a scooter, a CVT scooter or a motorcycle. Steven Ahern (*2011)* observes that with Direct Injection there will be additional costs compared to the air assisted injection. In the former, the main components are the air pump and the air injector. On the other hand, direct injection requires the addition of more expensive fuel injector, mechanical fuel pump and typically higher voltage injector driver. Duleep recommends that the direct injection lean burn technology like the one pioneered by Orbital could offer significant benefit at low speeds and idle, which are typical conditions for Indian driving. The technology can also allow reductions in NOx emissions without the need for a 3-way catalyst *(Duleep 2011).*

A wide variation is observed in the values of fuel efficiency benefits reported in various researches and reports by using different types of fuel injection systems. These have been presented in a consolidated manner in Table 33.

7.2.6 CONCLUSIONS ON THE TECHNOLOGY OPTIONS TO REDUCE FUEL CONSUMPTION

It can be concluded from the above that air assisted fuel injection is perhaps the best suited solution for 2-stroke engines to reduce emissions to levels proposed for BS IV and BSV as well as improve fuel economy significantly, say 25 to 30%. As regards the 4-stroke engines, port fuel injection, in combination with suitable after-treatment systems, may be the most cost-effective solution to meet the proposed future emission limit values. Adopting the port fuel injection will enable a finer control of the air-fuel ratios leading to several benefits such as a higher conversion efficiency of the after-treatment devices, a more consistent engine performance, and improved stability and durability. However, the fuel efficiency gain over the already efficient Indian two-wheelers may be marginal around 5 to 10% depending upon the model. Gasoline Direct Injection application to small engine seems to be technically feasible but high cost is a major factor. However, higher cost may get partly compensated by the 15 to 20% fuel efficiency improvement that seems to be achievable.

Table 33: Consolidated Results of Fuel Efficiency Benefits from Different Fuel Injection Systems

Source/Reference	Engine Type	Fuel Efficiency Improvement (%)	Nature of Estimate
Air Assisted Fuel Injection Used in 2-Stroke Engines			
Envirofit Retrofit Kit *(Bauer 2011)*	Bajaj Auto 3-wheeler	36	Preliminary results of actual measurements
(Archer 2001)	50 cc engine	50	IDC tests
(Leighton 2003)	Various Indian vehicles	33 - 40	IDC prediction
(Govindarajan 2005)	Not specified	25 - 30	General estimate
Port Fuel Injection Used in 4-Stroke Engines			
Hero Honda Glamour FI *(Bike India 2011)*	125 cc engine	11	Actual road conditions
TVS Apache RTR FI *(Bike India 2011)*	160 cc engine	10	Actual road conditions
HMSI Stunner CBF Fi *(Bike India 2011)*	125 cc engine	9.2	Actual road conditions
Honda (Claim)	All Models	6	Actual driving conditions
(Archer 2001)	150-200 cc engines	20	IDC tests
Honda Programmed FI	All Models	7	Steady speed
	All Models	10	Fuel economy test cycle
(Leighton 2003)	Various Indian vehicles	3 – 8.5	IDC prediction
(Ahern 2011)	Indian low bmep lean engines	2 - 4	General estimate
(Pundir 2011)	Not specified	4 - 10	General estimate
Gasoline Direct Injection Used in 4-Stroke Engines			
(Leighton 2003)	GDI Technology	13 - 16	IDC prediction
(Govindarajan 2005)	GDI Technology	20	General estimate

7.3 A REVIEW OF OTHER ADVANCED SOLUTIONS DEVELOPED FOR LARGER ENGINES TO IMPROVE FUEL EFFICIENCY

Several advanced technological solutions are being developed for passenger car and other four-wheeled vehicles to improve the fuel efficiency. Though many of these cannot be adopted on small two-wheeler engines, efforts are being made to apply these concepts to small engines also. A brief overview is given here.

7.3.1 VARIABLE VALVE TIMING AND LIFT – BAJAJ AUTO/IIT (MADRAS) DEVELOPMENT

Historically most spark ignition engines use fixed valve timing and lift which do not change with load and speed. It is well known that closing the intake valve early at light loads significantly reduces pumping losses and increases fuel efficiency since less engine power is lost in the intake process. This can be achieved by using Variable Valve Timing (VVT), also known as cam phasing. A single phaser installed on either the exhaust or intake camshaft can vary valve opening time relative to piston position. More than 10 per cent of passenger car models sold in India employ variable valve timing. Due to the challenge of installing complex mechanisms involving hydraulic and electronic systems, VVT is not being used on small engines. In this context, note must be taken of the recent development by Bajaj Auto and IIT Madras of a novel, fully mechanical, simple, compact and cost effective variable valve timing system suitable for small two-wheeler application *(Sheth 2006)*.

The system uses flyweights to exert a force on a cam, which floats on a shaft against a spring. The movement of the cam is axial and rotational due to helical grooves on the shaft. The system could start retarding the cam phasing after a predetermined speed. This is a simple system that is easily adaptable to small engines. The variable valve systems used on car engines are not easily adapted to small engines since they use hydraulic or electrical systems for their operation. On account of the continuously changing valve timing in a range of speeds, the developed system gave 8 to 10% higher power output, torque and higher volumetric efficiency at all speeds. The mass emissions of the engine appeared to have reduced by small amounts though the NOx increased marginally in the IDC testing. The IDC fuel efficiency increased from 67km/l to 70km/l – an improvement of 4.5%. On an actual road test, a fuel consumption gain of 5 – 7% was obtained. This research demonstrates the possibility of developing relatively simpler systems of VVT that may suit the requirements of low complexity and low cost imposed by small engines.

7.3.2 ENGINE FRICTION REDUCTION

The reduction of engine friction is an on-going effort. The level of friction in an engine is measured in normalized terms as friction mean effective pressure (FMEP). FMEP may constitute about 18 to 20% of the brake mean effective pressure at wide-open throttle. Major components that contribute to friction are, in order of importance, pistons and piston rings, valve train components, crankshaft and crankshaft seals, and the oil pump. Considerable work has gone into the design of these components to reduce friction and significant friction reduction technology is usually incorporated into modern engine designs. Various technologies are available to reduce engine friction *(EEA 2007)***.** Major Among these are:

- low mass pistons and valves
- reduced piston ring tension
- reduced valve spring tension
- surface coatings on the cylinder wall and piston skirt
- improved bore/piston diameter tolerances in manufacturing
- higher efficiency gear drive oil pumps

As a result of many of these friction-reducing technologies, auto-manufacturers have delivered total friction reduction of around 8% to 10% per decade, which is also the design lifecycle of most engines. About 20% to 25% reduction in FMEP is possible with further technology development at relatively low costs for engines that were redesigned in the 1996-2005 time frame. These technologies include dimpled pistons and piston rings (through shot peening), offset crankshafts for inline engines, piston coatings, and plasma metal sprays on cylinder bores. Steven Ahern *(2011)* seems to agree with Duleep, and feels that there have been some significant gains made over the last 10 to 20 year in spark ignition engines, particularly in the 4-stroke engines, and that it will be possible to get much more fuel economy out of them. Fiat has recently introduced the “multiair” engine that controls the airflow into the engine via valve timing and valve lift *(FIAT 2011).* Since there is no throttle body there is an improvement in pumping work. However, cost and complexity will be an important consideration.

Honda R&D Company has reported about their efforts to improve fuel economy of prototype single cylinder gasoline engine of 125 cc displacement by reducing friction and improving combustion *(Iijima 2009)*. Various solutions were employed to reduce friction that involved enhancement of the oil film retention by modifying the striation finish on piston skirt, adding the needle bearing to the rocker arm shaft, press-fitting the bush into the small end of connecting rod, reducing contact pressure with the piston ring, and spray coating molybdenum disulphide onto the shift fork. By applying these friction-reduction methods, the friction of the engine was reduced by 6% compared to the previous model, which was already employing the roller rocker arm and the offset cylinder. For improving combustion, the swirl control valve (SCV) was installed into the intake port by which both engine power and combustion under low load were improved. As a result, the fuel economy in ECE40 mode was improved by 7%, and the maximum power was improved by 8% compared to the previous model.

Friction reduction efforts need not be restricted by size of the engine. The only constraint might be cost. A formal effort is required on the part of the manufacturers of motorcycles. In this context, notice must be taken of the announcement made by Bajaj Auto last year about the launch of the world’s most fuel-efficient motorcycle. A distinguishing feature is the use of “Molykote” piston for reduced friction and improved engine efficiency *(India Automotive 2009)*.

7.3.3 IMPROVED LUBRICATING OIL FOR BETTER FUEL EFFICIENCY

In addition to reducing friction, lubricating oil also helps to limit wear and tear of moving parts, protect engine parts against corrosion and cooling the engine. It is the effect of lubricating oil on engine friction that impacts fuel economy. One way the lubricating oil reduces friction is in the hydrodynamic condition in which it separates the opposing metal surfaces and prevents metal-to-metal contact. In the boundary condition, the friction modifying additives in the lubricating oil alter the mating surfaces to reduce the friction losses occurring due to metal-to-metal contact. For instance the hydrodynamic condition exists in connecting rod big end and crankshaft main bearings whereas the boundary condition exists in the contact between the piston and the cylinder and between the cam and the follower.

Lubricating oils are designed to reduce friction losses from both types of lubrication, namely hydrodynamic and boundary, by tailoring the viscosity characteristics of the base oil and the formulation of the friction-modifying additives.

Viscosity rating of the lubricating oils, in terms of the SAE grades, is a primary characteristic that affects fuel economy. Friction modifying compounds are the second major factor affecting fuel economy. Additional fuel economy related specifications for oils have been developed by ILSAC (The International Lubricant Standardization and Approval Committee) that has a 'GF-3' rating for fuel-efficient oils, to account for all the above properties of oils.

Lubricating oils for small engines used in motorcycles are quite different from those for passenger car engines, particularly in respect of the additive formulations. Again, oils for 2-stroke engines are different from those for 4-stroke engines. The differences arise primarily from the significant differences in the lubrication systems of the two types of engines. In a 2-stroke engine, the lubricating oil is supplied along with the air-fuel charge either by pre-mixing it with the fuel or by means of a separate pump. The lubrication system is an all-loss system since the oil enters and leaves the engine along with the air-fuel mixture. This requires the oil to have good burning properties, as it manifests its quality in the exhaust stream as smoke. The good burning quality is ensured by ascertaining that the oil has an adequate 'Smoke Index' as defined in the Japanese specifications (JASO FA, FB and FC) of 2-stroke lubricating oils as a measure of the burning quality and the resulting smoke emission level of the oil. The 2-stroke oils that conform to JASO specifications are required to have a certain minimum 'smoke index' indicating their smoke emission characteristics. JASO FC has the highest 'smoke index' representing the least smoking oil. Synthetic oils generally have better burning quality. The 2-stroke lubricants do not seem to have any specific influence on the fuel efficiency of the engine.

The lubricating oil for the 4-stroke motorcycles, though essentially the same as its counterpart for four-wheeled vehicles, has certain major differences. Since motorcycles normally have transmission gears and a wet clutch system inside the crankcase, the gear lubricity and clutch friction performance are additionally required for motorcycle engine oils. Motorcycle engine oils are also required to face more severe condition than passenger car engine oils. For instance, most of the motorcycles in India are draft air cooled which requires that oil has lower volatility at higher temperature conditions, higher shear stability, anti-wear performance and gear pitting toughness *(Watanabe 2010).* The characteristics that the 4-stroke motorcycle engine oil must possess in addition to all those required for the passenger car engine oils are shown in Table 34. It is seen that better lubricity for gear protection and high friction for good clutch performance are important.

Table 34: Essential Characteristics of Motorcycle and Passenger Car Engine Oils

Motorcycle Engine Oils	Passenger Car Engine Oils
Detergency	Detergency
Dispersancy	Dispersancy
Oxidation Stability	Oxidation Stability
Anti-Wear Performance	Anti-Wear Performance
Rust Prevention	Rust Prevention
Low Volatility	Low Volatility
Fuel Efficiency	Fuel Efficiency
Lubricity for Gears	-
Clutch Performance	-

The fuel efficiency of passenger car engine oils has been improved through lower viscosity and use of friction modifiers. However, engine oils containing friction modifiers such as molybdenum compounds cannot be used in oils for four-stroke motorcycles, because motorcycles normally have a wet clutch system inside the crankcase and such engine oils can decrease the clutch capacity. The performance levels of four-stroke engine oils are specified in JASO T904 *(JASO 2006)*. The oils are classified into two basic grades, MA and MB, with further classification of MA grade as MA1 and MA2. The characteristics related to friction properties are summarized in Table 35. MB oils are classified as lower friction oils than MA oils. MA is used for applications in need of higher friction properties.

Table 35: Performance Classification Based on Friction Indices of JASO T-904

Evaluation Item	Standard Index	
	MA	MB
Dynamic Friction Index (DFI)	1.45 or greater	less than 1.45
Static Friction Index (SFI)	1.15 or greater	less than 1.15
Stop Time Index (STI)	1.55 or greater	less than 1.55

Studies carried out by Idemitsu Kosan Co., Ltd *(Kasai 2006)* have shown that certain compounds, such as polybutenyl succinimide borate, used as detergents or dispersants, showed a high friction coefficient for wet clutches. As a result of extensive testing of various formulations, the researchers could find a formulation of fuel saving 5W-30[10] engine oil containing Molybdenum compounds that can cope with both fuel efficiency and clutch capacity.

In response to a query, Seok Chen *(2011)* informed the author that "Honda has actively promoted the use of 10W30 SAE grade to be adopted to achieve fuel economy since 2005. Honda has shown fuel savings of 5% to 8% with a10W30 oil versus conventional 20W40 oil. Although the lower viscosity will improve fuel economy, the lubricant needs to be formulated with high quality base oil to avoid excessive evaporation (consumption) and with highly shear stable viscosity modifier to ensure stay-in-grade viscosity. Some OEM's choose to recommend 10W40 instead."

Four-stroke motorcycle lubricating oils conforming to the JASO MA grades are being sold in India. For instance, Indian Oil Corporation markets several grades of 4-stroke lubricating oils such as 'Servo 4T' and 'Servo 4T Zoom'. It also markets a brand named 'Servo 4T Goben' which is a high performance 4 stroke engine oil formulated with highly refined base oil fortified with tailor made additives to meet the requirement of Honda Japan for their motorcycles. 'Servo 4T Goben' of SAE 10W-30 grade conforming to API SJ / JASO MA, is claimed to provide a substantial fuel economy benefit in comparison to conventional four-stroke engine oils.

The situation regarding a standardization of these oils in India is not clear. It would be worthwhile if the Bureau of Indian Standards were to issue standards essentially adopting the JASO classification of 4-stroke lubricating oils and the same were to be mandated for production, import, sale and use in four-stroke motorcycles in India. This will help to prevent the use of inferior or unsuitable oils. A similar mandate was earlier issued by the Ministry of Environment & Forests for 2-stroke lubricating oils conforming to the smoke index of JASO FC grade *(MoEF 1996, MoEF 2006).*

7.3.4 ROLLING RESISTANCE

Vehicle rolling resistance depends on vehicle weight and the coefficient of friction between tires and road at a given speed. The friction coefficient varies with the tire material, tire width and inflation pressure. Reducing the friction coefficient can reduce rolling resistance and thereby lead to improved fuel efficiency. However, drastic reduction in friction coefficient also results in loss of tire grip to road giving rise to safety concerns. Pundir *(2008)* observes that an improvement of 1 to 1.5% in fuel economy can be achieved through reduction in rolling resistance, especially for the larger vehicles like 'Multi-Utility Vehicles (MUV)' and Sports Utility Vehicles (SUV). There is no information available on efforts to reduce rolling resistance of tyres used on two and three-wheelers. In India, according to the Automotive Tyre Manufacturers' Association (ATMA) "tremendous work is being carried out towards the development of tyres with modified special compounds, besides tyre construction aspect, to reduce rolling resistance

---

[10] 5W-30 stands for the SAE Viscosity Grade Classification for a multi-grade oil. The first part of the grade ("5W") refers to the oil viscosity when cold ("W" signifies winter grade). The lower this number, the less viscous is the oil at low temperatures. Oil viscosity at low temperature affects engine starting ability; less viscous oils makes cold starts easier. The second part ("30") refers to the oil viscosity when hot. The higher the number, the more viscous is the oil at high temperatures that provides better lubrication and reduces friction. Depending upon the low temperature and high temperature viscosities of oils, there are several multi-grade oils such as 5W-20, 10W-20, 10W-30, 10W-40, 20W-40 etc.

thus gaining in fuel consumption. However, the ultimate advantage is obtained by Radial Construction which is gradually finding its well-deserved place in Indian Industry" *(ATMA 2011).* However, no further information could be obtained from ATMA on the status of these efforts and the extent of fuel efficiency gain. It is felt that it would be worthwhile for tyre and vehicle manufacturers to work together on this aspect.

7.3.5 SMART STOP AND START

Stop- Start technology is a system that shuts off the engine when vehicle comes to full stop and restarts the engine when the driver taps the accelerator pedal. These systems have potential of improving fuel economy of cars by 5% to 8% and reducing simultaneously the idle emissions. 'SISS (Smart Idle Stop System)' have been developed that make the engine to stop at mid-piston stroke so that minimum restarting torque is required. SISS reduced fuel consumption by 8% on ECE 15 cycle *(Pundir 2008).*

These technologies are more easily adopted with the use of starter-generator systems like BAS (Belt driven Alternator-Starter) or integrated starter-generator machines. The application of the solution on small motorcycles seems to be difficult. Anecdotal information is that this system was tried out on one model of a scooter but did not receive a favourable response from the users.

It is learnt that Mahindra and Mahindra, a relatively new entrant in the two-wheeler market in India, has recently developed and patented a battery charging system for one of their scooter models that can help conserve fuel whenever the scooter is idling at traffic signals. The technology, named 'Micro Hybrid', is claimed to lead to a 5 per cent improvement in mileage *(Zigwheels 2012).*

7.3.6 TECHNICAL SOLUTIONS TO IMPROVE FUEL EFFICIENCY OF SMALL DIESEL ENGINES

Diesel engines are inherently more fuel-efficient than petrol engines due to their higher thermodynamic efficiency (measured in terms of brake specific fuel consumption) resulting from higher compression ratios and the absence of throttling. According to Pundir *(2008)* gasoline engines have more potential for fuel efficiency improvements compared to diesel engines. In addition, automotive diesel engines have already achieved high levels of fuel economy by going to direct injection (DI), adopting 4-valve technology and turbochargers. It is estimated that the gasoline engine has a 30 to 40% potential for fuel economy improvement over the standard stoichiometric, 4-valve engine employing port fuel injection. Switching over from petrol engine to diesel engine is, therefore, considered as one of the solutions to gain fuel efficiency and reduce CO_2 emissions.

7.3.6.1 CHANGE FROM IDI TO DI AND HSDI

Engines using Indirect Injection system (IDI) would benefit by changing over to Direct Injection (DI) system. The possibility of converting an existing engine from IDI to DI would depend upon various other design considerations such as technical feasibility, space etc. Though Direct Injection (DI) engines are more fuel-efficient than Indirect Injection (IDI) engines, they are not able to operate at high speeds. The modern High Speed Direct Injection (HSDI) engines are now finding application in many European automobiles. HSDI engine is 10 to 15 per cent more fuel efficient than IDI engines. In case of the three-wheelers, the Bajaj vehicle uses an IDI engine with a patented combustion system that gives an advantage in emissions. It is not possible to say whether the same engine will be able to meet the future emission limits without sacrificing fuel efficiency.

7.3.6.2 OTHER SOLUTIONS SUCH AS MULTIPLE VALVES, TURBOCHARGING ETC

Automotive diesel engines use multiple valves to gain 3 to 5 per cent improvement in fuel efficiency. Although not impossible, this may be difficult to apply to small engines due to lack of space in the cylinder head. Similarly turbocharging with intercooling can boost power output and give a 3 to 7 per cent fuel efficiency benefit. However, this may also not be a feasible solution for a small engine. Advanced technologies such as Common Rail Diesel Injection (CRDI) technology may also prove too costly and complex to be applied on small engines. The small engines may have to explore solutions involving optimization of combustion, automatic ignition timing device, friction reduction through improved materials and better lubricating oils, improved air filters etc.

8. AN ANALYSIS OF FUEL EFFICIENCY PROFILE OF CURRENT INDIAN TWO-WHEELERS

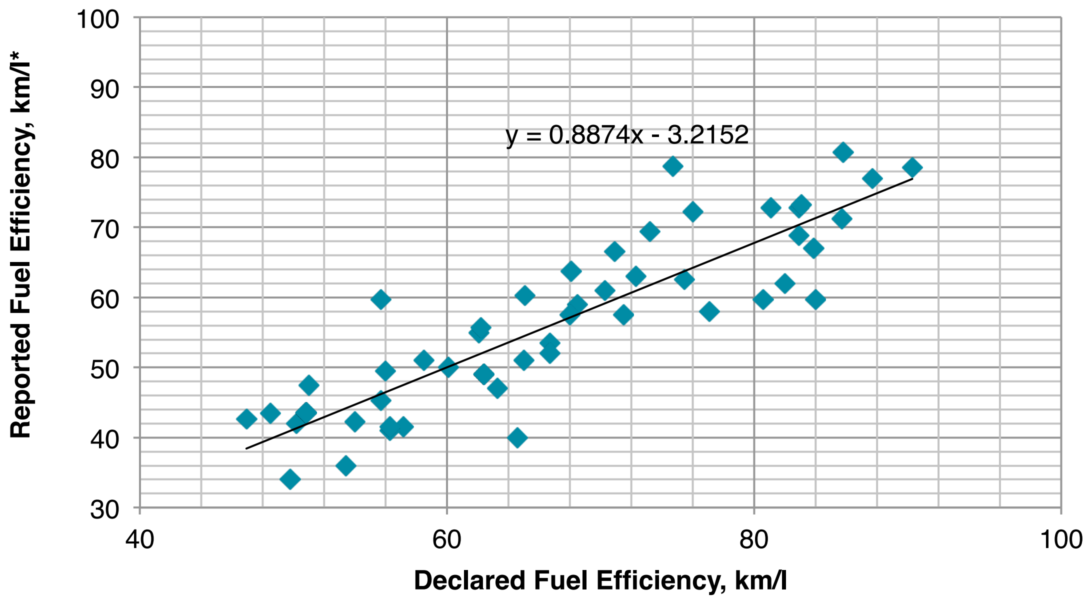
8.1 SOURCES OF DATA ON FUEL EFFICIENCY AND OTHER SPECIFICATIONS

Two main sources of data on fuel efficiency and other broad specifications of two-wheelers currently sold in the Indian market are available. One of these is in the website of SIAM which lists the fuel efficiency of two-wheelers declared by the manufacturers based on the value obtained at the time of type approval of the model *(SIAM 2011).* The fuel efficiency values are computed in km/l using the mass emission values of CO_2, CO and HC using a carbon balance method specified in the Type Approval test procedure *(CMVR 2011)*. The values are listed in an increasing order of the vehicle kerb weight. Data on engine capacity (cc) is also included. This is a part of a voluntary initiative by the manufacturers for the benefit of the consumers so that the prospective buyers could make an informed decision while selecting the product. While this data provides an accurate comparison of fuel efficiency of different models, it would not give a clear idea about the actual on-road fuel efficiency, which the user is likely to get.

Various magazines devoted to cars and two wheelers publish information regarding the broad technical specifications of various vehicle models of all Indian manufacturers. In addition, these magazines also give the prices of the vehicles. Some of the magazines have competent personnel who carry out tests on the various models after they are introduced in the market. The tests usually consist of measurement of fuel consumed when the vehicle is run under actual road conditions, which comprise the city, rural, and highway. Of course, the test reports consist of various other details regarding design features, style, acceleration, braking, lights etc. In the present report, values of fuel efficiency and other data published by a magazine by the name of 'Bike India' were used *(Bike India 2011).* The fuel efficiency value declared by the manufacturers is termed as the 'Declared' value and that obtained from the magazine is referred to as the 'Reported' value.

8.2 ANALYSIS OF THE FUEL EFFICIENCY DATA OF TWO-WHEELERS

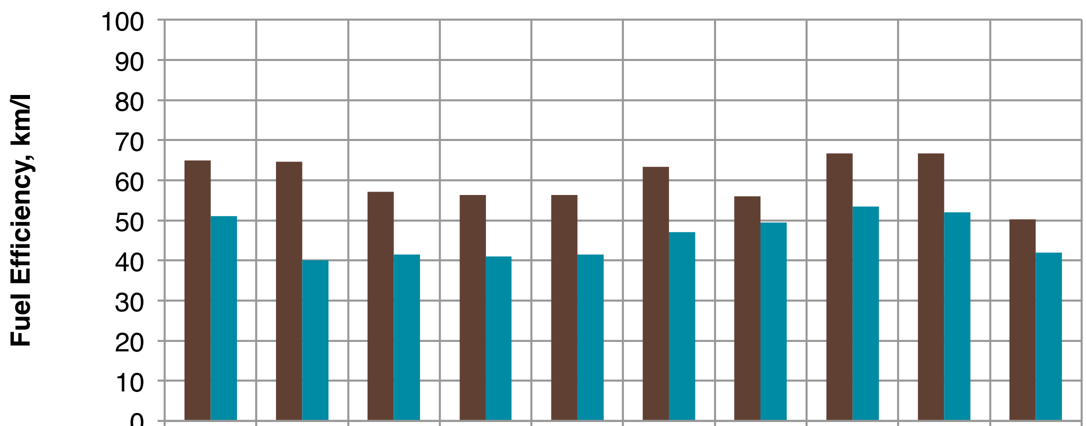
Figure 27 shows the correlation between the Declared and the Reported fuel efficiency values of 53 vehicles for which data could be obtained from both of the sources. It is observed that the 'Declared' value is higher than the 'Reported' value almost in all cases. This is understandable considering that the 'Reported' value is obtained by running the vehicle on road whereas the 'Declared' value is obtained from a chassis dynamometer test using the IDC.



*Reported values based on Road Test Data Published in "BIKE", April 2011

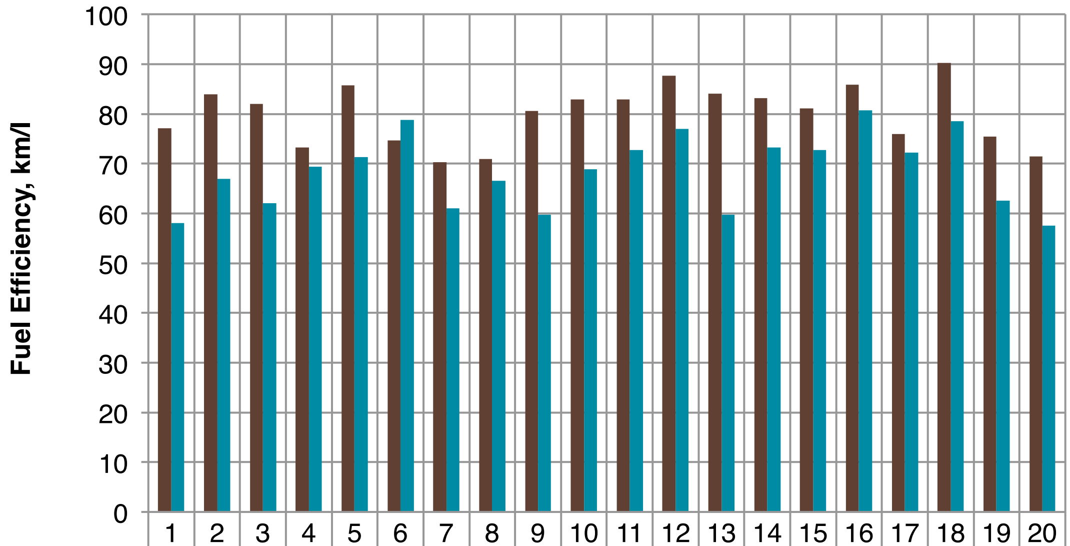
Figure 27: Correlation Between the 'Declared' and the 'Reported' Fuel Efficiency –Two-Wheelers

Figures 28, 29, and 30 respectively are graphical representations of the Declared and Reported fuel efficiency of Scooters of 75 to 125 cc, Motorcycles of 75 to 125 cc and Motorcycles of 125 to 250 cc capacity respectively.



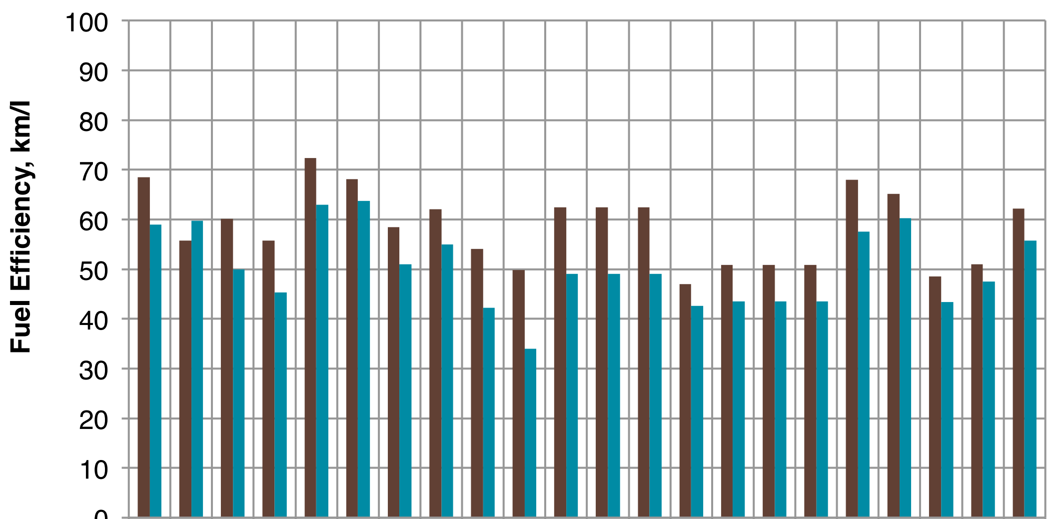
	1	2	3	4	5	6	7	8	9	10
Declared	65	64.6	57.18	56.3	56.3	63.3	56	66.7	66.7	50.22
Reported	51	40	41.5	41	41.5	47	49.5	53.5	52	42

Figure 28: Declared and Reported Fuel Efficiency of Scooters 75-125 cc (km/l)



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Declared	77	84	82	73	86	75	70	71	81	83	83	88	84	83	81	86	76	90	75	72
Reported	58	67	62	69	71	79	61	67	60	69	73	77	60	73	73	81	72	79	63	58

Figure 29: Declared and Reported Fuel Efficiency of Motorcycles 75-125 cc (km/l)

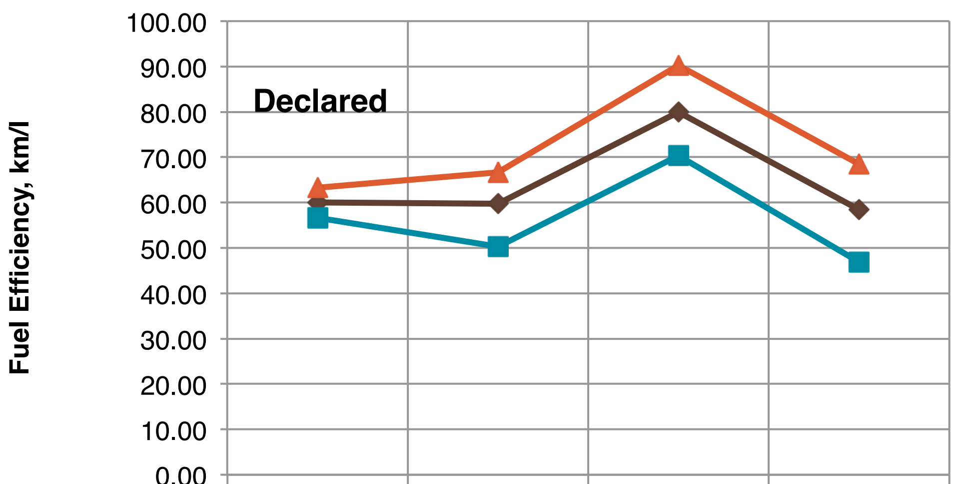


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Declared	69	56	60	56	72	68	59	62	54	50	62	62	62	47	51	51	51	68	65	49	51	62
Reported	59	60	50	45	63	64	51	55	42	34	49	49	49	43	44	44	44	58	60	43	48	56

Figure 30: Declared and Reported Fuel Efficiency of Motorcycles 125 – 250 cc

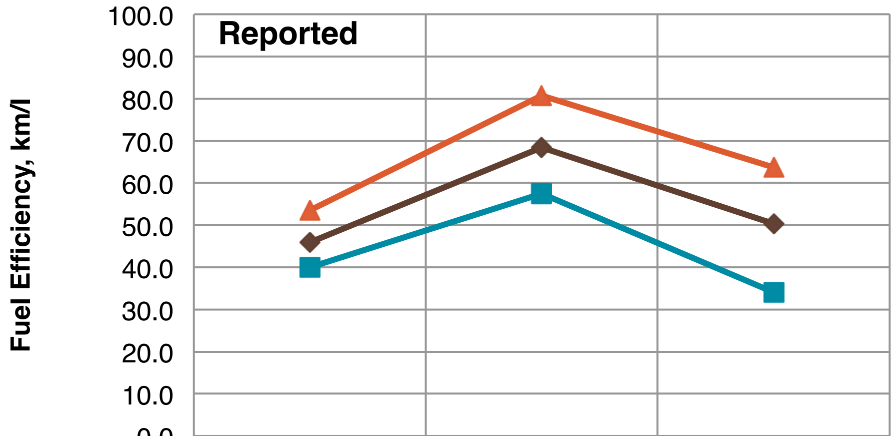
It is observed from the above figures that the differences between the Declared and the Reported fuel efficiency values appear to be consistent in all the categories of vehicles. Some further analysis was carried out with a view to gain more insights into the trends of fuel efficiencies across categories of vehicles, engine capacity ranges within each category. For a ready reference separate charts have been prepared for both Declared and Reported fuel efficiency values.

Figures 31 and 32 show the range of variations of Declared and Reported fuel efficiency of different categories of two-wheelers. While Figure 31 shows the declared data for all the categories and engine capacities, Figure 32 does not have reported data for mopeds and motorcycles above 250 cc capacity. It is interesting to note that motorcycles of 75-125 cc capacity range are the most fuel efficient followed by scooters with engines in the same capacity range. The fuel efficiency of motorcycles of 125-250 cc capacity range is somewhat better than that of the scooters of the same capacity range. The trends of fuel efficiency of motorcycles in the three engine capacity classes namely 75-125cc, 125-250 cc and above 250 cc are summarized in Figure 33. Both Declared and Reported values are shown in the same figure. It is interesting to note that the difference in the average fuel efficiency of motorcycles of 75-125 cc range and the next 125-250 cc range is quite significant – around 20% (reported) - while the difference in fuel efficiency between the next two capacity ranges namely 125-250 cc and >250 cc is even higher - around 38% (reported). This may be due to the differences in the distribution of vehicles of different engine capacities in the population.



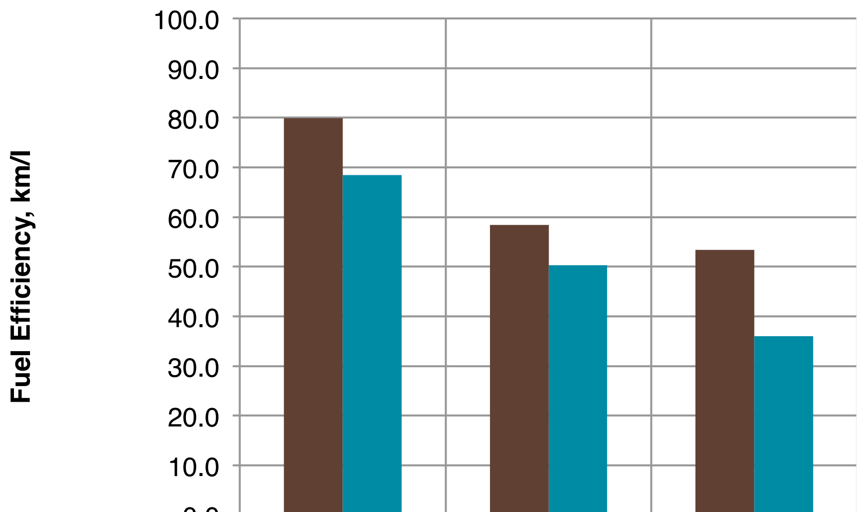
	Scooterette	Scooter, 75-125cc	Motorcycle 75-125cc	Motorcycle 125-250
Average	59.98	59.73	79.96	58.46
Min	56.70	50.22	70.30	46.93
Max	63.25	66.70	90.30	68.50

Figure 31: Range of Declared Fuel Efficiency of Different Categories of 2-Wheelers, (km/l)



	Scooter, 75-125cc	Motorcycle 75-125cc	Motorcycle 125-250
Average	45.9	68.5	50.3
Min	40.0	57.5	34.0
Max	53.5	80.8	63.8

Figure 32: Range of Reported Fuel Efficiency of Different Categories of 2-Wheeler



	Motorcycle 75-125cc	Motorcycle 125-250	Motorcycle >250cc
Average Declared	80.0	58.5	53.4
Average Reported	68.48	50.34	36

Figure 33: Average Declared and Reported Fuel Efficiency of Motorcycles of Different Capacities

A further analysis was carried out to see the relationship between the engine capacity (actual and not a range) and the fuel efficiency. Figure 34 shows the Declared and Reported fuel efficiency of scooters of 75-125 cc. A progressively reducing trend of fuel efficiency (poorer fuel efficiency) with increasing engine capacity can be seen. In fact there is a step reduction in the values for engines starting with 110 cc. All the vehicles lower than110 cc have a superior fuel efficiency and all those higher than 110 cc seem to have poorer fuel efficiency. The reason, subject to verification, may be because the scooters of higher engine capacities started appearing in the market to cater to those who were ready to accept lower fuel efficiency but wanted a better performance. A similar analysis was carried out for the motorcycles, taking all engine capacity ranges together. Similar results with the declared values are seen in Figure 35. Figure 36 is a similar chart using the Reported values. It is evident that, as expected, the fuel efficiency deteriorates as the engine capacity increases.

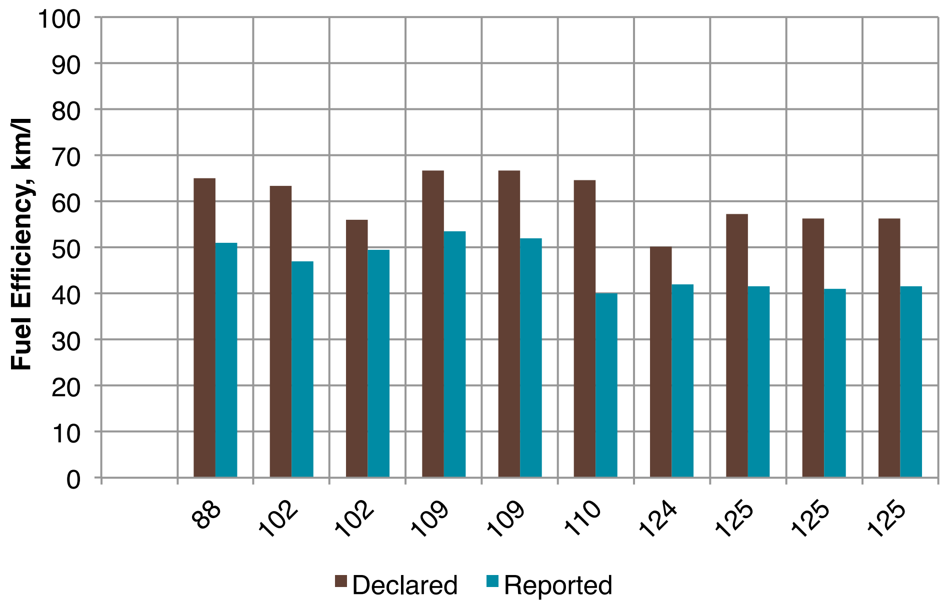


Figure 34: Declared and Reported Fuel Efficiency (km/l) of Scooters (75-125 cc) Related to Engine Capacity (cc).

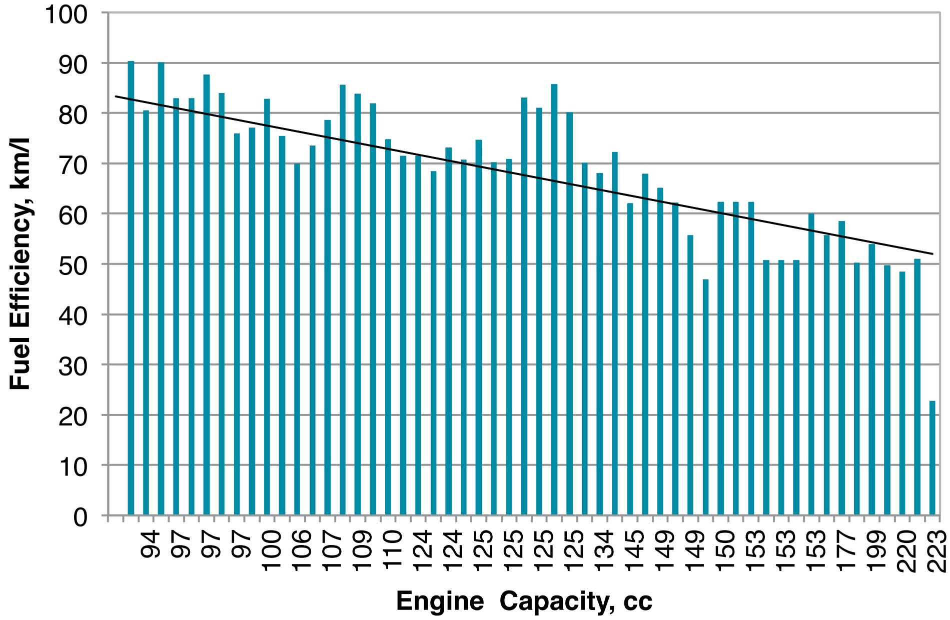


Figure 35: Declared Fuel Efficiency (km/l) of Motorcycles Related to engine capacity (cc) (all engine capacities)

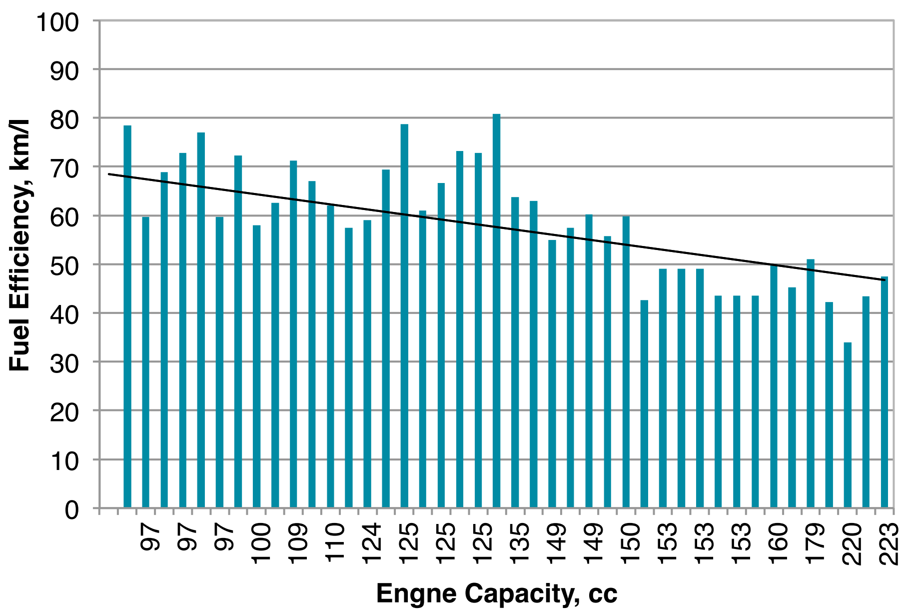


Figure 36: Reported Fuel Efficiency (km/l) of Motorcycles (all engine capacities) Related to engine capacity (cc)

However, the variations in the fuel efficiency values among models with the same engine capacity are also quite high. Since basic technologies used in different models may not be radically different from one another, the differences must be getting accounted for by the different approaches of optimization employed in each case. This is evident from a comparison of the declared fuel efficiency of various models *(SIAM 2011).* Figure 37 shows such a comparison for motorcycle models of different manufacturers, all of 125 cc capacity. It is seen that the fuel efficiency of the motorcycles produced by Hero Honda Motors Ltd seems to be clearly higher than that of models produced by other manufacturers except for the Bajaj motorcycles, which have fuel efficiency comparable to that of Hero Honda. It must be pointed out that the fuel efficiency figures used for this comparison are those 'declared' by the manufacturers measured under the IDC condition and can be used for a fair comparison. It may be argued that these differences indicate an exceptional situation. However, a similar trend is seen in case of motorcycles in the 125-250 cc range with engines of nearly exactly 150 cc capacity. Figure 38 shows that the fuel efficiency of Hero Honda motorcycles seem to be clearly higher than that of the other manufacturers' vehicles, though the differences are less pronounced.

It may be noted that the fuel efficiency comparisons have been made among vehicles with almost equal engine capacities, and not among vehicles with engine capacities falling within a range. The large differences in fuel efficiency could be attributed to the differences in the design features such as the combustion chamber, the carburettor, the intake manifold, and also to the optimization of the operating parameters such as the air-fuel ratio, ignition timing, valve timing etc.

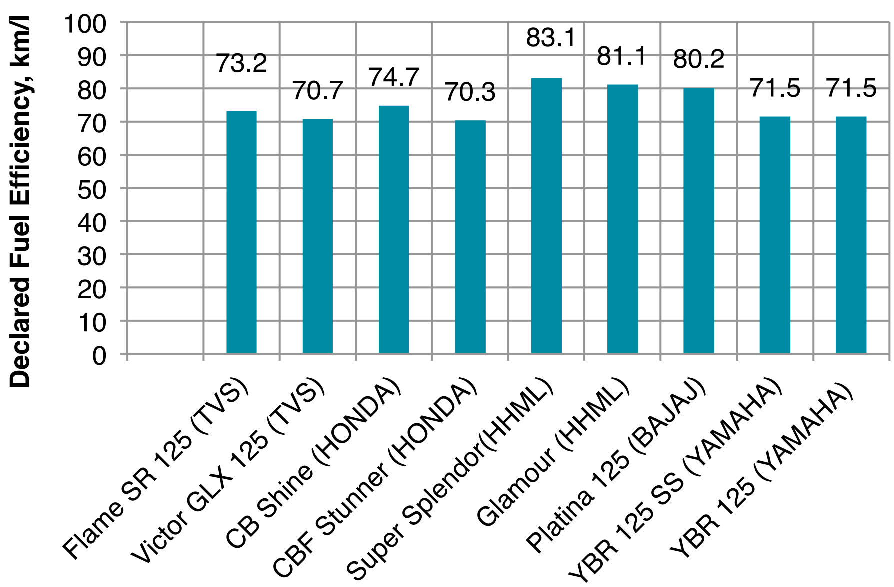


Figure 37: Comparison of Declared Fuel Efficiency of 125 cc Motorcycles of Different Manufacturers *(SIAM 2011)*

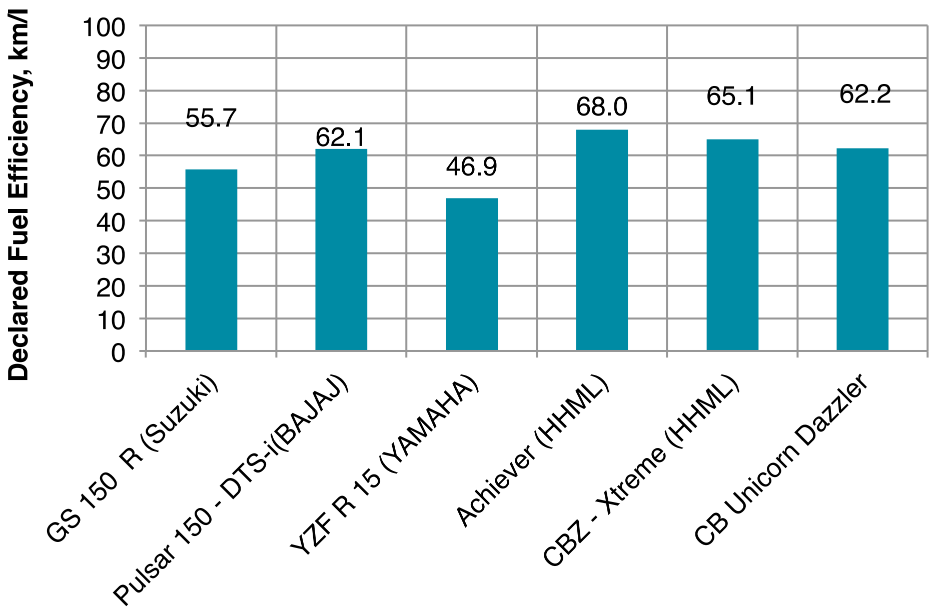


Figure 38: Comparison of Declared Fuel Efficiency of 150 cc Motorcycles of Different Manufacturers (*SIAM 2011*)

Differences could also be arising from variations in the test details, and other random variations that are associated with items of large volume production.

A further analysis was carried out to see if any relationship existed between the kerb weights of the vehicles and fuel efficiency. These are shown in Figure 39 for scooters, and Figures 40 for declared FE and Figure 41 for reported FE.

There does not appear to be clear relationship between the kerb weight and the fuel efficiency, both Declared and Reported, in case of scooters. This may be due to differences in the engine and transmission designs among the various scooters that may have a more dominant effect on fuel efficiency than kerb weight.

In case of motorcycles, however, there appears to be a clear relation between the kerb weight and both Declared and Reported fuel efficiency. It is necessary to clarify that the change in fuel efficiency with respect to the kerb weight cannot be attributed entirely to the weight although higher weight of the vehicle will lead to higher fuel consumption.

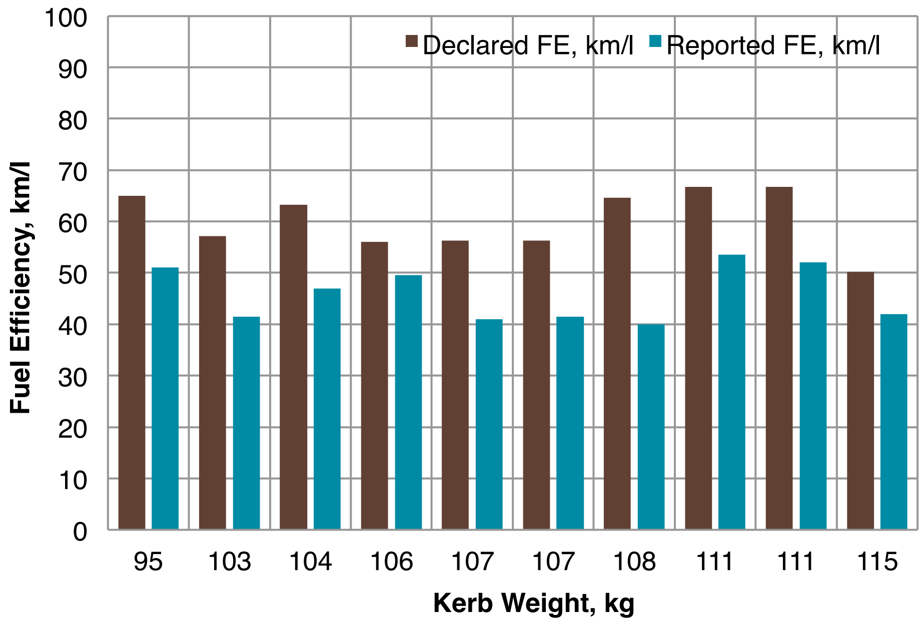


Figure 39: Relation between Kerb Weight (kg) and Declared and Reported Fuel Efficiency (km/l) of Scooters of 75 to 125 cc.

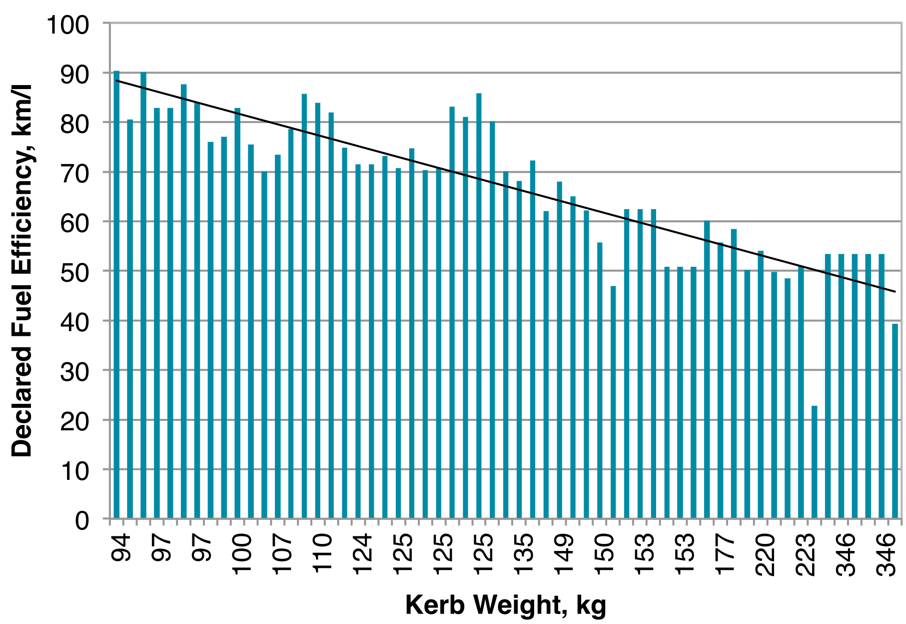


Figure 40: Relation between Kerb Weight (kg) and Declared Fuel Efficiency (km/l) of Motorcycles (All)

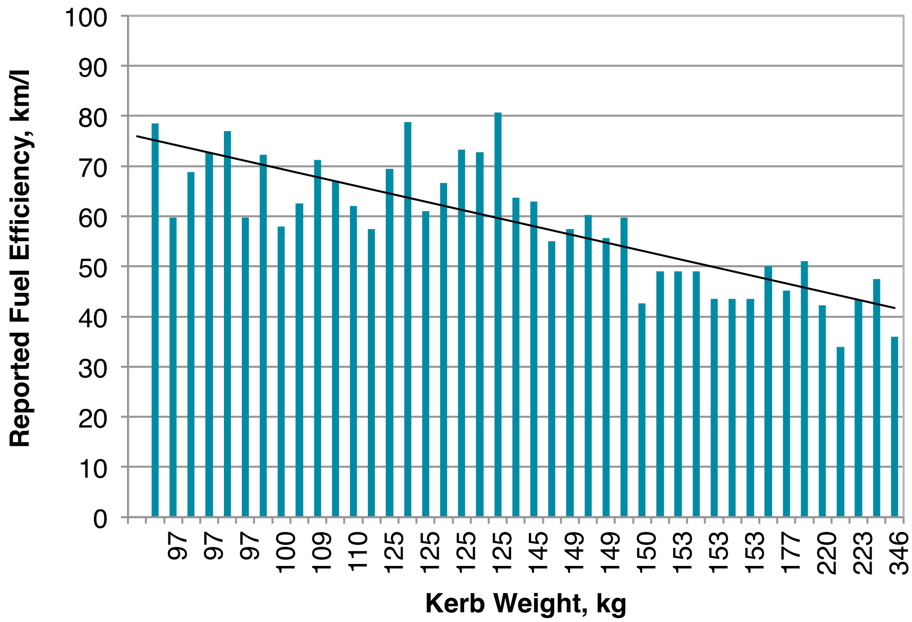


Figure 41: Relation between Kerb Weight (kg) and Reported Fuel Efficiency (km/l) of Motorcycles (All)

8.2.1 SUMMARY OF INFERENCES FROM THE ANALYSIS OF THE FUEL EFFICIENCY DATA OF 2-WHEELERS

The foregoing analysis of the fuel efficiency data on current two-wheelers in the Indian market shows the following main trends:

1) There is a good correlation between fuel efficiency values measured under IDC conditions and actual on-road fuel efficiency values. This applies to 2-wheelers of all categories and engine capacity classes.
2) The IDC fuel efficiency values are always higher than the values measured under actual road conditions
3) Motorcycles in the 75-125 cc capacity range are the most fuel-efficient followed by scooters with engines in the same capacity range. The fuel efficiency of motorcycles of 125-250 cc capacity range is somewhat better than that of the scooters of the same capacity range
4) Fuel efficiency shows a progressively decreasing trend with increasing engine displacement.
5) Fuel efficiency shows a progressively decreasing trend with increasing kerb weight in case of motorcycles. No such trend is seen in case of scooters.

8.3 FUEL EFFICIENCY DATA OF THREE-WHEELERS

Unfortunately, unlike in case of two-wheelers, neither SIAM nor the auto magazines publish any data of fuel efficiency of 3-wheeled vehicles. Some information comes through sometimes in magazine or newspaper articles and, occasionally, the websites of the manufacturers provide limited information. Some of this data has been summarized in Table 36 to give a general picture about the fuel efficiency of different types of three-wheeled vehicles manufactured by Bajaj Auto. (Data of other makes and models of three-wheelers were not available).

Data of three-wheelers from the pre-1996 time period have been shown in Table 36 with a view to highlight the progressive improvements that have taken place over the years. The year 1996 was the first year in which fairly stringent emission limits values were introduced in India. The emission limit values of 1991 – the very first year of emission regulations – which were almost entirely based on the then prevailing European standards, were so lenient that they could be met with minor tuning of the engines. Meeting the 1996 standards required major optimization work, including some basic design changes of the ports, intake systems, combustion chamber etc., which resulted in significant improvements in the fuel efficiency also. Further design improvements were carried out to meet the year 2000 emission standards, though these engines required catalytic converters to meet the emission standards. The 2-stroke DI engine represents the state-of-the-art technology as far as small two and three-wheelers are concerned and has the best fuel efficiency achieved so far – almost twice as much as the 1996 model. In fact, the 2-stroke DI is seen to be even more fuel-efficient than the diesel engine.

Table 36: Fuel Efficiency of Different Types of Three-Wheelers

Vehicle Type	Engine Type	Model Year	Engine cc	On road fuel efficiency, km/l	Reference
Petrol	2-stroke,carb*	Pre-1996	145	20	GTZ^
Petrol	2-stroke, carb*	Post-1996	145	25 - 27	GTZ^
Petrol	2-stroke, carb*	Post 2000	145	27 - 29	GTZ^
Petrol	4-stroke, carb*	Post 2000	175	30 – 31	GTZ^
Diesel	4-stroke, IDI**	Post 2000	415	38	Bajaj#
Petrol	2-stroke,DI@	2007	145	44	Bajaj@

* Carb stands for carburettor
** IDI stands for Indirect Injection
^ Ref GTZ," Sustainable Transport, Sourcebook for Policy-Makers in Developing Cities, Module 4c, Two- and Three-Wheelers"
# Bajaj website <www.bajajauto.com>
@ Bajaj Auto Press News, Business Line, December 9, 2007

8.4 SETTING FUEL EFFICIENCY STANDARDS

Though fuel efficiency standards for passenger vehicles have been in existence in several countries, except for Taiwan and China, both of which have large population of two-wheelers, no other country has brought in any legislative control of fuel efficiency of 2 and 3-wheeled vehicles. There is, however, a growing realization of the need to introduce fuel efficiency standards for 2 and 3-wheelers not only to conserve petroleum fuel but also due to their increasing contribution to GHG emissions. Since China and Taiwan have already introduced fuel efficiency standards for two-wheeled vehicles, a brief review is first made of these standards before discussing the proposals for fuel efficiency standards for Indian 2-wheelers.

8.4.1 INTERNATIONAL EXPERIENCE – TAIWAN AND CHINA

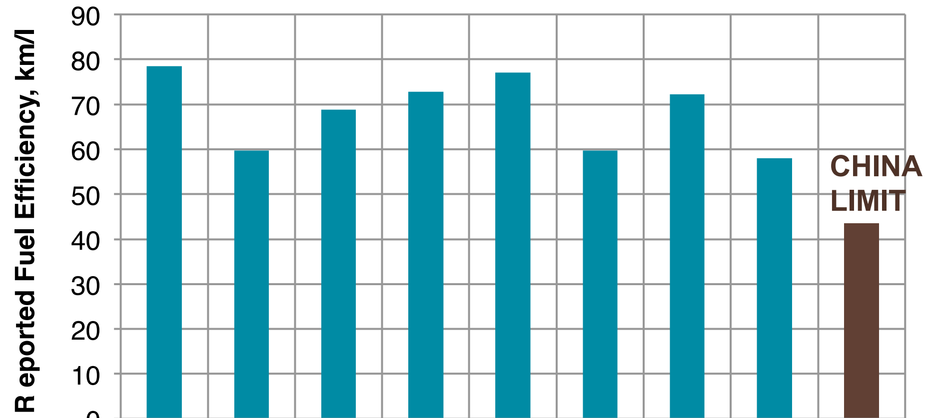
China and Taiwan are the only two countries that have established fuel efficiency standards for two-and three-wheelers. The details of the limit values in these two countries are summarized in Table 37 (*Kamakate 2009*). Fuel consumption is the weighted average of the results of a running mode test (ECE-4 and ECE-R40) and a constant speed test (speed varies by engine size category). The fuel consumption test procedures are based on the measurement methods described in the International Standards Organization (ISO) standards 7860 for motorcycles and 7859 for mopeds. In Taiwan, the fuel economy test is the weighted average of results on an urban driving cycle (ECE-15)[11] and a constant speed test (50 km/h for motorcycle and 40 km/h for mopeds).

Table 37: Fuel Consumption Limits for Motorcycles in China and Taiwan *(Kamakaté 2009)*

Engine size, cc	China 2-Wheeler	China 3-Wheeler	Taiwan 2-Wheeler
≤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

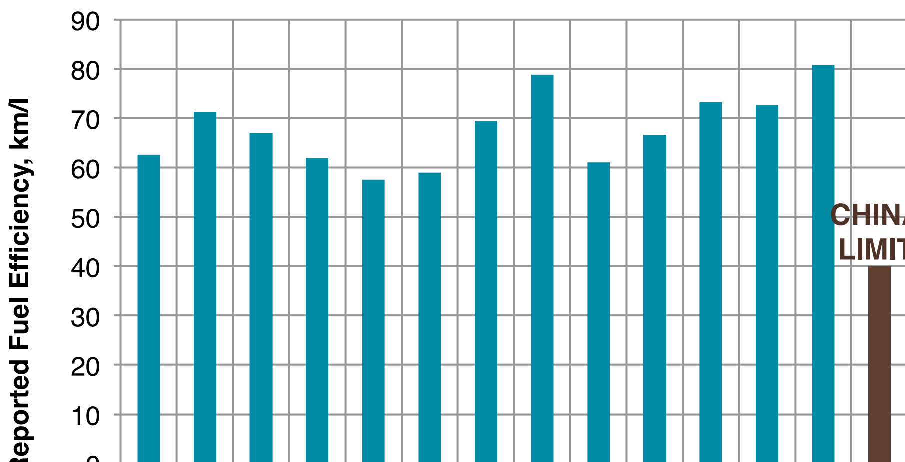
[11] ECE 15 is now obsolete and is replaced by ECE 83.

A comparison has been made between the fuel economy standards in China with the values of fuel efficiency of Indian vehicles. Only the ‘reported’ values of fuel efficiency of Indian motorcycles have been used for the comparison. It needs to be noted that there may be differences arising out of the fact that the China limits are as per a standard test procedures whereas the Indian motorcycle values are representative of actual road conditions. The comparisons are shown in Figures 42, 43, 44 and 45.



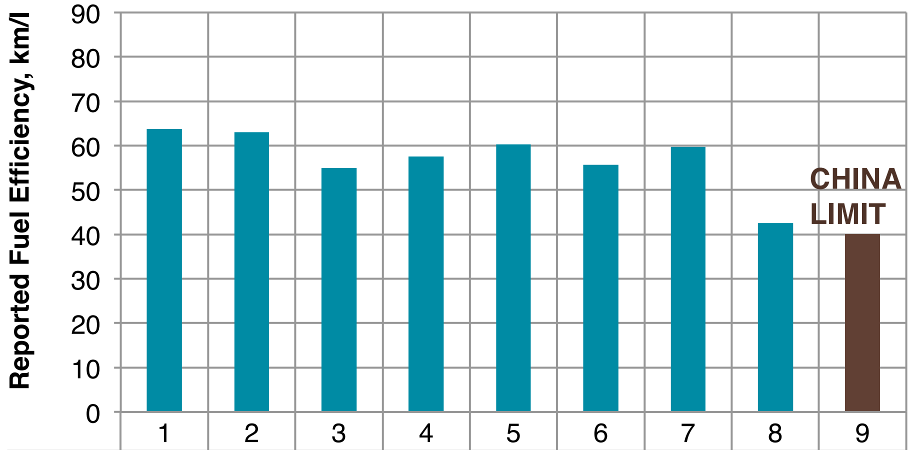
	1	2	3	4	5	6	7	8	9
FE, km/l	79	60	69	73	77	60	72	58	43

Figure 42: Comparison Between Reported Fuel Efficiency of Motorcycles (>50-100 cc) and China Limits



	1	2	3	4	5	6	7	8	9	10	11	12	13	14
FE, km/l	63	71	67	62	58	59	69	79	61	67	73	73	81	40

Figure 43: Comparison Between Reported Fuel Efficiency of Motorcycles (100-125 cc) and China Limits



	1	2	3	4	5	6	7	8	9
FE, km/l	64	63	55	58	60	56	60	43	40

Figure 44: Comparison Between Reported Fuel Efficiency of Motorcycles (125-150 cc) and China Limits

It is seen from the figures that in all classes of motorcycles, the 'Reported' fuel efficiency of all the vehicles considered is significantly higher than the limits for the class. The differences are the highest in the 100-125 cc class, which may be due to the fact that the Indian motorcycles in this class are designed for high fuel efficiency. The differences in the other three categories namely >50-100 cc, 125-150 cc class and the 150-250 cc class are relatively small.[12]

[12] The comparisons of fuel efficiency of Indian vehicles with the limits in China have been made only to show the magnitude of the differences. These conclusions need to be viewed with caution. Fuel efficiency (km/l) measured using standardized test cycles is usually higher than that obtained from road tests.

Fuel efficiency values obtained from tests using different standard conditions could also differ due to the severity of the tests. For instance, the China test procedure requires a weighted average to be taken of two tests, one using the 'ECE 40 European Driving Cycle (EDC)' and another a constant speed test, the latter usually yielding higher fuel efficiency values than driving cycle tests. The "declared" fuel efficiency of Indian vehicles is based on a test using the IDC and does not involve a constant speed test. While the possibility of IDC being less severe than the EDC could lead to higher fuel efficiency values of Indian vehicles compared to the China limits, the use of the additional constant speed test in the China procedure would perhaps offset this. Though the above may reasonably justify the comparison between the China limits and India fuel efficiency made above, it cannot be denied that a correct picture can emerge only by comparing results of the same vehicle using different test methods and different vehicles using the same test procedure. Presently, there is no data of this nature.

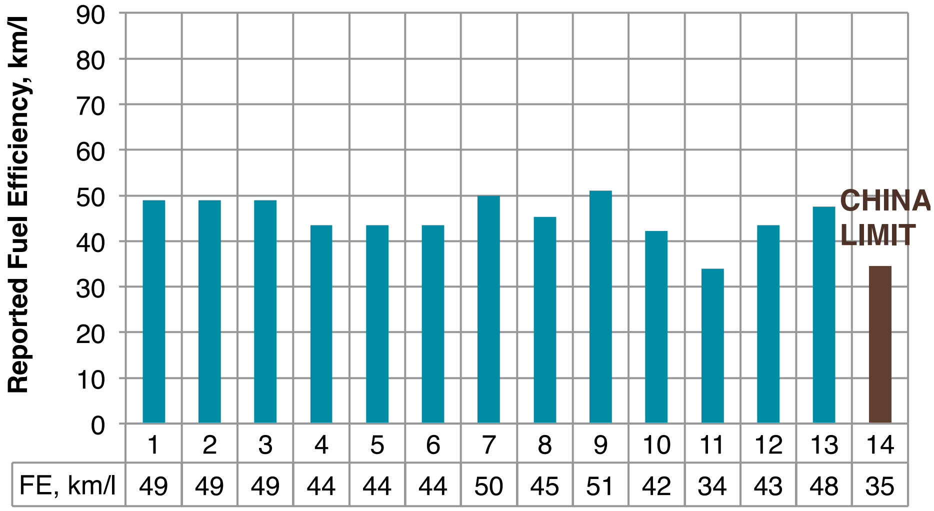


Figure 45: Comparison Between Reported Fuel Efficiency of Motorcycles (150-250 cc) and China Limits

8.4.2 SETTING UP FUEL EFFICIENCY STANDARDS IN INDIA

Discussions have been going on regarding setting up fuel efficiency standards for various classes of vehicles in India. This would be first done for passenger cars for which discussions are in progress.[13] The standards for two and three-wheelers are likely to be taken up after three or four years. In the meantime, as described in an earlier section, the industry has started a voluntary declaration of fuel efficiency of all new models. While the fuel efficiency, obtained under IDC condition, is declared to the customer at the showrooms, the consolidated information is available on the SIAM website *(SIAM 2011).*

Fuel efficiency norms for larger four-wheeled vehicles have been in force in many countries. Different countries have different approaches to specifying fuel efficiency standards, the test methods, vehicle classification etc. *(ICCT 2011).* Setting up the norms would depend upon the status of fuel efficiency of the current vehicles. For India, the 'Declared' data may form the basis of a regulation. To aid the process of formulation of the standards, the available data has been analysed in terms of per cent of total vehicles that satisfy different levels of fuel efficiency classes. This has been done separately for scooters (75-125 cc), motorcycles (75-125 cc) and (125-250 cc). The fuel efficiency class interval used is 5km/l. The result of this analysis is shown in Figures 46, 47 and 48 for the above vehicles.

[13] The Bureau of Energy Efficiency, an independent authority designated by the government of India to introduce fuel efficiency standards for various sectors of the economy has recently put up a discussion paper giving proposals for fuel efficiency standards for passenger cars. A two-pronged approach has been taken involving the medium and long-term standards for new cars sold by them over a ten-year time frame and introduction of labeling on all new cars to providing consumer information (www.beeindia.in).

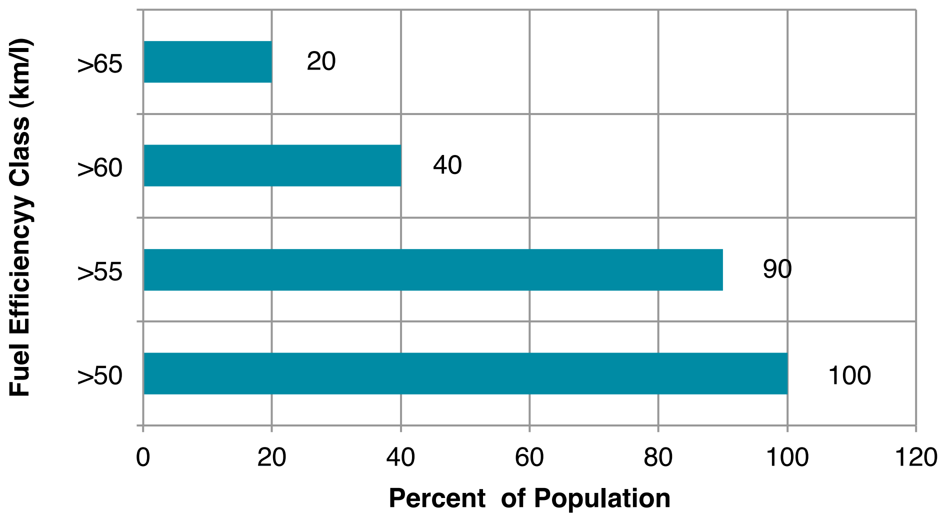


Figure 46: Frequency Distribution of Declared Fuel Efficiency of Scooters (75-125 cc), km/L

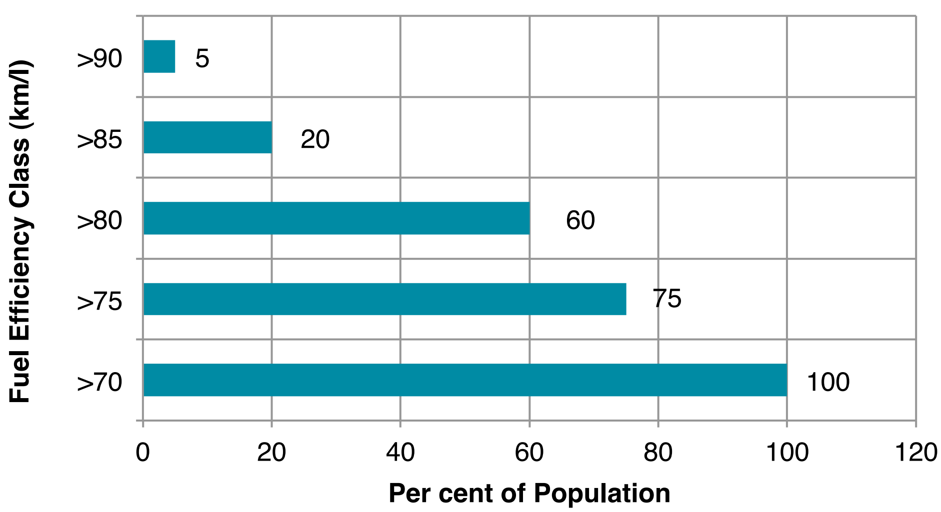


Figure 47: Frequency Distribution of Declared Fuel Efficiency of Motorcycles (75-125 cc), km/l

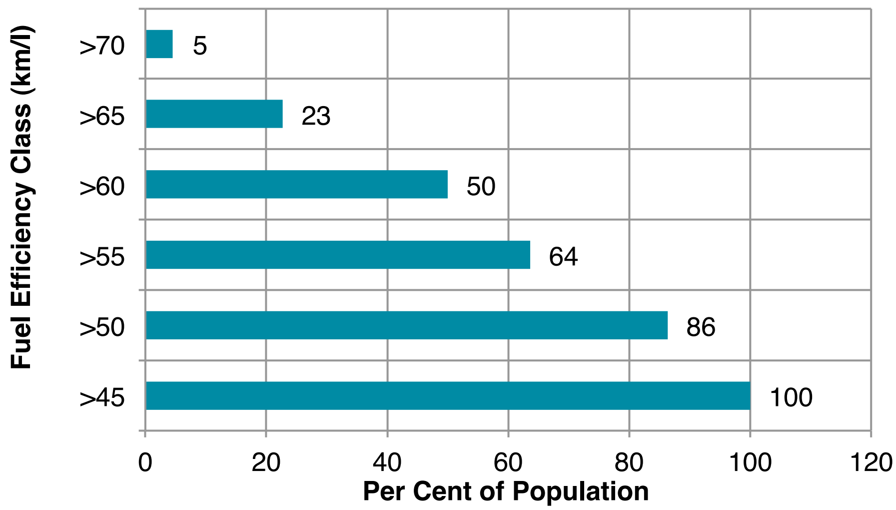


Figure 48: Frequency Distribution of Declared Fuel Efficiency of Motorcycles (125-250 cc), km/l

Some of the interesting observations from Figures 46 to 48

- All scooters (75-125 cc) have their declared fuel efficiency higher than 50 km/l.
- The Declared Fuel efficiency of 40% of these scooters is above 60 km/l
- All motorcycles of 75-125 cc have their Declared fuel efficiency higher than 70 km/l
- The Declared Fuel efficiency of 60% of these motorcycles is above 80 km/l
- All motorcycles of 125-150 cc have their Declared fuel efficiency higher than 45 km/l
- The Declared Fuel efficiency of 65% of these motorcycles is above 55 km/l

8.5 CO_2 EMISSION REGULATIONS

There is no proposal at present to regulate CO_2 emissions of two and three-wheelers, or for any category of vehicles in India. The issue is closely linked with fuel efficiency, which has already been addressed in this report. As such, CO_2 emission is not being taken up separately. An interesting observation by ACEM concerning the role of two and three-wheelers in reducing overall GHG emissions from the transport sector (*ACEM 2009)* is given below:

> *"PTWs appear as much more energy efficient means of transportation than passenger cars and their activity should be promoted as a measure to further control GHG emissions from road transport. The energy efficiency labelling regulation should be formulated in a way that will not affect the sensitive PTW market."*

The system of labelling for energy efficiency of various appliances is already in place in India. This task is performed by the 'Bureau of Energy Efficiency - BEE" under the Ministry of Power. It is understood from reliable sources that the fuel efficiency norms for the transport sector, whenever introduced, will be issued by the BEE. However, the implementation of the norms will be done by the Ministry of Road Transport and Highways- MoRTH.

9. ROLE OF FUELS AND LUBRICANTS

9.1 FUEL QUALITY

Fuel quality is an inseparable part of vehicular emission management. Most technical solutions will work effectively only if fuel of appropriate quality is used. For this discussion, it is assumed that the use of leaded fuel is no longer an issue since no leaded petrol is sold anywhere in India.[14] It is normally observed that the characteristics of fuel required for satisfactory performance of four-wheeler engines are also adequate for two and three-wheelers.

The main items of specifications of petrol required for meeting the BS III and BS IV emission standards that may have a special significance for small two and three-wheelers are described in Table 38. It is observed from the specifications that there is no difference between the fuels for BS III and BS IV emission standards except for the maximum allowed sulphur, olefin and aromatics content.

It must be pointed out that specific literature on the problems faced by motorcycles that could be attributed to fuel properties is extremely scarce. Impacts of certain main characteristics have been estimated from the limited available data and the combustion similarities between these and other internal combustion engines *(ADB 2008)*. These have also been summarized in Table 38 based on the above reference and extending the known effects on four-wheelers. An important reason for possible differences in the impact of fuel quality on small 2-wheeler engines is the fact that the latter continue to use carburettors whereas the former have completely switched over to fuel injection. Carburetted engines are more susceptible to problems of cold starting and driveability arising from distillation characteristics and Reid Vapour Pressure. These characteristics also affect evaporative emissions from the fuel tank and the carburettor.

It is possible that the 2-wheelers could use higher compression ratios to take advantage of the high Octane Number of the available fuel. This possibility may, however, vary from model to model and is subject to confirmation by the manufacturers. Opinions of experts on this possibility may differ. Based on the feedback received by them from 2-3 -wheeler industry, Indian Oil Corporation (R&D), the largest supplier of petrol in India, feels that the two and three-wheeler manufacturers "are designing the engines for Indian market based on the quality of fuel available in the country. Hence, they are taking advantage of higher octane fuels for achieving improved fuel efficiency" *(Malhotra 2011)*.

---

[14] The elimination of lead (tetraethyllead) in petrol as an Octane Number booster led to the use an alternative Methylcyclopentadienyl Manganese Tricarbonyl (MMT) in some countries. The use of this chemical is banned in some countries on grounds of being a health hazard and also damaging to the engine and the catalytic converter.

India is one of the countries that has volunteered not to use it (*Kamakaté 2009).* Cross referred to International Council on Clean Transportation Methylcyclopentadienyl Manganese Tricarbonyl (MMT): A Science and Policy Review. San Francisco, CA, USA *(ICCT 2008)..*

Gum content is a very important factor where 4-stroke engine 2- and 3-wheelers are concerned. There have been several cases of intake system deposits and intake valve bending on motorcycles due to deviations in the gum content. This can lead to increase in emissions in cases where catastrophic damage does not take place, or, until it takes place.

Table 38: Characteristics of Petrol for Vehicles Complying with BS III and BS IV for Four-Wheelers Emission Regulations and their Impact on 2-3-Wheelers

Characteristic	BS III (Regular grade)	BS IV (Regular grade)	Impact on 2-wheelers
Distillation, Recovery up to70 ^{0} C, %volume Final boiling point, FBP, ^{0} C max	10 – 45 210	10 – 45 210	Effect on cold starting and warm up Higher FBP can improve fuel efficiency
Research Octane Number (RON) min	91	91	May allow use of higher compression ratios leading to better fuel efficiency
Motor Octane Number (MON), min	81	81	Same as above
Gum content, (solvent washed), mg/100ml, max	5	5	Excessive gum content leading to intake system deposits and intake valve bending, May lead to deterioration of emission and fuel efficiency
Sulphur, total, mg/kg, max	150	50	Effect on performance of catalytic converter less severe since no oxygen sensor is used at present
Lead Content (as Pb), g/l, max	0.005	0.005	Premature catalyst damage
Reid Vapour Pressure, (RVP), kPa, max	60	60	Can affect cold starting and warm up
Benzene Content, %vol, max	1	1	Affects evaporative and exhaust benzene emissions
Olefin Content, %vol, max	21	21	Increase in deposit build up
Aromatic Content, % vol, max	42	35	Increase in exhaust benzene emission
Oxygenates Content, vol% max Methanol Ethanol, Isopropyl alcohol Tertiary Butyl alcohol Ethers containing 5 or more carbon atoms per molecule Other oxygenates	3 5 10 7 15 8	3 5 10 7 15 8	Oxygenates add oxygen to the air-fuel mixture causing cold starting and driveability problem but may reduce CO and HC emissions Fuel efficiency may deteriorate

The significance of sulphur content for small 2-wheelers is the same as that for 4-wheelers, namely adverse effect on the performance and life of the catalytic converter. However, the severity of the effect is less on account of the fact that present 2-wheelers do not use oxygen sensor, which are also adversely affected by the fuel sulphur. The importance of sulphur content will increase once use of three-way catalytic converters with closed loop systems starts to meet the proposed BS IV and BS V emission standards.

Use of 5% ethanol is mandatory in India, which may not have a major influence on fuel efficiency but may help to reduce engine out emissions of CO and HC.

9.1.1 POLICY RECOMMENDATIONS REGARDING FUELS

It can be concluded from the above discussion that the quality of fuel as per the specifications for BS III and BS IV compliant four wheelers may be adequate for two and three-wheeled vehicles also. In fact, subject to confirmation from the vehicle manufacturers, it may be possible to take advantage of the high Octane Number by using higher compression ratios to gain on fuel efficiency.

9.2 LUBRICATING OILS

The important role of lubricating oils in the emission performance and fuel efficiency of small 2-stroke and 4-stroke engines has been previously discussed in detail. Suffice it to say that both 2-stroke and 4-stroke engines require specially formulated lubricating oils, which are different from the crankcase motor oils used in passenger cars. While the 2-stroke engine lubricating oils require special properties to minimize smoke and PM emissions, 4-stroke engine oils are required to ensure good high temperature performance and minimizing clutch slippage.

9.2.1 POLICY RECOMMENDATIONS REGARDING LUBRICATING OILS

The current specifications for lubricating oils do not provide for the requirements of oils for small 4-stroke engines. The Bureau of India Standards (BIS), which is responsible for issuing national standard specifications for lubricating oils, has issued a standard for air-cooled 2-stroke engines *(BIS 2002)*. This standard covers all the requirements discussed previously in this report to ensure good emission performance of the 2-stroke engine oils. The standard for air-cooled 4-stroke engine oils has not yet been issued though the intention to do so is expressed in the published standards for 2-stroke oils. The main recommendation, therefore, would be for BIS to expedite the finalization of the standards for 4-stroke lubricants. The specification should take note of the most recent developments that help to improve the fuel efficiency of the 4-stroke engine. The possibility of mandating these specifications, as done in the case of 2-stroke lubricants, may also be explored which will ensure that oils of inadequate quality are not used.

10. ALTERNATIVE FUELS

10.1 FUELS FROM RENEWABLE SOURCES:

Several alternative fuels are being considered for use in four-wheeled gasoline vehicles, which will, no doubt, be considered for use on two and three-wheelers as well. Alternative fuels that come from renewable sources, such as bio-fuels, are being considered actively with a view to reducing Greenhouse Gas (GHG) emissions and conserving the limited fossil fuel resources. So far, however, these have been used to blend with the conventional fuels due to the constraints of producing them in large enough quantities to meet the requirement of all the road transport vehicles. The most common among these for petrol driven engines is bio-ethanol. A petrol-ethanol blend containing up to 10% ethanol may help to reduce CO and HC without any serious adverse impact. Fuel efficiency may deteriorate, though this may not be noticeable. As said before, use of 5% ethanol in petrol is mandatory in India.

10.2 FUELS FROM NON-RENEWABLE SOURCES:

10.2.1 TWO-WHEELERS

Alternative fuels from non-renewable resources such as Compressed Natural Gas (CNG) and Liquefied Petroleum Gas (LPG) are used in vehicles mainly with a view to reduce local pollutant emissions. CNG and LPG are gaseous fuels that burn cleaner in internal combustion engines and hence produce less particulate emissions. Use of these fuels in vehicles requires the installation of special pressurized fuel tanks and a system of fuel handling consisting of a set of pressure regulators and carburettors or injectors. The gaseous nature of these fuels (under normal ambient conditions) and the requirement of storing them under pressure on board the vehicle require several safety measures to be installed on the vehicles[15]. All this adds substantially to the cost and complexity.

Space available in a two-wheeler to install the gaseous fuel tank, mostly cylindrical in shape, and the pressure regulators is very limited. One of the problems with motorcycles is that the petrol tank is installed right in front of the rider and is an important aesthetic part of the bike. It is difficult to install a cylindrical tank in the space where the current fuel tank is located and, at the same time make it look pleasing. In case of most scooters, the petrol tank is located under the seat and, in order to utilize the space optimally, is made of molded plastic, often in irregular shapes to suit the space available. The installation of cylindrical gas tanks is even more difficult in this case. Gas tanks of small sizes with suitable claddings to retain the aesthetic looks tend to be too small to give any reasonable range. Most areas where these gases are currently used on three and four-wheelers, the number of gas dispensing stations is limited. This necessitates the provision of adding a ‘limp-home’ petrol system that requires additional space and expenditure.

---

[15] LPG is gaseous at ambient temperature and pressures though it is stored at moderate pressures in a liquefied form in the tank. CNG is gaseous even at high pressures and liquefies only at very low temperatures

The high cost of installing the gas handling system on small low-cost two-wheelers is another important barrier to the introduction of gaseous fuels on a wide scale.

10.2.2 THREE-WHEELERS

As mentioned earlier in section 2.2.8 and BOX 1, CNG came into use in three-wheeled vehicles in India more than a decade ago. Subsequently, later model year vehicles, viz., post-1991, came to be allowed to retrofit CNG or LPG kits. The current situation is that all auto-rickshaws in Delhi are powered by CNG. So are all buses and taxis. Many other cities such as Mumbai, Surat and more recently Pune now have many three-wheelers and four-wheelers that operate on CNG or LPG.

CNG offers an attractive option to the auto-rickshaw operator as it is more economical due to the inherently superior fuel efficiency of the 4-stroke engine and the lower price of CNG. The only negative aspect is the higher initial price, a part of which could be offset by cheap loans and interest subsidies. Use of LPG in three-wheelers is also progressively increasing in many cities. Most of this is a result of orders issued by the state governments resulting from the directions of the Supreme Court.

Most four-wheelers have to compromise on luggage space in the boot, a large part of which is occupied by the CNG or LPG cylinder, controls and related plumbing. In case of the three-wheeler, the CNG/LPG cylinder is fitted under the passenger seat where adequate room is available for the same.

10.3 IMPACT OF CNG AND LPG ON EMISSIONS

Although it is often said that use of CNG and LPG reduces emission of all types of pollutants, this is not the case, as can be seen from Table 39 *(Iyer 2004)*.

It is seen that, CO emission decreases by about 20 per cent with the use of CNG and LPG compared to that of a four-stroke engine fitted with a catalytic converter. The NOx emission, however, is higher by about 28 per cent. There is a large increase in the Total Hydrocarbon emission – around two and a half times in case of CNG and about 75 per cent higher in case of LPG. However, in case of CNG, it is customary to take into account only the 'Non-Methane Hydrocarbons' (NMHC). In that case, it is seen that there is actually a 75 per cent reduction in the hydrocarbon emission. Similarly, if only 'Reactive Hydrocarbons' (RHC) were to be considered in case of LPG there is a 10% reduction in hydrocarbon emission.

In case of the 2-stroke engine, fitted with a catalytic converter, CO is 20 per cent lower with CNG while there is a 20 per cent increase in case of LPG. There is an 80 per cent reduction in NOx with CNG while it increases to more than twice the amount with LPG. Total HC emission is nearly three to three-and-a-half times that of the petrol engine with LPG and CNG respectively. In this case also, NMHC is 80 per cent lower with CNG but still 60 per cent higher than the petrol version.

Table 39: Emission Characteristic of Three-Wheelers with CNG and LPG

Vehicle Type	**Gaseous Emissions, g/km**				**PM, g/kWh**
	CO	THC	NMHC/RHC#	NOx	
4-Stroke Petrol + Cat*	1.2	0.68	-	0.56	
4-Stroke CNG	1.0	2.4	0.17	0,75	
4-Stroke LPG	0.94	1.19	0.6	0.7	0.51
2-Stroke Petrol +Cat	1.0	1.6	-	0.1	
2-Stroke CNG ^	0.8	5.74	0.29	0.02	
2-Stroke LPG	1.22	5.18	2.59	0.22	4.3
Data Source	Tests	Tests	Tests	Tests	AFP Report !

* Catalytic Converter
# NMHC (Non-Methane HC), for CNG = {1-Methane content}
# RHC (Reactive HC), for LPG = {0.5 x THC}
^ Old Vehicle retrofitted with CNG kit
! Auto-Fuel Policy Committee Report

The most important advantage of using CNG and LPG is the reduction in the PM emissions. There is no data available on this important pollutant emission. Data that was quoted in the Auto-Fuel Policy report *(Mashelkar 2002)* has been included in Table 39. It is noted that PM emission from 2-stroke LPG is seen to be much higher than that of 4-stroke engines. This could be explained by the higher oil consumption of 2-stroke engines leading to emission of unburned oil showing itself as PM. One could conclude from these results that on the whole, CNG is more environmentally friendly than LPG except for a small increase in NOx emissions.

In a recently concluded study Reynolds et al. *(2011)* carried out chassis dynamometer emission testing on 30 in-use auto-rickshaws to quantify the impact of switching from gasoline to CNG in spark-ignition engines. Thirteen test vehicles had two-stroke CNG engines and 17 had four-stroke CNG engines, of which 11 were dual-fuel and operable on a back-up petrol system. They found that the mean fuel-based PM2.5 emission factor (in terms of grams of pollutant per kg of fuel) for CNG 2-stroke was almost 30 times higher than for CNG 4-stroke and 12 times higher than for petrol 4-stroke. Global warming commitment (fuel based in terms of g/kg) associated with emissions from CNG 2-stroke was more than twice that from CNG 4-stroke or Petrol 4-stroke, due mostly to CH_4 emissions.

10.4 ESTIMATIONS OF FUEL EFFICIENCY OF THREE-WHEELERS USING CNG AND LPG

Certain estimations of fuel efficiency of three-wheelers using CNG and LPG have been put together in Table 40. These are based on the author's past association with the three-wheeler industry and some anecdotal information from the actual users.

Table 40: Estimations of the fuel efficiencies of three-wheelers using CNG and LPG

2-Stroke or 4-Stroke	Fuel	Catalytic Converter	Fuel Efficiency, km/kg
2-Sroke	Petrol	yes	44
2-Sroke	LPG	yes	46
2-Sroke	CNG	yes	40
4-Sroke	Petrol	yes	47
4-Sroke	LPG	yes	53
4-Sroke	CNG	no	57

All the data has been given in terms of km/kg due to the differences in the densities of the fuels considered. Also, the users of CNG and LPG vehicles buy the fuel in kilograms and are more familiar with the calculation of mileage in the same terms. For making a valid comparison, the fuel efficiency of petrol vehicles has also been converted to km/kg assuming the density of petrol to be 0.73kg/litre. As per the data, 4-stroke CNG engine seems to be the most fuel-efficient followed by the 4-stroke LPG. Use of CNG on 2-stroke engines does not seem to be giving any fuel efficiency benefit, though use of LPG does give a marginal 5 per cent higher mileage.

10.5 PRICES OF CNG AND LPG THREE-WHEELERS

Exact prices of various models of three-wheelers could not be obtained. However, somewhat dated information indicates that a four-stroke CNG vehicle was priced at Rs 1,08,000/- while the price of a two-stroke CNG version was Rs 99,500/-. The price of the LPG three-wheeler was approximately Rs 95,000/-.

10.6 FUTURE OF CNG AND LPG

It is evident from the foregoing discussion that CNG and LPG can be used as solutions only in limited areas and not on a wide scale. However, since these vehicles are also required to meet the emission standards prescribed for their respective categories, it will be necessary to carry out further technical developments to improve their emission characteristics, fuel efficiency and costs. In this context, the research done by the University Science, Malaysia provides useful indicators of the directions for further work *(Teoh 2008)*. The research report claims that Direct Injection of gaseous fuels holds the possibility of achieving improvements similar to GDI. Because gaseous fuels are typically stored and supplied from pressurized tanks, use of DI systems on them does not require fuel pumps. Also no pressurized air assistance is required as in the case of gasoline. There is thus no need for an air compressor and separate air and fuel injectors. This should result in a significantly lower cost for the gaseous fuel DI system. Additionally with only minor adjustments the system may be used with many different gaseous fuels, such as Liquefied Petroleum Gas (LPG), Compressed Natural Gas (CNG), biogas, hydrogen and propane.

In the reported study, Direct Injection of propane was applied as a retrofit to an existing carburetted two-stroke motorcycle engine of 118 cc displacement to determine the potential emissions and fuel economy improvements. According to the measurements done, Direct Injection of propane should reduce fuel consumption by approximately 17%. This is significantly less than GDI systems, which may reduce fuel consumption by 30 to 40% over the whole operating range.

The paper also gives a few estimates of the costs of the gaseous DI system compared to Electronic Fuel Injection (EFI) and gasoline DI. In large volumes (10,000 units per month) typical EFI systems add a little more than 100 US$ to the price of a motorcycle. GDI retrofits are available for approximately $US 250, however it is likely that this could come down to below $US 200 in high volumes. Apart from the pressurized fuel tank the gaseous DI system should actually be less expensive than the gasoline EFI system. The gaseous fuel DI system requires a slightly more expensive direct injector, but does not require a fuel pump, separate fuel injector or an air pump.

11. UNCONVENTIONAL FUELS

11.1 HYDROGEN AND HYDROGEN-CNG BLENDS

Hydrogen is considered as an important future fuel for motor vehicles. It can be used either as a fuel burnt directly in the internal combustion engine or as a source of electricity to drive the electrical propulsion motor. Both of these are technically feasible options. The most important problem for use of hydrogen is that of its storage on board the vehicle. The options being explored are in high-pressure tanks in a gaseous state or in adsorbing materials such as metal hydrides. The possibility of using blends of CNG containing smaller proportions of hydrogen is being seriously explored to overcome the short supply of hydrogen on a commercially viable scale. For both of these options, their use on two-wheelers will have the same constraints as other gaseous fuels.

11.1.1 MAHINDRA'S HYDROGEN THREE-WHEELER:

In September 2009, Mahindra & Mahindra, a relatively late entrant into the two and three-wheeler market, showcased a hydrogen-powered three-wheeler. The 396 cc naturally aspirated internal combustion engine is capable of generating 4.5 kW at 3600 rpm. The engine uses electronic fuel injection and ignition systems. Gross vehicle weight of the vehicle is 850 kg. Hydrogen is stored in carbon fibre composite hydrogen cylinders at a pressure of 200 bar. Storage capacity is 0.6 kg. The vehicle has a remarkable fuel efficiency of 95 km /kg.

This product is a result of Mahindra's sustainable mobility program, which has given products like the CNG Pick-Up and Mahindra Micro-Hybrids *(Zigwheels 2011*). This vehicle has been chosen by the International Centre for Hydrogen Energy Technologies, (ICHET) (a project of the United Nations Industrial Development Organization –UNIDO - supported by the Turkish Ministry of Energy and Natural Resources) as a part of their demonstration project which aims at introducing hydrogen as the most environmentally friendly gaseous fuel, opening the way to drastic reduction of the levels of air pollutants in urban areas. The vehicle has been designed by ICHET in collaboration with Mahindra & Mahindra. A fleet of 15 of these three-wheeled vehicles along with its refuelling facility will be located at New Delhi's Pragati Maidan exhibition site *(ICHET 2011).*

11.2 BATTERY ELECTRIC AND HYBRID VEHICLES

11.2.1 BATTERY ELECTRIC TWO-WHEELERS

Two-wheelers driven by electric motors are being produced in India. There are at least ten manufacturers among them producing nearly 25 models of two-wheeled vehicles powered by electric motors. Electrotherm and Hero Electric are key players in the two-wheeler EV category. Others include E- VO India, Lohia Auto, TVS Motors, Avon, BSA, Ultra motors and others. Among all these, Electrotherm India, makers of Yobyke, is considered as India's largest manufacturer of electric battery operated two-wheelers and has sold over 75,000 units so far. Earlier, in April 2008 TVS, a major manufacturer of motorcycles, scooters and three-wheelers had launched their electric scooterette 'Scooty Teenz Electric' with high hopes of selling around 40,000 units per year. However, it stopped the production in May 2009 as it received a lukewarm response from the market. As per a recent announcement, the company has decided to re-enter the Indian electric scooter market with some existing as well as new models *(Zigwheels 2011).* According to the Motor Vehicles Act, a vehicle that is powered by a motor of less than 250 W continuous power for 30 minutes and has a maximum speed of not more than 25 km/h is not to be considered as a motor vehicle[16] *(MVA 1989)*. As such, these vehicles do not have to comply with any of the standards for safety etc. and driving these vehicles does not require a driving license. The only requirement is to obtain a certificate that the vehicle does not produce a continuous power of more than 250Watts for 30 minutes. As a result, more than three-fourths of the 25 models in the market are powered by brushless DC motors of 250 W and use 48 volt batteries, some of which are the VRLA (Valve Regulated Lead Acid) type. A few models use electric motors of higher power ratings ranging from 500 to1800 Watts. These vehicles are classified as regular motor vehicles and are required to be Type Approved as per the procedures laid out for such vehicles *(AIS 2011).* Typical specifications of slow speed (below 25 km/h speed) and high-speed (above 25 km/h speed) battery electric vehicles are shown in Table 41.

The sub-250W electric scooters are available at prices ranging from Rs 25,000 to Rs 35,000. The higher-powered versions are available at prices ranging from Rs 35,000 to 40,000. According to Electrotherm, low-speed (250 W motor power) models have caught the fancy of school students who need not get a license to drive them.

Table 41: Typical Specifications of a Low Speed and a High Speed Battery Electric 2-wheeler vehicle in India

Description	Low Speed vehicle	High Speed vehicle
Speed (km/h)	25	45
Range (km/charge)	70	65
Motor output (Watts)	<250	800
Battery Type	SLA 48V/20Ah	VRLA 48V/33Ah
Charger	48V, 3A	N
Battery Charging time, hr	6-8	8
Net Carrying capacity, kg	NA	140
Gradeability, degrees	NA	9
License	Not required	Required

Factors that can attract customers to electric scooters are safety and economy. The low speed of the vehicle inspires young persons who are not eligible to get driving licences to use it. The

[16]A similar provision exists if the vehicle is powered by a thermic engine of less than 25 cc cubic capacity

second factor is the economy of ownership. As per industry estimates, assuming a 60 km drive every day, an EV user can end up saving Rs 12,000 a year, including the replacement cost of the batteries *(SMEV 2011)*.

11.2.2 CURRENT ANNUAL SALES AND EXPECTED GROWTH OF ELECTRIC TWO-WHEELERS:

Accurate figures of annual sales of electric two-wheelers are not readily available. SIAM statistics (and accordingly the SegmentY statistics), report sales only of their member companies. So far they have been reporting data of Electrotherm and TVS, which do not reflect the total sales of electric two-wheelers.

According to the recently formed Society of Manufacturers of Electric Vehicles (SMEV) *(SMEV 2011)* total sales of electric vehicles in the country (97-98% of which are two-wheelers) in the financial year 2008-09 was 1,10,000 units *(Financial Express 2009).*

According to the President of the SMEV, the electric scooters sale constitutes a very small percentage of the total 2-wheeler sale. Against 9 million petrol two-wheelers sold in 2009-10, electric-bikes are just 100,000 in numbers. However, the industry is quite optimistic about a significant growth in the electric two-wheeler market as a result of a package of incentives of Rs 95Crores (Rs 950 million, approximately equal to US$ 21 million) recently announced by the Ministry of New and Renewable Energy (MNRE) *(Economic Times 2010).*

11.2.3 BATTERY ELECTRIC THREE-WHEELERS

Several efforts have been made to develop battery electric auto-rickshaws. Notable progress was made by Bajaj Auto to develop an auto-rickshaw using state-of-the-art drive unit technology. The vehicle used an axial flux permanent magnet brushless DC motor and controller to obtain superior system efficiency (*GTZ 2009*). The prototypes ran on lead acid batteries. The plan to produce this vehicle in larger number seems to have been shelved. Earlier efforts to develop electric three-wheelers by Mahindra have also met the same fate. It is normally believed that electric vehicles using conventional technologies are not expected to have widespread applications in developing countries in South and South East Asia. The Chinese two-wheeled battery electric vehicles are an exception.

11.2.4 GOVERNMENT INCENTIVES FOR PROMOTION OF RENEWABLE FUELS

11.2.4.1 INCENTIVE FOR ELECTRIC VEHICLES FROM MNRE

As per a scheme approved by the Ministry of New and Renewable Energy (MNRE), the government will provide financial incentive for each electric vehicle sold in India during the remaining part of the 11th Plan-- 2010-2011 and 2011-2012.

The scheme, effective from November 11, 2010, envisages incentives of up to 20 per cent on ex-factory prices of the vehicles, subject to a maximum limit. The cap on the incentive will be Rs 4,000 for low speed electric two-wheelers, Rs 5,000 for high-speed electric two-wheelers, Rs 60,000 for seven seater three-wheeler and Rs one lakh (Rs 100,000) for an electric car.

As per the notification by the MNRE, the government will take up "dissemination of two wheelers, three wheelers and four wheelers Battery Operates Vehicles (BOV) and R&D and technology demonstration and other activities in the area of Alternative Fuels for Surface Transportation at a total cost of Rs 95 crore during the remaining period of the 11th Plan". For this fiscal, the government will support 20,000 units and 10,000 units of low and high-speed two-wheelers respectively, while it will be 80,000 units and 20,000 units in 2011-2012. The government has also decided to incentivize 100 units of three-wheelers and 140 units of passenger cars in the rest of this fiscal, while it will be 166 units and 700 units in the next financial year.

11.2.4.2 PROVISIONS IN THE GOVERNMENT OF INDIA BUDGET FOR THE FISCAL 2011-2012

As a part of his budget for the fiscal year 2011-2012, the Finance Minister announced a "National Mission for Hybrid & Electric Vehicles" to promote their adoption as well as incentivize them. Critical parts/assemblies required to manufacture hybrid vehicles would be granted exemption from the basic custom duty of 10% and special CVD. A concessional rate of 5% excise duty will be granted to hybrid vehicles if manufactured locally. In addition, the excise duty on kits used for conversion of fossil fuel vehicles into hybrid vehicles has been reduced from 10% to 5%, thereby making them cheaper. Technology for such kits has been developed indigenously and the move will not only promote adoption by customers but will also help the R&D for such technologies *(Economic Times 2011)***.** The above is in continuation of the incentives the Finance Minister gave in the last fiscal year in the form of full exemption from basic customs duty and a concessional rate of Central Excise duty of 4 per cent provided to specified parts of electrical vehicles.

11.2.5 CHARGING STATIONS FOR ELECTRIC VEHICLES

An important impediment in the popularization of battery electric vehicles is the problem of charging the batteries. The owners of electric vehicles are required to charge the batteries at home overnight from their domestic power outlets. This proves to be a limitation for people living on higher floors of multi-storied housing complexes. The availability of locations for 'opportunity charging' will be a great advantage.

Hero Electric is installing charging stations in conjunction with garage owners termed as Hero Electric PGOs (Preferred Garage Owners) across Delhi & Chandigarh. Thereafter, it will be setting up charging stations in several places like parking lots, malls, schools, and other convenient places throughout the country to help develop the transportation infrastructure needed to support electric vehicles.

Hero Electric was the first EV Manufacturer to launch the concept of Charging Stations for Electric two-wheelers in Delhi and first of its kind in India. The charging stations are designed in-house at Hero Electric R&D design centres and are capable of charging the battery in the shortest possible time. The charging station at Hero Electric PGO's has electronic timers along with DC regulated power supply which allows the electric 2-wheeler to charge in the multiples of 1 - 2 hours and the consumer will be charged Rs 5 for an hour's charge, Rs10 for 2 hours and so on. The user can run the vehicle for approximately 10-20 km in an hour of charge depending on the condition of the battery.

11.2.6 HYBRID VEHICLES

There are no significant developments of hybrid two-wheeled vehicles in India so far. The only hybrid two-wheeler development that has been reported is by Suzuki in collaboration with Intelligent Energy, a British company (Intelligent Energy 2011). The vehicle called the ENV (Emission Neutral Vehicle) is an electric motor prototype powered by a hydrogen fuel cell.

The vehicle and the fuel cell centre respectively weigh approximately 80 and 20 kilograms. It uses a proton-exchange membrane fuel cell to generate about 8HP or 6 kilowatts. The Discovery Channel has indicated it can reach approximately 80 km/h and, on a full tank, may ride continuously for about 4 hours and travel a distance of 160 km. The motorcycle is a preproduction prototype, which will sell for approximately $6000 (*Youtube, 2006*).

11.3 SUMMARY OF BATTERY ELECTRIC AND HYBRID VEHICLES

Battery electric vehicles are slowly getting popular in the Indian market, though the volume of this market is miniscule compared to the market for electric two-wheelers in China. However, with the new incentives offered by the government, one could expect a rapid growth in the 2W EV market. As can be seen in Figure 49, the electric two-wheeler industry itself is very optimistic about this though it expects that there can be a near doubling of sales if ‘supportive and enabled environment’ were to be created.

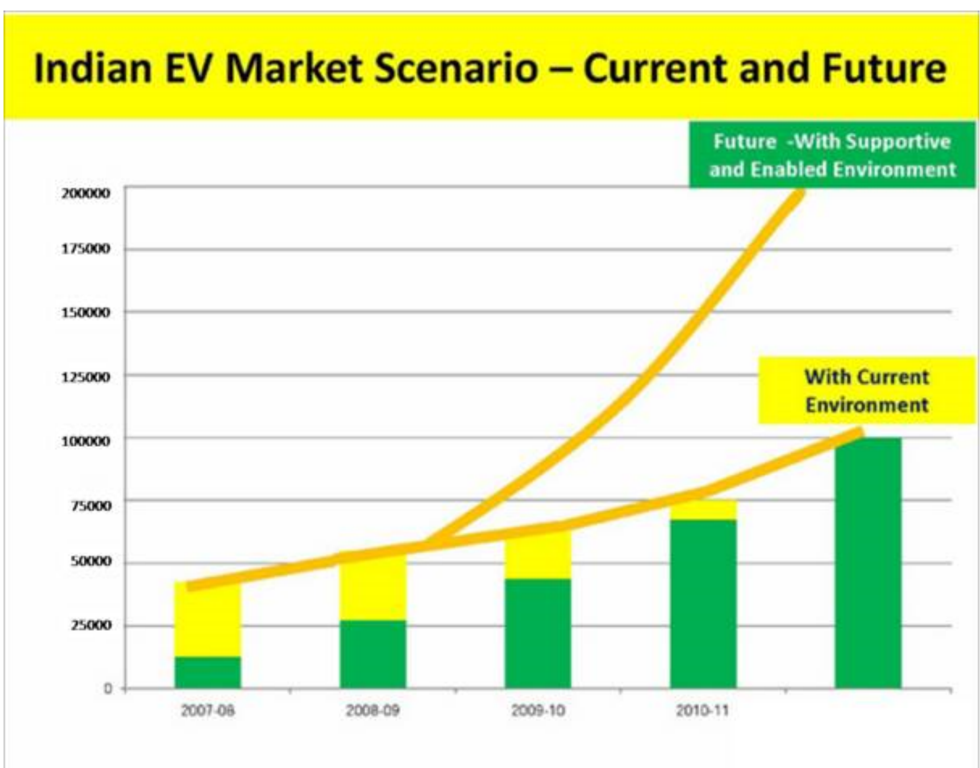


Figure 49: Projection of Growth of Battery Electric Two-Wheelers in India (*SMEV 2011*)
Courtesy of Society of Manufacturers of Electric Vehicles

12. SUMMARY AND RECOMMENDATIONS

1. General: Two and three-wheelers will continue to play an important part in the Indian urban transportation system. Due to their large and fast growing numbers there is a sense of urgency to accelerate the process of further reduction in emissions and fuel consumption. Two-wheelers as personal transport and three-wheelers as intermediate public transport have significant shares of urban mobility in India. The primary reasons for this are inadequacy of reliable, efficient and economic public transport and low affordability of cars. Since urban transport infrastructure is not keeping pace with the rapid growth of the economy, the demand for two and three-wheelers is increasing at a rate faster than that of economic growth. Indications are that this trend will continue in the coming decade or two leading to a fast growth in their share of the urban vehicle population. Preference for two-wheelers as personal transport and three-wheelers as intermediate public transport is also spurred by the unique advantages they offer over other modes. These include low ownership cost, good fuel efficiency, good manoeuvrability etc. Their burden on the transport infrastructure in terms of road and parking space requirement is also low. Further, efforts during the last decade and a half by the governments and manufacturers have led to considerable reduction in air pollutant emissions and fuel consumption. However, due to their large and fast growing numbers, there is a sense of urgency to accelerate the process of bringing in further policy measures and technological improvements that will make these vehicles cleaner and more fuel-efficient.

This can be achieved by introducing the next two stages of emission standards in reasonably quick succession supported by the introduction of hitherto neglected measures such as those for evaporative emissions, improved durability and measures to improve the management of in-use vehicles, such as periodic vehicle inspection (PUC), In-use Conformity Testing (IUC) and OBD. Introduction of appropriate fuel efficiency standards will also provide incentives to bring about improvements in the overall efficiency of the vehicles.

2. Profile of the Market and the Products: The two-wheeler market is dominated by motorcycles using 4-stroke petrol engines of 75 –125 cc capacity (60%), followed by those of 125-250 cc engines (20%). Scooters and Mopeds have 15% and 6% shares of the market. Motorcycles and Scooters were switched over to 4-stroke engines over the last decade and a half. Mopeds continue to use 2-stroke engines possibly because of demand for low initial and maintenance costs. Among three-wheelers, passenger carriers using 2-stroke petrol engines dominate the market. Several vehicle models use 4-stroke engines running on petrol or CNG or LPG. Many passenger and goods three-wheelers use small single cylinder diesel engines.

3. Current Emission Standards and their Compliance: Emission standards for two and three-wheelers have been getting progressively stringent over the last two decades. The present BS III standards are among the most stringent ones globally. Compliance with these evolving standards was accomplished by a progressive shift from 2-stroke to 4-sroke engines over the years, the process getting aided by changing market preferences. In addition to the switch to 4-strokes, other technical solutions such as optimization of engine parameters to reduce “engine out” emissions, use of oxidation catalytic converters and secondary air injection were also employed to meet emission standards. These measures were required to varying extents by the 4-stroke engines as well to meet the BS III standards.

In case of three-wheelers, the switch to 4-stroke was not quite as successful probably due to customer resistance to accept a more complex and a costly product and continue to use suitably calibrated 2-stroke engines and fitted with catalytic converters. Some penetration of 4-stroke did take place in select markets while many others shifted to CNG or LPG depending upon government mandates or easy availability of the fuel at lower cost. Many 3-wheelers are now powered by single cylinder diesel engines. Diesel 3-wheelers have a separate set of emission standards, which are met mostly through improved calibration and optimization.

4. Future Emission Standards: The primary issue affecting the future course of emission standards pertains to the introduction of the Global Technical Regulations. India has been actively participating in the activities of the UNECE in the development of global standards for two-wheeled vehicles. UNECE has now issued the Global Technical Regulation No 2 (GTR 2) prescribing a world harmonized test cycle (WMTC) and a few alternative sets of emission limit values for the participating countries to choose from. As a part of its commitment to transpose the GTR 2 into the countries own regulations, the government, in the month of December 2010, issued a draft regulation to be used as an alternative to BS III. The standard adopted in this regulation prescribes a combined limit for HC and NOx to cater to the requirements of engines employing lean air-fuel ratio calibration that improves fuel efficiency but leads to high NOx emission. Reducing NOx emission would necessitate the use of richer air-fuel mixtures causing deterioration in fuel efficiency, and, concomitantly, increase in CO2 emission. Reducing NOx emission while retaining the advantage of low fuel consumption and CO2 emission requires the adoption of advanced technologies not yet well established for use on small vehicles.

There is no official indication regarding further progression of emission standards. Since studying the feasibility of technologies to meet the future, more stringent, standards is one of main objectives of this study, a set of new emission standards for the next two stages based on GTR2 and on the lines of EU proposals has been proposed. These have been named as BS IV and BSV, to be enforced from the years 2015 and 2020.

5. Technical Solutions to Meet the Proposed Standards: A detailed assessment of possible solutions that could be used to meet the proposed standards was carried out based on study of the literature, reported experience of other countries, and views of eminent experts in the field. The study shows that some vehicle models may meet the proposed BSIV standards using optimization and calibration techniques along with improved after-treatment systems, while many others may require use of advanced technologies such as fuel injection. Meeting the proposed BS V standards will be more challenging and may require many models to adopt fuel injection as well as improved oxidation catalysts or three-way catalysts in a closed loop system. The best suited injection systems will be the air-assisted injection for 2-stroke engines and port fuel injection for 4-stroke engines. The fuel efficiency gains by using fuel injection in case of 4-stroke engines may be limited by the fact that the basic Indian engines are calibrated for high fuel efficiency.

A few vehicles with fuel injection have already been introduced in the market by a few manufacturers with a positive response from the users. This experience would be beneficial while introducing fuel injection on a wider scale. The study shows that there will be a need to bring down the cost of the fuel injection system components. Manufacturers can take advantage of the several cost reduction possibilities that have been developed and described in this report. The study also shows that new combustion systems using stratified charge and controlled auto-ignition are being developed by reputed researchers and may emerge as potential technologies of the future with very low emissions and fuel consumption.

6. Measures Other Than Tailpipe Emission Standards: Two important aspects have been studied; one is the introduction of evaporative emission regulations and the other to improve the durability requirements. The proposal by the manufacturers to introduce the evaporative emission standards along with the next stage of emission standards may be reviewed and the possibility of an earlier and an independent introduction may be explored. It would be appropriate to introduce a limit of 2g/test using SHED test method. There is also a need to review the present provisions of durability and revise them suitably. The main area of improvement pertains to the need to introduce a system that makes it mandatory for the manufacturers to demonstrate the durability of emission control in a suitable manner and the second aspect is to consider the feasibility and benefit of enhancing the durability mileage from the present 30,000 km to, say, 50,000 km.

7. Management of In-Use Vehicle Emissions: Four main aspects of managing emission control of in-use vehicles were evaluated in the study. These include the Conformity of Production (COP), Periodic Vehicle Inspection (PUC), In-Use Conformity Testing (IUC) and On Board Diagnostics (OBD). Among these, the present COP system seems to be quite satisfactory and does not need any major changes. The deficiencies of the existing PUC system (for all categories of vehicles) are well known. In addition to a complete revamping of the existing system, a major improvement, particularly in relation to two and three-wheelers, can be achieved by adopting the ARAI 2-wheeler loaded mode test as a part of the regular procedure for periodic vehicle inspection. It will be necessary to institute further development work to fine-tune the system and gain more experience. In-use Conformity Testing (IUC), which is not included in the present Indian regulations for any vehicle category, may be introduced after a comprehensive study of the feasibility and effectiveness. Since the study will require considerable expense and time, it would be worthwhile to begin the process based on the experience of the system in Taiwan, the only country to have an IUC system for 2 and 3-wheelers. The OBD system should be considered for being mandated for vehicles using fuel injection or any other form of electronic fuel management system.

Retrofitting old vehicles with new components to upgrade their performance, such as the Direct Injection kit on two-stroke engines done by ‘Envirofit’ or enable operation on cleaner gaseous fuels such as the CNG auto-rickshaws in Delhi can help to reduce emissions and fuel consumption. However, these would require several supporting measures to be taken, such as putting in place the infrastructure for gas supply and ensuring access to financial incentives. Significant gains in emission can be achieved by fixing age limits for vehicles after which they can no longer be considered as fit for road use.

8. Technology measures to Improve Fuel Efficiency: Introduction of fuel injection brings about improvement in fuel efficiency, which is significant in 2-stroke engines but marginal in 4-stroke engines, which are already tuned for good fuel efficiency. These improvements come from improved air-fuel ratio control, better mixture preparation, reduced scavenging losses and improved combustion. To achieve further improvement in fuel efficiency, it is necessary to explore other avenues that help to reduce friction and improve overall efficiency of the vehicle. It will be worthwhile to explore the possibility of using some of the measures successfully adopted on four-wheeled vehicles in 2 and 3-wheelers. These may typically include variable valve timing, reducing rolling resistance, reducing engine friction, improved lubricating oil, smart start-stop arrangement etc. In case of diesel engine powered 3-wheelers, significant fuel efficiency gain can be obtained by adopting high-speed direct injection (HSDI) approach. There is a need to institute time bound R&D work in all these potential areas.

9. Setting up Fuel Efficiency Goals: Even though the Indian 4-stroke engine powered two and three-wheelers are already designed for high fuel efficiency, continuous efforts must be made to bring about further improvements. Setting formal goals to be achieved in a time bound fashion will serve as an incentive for bringing about further improvements. This will also help to reduce the GHG emissions from these vehicles. While setting up fuel efficiency goals, it will be useful to take into account the fuel efficiency profile of the present vehicles given in this report and the technical feasibility of achieving the goals. Lessons learned in other countries, such as China and Taiwan, may also be taken into account. Since the vehicle manufacturers would require adequate time to carry out the necessary developments to meet the fuel efficiency standards, and, since some of the emission control technologies may have a negative impact on the fuel efficiency, it would be prudent to introduce the fuel efficiency standards along with the next phase of emission standards namely BS IV in the year 2015.

10. Role of Fuels and Lubricants: No major recommendations are made regarding fuel quality since available fuels suitable for four-wheelers are suitable for small 2 and 3-wheelers also. Regarding lubricating oils, there is a need to expedite the formulation of standards for 4-stroke motorcycle engines, on the lines of JASO MA, to cater to the specific requirements of motorcycles compared to those for passenger car engines. The standard should take into account the latest developments in the field of 4-stroke motorcycle lubrication in respect of viscosity and additives usage as shown in this report.

11. Alternative Fuels and Alternative Power Units:

11.1. CNG and LPG: The most commonly used alternative fuels are CNG and LPG. Presently their usage is mostly in three-wheelers. Their use in two-wheelers, though technically feasible, is not practically feasible due to limitation of space in the vehicle for installing the cylindrically shaped gas tank and the various valves and regulators. Due to their gaseous nature at ambient conditions, these fuels burn cleanly in the engine thus producing low PM emissions. However, their impact on the emission of other pollutants is variable. Test results show that there is a reduction in CO emissions – up to 20%, but the Total HC and NOx is may show increase in some cases. In fact, catalysts are required to be used on LPG engines to meet the BSIII standards for Total HC. The use of CNG in 4-stroke engines improves its fuel efficiency over the petrol version though the impact in other cases is variable. Looking at the future, due to limited availability for vehicular usage, both of these fuels will remain niche market solutions and cannot be considered for widespread usage.

11.2. Hydrogen: Use of hydrogen in any category of vehicle is still mostly in the development phase. A three-wheeler using hydrogen as an IC engine fuel is undergoing user trials under the aegis of the International Centre for Hydrogen Energy Technologies, (ICHET) (a project of the United Nations Industrial Development Organization –UNIDO - supported by the Turkish

Ministry of Energy and Natural Resources) as a part of their demonstration project. Though the remarkable fuel efficiency of 95km/l of this engine, and almost zero emissions, makes this technology very attractive, the problems of easy and cheap access to hydrogen through filling stations and its storage on board the vehicle will be the main barriers that will need to be overcome.

11.3. Battery Electric Vehicles: There is a small but growing market for small battery operated electric vehicles. Ten manufacturers among them produce about 100,000 vehicles per year that are distributed in 25 different models. Although these constitute only about 1% of the total 2-wheeler market, the manufacturers of the electric vehicles are quite optimistic about a faster growth, thanks to the extensive package of incentives of the government designed to encourage the development of battery operated two, three and four – wheelers. Nevertheless, it is difficult to foresee a growth anywhere near that achieved in China in the past few years.

Most of these two-wheelers are powered by brushless DC motors of less than 250W power and have maximum speeds of less than 25km/h. These specifications exempt these vehicles from complying with the motor vehicle rules and do not require driving license. There are, however, larger vehicles with electric motors of up to1kW output. No battery electric three-wheeler is in the market though strong efforts were made a few years ago to develop vehicles with state-of-the art technology.

13. RECOMMENDED TIME LINES

Suggested timelines for the implementation of various recommendations made in the above section are given in Table 42.

Table 42: Time Line Recommended for Implementing Various Recommendations

S No	Regulation	Description	Year of Introduction	
			2015	2020
1	Mass Emission	BS IV, using GTR cycle and limits	√	
2	Mass Emission	BS V, using GTR cycle and limits		√
3	Evaporative Emission	2g/test using SHED	√ *	
4	Durability	Increase to 50,000km	√	
5	PUC Inspection	Adopt ARAI loaded mode test	√	
6	In-use conformity testing	System as per Taiwan	√	
		After study of feasibility and effectiveness		√
7	On Board Diagnostics (OBD)	For vehicles using electronically controlled fuel management	√	
8	Fuel Efficiency Standards	Proposals to be worked out	√	
9	4-stroke engine lubricant	Mandate as per JASO MA	√	

*To be introduced at the earliest possible

REFERENCES

1. *ACEM 2009, "*The Motorcycle Industry in Europe, ACEM Report" "Association des Constructeurs Européens de Motocycles". Web access: <http://www.acem.eu/publiq/ACEM_REPORT.pdf > accessed on May 15, 2011
2. *ACMA 2011***,** Automobile Component Manufacturers Association, web access http://www.acmainfo.com/industry-statistics.htm
3. *ADB 2008, "*A Road Map for Cleaner Fuels and Vehicles in Asia", TA 6144 (REG): Better Air Quality Management in Asia, Asian Development Bank, November 2008
4. *Ahern 2011,* Steven Ahern, Orbital Engine Company, Personal Communication.
5. *AIS 2011,* "Automotive Industry Standards", AIS 038 "Requirements for Construction and Functional Safety", AIS 039 "Measurement of Electrical Energy Consumption", AIS040," Method of Measuring the Range", and AIS041, "Measurement of Net Power and the Max.30 Min. Power", web access: https://www.araiindia.com
6. *Akamatsu 2004*, Shunji Akamatsu, Tomoya Kono, Hiroaki Miyata and Mamoru Uraki,"Research into New Emission Control Techniques for Motorcycles to Achieve the EURO-3 Regulation, Paper Number SAE 2004-32-0032.
7. *Archer 2001*, Archer, M. and Bell, G., "Advanced Electronic Fuel Injection Systems – An Emissions Solution for Both 2 – and 4- Stroke Small Vehicle Engines", SAE Paper Number 2001 – 01 – 0010)
8. *ATMA 2011,* Automotive Tyre Manufacturers' Association, web access: http://www.atmaindia.org/Technology.htm
9. *Badami 2006,* Badami, M.G**,** Iyer, N.V., 2006, "Motorized two-wheeled vehicle emissions in India: behavioural and institutional issues" Transportation Research Record 1954, 22–28.).
10. *Bajaj 2011*, Bajaj Auto Ltd, web access <www.bajajauto.com>
11. *Bajaj 2011,* Bajaj Auto Ltd, web access http://www.indiaautomotive.net/2009/06/bajaj-launches-eco-friendly-re-gdi.html (accessed on March 10, 2011)
12. *Bajaj Patent(1),* "Internal Combustion Engine with Improved Combustion Characteristics", Indian Patent Number IN195904 granted to Bajaj Auto Ltd, web access http://www.ipindiaonline.gov.in/patentgrantedSearch/(S(rx3wdamlcgerzbvi5cx54255))/displayApplication.aspx?application_number=649/MUM/2002 .
13. *Bajaj Patent(2),*"An Improved Ignition System for 2 or 3 Wheeled Vehicles" Indian Patent No IN208578, granted to Bajaj Auto Ltd.,web access http://www.ipindiaonline.gov.in/patentgrantedSearch/(S(vpmyzy552wj2txyyesrpib55))/displayApplication.aspx?application_number=207/MUM/2002
14. *Bauer 2011*, Tim Bauer, Envirofit, Personal communication
15. *Bike India 2011,* Bike India, Volume 6, Issue 009, April 201, web access, www.bikeindia.in
16. *BIS 2002,* "Indian Standard for Lubricants for Air Cooled Spark Ignition Engines – Specification", Bureau of India standards, IS:14234 (Part 1): 2002
17. *Business Line 2007,* Business Line, December 9, 2007
18. *Cathcart 2004***,** Geoffrey Cathcart, Rodney Houston and Steven Ahern, "The Potential of Gasoline Direct Injection for Small Displacement 4-Stroke Motorcycle Applications", SAE Paper 2004-32-0098.

19. *Chao Lung, Chen 2011*, Chao Lung, Chen, Industrial Technology Research Institute, Taiwan, Personal Communication
20. *Chen 2011*, Seok Chen Infineum Singapore – Personal communication, March 2011
21. *CMVR 2011,* MoRTH/CMVR/ TAP-115/116, ISSUE NO.4, PART XIII, STANDARDS FOR PETROL / DIESEL ENGINED VEHICLES, Chapter X, "Type III Test: Description of the Ageing Test for Verifying the Durability of Anti-Pollution Devices from Two and Three-Wheelers").
22. *Colombo 2010,* Paolo Colombo, "Closed Loop Controlled Electronic Carburation System", SAE 2010-32-0115).
23. *Cromas 2004,* J. Cromas, J. B. Ghandhi, "Lubricating Oil Contribution to Direct-InjectionTwo Stroke Engine Particulate Emissions":,SAE 2004-32-0012,
24. *Czerwinski 2006,* Jan Czerwinski and Pierre Comte, Bo Larsen and Giorgio Martini, Andreas Mayer, "Research on Particle Emissions of Modern 2-Stroke Scooters", SAE 2006-01-1078
25. *Dias 2008,* Chris Dias , Alfred Reck, "The Cost-effective Technology Applications of Turbulent Structures in Metallic Honey Comb Substrates", Better Air Quality Workshop, Bangkok,12-14 November, 2008
26. *Dias 2011,* Chris Dias, (Emitec), Personal communication
27. *Duleep 2011,* Duleep K. Gopalakrishnan, Personal communication
28. *Duret 2011*, Pierre Duret (IFP), Personal communication, April2011
29. *Economic Times 2010)*, The Economic Times 22 Nov, 2010
30. *Economic Times 2011)*, ECONOMICTIMES.COM, 28 Feb, 2011
31. *EEA 2007,* "Technologies to Improve Light-Duty Vehicle Fuel Economy", Energy and Environmental Analysis, Inc, September, 2007)
32. *Envirofit 2008,* "Comparison of Retrofit Options For Carburetted Two-Stroke Engines, (PRELIMINARY RESULTS), Sub-workshop 20: Reducing Air Pollution and Greenhouse Gas Emissions from In-Use Vehicles, Better Air Quality (BAQ) 2008, Bangkok, Thailand, web access: Envirofit www.envirofit.org
33. *EU 2010,* Proposal for a EUROPEAN PARLIAMENT AND COUNCIL REGULATION Regulation (EU) No .../2010 of the European Parliament and of the Council on the approval and market surveillance of two- or three-wheel vehicles and quadricycles, /* COM/2010/0542 final - COD 2010/0271 */, 04/10/2010
34. *Favre 2009,* Cécile Favre; Dirk Bosteels; John May, Ian De Souza; Leon Beale; Jon Andersson, "An Emissions Performance Evaluation of State-of-the-Art Motorcycles Over Euro 3 and WMTC Drive Cycles", SAE Paper 2009-01-1841.
35. *FIAT 2011,* FIAT , web access: <http://www.fptmultiair.com/flash_multiair_eng/home.htm>).
36. *Financial Express 2009,* Financial Express,April20, 2009
37. Gandhi, K.K., 2011, SIAM, Personal Communication
38. Govindarajan S., 2005,"Fuel Management System for Petrol Engines – State of the Art in Electronic Fuel Injection", Symposium on International Automotive Technology, 2005, ARAI, Pune
39. Govindarajan S., (UCAL), 2011,Personal Communication.
40. *GTZ 2009*, "Sustainable Transport: A Sourcebook for Policy-Makers in Developing Cities", Module 4c,Two- and Three Wheelers, web access: http://www.sutp.org
41. *HMSI 2011,* Honda Motorcycles and Scooters India, web access http://www.honda2wheelersindia.com/cbf_stunner_pgm-fi/about.html

42. *Honda 2003,* Honda Worldwide , web access http://world.honda.com/news/2003/2031003.html
43. *ICCT 2011,* “Passenger Vehicle Greenhouse Gas and Fuel Economy Standards: A Global Update” , web access: http://www.theicct.org/passenger-vehicles
44. *ICHET 2011,* Centre for Hydrogen Energy Technologies, web access: http://unidoichet.org/index.php?option=com_content&view=article&id=258%3Ah2-three-wheelers&catid=15&Itemid=13&lang=en) (accessed on 05/05/2011).
45. *Iijima 2009,* Satoshi IIJIMA, Ryo KUBOTA, and Kazunori KIKUCHI, “Development of Technologies for Improving Fuel Economy of Small Motorcycle Engines”, 2009-32-0083.
46. *India Automotive 2009,* India Automotive **–** JUNE 23, 2009, “DTS Si Version 2.0 Bajaj Auto claims to have launched the world’s most fuel-efficient engine series**.**
47. *India Automotive 2010***,** web access: http://www.indiaautomotive.net/2010/10/indian-motorcycle-market-double-digit.html
48. *India Automotive 2011*, web access: http://www.indiaautomotive.net/2009/06/bajaj-launches-eco-friendly-re-gdi.html (accessed on March 10, 2011)
49. *Intelligent Energy 2011,* Intelligent Energy, web access: http://www.intelligent-energy.com)
50. *Ishibashi 2000,* Yoïchi Ishibashi, “Basic Understanding of Activated Radical Combustion and Its Two-Stroke Engine Application and Benefits”, SAE 2000-01-1836
51. *Iyer 2003,* Iyer Narayan V. “Role of Three-Wheeled Vehicles in Urban Transportation in South Asia”, ‘Smart Urban Transport’, Vol 2, Number 2, July 2003, web access <www.smarturbantransport.com>.
52. *Iyer 2004,* N.V.Iyer, “Managing Two and Three-Wheeler Emissions” National Workshop on the Improvement of Urban Air Quality of Pakistan,13 - 15 December, 2004, Lahore, Pakistan.
53. *Iyer 2007,* N.V.Iyer,“Management of In-Use Motorcycle Emissions – the Indian Experience”, Workshop on Motorcycle Emission Control in Major Cities Program – International Experience and Vietnam Conditions, Hanoi, March 06, 2007.
54. *Iyer 2007*, Narayan V. Iyer and Madhav G. Badami, “Two-wheeled Motor Vehicle Technology in India: Evolution, Prospects and Issues”, Energy Policy 35 (2007) 4319–4331
55. *JASO 2006,* Motorcycles – Four Stroke Cycle Gasoline Engine Oils JASO T903, 2006.
56. *Jayat 2009,* Francois Jayat and Alfred Reck, Roland Kirchberger, Matjaz Korman, Niko Bretterklieber and Gernot Mayer, “Application of a New Metal Catalyst Substrate Generation for Two and Three Wheelers”, SAE 2009-26-014).
57. *Kamakaté 2009,* Fatumata Kamakaté, “Managing Motorcycles: Opportunities to Reduce Pollution and Fuel Use from Two- and Three-Wheeled Vehicles”, International Council on Clean Transportation, October 2009
58. *Karle 2003,* U.S.Karle, Amit Kumar, Madhuri Marathe, “Development of Electronic Caburettor for 4-Stroke Two-Wheeler Vehicles”, SAE 2003-26-0025.
59. *Kasai 2006,* Moritsugu Kasai and Katsuhiko Nakajima “Fuel Saving Four-Stroke Engine Oil for Motorcycles ” SAE Paper Number 2006-32-0014.
60. *Kojima 2000* , Kojima, M., Brandon, C., Shah, J., 2000. Improving Urban Air Quality in South Asia by Reducing Emissions from Two-stroke Engine Vehicles
61. *Leighton 2003,* Sam Leighton and Steven Ahern, “Fuel Economy Advantages on Indian 2-Stroke and 4-Stroke Motorcycles Fitted with Direct Fuel Injection”, SAE 2003-26-0019

62. *Malhotra 2011,* R.K.Malhotra, IOC R&D, Personal Communication
63. *Marathe 2011,* S R Marathe**,** Director ARAI, personal communication
64. *Marathe M 2011,* Personal Communication)
65. *Mashelkar 2002,* R.A. Mashelkar., et al. "Report of the Expert Committee on Auto Fuel Policy", Government of India, New Delhi, 2002
66. *Meszler 2007,* Dan Meszler "Air Emissions Issues Related to Two and Three-Wheeled Motor Vehicles - an Initial Assessment of Current Conditions and Options for Control - July 2007
67. *MoEF 1996)***, "**2-T Oil (Regulation of Supply and Distribution) Order, 1998". dated 31-12-1996 GSR 778(E), Ministry of Environment and Forests
68. *MoEF 2006,* "2-T Oil (Regulation of Supply and Distribution) Amendment Order 2006" dated 17-11-2006, GSR 714(E) Ministry of Environment and Forests).
69. *MoRTH 2003,* Ministry of Road Transport and Highways, Notification No GSR720E (Bharat Stage II).
70. *MoRTH 2004,* GSR 111E dated 10.2.2004 Ministry of Road Transport and Highways, (In-Use Emission Limit Values)
71. *MoRTH 2009,* Ministry of Road Transport and Highways, Notification No GSR 84(E) (Bharat Stage III)
72. *MoRTH 2010,* Ministry of Road Transport and Highways, Draft Notification No GSR1034(E) dated 31st December, 2010, (WMTC Standards)
73. *MVA 1989,* Motor Vehicles Act.
74. *Nakamura 2003,* Michihisa Nakamura, Yuuichirou Sawada and Shigeki Hashimoto, "Fuel Injection System for Small Motorcycles", 2003-32-0084.
75. *Nishida 2009,* Kenji Nishida, Hisashi Sakuyama, Takahiro Kimijima," Improvement of Fuel Economy Using a New Concept of Two-Stroke Gasoline Engine Applying Stratified-Charge Auto-Ignition", SAE 2009-28-0009
76. *Ntziachristos 2006,* Leonidas Ntziachristos, Athanasios Mamakos, Zissis Samaras, Anastasios Xanthopoulos, Eleftherios Iakovou, "Emission control options for power two wheelers in Europe, Atmospheric Environment, 40 (2006), 4547-4561.
77. *Ntziachristos 2009,* Leonidas Ntziachristos, Savas Geivanidis, Zissis Samaras, Anastasios Xanthopoulos, Heinz Steven, Bernd Bugsel, "Study on possible new measures concerning motorcycle emissions - Final Report – Revised Version, Report No: 08.RE.0019.V4, Thessaloniki, September 2009)
78. *Oswald 2010,* Roland Oswald, Andreas Ebner and Roland Kirchberger, "High Efficient 125- 250 cm3 LPDI Two-Stroke Engines, a Cheap and Robust Alternative to Four-Stroke Solutions?" SAE 2010-32-0019
79. *Pace 2009,* Lorenzo Pace**,** Francois Jayat, Roman Konieczny, Martin Forster, Richard Humer, Daniel Mairhörmann, Rudolf Prem, "Innovative 2 Wheeler Substrate Developments for EU5", SAE 2009-32-0102**.**
80. *Palke 1999,* D. R. Palke and M. A. Tyo,"The Impact of Catalytic After-treatment on Particulate Matter Emissions from Small Motorcycles, SAE 1999-01-3299)
81. *Piaggio 2011*, Piaggio Vehicles Pvt Ltd., web access (www.piaggio.co.in)
82. *Pundir 2008,* B. P. Pundir, "Fuel Economy of Indian Passenger Vehicles - Status of Technology and Potential FE Improvements", Greenpeace India Society, Bangalore, November 2008.
83. *Pundir 2010, B.P.Pundir, "IC Engines: Combustion and Emissions", page 177, Narosa Publishing House, New Delhi, 2010, (web access: www.narosa.com)*

84. *Pundir 2011*, Pundir B.P. Persoanal Communication
85. *Raney 2011,* David Raney, Raney Associates, Personal communication)
86. *Ravenhill 2009*, P. Ravenhill, T. Drake, R.Hoolahan, B.Smither, I.McFarlane, J. Allen, G.Farmer, “Low Cost Electronic Fuel Injection for Motorcycles and Utility Engines”, SAE 2009-32-0149).
87. *Reynolds 2011,* Conor C.O.Reynolds, Andrew P. Grieshop and Milind Kandlikar, “Climate and Health Relevant Emissions from in-Use Indian Three-Wheelers Fueled by Natural Gas and Gasoline”, Environmental Science and Technology, 2011, 45 (6) pp 2406 – 2412 (February 15, 2011), <pubs.acs.org/est>
88. *Rijkeboer 2005,* R.Rijkeboer, D.Bremmers, Z.Samaras, L.Ntziachristos, “Particulate Matter Regulation for Two-Stroke Two-Wheelers: Necessity or Haphazard Legislation?”, Atmospheric Environment, 39 (2005) 2483-2490.
89. *Sakai 1999,* T.Sakai, T.Nakajima, H.Yamazaki, “O-PM/Emitted Matters Caused by Two-Stroke Engine Oil and I\its Reduction”, SAE Technology Paper 1999-01-3260
90. *Sheth 2006,* Nitin R. Sheth, A. Ramesh, “Development of a Variable Valve Timing System for Improving the Performance of a Small Two Wheeler Engine, SAE 2006-32-0104)
91. *SIAM 2011,* Society of Indian Automobile Manufacturers, web access www.siamindia.com,
92. *Singh, H. 2011, “* Advance Two Wheeler Emission Technologies and Approach for Next Stage Emission norms”, 4th International Conference on “ECT 2011 – After Treatment Technologies, 2013 & beyond”, ECMA, New Delhi, November 9 – 10, 2011,
93. *SMEV 2011,* Society of Manufacturers of Electric Vehicles, web access: http://www.smev.in
94. *Sud-Chemie 2008*, “Catalytic Converter Design for Two-Wheelers”, Presentation by Sud-Chemie at the Better Air Quality workshop, Bangkok, November 12 – 14, 2008)
95. *Taiwan EPA 2007*, Vehicular Air Pollutant Emission Standards, ROC Taiwan, Regulations, Current, Last revision on June 28 2007
96. *Takasu 2008*, Kouji Takasu, Hisatoshi Kinoshita and Ryusuke Kato, “Effects on Fuel Economy and NOx Emission Using Stratified Charge and EGR System for a Single Cylinder Motorcycle Engine, SAE SAE 2008-32-0018.
97. *Teoh 2008, Yew Heng Teoh, Horizon Gitano-Briggs and Khairil Faizi Mustafa, “Performance Characterization of a Direct Injection LPG Fuelled Two-Stroke Motorcycle Engine”, SAE 2008-32-0045*
98. *TVS 2011, TVS Motor Company 2011, web access < www.tvsmotor.in>*
99. *UNECE 2005, ECE/TRANS/180/Add.2, Dated 30 August 2005*
100. *UNECE 2007, ECE/TRANS/WP.29/AC.3/19.*
101. *UNECE 2008, ECE/TRANS/180/Add.2/Amend.1/Appendix1*
102. *UNECE 2008,* “Report on data collection as a basis for the discussion about the introduction of performance requirements in GTR No. 2 (World-wide harmonized motorcycle emission test cycle (WMTC”), Informal document No. GRPE-56-1, (56th GRPE, 3-6 June 2008, agenda item 4),
103. *UNECE 2011(1), ECE/TRANS/WP.29/GRPE/2011/4)*
104. *UNECE 2011 (2) ECT/TRANS/180/Add.2/Amend.2, October 28, 2011*
105. *Watanabe 2010, Nobuaki Watanabe, “Study of Lower Viscosity Motorcycle Engine Oils for Fuel Saving” ,SAE Paper Number 2010 - 32-0123)*

106. *Winkler 2005, Franz Winkler, Roland Kirchberger, Oliver Schoegl, Stephen Schmidt. "Strategies to Reduce Scavenge Losses of Small Capacity 2-Stroke Engines, Pressurized by the Common Market Costs", SAE Paper No. 2005-32-0098.*
107. *You Tube 2006. "Fuel cell motorcycle". youtube.com.*
108. *Zigwheels 2011, Zigwheels, web access: http://www.zigwheels.com/news-features/recent-launches/honda-cbr250r-launched-in-india-at-rs-151-lakh/7896/1*
109. *Zigwheels* 2012*, web access: http://www.zigwheels.com/news-features/news/mahindra-2-wheelers-inaugurates-new-rd-centre-in-pune/13503/2 Accessed on July 08, 2012*

ANNEX I

MARKET SHARE DETAILS FOR 2- AND 3-WHEELERS

Table AI-1: Market Share of Different Manufacturers (numbers) for All Categories of 2-Wheelers

DOMESTIC SALE, 2009-10	**NUMBERS**								
	TVS	MAHINDRA	HHML	HMSI	SUZUKI	BAJAJ	YAMAHA	ENFIELD	TOTAL
MOPED	564584	0	0	0	0	0	0	0	564584
SCOOTERETTE	24568	1625	0	0	0	0	0	0	26193
SCOOTER 75-125 cc	274802	68077	208440	739657	140983	3759	0	0	1435718
SCOOTER 125-250 cc	0	345	0	290	0	0	0	0	635
MOTORCYCLE 75-125 cc	359689	0	4055304	25049	0	928878	62555	0	5431475
MOTORCYCLE 125-250cc	132669	0	238687	427055	47486	852870	160715	0	1859482
MOTORCYCLE >250cc	0	0	6	0	43	35	0	50098	50182
	1356312	70047	**4502437**	1192051	188512	**1785542**	223270	50098	9368269

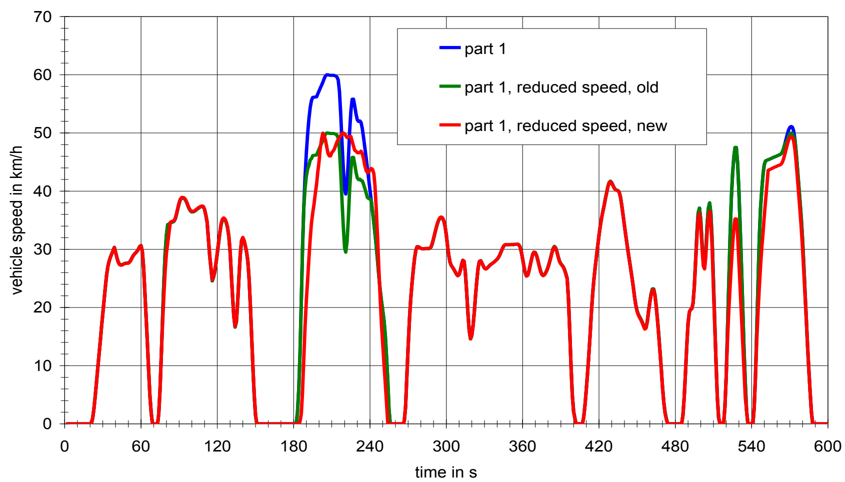
Table AI-2 Market Share of Different Manufacturers (per cent of all vehicles) for all Categories of 2-Wheelers

DOMESTIC SALE, 2009-10	**% OF TOTAL 2W SALE**								
	TVS	MAHINDRA	HHML	HMSI	SUZUKI	BAJAJ	YAMAHA	ENFIELD	TOTAL
MOPED	6.027	0	0	0	0	0	0	0	6.027
SCOOTERETTE	0.262	0.017	0	0	0	0	0	0	0.280
SCOOTER 75-125 cc	2.933	0.727	2.225	7.895	1.505	0.040	0	0	15.325
SCOOTER 125-250 cc	0	0.004	0	0.003	0	0	0	0	0.007
MOTORCYCLE 75-125 cc	3.839	0	43.288	0.267	0.000	9.915	0.668	0	57.977
MOTORCYCLE 125-250cc	1.416	0	2.548	4.559	0.507	9.104	1.716	0	19.849
MOTORCYCLE >250cc	0	0	0	0	0	0	0	0.535	0.536
	14.478	0.748	**48.061**	12.724	2.012	**19.059**	2.383	0.535	100.000

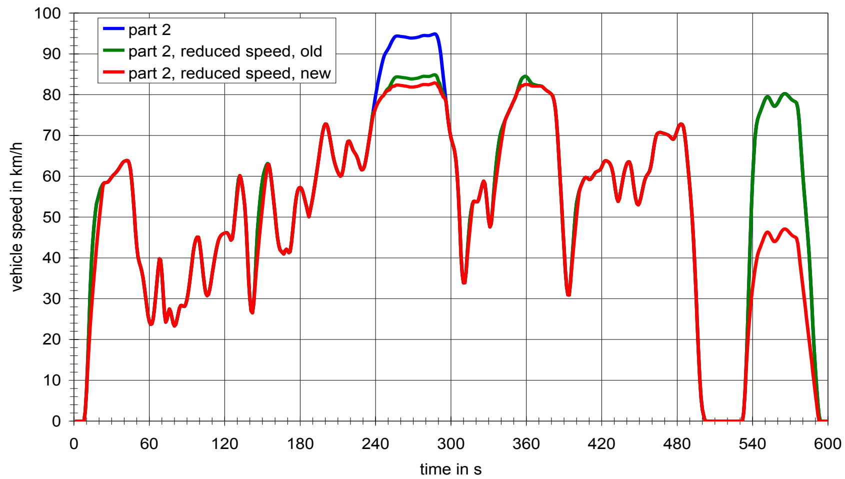
ANNEX II

WMTC DRIVING CYCLES FOR TYPE 1 TESTS

WMTC CYCLE, PART1, ORIGINALLY PROPOSED ‘REDUCED SPEED’ AND NEW ‘REDUCED SPEED’



WMTC CYCLE, PART2, ORIGINALLY PROPOSED 'REDUCED SPEED' AND NEW 'REDUCED SPEED'



WMTC CYCLE, PART 3, ORIGINALLY PROPOSED

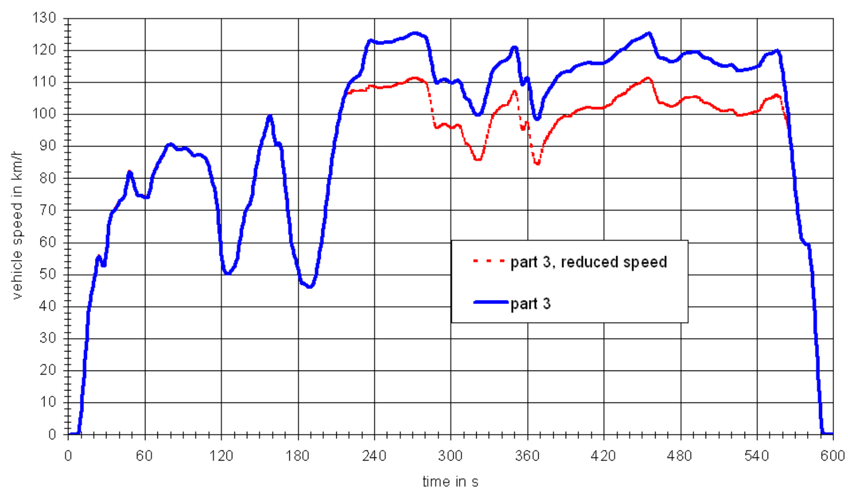


Table AII.1. Weighting Factors to be used for different parts of the WMTC drive cycle

Vehicle class	Cycle	Weighting	
Class 1	Part 1, cold	w_1	50 per cent
	Part 1, hot	w_{1hot}	50 per cent
Class 2	Part 1, cold	w_1	30 per cent
	Part 2, hot	w_2	70 per cent
Class 3	Part 1, cold	w_1	25 per cent
	Part 2, hot	w_2	50 per cent
	Part 3, hot	w_3	25 per cent