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AIR QUALITY IMPACT ASSESSMENT BY CHANGEOVER TO CNG BUSES IN DELHI

FINAL REPORT

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AIR QUALITY IMPACT ASSESSMENT BY CHANGEOVER TO C.N.G. BUSES IN DELHI

1. Introduction

CNG buses have been made mandatory in Delhi from 1st April 2001. Due to inability to effect this changeover and various operational difficulties, this deadline has been extended by 6 months to 30th September 2001. The motivation of this changeover is to reduce emission from buses because C.N.G. fuelled buses are expected to be less polluting than diesel fuelled buses, which in turn will improve the ambient air quality. The changeover increases the cost of the bus, a cost that will be eventually borne by the bus users. With about 40% of the chartered bus users and 20% of stage carriage (DTC, blue line, etc.) bus users owning 2-wheelers, this increase in bus fares could make 2-wheelers economical for some of them. Consequently, some of these bus users are likely to give-up bus transport and travel by their personal 2-wheelers or cars, most of which are 2-stroke and 4 stroke petrol engines. As a result, the gains in emission reduction from buses are likely to be offset by increased use of 2-wheelers and some cars. Yet another option would be to convert part or the entire fleet to Euro II standard diesel engines. This change-over, entails lower costs than conversion to CNG and results in some reduction in emissions. In the analysis presented below, change in emissions under these different scenarios has been described.

These vehicular emission data are well correlated to road-side ambient air quality. It cannot, however, be correlated with the ambient air quality that is influenced by all other emitting sources, such as, stationary diesel generators, portable generators, factories, wood burning stoves, and kerosene cooking stoves, amongst others. Even when such an exercise is carried out, the impact of changeover to CNG is likely to be overshadowed by emissions from all these other sources. Since data on these sources is unavailable, the impact on ambient air quality because of changeover to CNG has not been estimated quantitatively.

2. Methodology

2.1 Traffic flow measurements

In 1994, measurements of mode-wise vehicular traffic were performed at 14 locations [1]. The data is comprised of number of vehicles by type, e.g. 2 wheeler, 3-wheeler, car, truck, buses, LCVs, etc., passing through a location in a given time period during morning peak traffic. The per hour flow rate of vehicles has been reported in the publication. For the present study, three of these locations were selected for making measurements - Vikas Marg (near ITO crossing), Nanakpura (on Ring Road) and AIIMS (on Aurobindo Marg). The basis of the selection of the locations was the wide variation in the ratio of the number of 2-wheelers to the number of buses (0.1 at Vikas Marg and 0.3 at Nanakpura). During morning peak traffic, the number of vehicles by type, i.e. 2-wheeler, 3-wheeler, cars and buses, passing a location were counted. These data have been presented on a per hour basis and are presented in Table 1.

Table 1: Measurement of vehicular flow rates per hour (July 2001)

	Vikas Marg	Nanakpura	AIIMS
2-wheelers	3993	2457	1086
3-wheelers	558	389	419
Cars	2235	1851	948
buses	255	273	170
total	7041	4970	2623

Registration data of vehicles has not been used because it does not correlate with the actual number of vehicles used in Delhi, i.e. vehicles on road. For example, the total number of motorised vehicles registered in Delhi 2000 is reported to be 3.48 million [2]. The current population of Delhi is about 14 million with 2.8 million households, and this works out to 1.2 vehicles per household. This number is an overestimation because the income distribution in Delhi is such that 20-30% households cannot afford to own a motorised vehicle. Therefore, we have used the actual traffic flow data to estimate spot emission figure.

The modal share by vehicle type in July 2001 and 1994 are shown in Figures 1(a) and 2(a), respectively. Figure 1(a) shows that 2-wheelers form the single largest mode of transport followed by cars. In comparison with the 1994 data, there has been an increase in the modal share of cars, except at AIIMS where the share has remained almost unchanged.

With the same vehicle data and occupancies of 1.3 for 2-wheelers and 3-wheelers, 1.5 for car and 75 for bus, the total number of passengers travelling by each mode have been calculated. This modal share of passengers for July 2001 and 1994 presented in Figures 1(b) and 2(b), respectively. While buses continue to meet the bulk of the transportation needs, transporting between 70-90% of the passengers, their absolute share has shown a decrease. There is, therefore, evidence of a shift from buses to personal transport (2-wheelers and cars) during the period 1994 to 2001. This shift has occurred for a variety of reasons, none of which are related to the CNG issue and is likely to continue unless public transport is made more comfortable, efficient and safer.

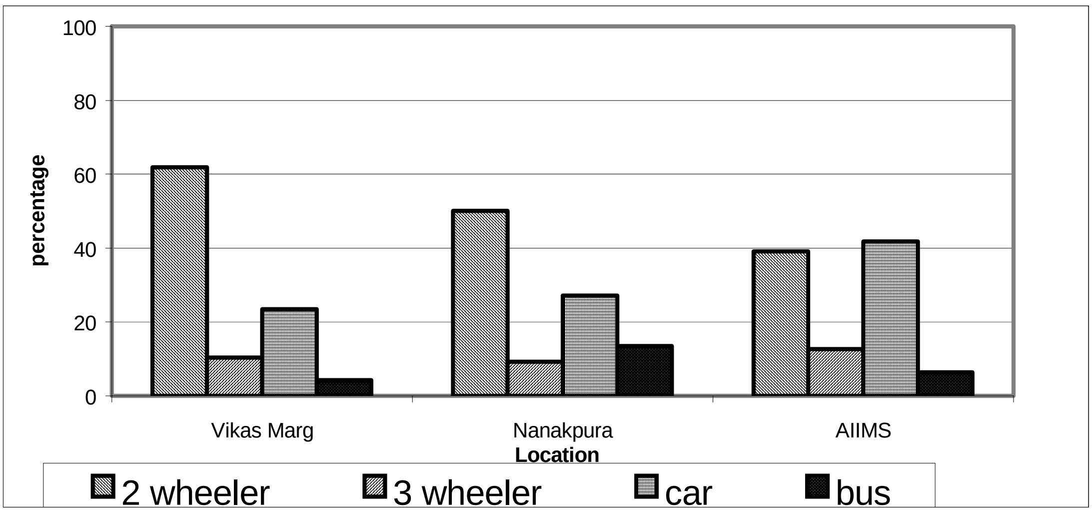

Fig. 1(a): Modal share of vehicles (July 2001).

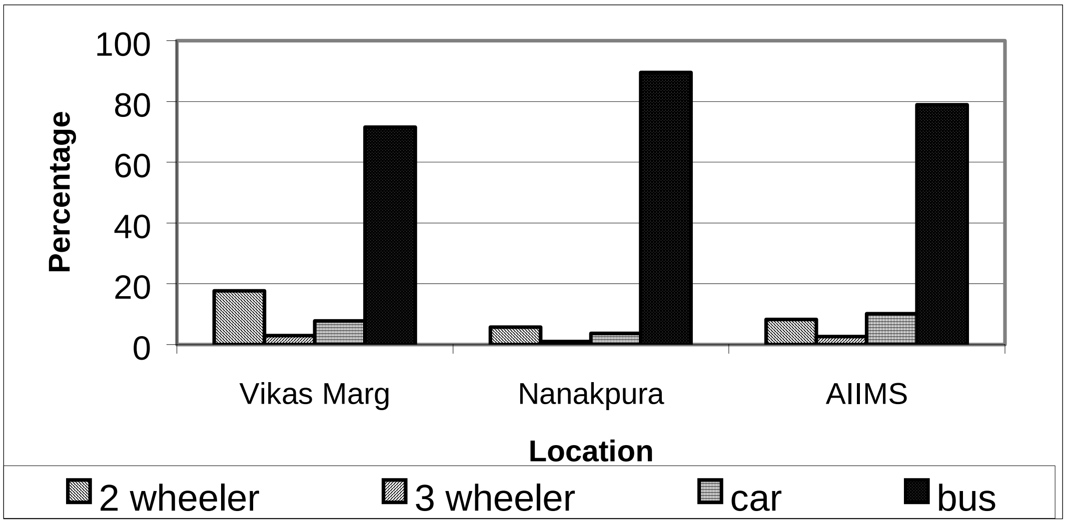

Fig. 1(b):Modal share of passengers (July 2001).

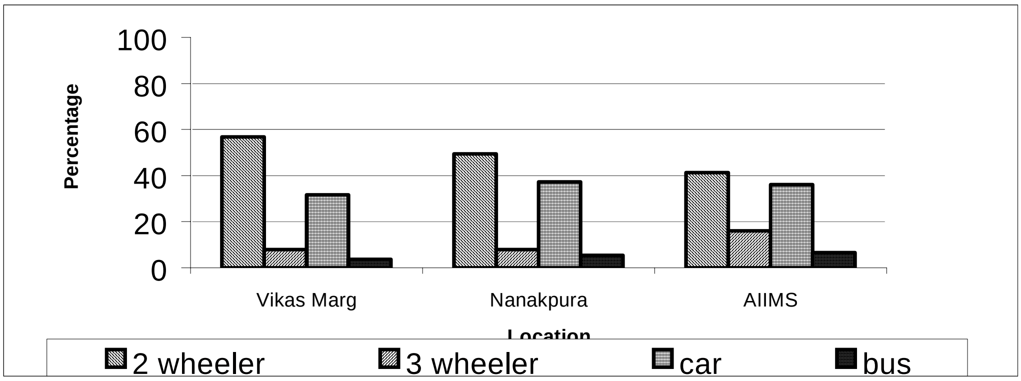

Fig. 2(a).: Modal share of vehicles (1994).

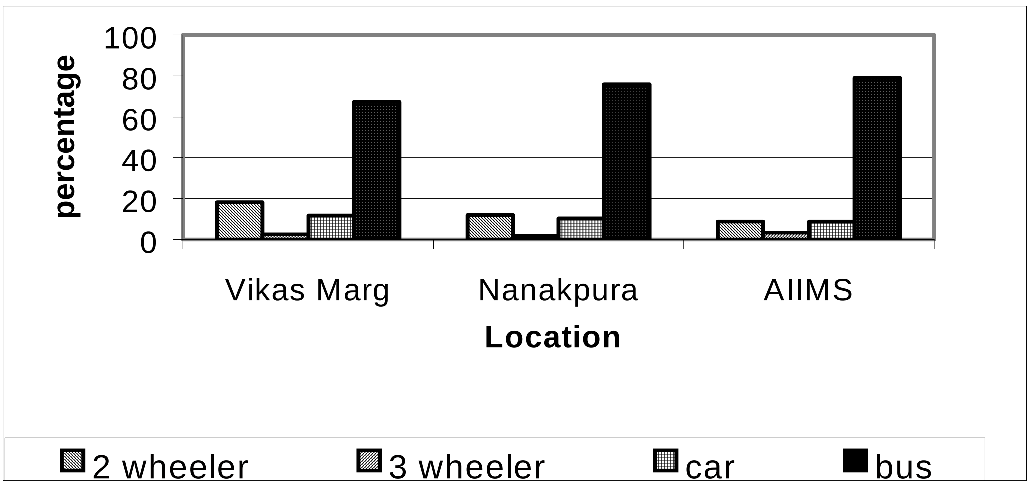

Fig. 2(b).: Modal share of passengers (1994).

2.2 Emission data for current vehicles

The next step required emission data by vehicle type and age. In an exhaustive report on vehicular emissions [3], the CPCB has given emission of different pollutants by vehicle type and age. The data relevant to this study are emissions from 2-wheelers, 3-wheelers, cars and buses. The pollutants considered are Carbon monoxide (CO), hydrocarbons (HC), oxides of Nitrogen (NOx) and particulate matter (PM). Emissions of these pollutants are given by vehicle age and are presented in Table 2.

Table 2: Emission from different type of vehicles (Ref.[3])

Vehicle Type	Age (years) (w.r.t. 2001)	Pollutant emitted (g/km)			
		CO	HC	NOx	PM
2-wheeler 2 stroke	0-5	4	3.3	0.06	0.1
	5-10	6.5	3.9	0.03	0.23
	10-15	6.5	3.9	0.03	0.23
3-wheeler 2 stroke	0-5	8.6	7	0.09	0.15
	5-10	14	8.3	0.05	0.35
Car (petrol)	0-5	3.9	0.8	1.1	0.05
	5-10	9.8	1.7	1.8	0.06
	10-15	9.8	1.7	1.8	0.06
Bus (Diesel)	0-5	4.5	1.21	16.8	1.6
	5-10	5.5	1.78	19	3

2.3 Emission data for CNG and Euro II Diesel buses

Reliable data on emission from CNG and Euro II diesel buses is scarce. Most of this data is for European buses [4] that is not well reflective of Indian conditions. Limited data are available from the two manufacturers of bus chassis in India, Ashok Leyland [5] and Telco [6]. Most of these are for new buses and do not factor performance degradation with time and maintenance procedures. These data have been compiled in Table 3; for comparison, data of existing diesel buses are also included. The data available are per unit power produced, i.e. pollutant grams per kWh. For conversion to grams per kilometer an average mileage of 3.4 km/liter has been assumed. The resulting factor has been used for converting the per kWh data to per kilometer basis, as presented in Table 3. Given the variability in this data, a representative set of emission levels has been selected for the analysis and these are listed in the table. However, our estimates will give a conservative estimate and the real emissions are likely to be higher. This dearth of data on CNG and Euro II Diesel buses of different make, and especially the effect of vehicle age, needs to be urgently addressed by extensive laboratory and on-road measurements with state-of-the-art techniques.

Table 3: Emission from new buses with different fuels and makes (Ref.[3,4 5 &6])

Fuel used	Data source	Pollutant emitted (g/km)			
		CO	HC	NOx	PM
Diesel	CPCB	4.5	1.21	16.8	1.6
CNG	Ashoka Leyland	9.36	3.90	9.72	0.042
	Telco	5.04	2.52	10.26	0.093
	Milbrook	6.2	3.0	10.0	0.05
	Current study	6.0	3.0	10.3	.09
Euro-II Diesel	Telco	3.1	1.08	17.67	0.34
	Milbrook	2.0	1.1	12.0	0.2
	Current study	3.1	1.08	15	0.34

3. Emission analysis with current vehicles

Emissions from current vehicles, using the above data are presented here. This data forms the base case, i.e. the road condition as of July 2001, against which changes under different scenarios have been compared. The product of the number of vehicles for each type and age with their emission of each pollutant summed up for vehicles of all ages given the total emission of that pollutant per kilometer per hour. This calculation has been performed for each of the four pollutants. This data is presented in Tables 4(a), 4(b) and 4(c) for Vikas Marg, Nanakpura and AIIMS respectively.

Table 4(a). Pollutants emitted by different types of vehicles at Vikas Marg

Vehicle	Pollutant emitted (gms per km per hour)			
	CO	HC	NOx	PM
2-wheelers	22627	14774	160	745
3-wheelers	6305	4269	39	140
cars	15968	2894	3318	124
buses	1224	352	4451	514
(Total)	46124	22289	7968	1523

Table 4(b). Pollutants emitted by different types of vehicles at Nanakpura

Vehicle	Pollutant emitted (gms per km per hour)			
	CO	HC	NOx	PM
2-wheelers	13923	9091	98	459
3-wheelers	4407	2984	27	97
cars	13225	2397	2749	102
buses	1311	377	4767	552
(Total)	32866	14849	7641	1210

Table 4(c). Pollutants emitted by different types of vehicles at AIIMS

Vehicle	Pollutant emitted (gms per km per hour)			
	CO	HC	NOx	PM
2-wheelers	6154	4018	43	203
3-wheelers	4746	3213	29	105
cars	6771	1227	1407	53
buses	816	235	2968	343
(Total)	18487	8693	4447	704

The modal share at each of the three locations of Vikas Marg, Nanakpura and AIIMS are presented in Figures 3(a), 3(b) and 3(c), respectively.These data show that the dominant emitters of CO are 2-wheelers, 3-wheelers and cars; with buses contributing less than 5%. 2-wheelers account for almost half of the CO emissions consisting 49% at Vikas Marg, 42% at Nanakpura and 33% at AIIMS. Cars emit between 35% and 40% of CO. 3-wheelers account for 13% of CO emissions at Vikas Marg and Nanakpura, but for 27% at AIIMS. This contribution will change as more of them convert to CNG or 4-stroke engines.

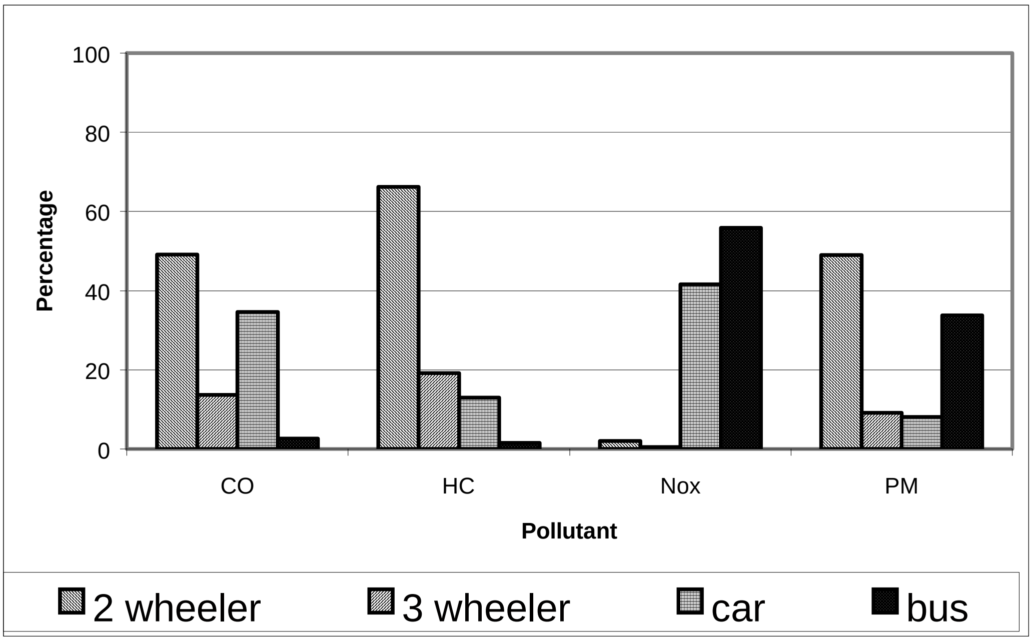

Fig. 3(a).: Modal share of pollutants at Vikas Marg (July 2001).

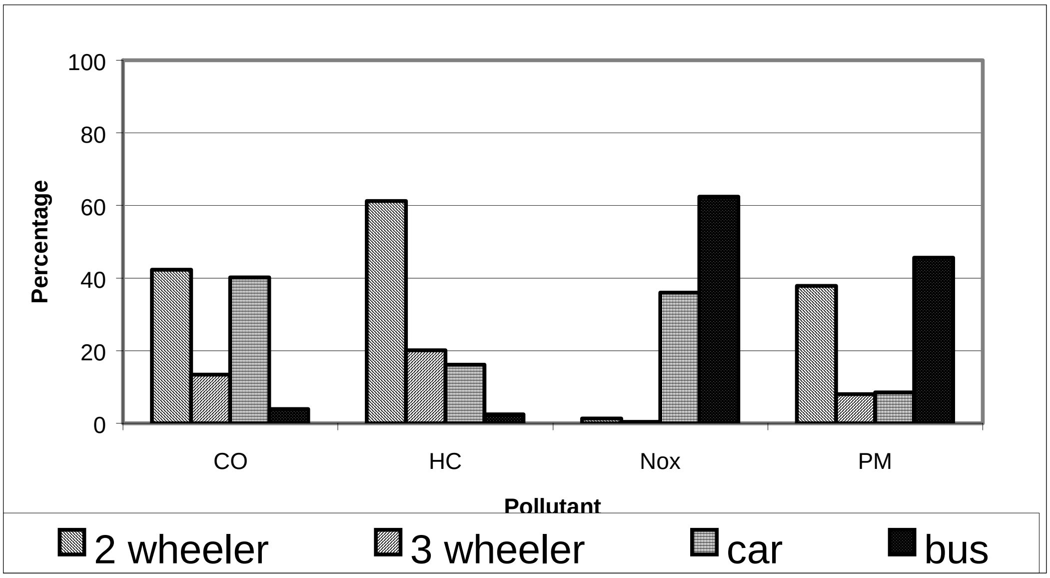

Fig. 3(b).: Modal share of pollutants at Nanakpura (July 2001).

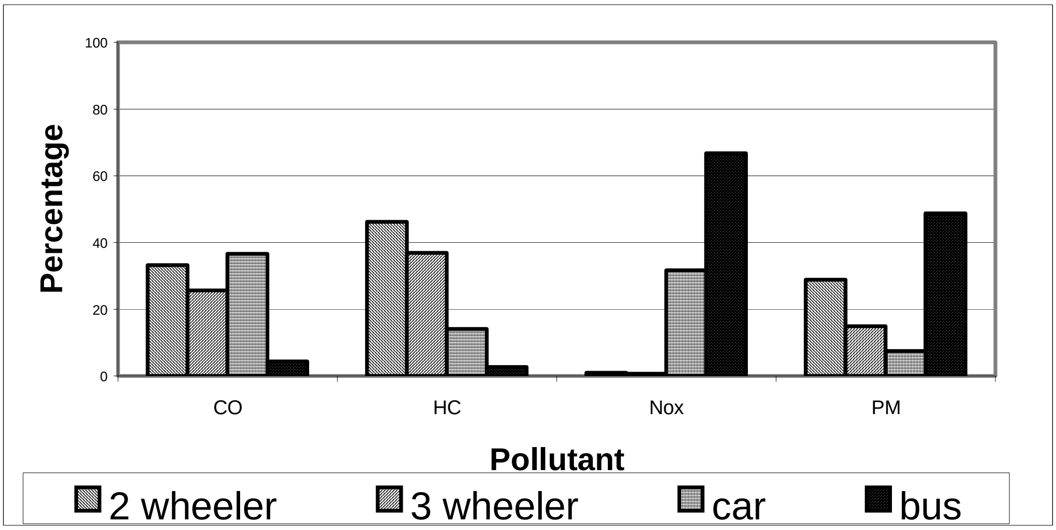

Fig. 3(c).: Modal share of pollutants at AIIMS (July 2001).

The bulk of HC emissions are from 2-wheelers - between 46.2% (at AIIMS) and 61.2% (at Vikas Marg). At AIIMS, 3-wheelers are the second largest contributor of HC (37%) but this share is 20% at the other two locations. Cars contribute about 15% of the HC emissions. The smallest contributions to HC emissions - less than 3% - is from buses.

The main contribution to NOx emissions is from buses and cars in that order, 2- and 3-wheelers contribute less than 2%. Thus, the bus is the main emitter of NOx, its share being 55%-65%. Following buses, cars are the second largest emitter of NOx contributing between 30%-40%.

The particulate matter emission share shows some interesting trends. First, 3-wheelers and cars together account for a little less than 20% of PM emissions.

Buses account for 35%-50% of PM emissions and 2-wheelers for the remaining 30%-45%. Thus, 2-wheelers and buses are major emitters of PM.

This data shows that there is no single transport mode that accounts for a bulk of all pollutant emissions. Therefore, a strategy for reducing emissions must tackle all transport modes simultaneously and not just one mode, buses in the present situation.

The data per passenger for each mode are shown in Figure 4. The data shows that in transporting one person a distance of one kilometer, the least polluting mode is the bus, diesel fuelled in this case. 2-wheelers and cars are the leading polluters as far as meeting the transportation needs are considered. Unlike the modal data presented in Figure 3, there is no ambiguity that the least polluting mode, independent of the pollutant considered, is the bus.

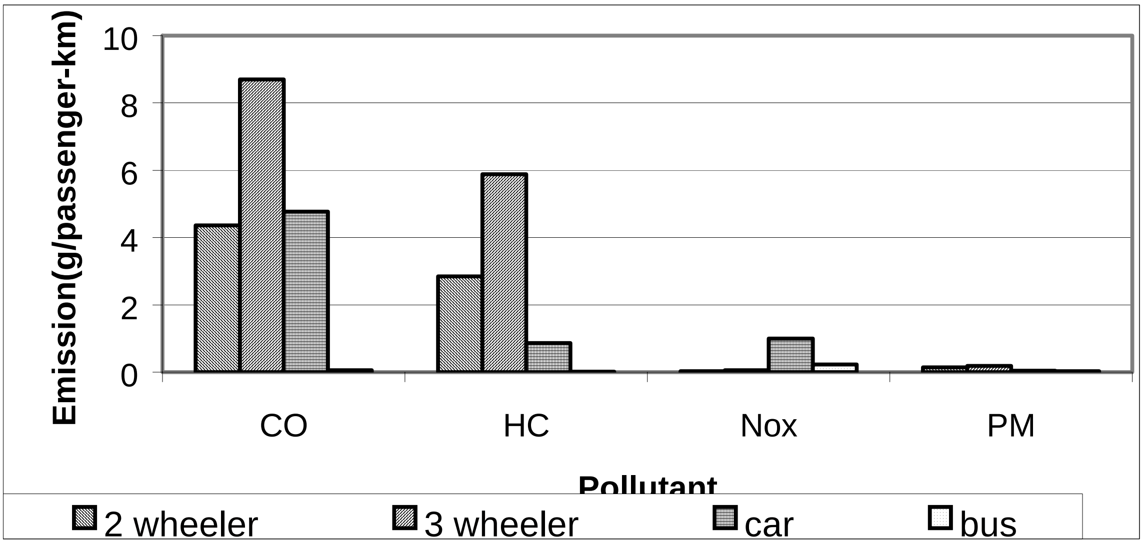

Fig. 4: Pollutant emission per passenger per kilometer from each vehicle type

4. Results

In the following sections, the impact of conversion of buses to CNG is presented.

4.1 Changeover of entire bus fleet to C.N.G. without shift to 2-wheelers

If the entire existing bus fleet is converted to CNG under existing conditions, the emissions will be affected by changes in bus emissions alone. This modification when incorporated into the base case gives the scenario for full fleet conversion to CNG. The resulting changes are shown in Figure 5. CO and HC emissions increase marginally, by 1% and 3%, respectively. There is a decrease in NOx emissions varying between 23% and 27%. The largest reduction takes place in particulate matter emissions - 32% at Vikas Marg, 43.5% at Nanakpura and 46.5% at AIIMS.

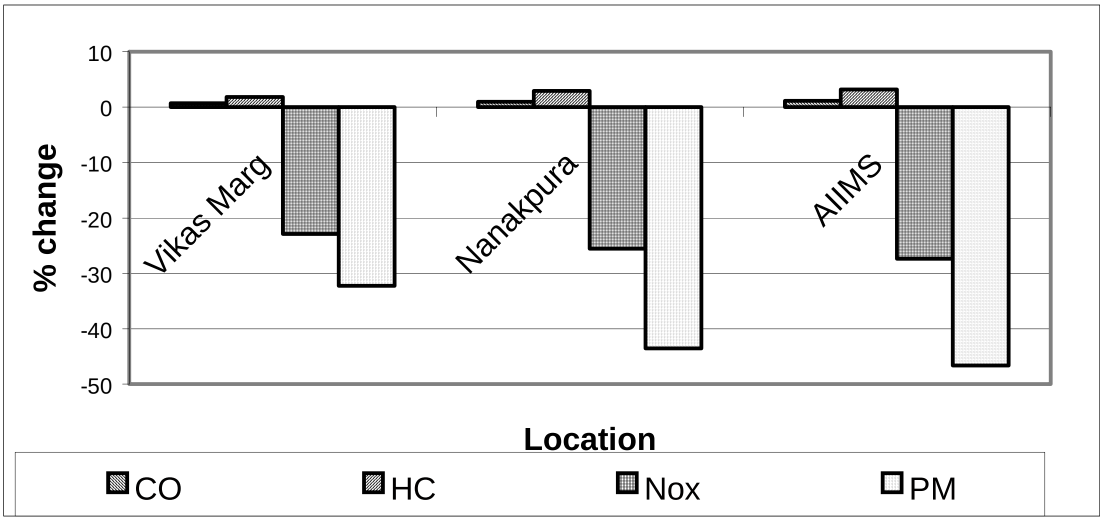

Fig. 5: Change in emissions when all buses are CNG fuelled.

Thus, it appears that there are clear gains in reducing PM emissions by conversion to CNG. This conversion, though, increases CO and HC emissions. The gains of this reduction need to be considered in the light of the following:

a) High ambient PM levels in Delhi is not due to transportation. A significant fraction of particulate emission in the ambient air quality in the city of Delhi is also contributed by factories, home industrial generators (petrol, kerosene and diesel), cooking done by wood, and burning of leaves.
b) It is known that smaller particles go deeper in the lungs and have adverse health effects. It is also known that CNG using engines produce a higher proportion of these particles.
c) The data used for CNG emissions are based on new dedicated engines running under ideal laboratory conditions. With use, emissions are likely to be higher, especially because of the burning of lubricating oil in aged vehicles. The efficiency of catalytic convertors is also likely to reduce with time.
d) Data for buses with retrofit engines, which are likely to be emitting more pollutants, has not been used.

Thus, the gains in reduction of PM emissions by CNG conversion are likely to be felt by persons in the vicinity of roads, the health aspects of which are not likely to be significant.

4.2 Changeover to C.N.G. and shift of bus passengers to 2-wheelers

As discussed earlier, accompanying the changeover to CNG, is the fact that higher fares will force some bus users to travel by their personal 2-wheelers. The marginal cost of running a 2-wheeler is approximately Rs. 0.75 per km. The chartered and school buses are charging more or less the same rate from the commuters. 43% of the chartered bus users own 2-wheelers and 11% own cars [7]. Any increase in bus fares is likely to result in commuters traveling by their own vehicles. The switch is perceptible even in today's scenario where school buses have converted to CNG and fares have been hiked to a tune of 70 to 100%. Anecdotal evidence from newspapers and personal experience confirms that the shift to 2-wheelers and cars has already started. . Exact numbers are difficult to predict. Therefore, a parametric study has been performed for estimating the impact of 5, 10 and 15% shift of bus users to 2-wheelers. We have not included the shift to cars, as we are making the most conservative estimates. In reality the scenario is likely to be worse. The corresponding increase in the number of 2-wheelers has been worked out on the basis of 2-wheeler occupancy of 1.3, used earlier. Further, this shift in passengers will not reduce the number of buses plying on the road. The fact that this increase in the number of 2-wheelers will increase road congestion (one bus occupies the same road space as four 2-wheelers) and will adversely affect the driving cycle and, hence, increase emissions, has not been considered. The emission estimates presented here are, therefore, conservative estimates on this count also. Figures 6, 7 and 8 show the effect of 5%, 10% and 15% changeover to 2-wheelers.

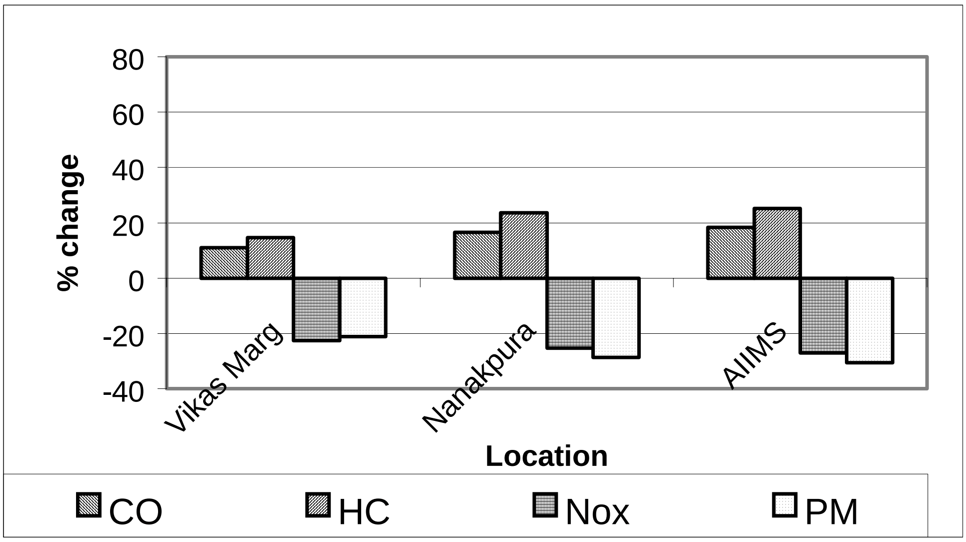

Fig. 6: Change in emissions when all buses are CNG fuelled and 5% of the bus passengers shift to 2-wheelers.

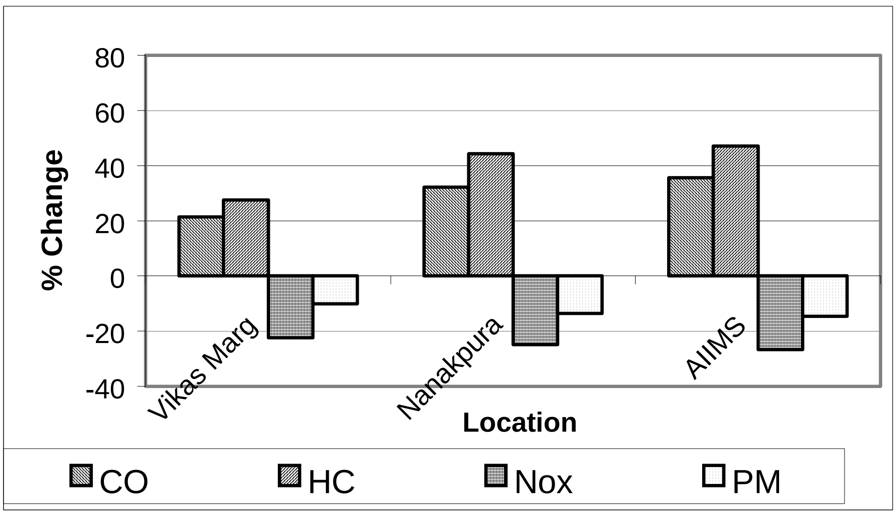

Fig. 7: Change in emissions when all buses are CNG fuelled and 10% of the bus passengers shift to 2-wheelers.

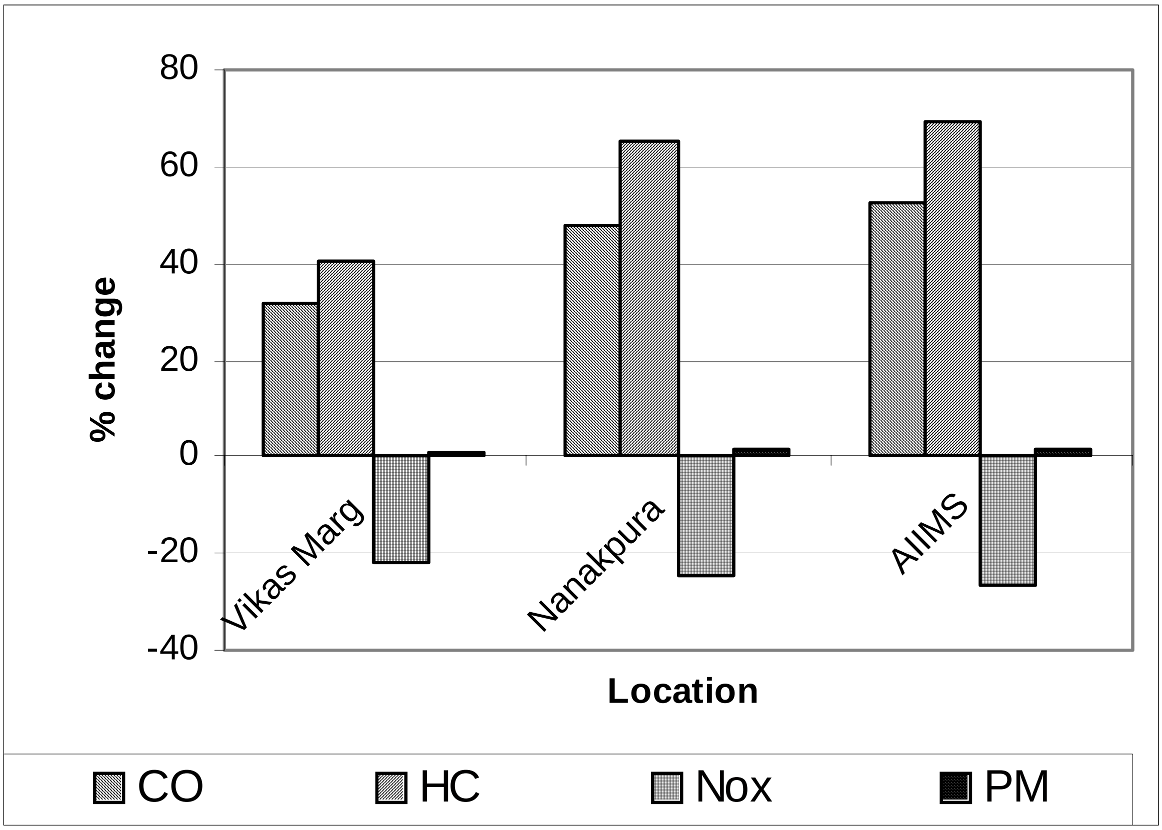

Fig. 8 : Change in emissions when all buses are CNG fuelled and 15% of the bus passengers shift to 2-wheelers.

Figure 6 shows that a 5% shift increases CO emissions by 10-18% and HC emissions by 15% - 25%. The reduction in NOx is 23%-27%, and reduction in PM is between 21% and 30%.

For 10% shift, CO emission increases buy 21%-32% and HC increases by 28% - 44%. Reduction in NOx is 22% - 27% and in PM the reduction is 10%-15%.

A 15% shift increases CO by 32% - 53% and HC by 40%-69%. NOx emissions still exhibit a reduction by 22% - 26%. PM emissions show an increase of about 1.5%. Thus a 15% shift will increase the total emissions of all pollutants except NOx due to vehicular traffic.

Graphical representation of the above trends are shown in Figure 9(a), 9(b) for Vikas Marg, 9(c) 9(d) for Nanakpura and 9(e), 9(f) at AIIMS. The absolute values of the emissions per hour are shown here as function of percentage shift of bus users to 2-wheelers. The data shows that gains of conversion to CNG, which occur only for NOx and PM are reduced when this shift occurs. It is interesting to note that the gains in reduction of PM emissions are entirely lost when a 15% shift occurs. Increases in CO and HC emissions, due to shift to CNG, are further accelerated when passengers shift to 2-wheelers from buses. Conversion to CNG, therefore, does not reduce all pollutant emissions, the gains being restricted to NOx and PM only.

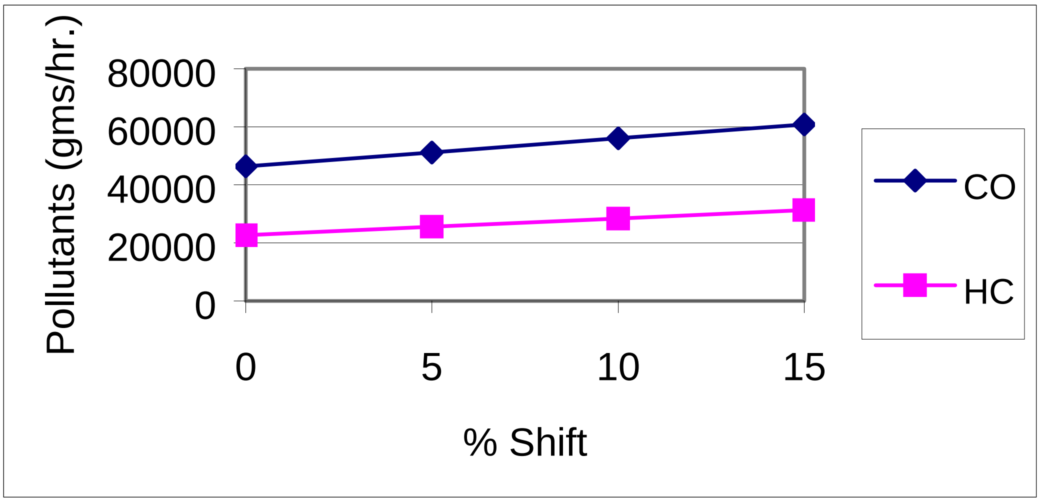

Fig. 9(a): Variation of total emissions of CO and HC when all buses are CNG fuelled and passengers shift to 2-wheelers at Vikas Marg.

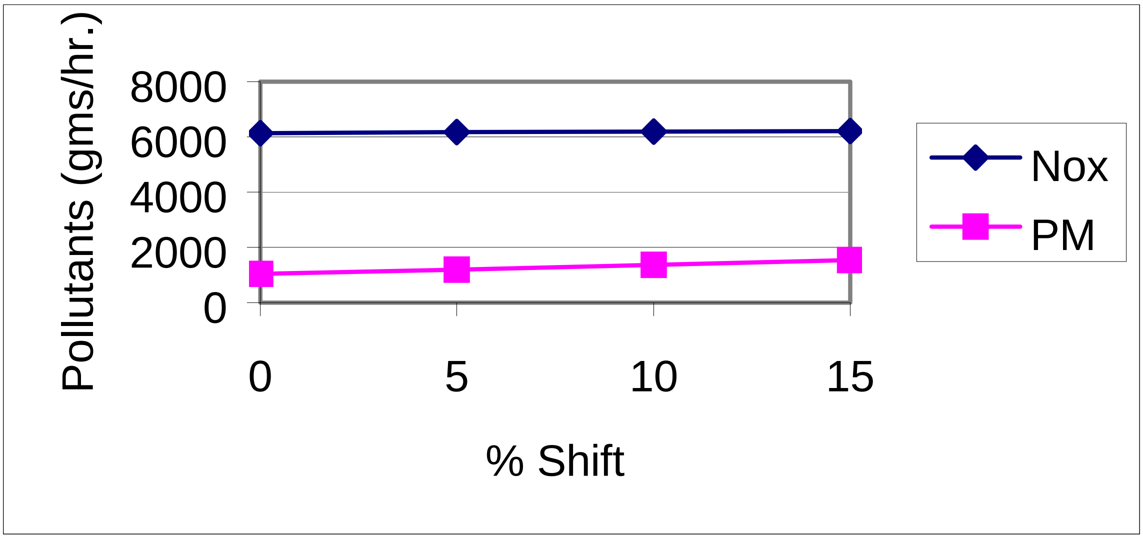

Fig. 9(b): Variation of total emissions of NOx and PM when all buses are CNG fuelled and passengers shift to 2-wheelers at Vikas Marg.

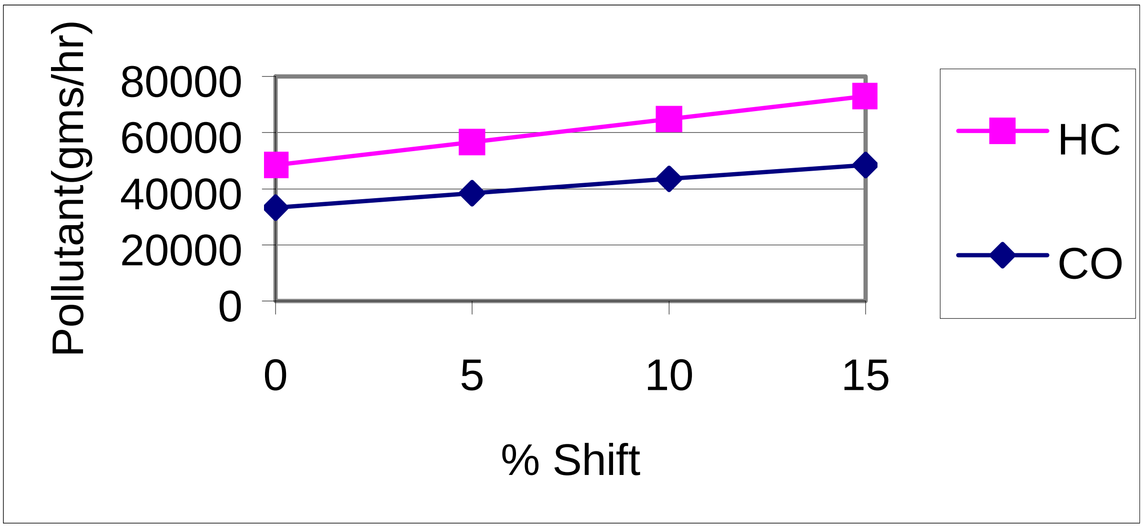

Fig. 9(c): Variation of total emissions of CO and HC when all buses are CNG fuelled and passengers shift to 2-wheelers at Nanakpura.

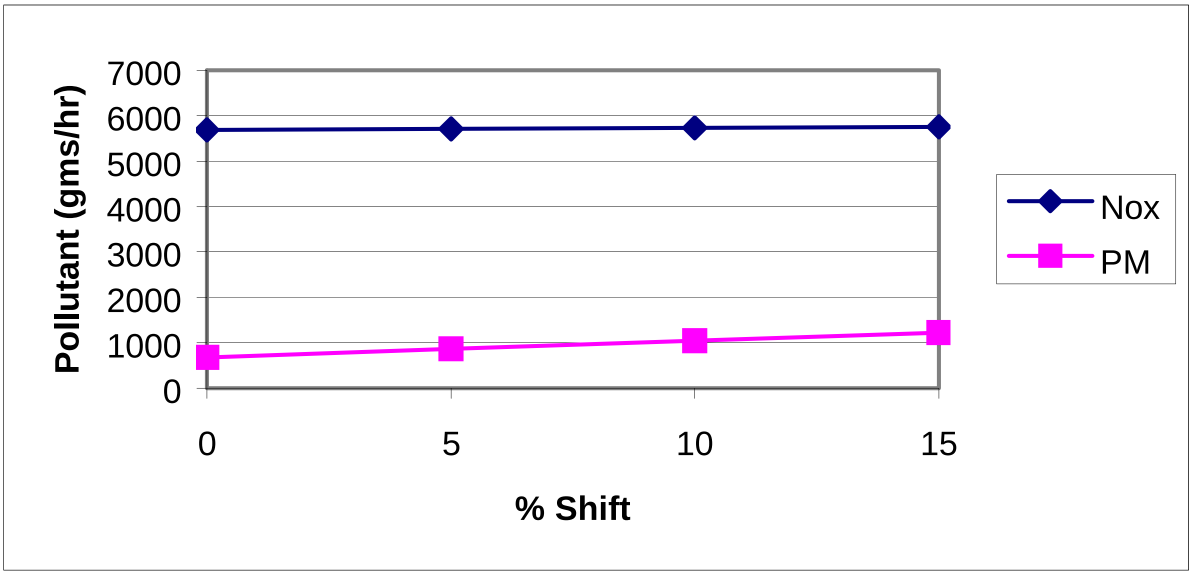

Fig. 9(d): Variation of total emissions of NOx and PM when all buses are CNG fuelled and passengers shift to 2-wheelers at Nanakpura

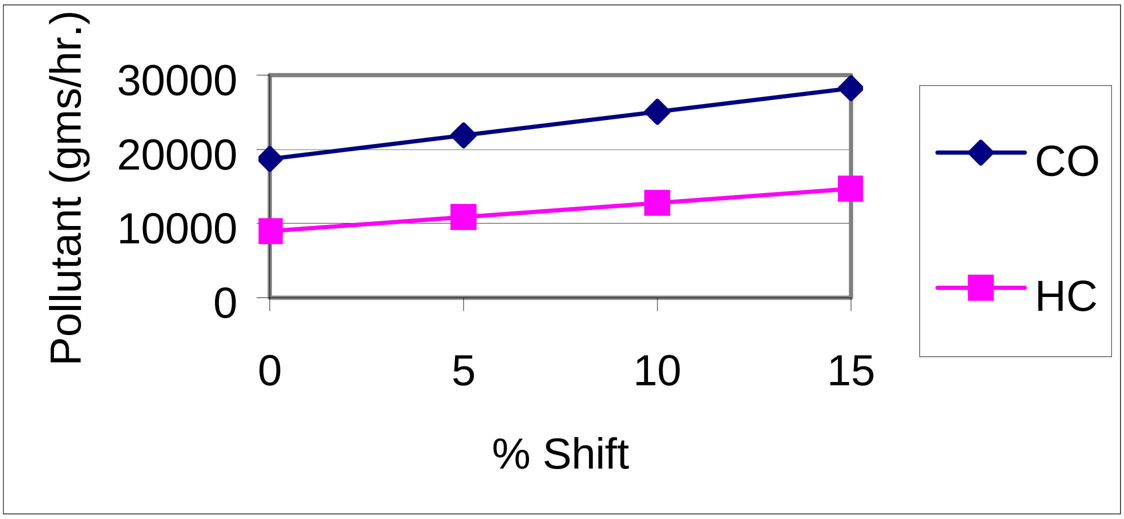

Fig. 9(e): Variation of total emissions of CO and HC when all buses are CNG fuelled and passengers shift to 2-wheelers at AIIMS

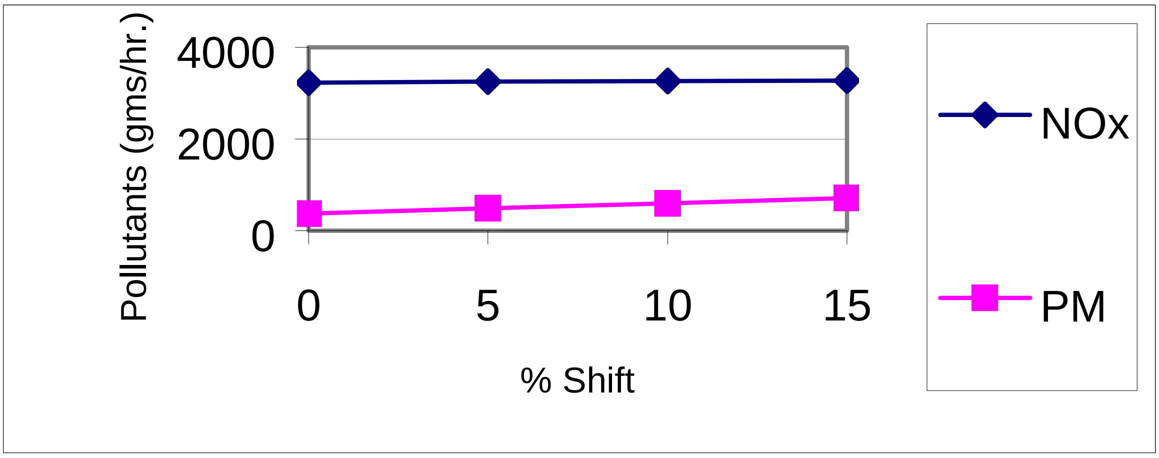

Fig. 9(f): Variation of total emissions of NOx and PM when all buses are CNG fuelled and passengers shift to 2-wheelers at AIIMS

4.3 Changeover to Euro II Diesel buses

In these sets of calculations, changeover of buses to Euro II Diesel and a 50-50 mix of changeover to CNG and Euro II Diesel has been considered. Shift of bus passengers to 2-wheelers has not been considered; it is expected that the increase in fares will be marginal and may not cause a significant shift to 2-wheelers.

(a) Full changeover to Euro II Diesel

Figure 10 shows the change in emissions as compared to the base case. Reductions in CO and HC emissions are marginal and not very substantial. NOx reductions of up to 10% are realizable when the entire fleet is converted to Euro II diesel. Reductions in particulate matter are also realized - 28% at Vikas Marg to 41% at AIIMS. There is, therefore, an overall gain by conversion to Euro II diesel unlike conversion to CNG where the gains are restricted only to NOx and PM. This conversion will also result in a fare increase that will not be as steep as that for CNG conversion. Fare increases are, hence, likely to be moderate and the shift to 2-wheelers may not be significant.

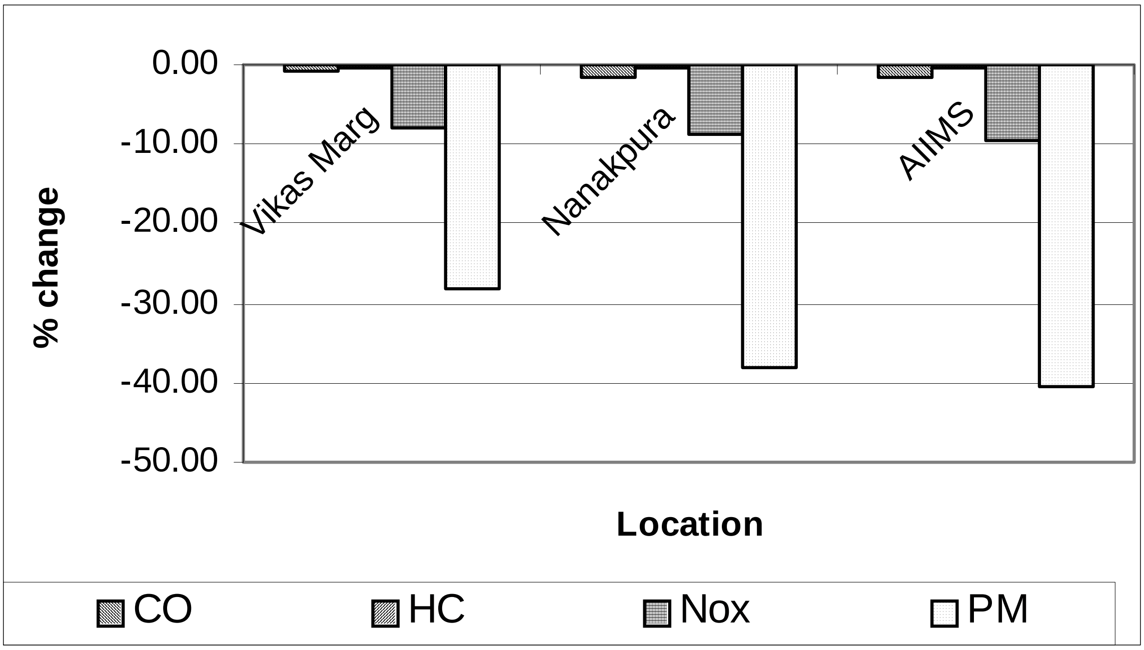

Fig. 10.: Change in enissions when all buses are Euro II Diesel.

(b) 50% changeover each to Euro II Diesel and CNG

The impact of changeover of half the bus fleet each to CNG and Euro II diesel is shown in Figure 11. Total emissions of CO are not affected. There is a marigial (about 1%) increase in HC emissions. Reductions ranging between 15-18% occur in NOx emissions. The largest reduction occur in PM emissions, varying between 30-44%. Thus, overall, there is favourable impact on pollutant reduction by having a mixed fleet of buses fuelled by CNG and Euro II diesel.

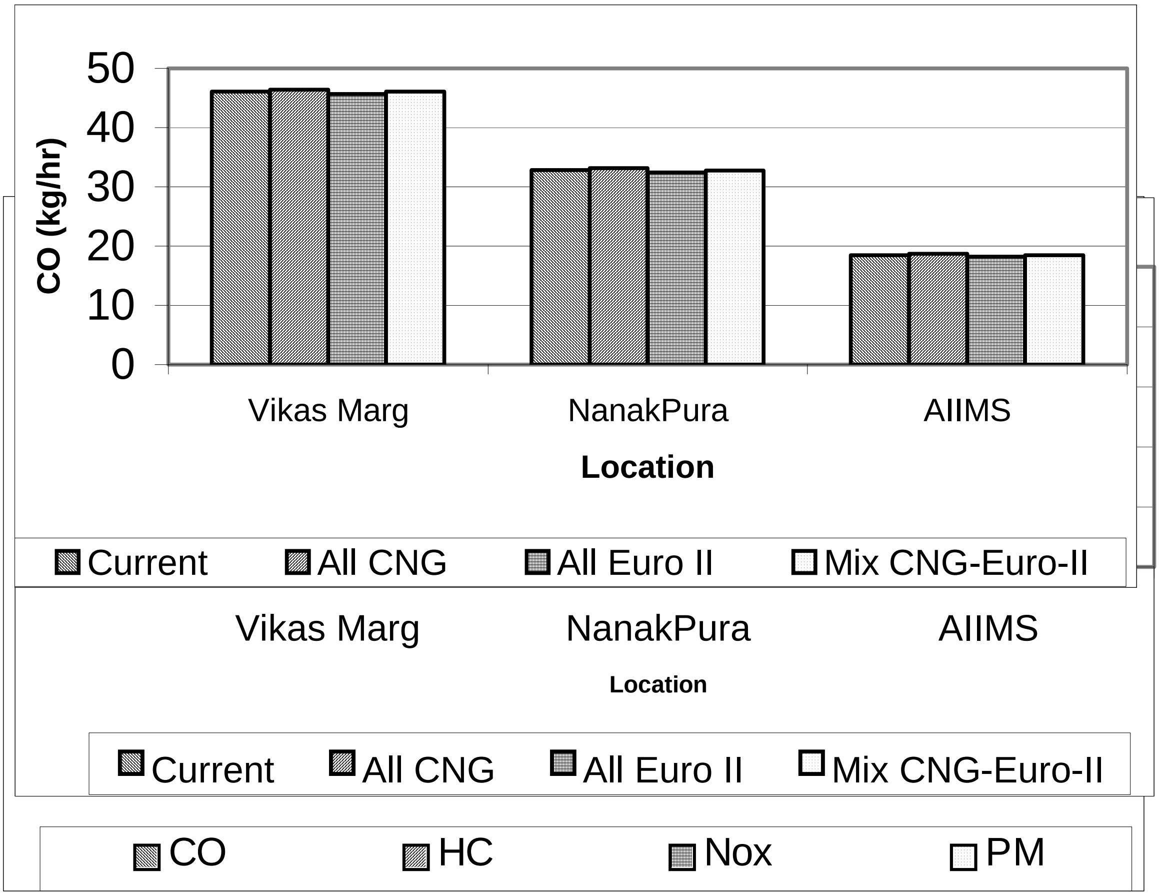

Fig. 11: Change in emissions when 50% buses are CNG fuelled and 50% buses are Euro II Diesel

4.4 Comparison of the effects of changing bus fuels

Four cases of bus fuels studied are summarized in Figures 12 (a), (b), (c) and (d) for total emissions of CO, HC, NOx and PM, respectively. The impact on total CO emissions is negligible, Figure 12(a). Similarly, the impact on total HC emissions is also negligible. Total NOx emissions decrease under all changeover possibilities; the largest effect (about 25%) is for changeover to CNG fleet. The second best reduction is in a 50% mix of CNG and Euro II diesel buses and least reduction in entire conversion to Euro II diesel. Reductions in particulate matter emissions are significant under all conversion scenarios. It is interesting to note that total PM emission from any of the conversions is comparable. It is up to 30% less than the existing case. The reason lies in the fact that other transport modes also contribute substantial quantities of PM. Thus, conversion to either CNG, Euro II diesel or 50%-50% mix of CNG-Euro II diesel give similar advantages in terms of reduction of the four pollutants.

Fig. 12(a): Comparison of CO emissions under various scenarios of bus fuels without shift to 2-wheelers.

Fig. 12(b): Comparison of HC emissions under various scenarios of bus fuels without shift to 2-wheelers

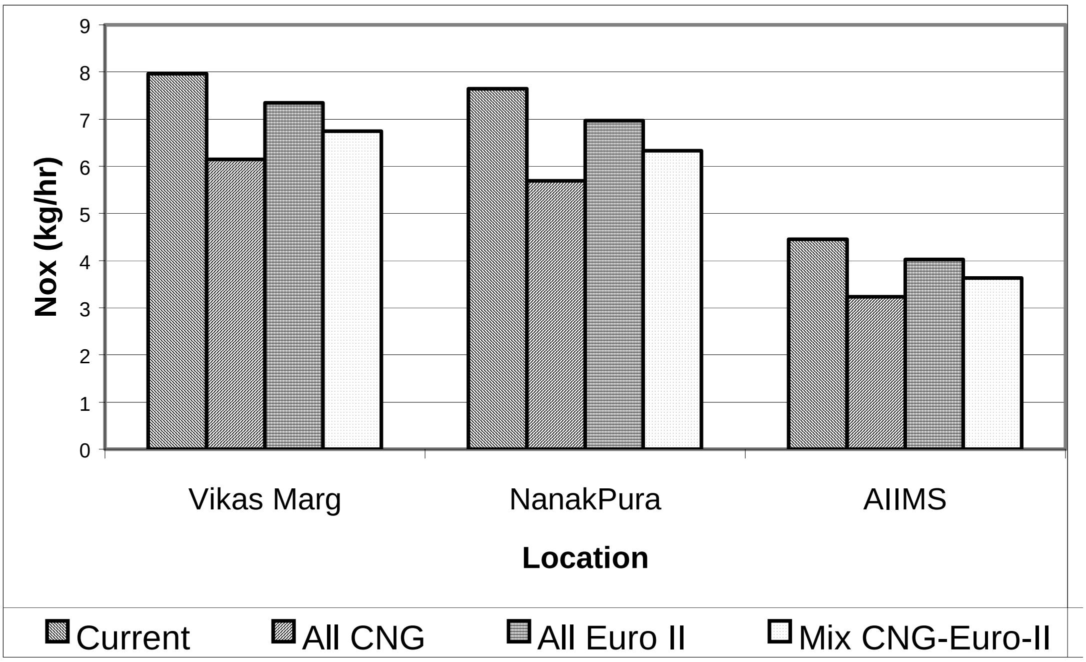

Fig. 12(c): Comparison of NOx emissions under various scenarios of bus fuels without shift to 2-wheelers.

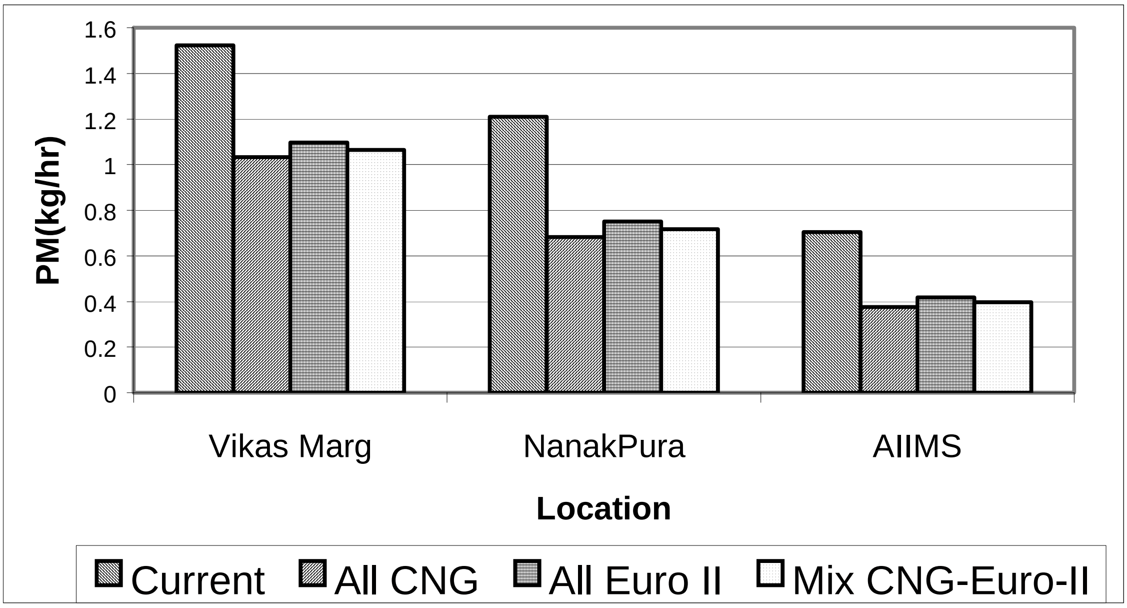

Fig. 12(d): Comparison of PM emissions under various scenarios of bus fuels without shift to 2-wheelers.

Figures 13(a-d), 14(a-d) and 15(a-d) show the total emissions of CO(a), HC(b), NOx(c) and PM(d) for different scenarios with the CNG fleet and 5%, 10% and 15% shifts to 2-wheelers respectively. As discussed above, no shifts have been considered for the Euro-II case, as the change in capital cost of bus due to a change of fuel to Euro-II will be much less as compared to CNG. In case of a mixed fleet of Euro-II and CNG buses, the CNG buses will be forced to keep the same fares as that of Euro-II and hence no change in fares would be expected.

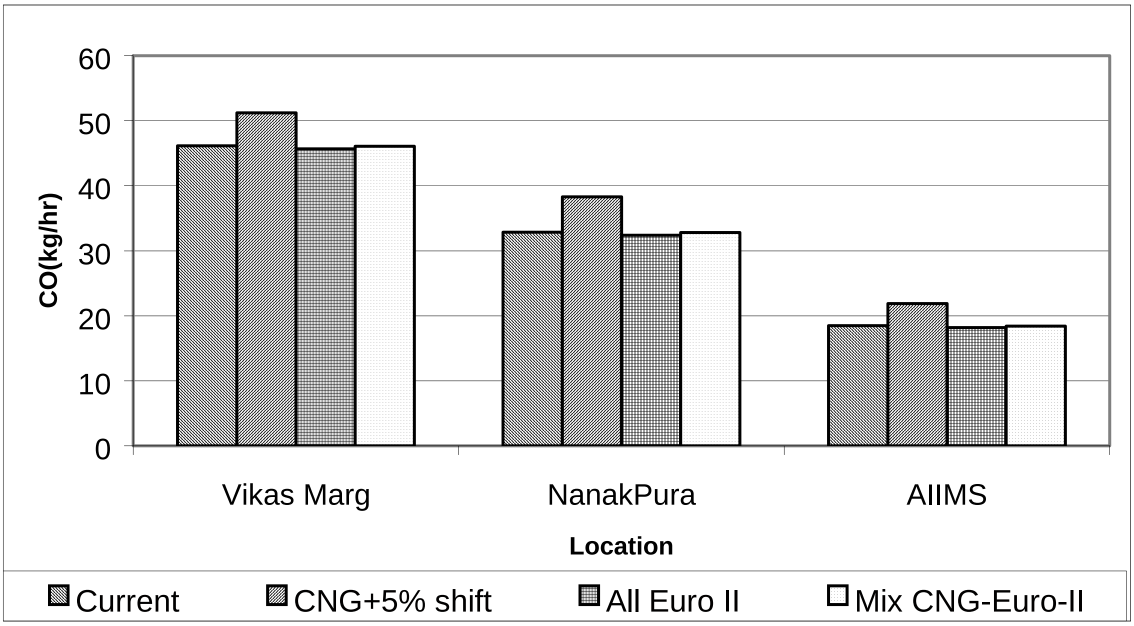

Fig. 13(a): Comparison of CO emissions under various scenarios of bus fuels with 5% shift to 2-wheelers in case of CNG

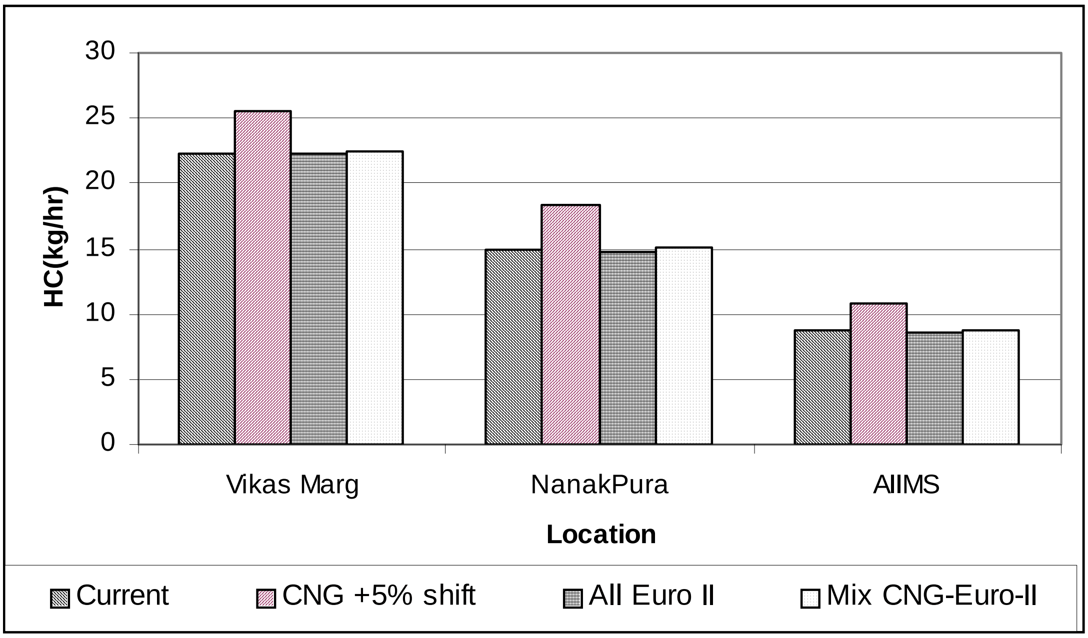

Fig. 13(b): Comparison of HC emissions under various scenarios of bus fuels with 5% shift to 2-wheelers in case of CNG

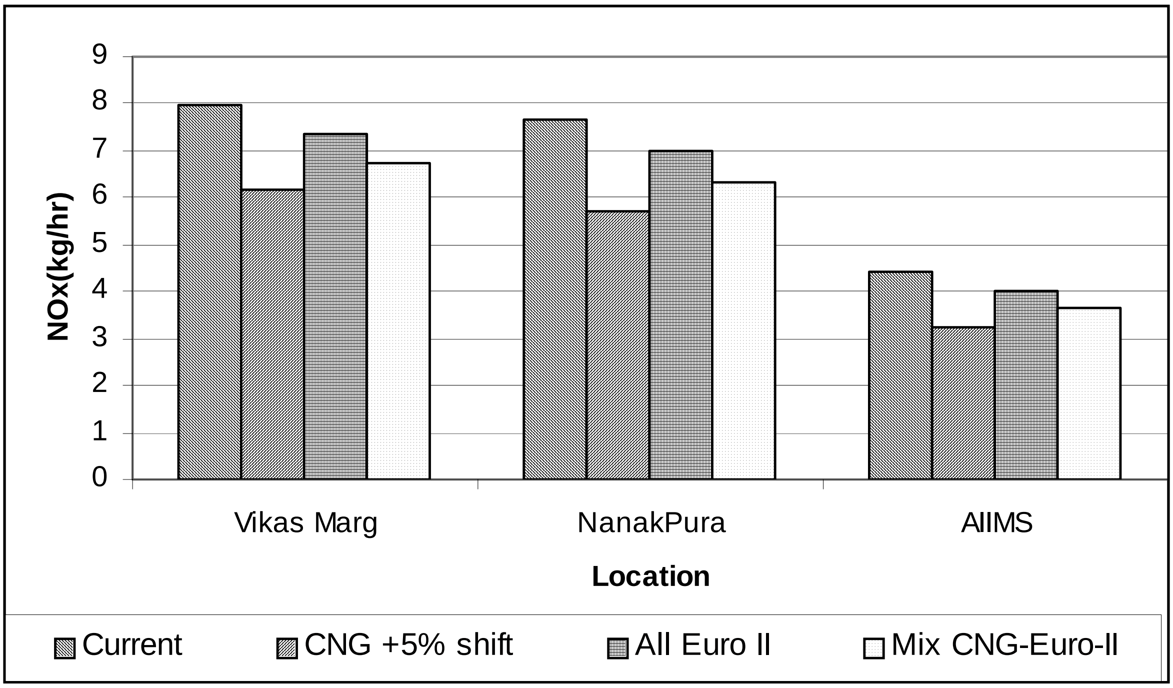

Fig. 13(c): Comparison of NOx emissions under various scenarios of bus fuels with 5% shift to 2-wheelers in case of CNG

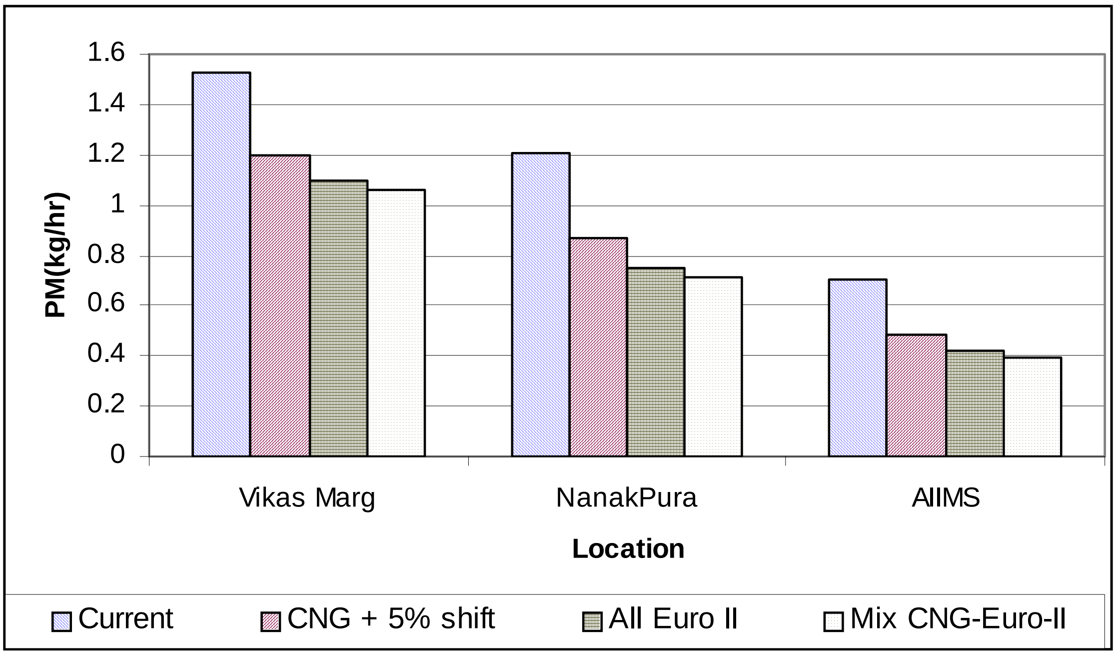

Fig. 13(d): Comparison of PM emissions under various scenarios of bus fuels with 5% shift to 2-wheelers in case of CNG

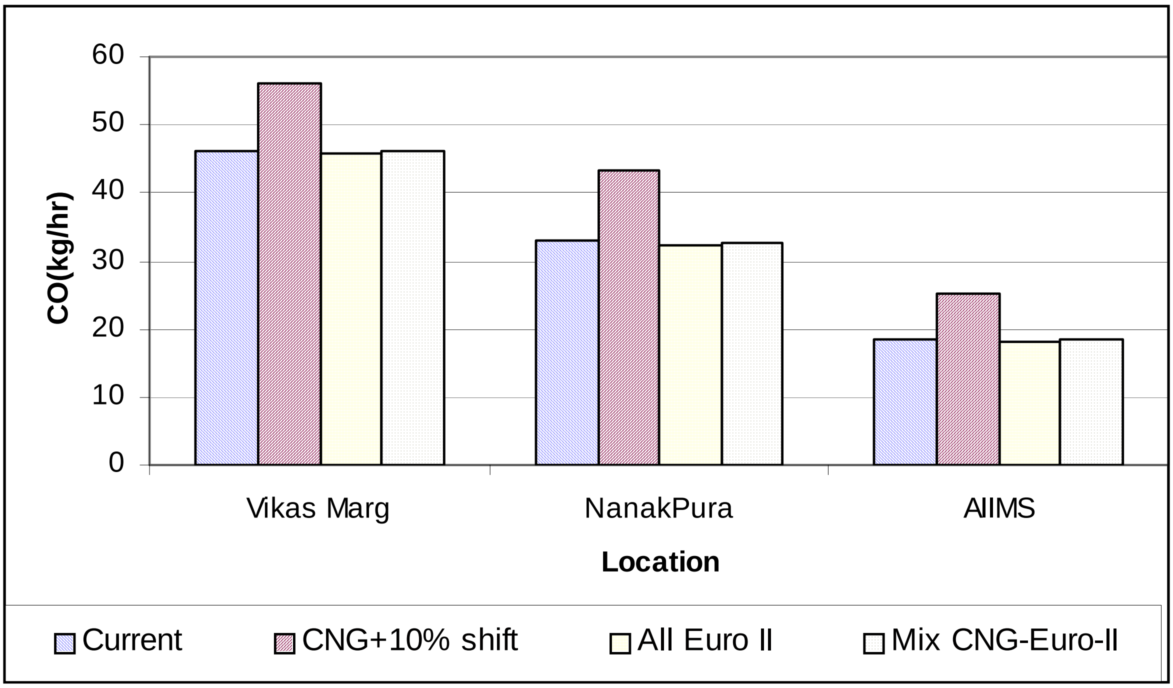

Fig. 14(a): Comparison of CO emissions under various scenarios of bus fuels with 10% shift to 2-wheelers in case of CNG

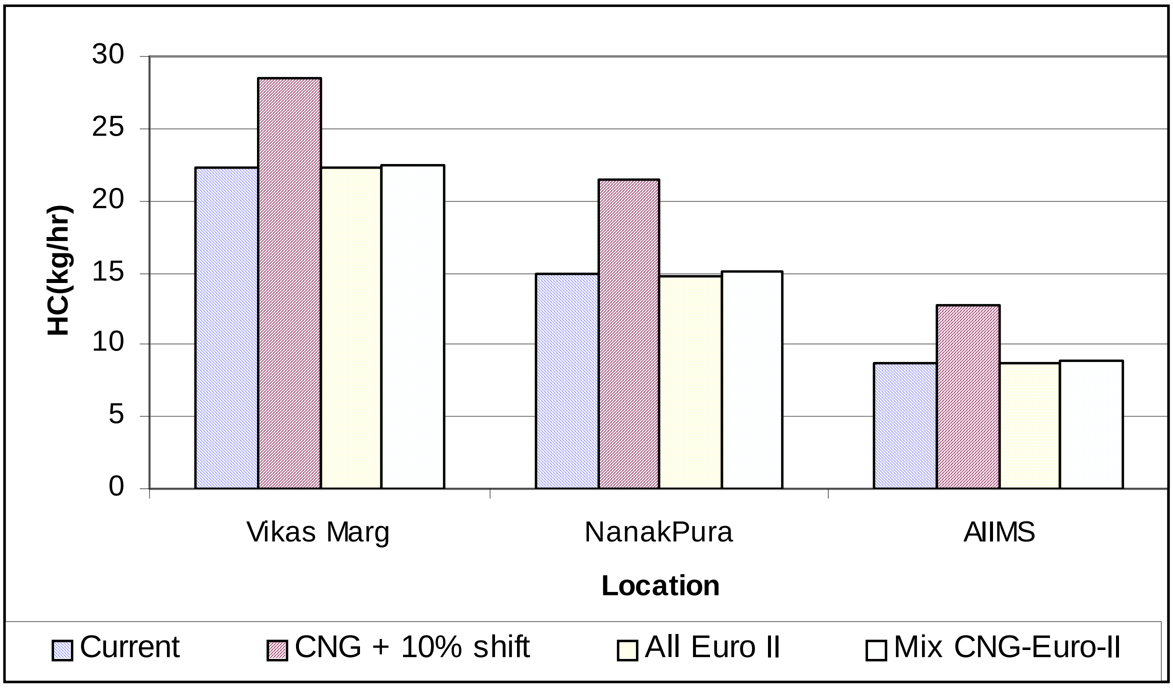

Fig. 14(b): Comparison of HC emissions under various scenarios of bus fuels with 10% shift to 2-wheelers in case of CNG

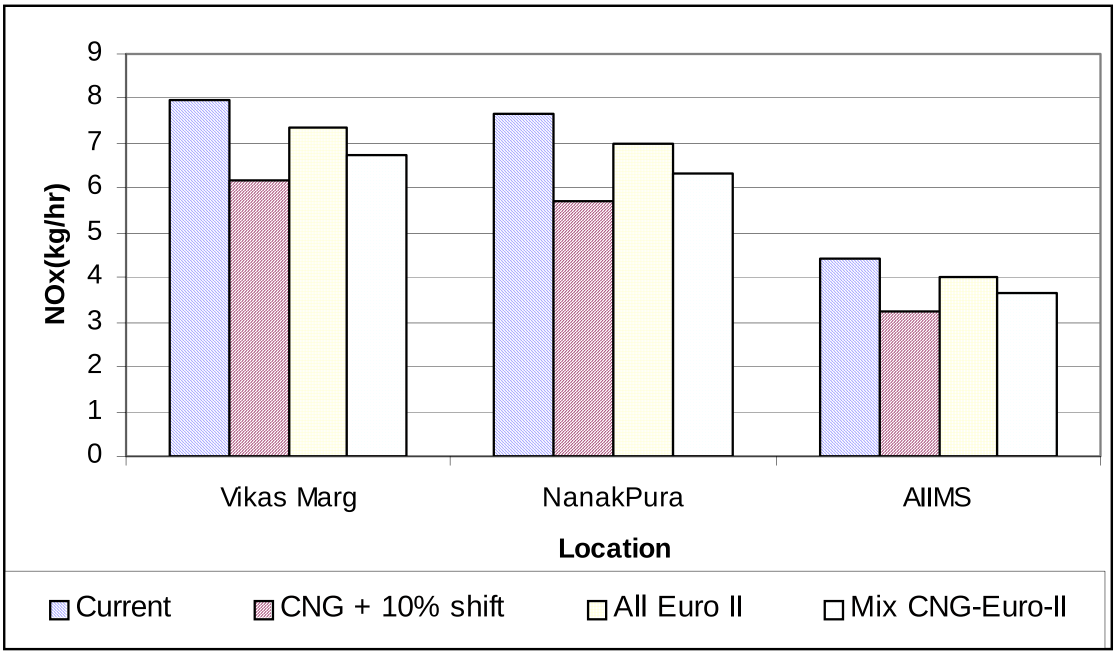

Fig. 14(c): Comparison of NOx emissions under various scenarios of bus fuels with 10% shift to 2-wheelers in case of CNG

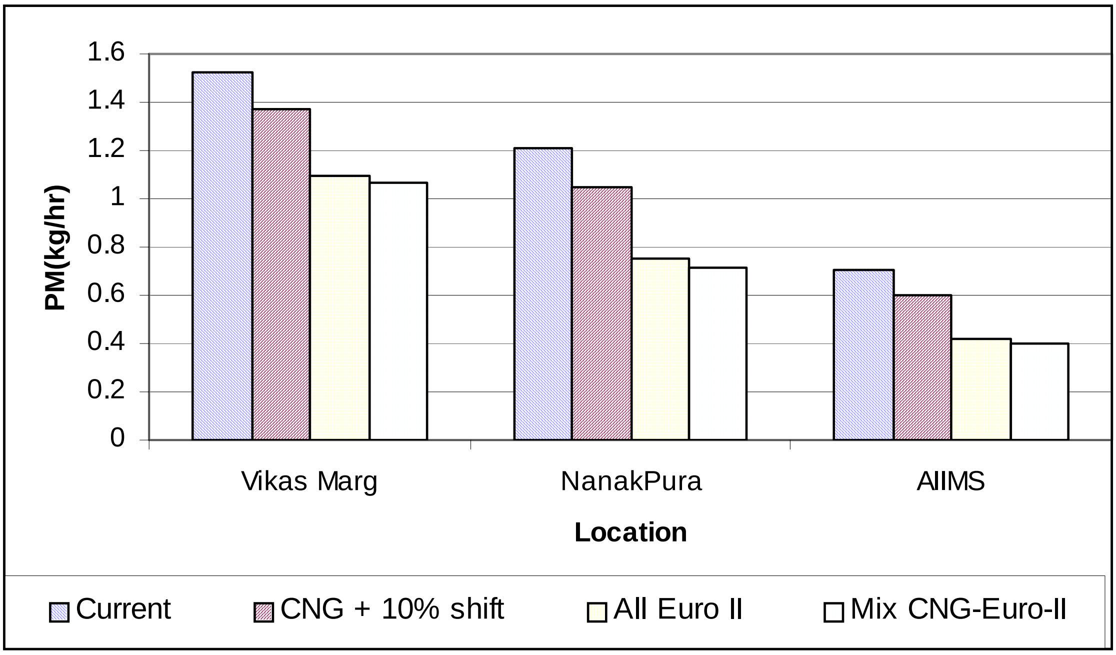

Fig. 14(d): Comparison of PM emissions under various scenarios of bus fuels with 10% shift to 2-wheelers in case of CNG

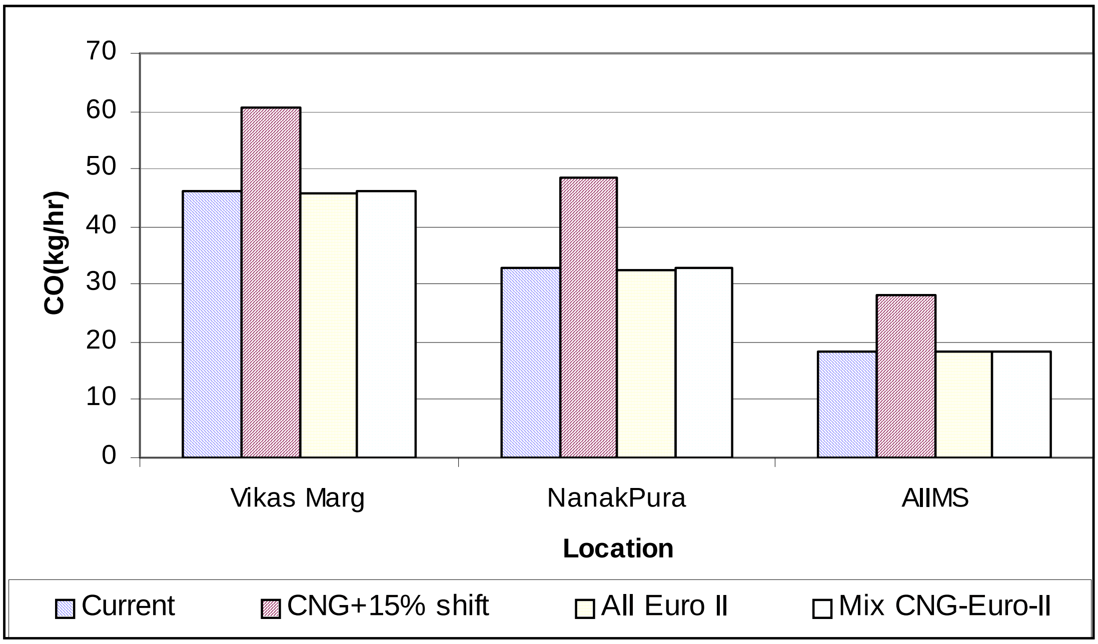

Fig. 15(a): Comparison of CO emissions under various scenarios of bus fuels with 15% shift to 2-wheelers in case of CNG

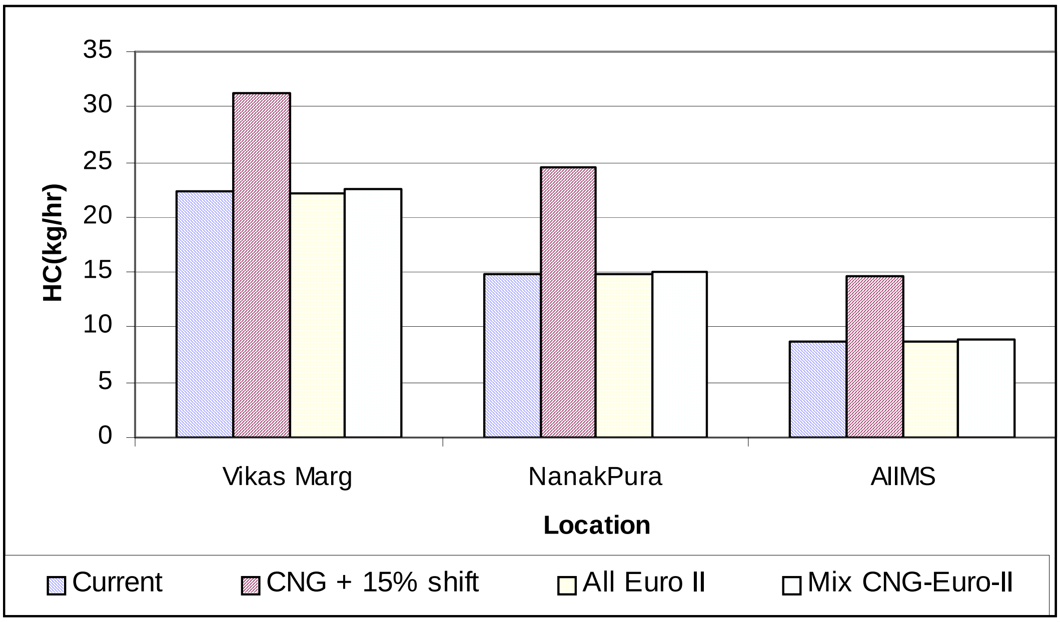

Fig. 15(b): Comparison of HC emissions under various scenarios of bus fuels with 15% shift to 2-wheelers in case of CNG

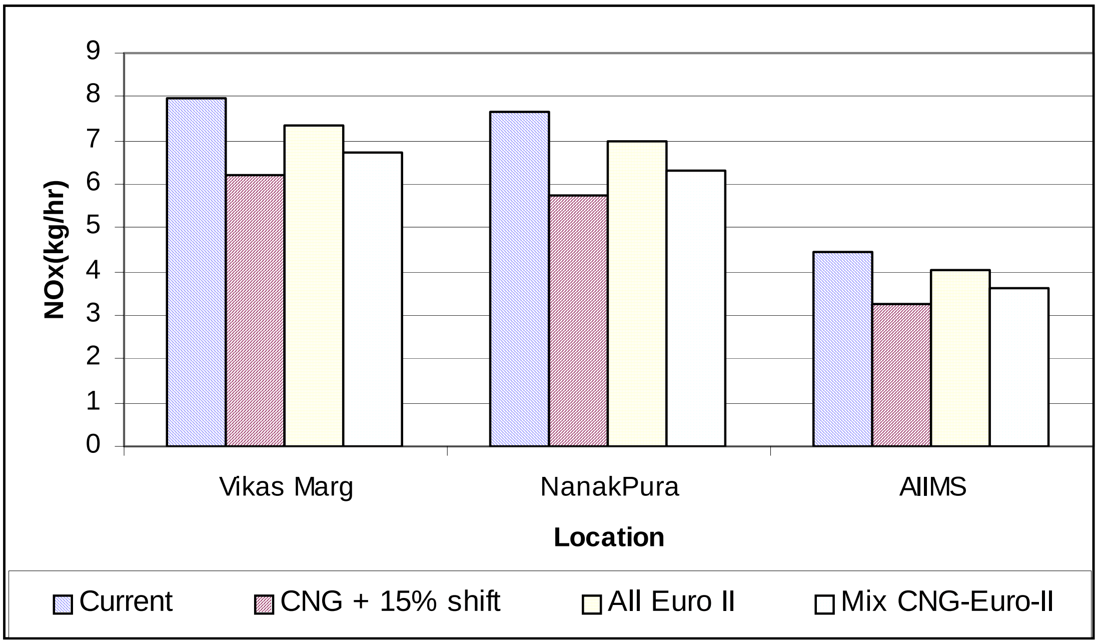

Fig. 15(c): Comparison of NOx emissions under various scenarios of bus fuels with 15% shift to 2-wheelers in case of CNG

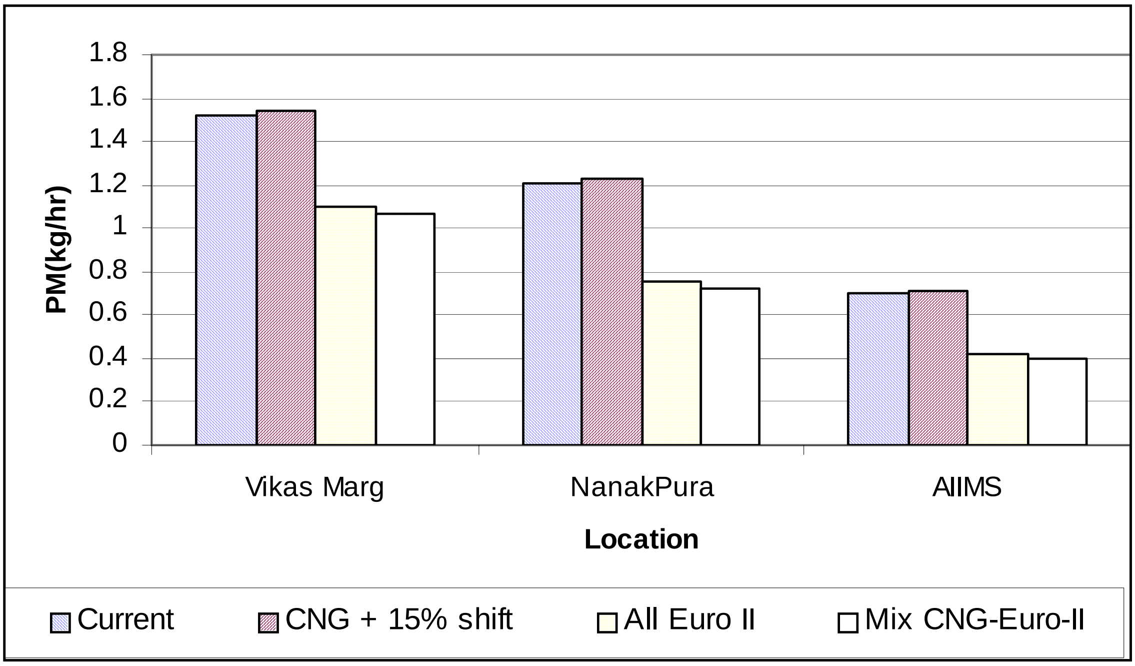

Fig. 15(d): Comparison of PM emissions under various scenarios of bus fuels with 15% shift to 2-wheelers in case of CNG

5. Conclusions

This study can be summarized as under:

(i) Conversion to CNG reduces NOx and PM emissions but increases CO and HC emissions from buses. The total cumulative health effect of increase in CO and HC and decrease in NOx and Suspended Particulate Matter (SPM) has not been evaluated in this study. No decision should be taken without such an evaluation.

(ii) There are no major differences in total emission from vehicles based on present traffic mix whether all buses use CNG, all buses use Euro-II engines or the mix is half and half between these two technologies.

(iii) As bus passengers shift from bus to 2-wheelers as a result of fare increases, the emission of all pollutants increases. Reductions in vehicular PM emission are realized only if the shift is less than 15%. For even a 5% shift of passengers from buses to 2-wheelers CO emission increases by 10% to 18% and HC emission increases by 15% to25%. These numbers rise to 32% to 53% and 40% to 69% for CO and HC respectively for a 15% shift. Even the PM emission shows an increase of about 1.5% for a 15% shift. The relative decrease in NOx is 22% to 26% for this case. These estimates are conservative as all the shifts have been assumed to be from buses to 2-wheelers and not to cars. Further, the increased congestion due to additional number of vehicles is likely to increase the emission levels of the pollutants.

(iv) Two-wheelers and buses are comparable contributors to PM emissions and, hence, any strategy for reducing PM emissions must target both these modes.

(v) The per person per kilometer emission of every pollutant is lowest for bus travel and highest for cars and 2-wheelers, in that order.

(vi) Trends between 1994 and this study show that there has been a significant shift to cars and two wheelers. Unless this shift is controlled it would be difficult to control increase in emissions. This can only be done if bus transport is improved and fares not increased. A comprehensive policy regarding this has to be put in place before major technological changes are mandated.

(vii) A vast majority of people continue to travel by buses and their interests must be given the highest priority.

(viii) This study has not considered the pollution caused by SPM less than PM10 as no data are available regarding the same. It is known that smaller particles go deeper in the lungs and have adverse health effects. It is also known that CNG using engines produce a higher proportion of these particles.

(ix) Ambient air quality estimates have not been made in this study as data for other sources is not available. However, since there may be thousands of petrol, kerosene and diesel generators in Delhi, their contribtion to SPM and NOx would be substantial. Therefore, the actual reduction in NOx and SPM levels in ambient air would be much less than that calculated for vehicular emission alone. The limited benefit of complete CNG conversion with no passenger shift to personal modes would be significantly reduced. With shifts to personal vehicles the benefit may be offset at much lower levels than 15% as calculated earlier.

Recommendations

1. Emission standards should not specify particular fuels or technologies as such measures encourage monopolies and discourage technology innovation and competition in industry. They should only lay down regulations regarding emissions from engines and associated fuel quality.
2. The results of this study show that the benefits of converting the full bus fleet are not clear as there is not much improvement in overall air quality if the calculations are based on the actual traffic conditions and modal shares present on Delhi roads. The increase in fares as a result of more expensive buses is likely to shift bus passengers to cars and two wheelers and thus increase total pollution. Therefore, the requirement that all buses convert to CNG should be reassessed and put on hold until more definitive data are available.
3. It is not advisable for a whole bus fleet of a city to be based on the same technology of the same age. This can result in major disasters if something goes wrong. This will also preclude induction of new technologies as they become available in the future. A plan for a phased technology change should be developed and instituted.
4. The benefits of better technologies will be defeated if bus passengers shift to personal modes of travel due to fare increases. Therefore, the government must put in place a comprehensive policy of financing of public transport including cross subsidies. This could be done by invoking the "polluter pay principle". The data in this study show that cars and two wheelers have the highest pollution per passenger transported. Therefore, owners of cars and two-wheelers must be made to pay a pollution tax, the proceeds from which could be used for financing more efficient bus transport.
5. The problem of shift to 2-wheelers and cars from public transport has to be addressed irrespective of the fuel used by buses. Therefore, public transport has to be made more convenient, safe and efficient. The safety and efficiency of bus transport, and its attractiveness for users could be increased substantially if modern low floor buses are inducted in the Delhi fleet. This cannot be done if gas cylinders are fitted below the bus floor (present technology). Therefore, all future CNG buses should be required to have gas cylinders integrated in the roof of the bus.

References

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[6] Ramnath, J., Telco, Mumbai, 2001, Personal Communication.

[7] RITES, 1997. Route rationalisation and T.T. formulation study for bus system in Delhi.

ANNEXURE - I : BRIEF INFORMATION ABOUT IIT DELHI AND TRIPP

About IIT Delhi

Indian Institute of Technology Delhi is one of the six Institutes of Technology created as centres of excellence for higher training, research and development in science, engineering and technology in India, the others being at Kanpur, Kharagpur, Madras Bombay and Guwahati. Established as College of Engineering in 1961, the Institute was later declared an Institution of National Importance under the "Institutes of Technology (Amendment) Act, 1963" and was renamed "Indian Institute of Technology Delhi". It was then accorded the status of a deemed university with powers to decide its own academic policy, to conduct its own examinations, and to award its own degrees.

Administration

I.I.T.Delhi is an autonomous statutory organisation functioning within the "Institutes of Technology Act" as amended by "The Institutes of Technology (Amendent) Act, 1963". The six Indian Institutes of Technology (others being at Bombay, Kanpur, Kharagpur, Madras and Guwahati) are administered centrally by the IIT Council, an apex body established by the Government of India to co-ordinate activities of these Institutes. The Minister for Human Resource Development of the Government of India is the Chairman of the Council. Each Institute of Technology has a Board of Governors responsible for its overall administration and control. Shri Vijay R.Kirloskar is the Chairman of the Board of Governors of this Institute.

The Senate decides the academic policy of the Institute, and approves curriculum, courses and examination results. It appoints committees to look into specific academic matters arising from time to time. The teaching, training and research activities of various departments at the Institute are constantly under review to improve both facilities and standard. The Director of the Institute is the Chairman of the Senate. Financial advice to the Institute is rendered by the Finance Committee. Similarly, there is a Buildings & Works Committee to advise on matters relating to buildings and works activity. These committees are appointed by the Board of Governors.

In addition, there are a number of other committees like the Board of Undergraduate Studies, Board of Postgraduate Studies and Research, Board of Educational Research and Planning etc. appointed by the Senate to help the administration in the efficient running of the Institute.

Objectives

The objectives include:

- offering instruction in engineering and applied sciences at a level comparable to the very best in the world;
- providing best facilities for postgraduate studies and research;
- providing leadership in curriculum planning and laboratory development:
- developing programmes for faculty development both for its own staff and for teachers of other engineering institutions:
- developing close collaboration with industry through exchange of personnel and undertaking consultancy projects.
- developing strong collaboration links with other academic and research institutions in the country and abroad;
- anticipating the technological needs for India and to plan and prepare to cater to men:

- developing continuing education programmes:
- preparing instructional resource material in the conventional as well as the audiovisual me video and the computer based modes:
- catering to the development of a culture for maintenance and conservation.

Collaborative Programmes / MoUs

The Institute is actively involved in collaborative programmes internationally and nationally in order to remain at the forefront on the scientific and technological developments and to share its experience with them. At present, a large number of collaborative research projects are in operations with the institutions in U.K., France, U.S.A., Italy, Netherlands, Norway, Japan, Germany, Sweden and Austria. Some of the facets of these collaborations include students and faculty exchange, joint research and fellowships for training at the doctoral and post-doctoral level.

Academic Statistics

Faculty including Scientific Staff / Programmers 463
Administrative & Support Staff 1,673

Students

U.G. including 5-year M.Tech 1,501
P.G.(M.Tech./M.Sc./D.I.I.T.) 1,478
M.B.A. 174
M.Des. 39
M.Sc. (Research) 61
Ph.D. 629

Degrees Awarded (till 2000)

B.Tech. 8,116
M.Tech. 8,470
M.Des. 44
M.Sc. 1,381
M.Sc. (Research) 64
M.B.A 136
5-year M.Sc./M..Tech. 228
D.I.I.T. 622
Ph.D. 2,354

About TRIPP

The Transportation Research and Injury Prevention Programme (TRIPP) at the Indian Institute of Technology (Delhi) is an interdisciplinary programme focussing on the reduction of adverse health effects of road transport. TRIPP attempts to integrate all issues concerned with transportation in order to promote safety, cleaner air, and energy conservation. Faculty members are involved in planning safer urban and inter-city transportation systems, and developing designs for vehicles, safety equuipment and infrastructure for the future. Activities include applied research projects, special courses and workshops, and supervision of student projects at post graduate and undergradute levels. Projects are done in collaboration with associated departments and centres at IIT Delhi, government departments, industry and international agencies.

Expertise

- Transportation planning and traffic flow analysis for optimising mobility and minimising accidents and pollution.
- Vehicle crash modelling, road safety studies, safer vehicle and helmet design.
- Studies related to public transport, traffic management, road design and land use planning.
- Epidemilogy of factors associated with road traffic injuries, injury analysis and pre hospital care.
- Studies on vehicle technology and engines to minimise fuel consumption and pollution.

APPENDIX - BIODATA OF THE INVESTIGATORS

Name : Sanjeev Sanghi
Designation : Associate Professor
Date of Birth : 21-09-1962
Education :

Degree	Institute	Field(s)	Year
B. Tech.	Indian Institute of Technology, Kanpur	Mechanical Engineering	1985
M.S.	Cornell University, U.S.A.	Mechanical Engineering	1988
Ph.D.	The Levich Institute, City Univ. of New York, U.S.A.	Mechanical Engineering	1991

Fields of interest : Fluid mechanics, Turbulent flows, Two-phase flows, Non-linear mechanics and chaos, Development of educational software.

Experience :

Post	Institute	Department	From - To
Assoc. Professor	I.I.T. Delhi	Applied Mechanics	Jan. 2000 - Present
Asst. Professor	I.I.T. Delhi	Applied Mechanics	Dec. 1993 – Jan. 2000
Lecturer	I.I.T. Delhi	Applied Mechanics	Jan. 1992 - Nov. 1993

Sponsored Projects :

Title	Funding Agency	Amount	Duration	Status
Development of virtual laboratory modules	Commonwealth of Learning, Vancouver	2.2 Lakhs	1994-96	Completed
Modernization of fluid mechanics laboratory	MHRD	7.0 Lakhs	1999-2001	Completed
Design and development of microflap wing device	ARDB	5.8 Lakhs	2001-2003	In progress
Preparation of course material for fluid mechanics course	AICTE	5000	1996-97	Completed

12 publications in international journals and refereed conferences.

S. R. KALE

EDUCATION

Ph.D., Mechanical Engineering, Stanford University, 1984
M.S. Mechanical Engineering, Stanford University, 1981
B.Tech., Mechanical Engineering, IIT Delhi, 1977

PROFESSIONAL EXPERIENCE

Mechanical Engineering Department, IIT Delhi *(June 1989 – present)*
Teaching and research in heat transfer, particle-laden flows, combustion and energy conversion.

***West Virginia University, Morgantown, WV, USA* (July 1985 – May 1989)**
Research on (i) single particle dynamics (especially related to pulverized coal combustion), fluidized beds, and effects of particles in the lung.

Hunter Geophysics, Mt. View, CA, USA *(August 1984 – July 1985)*
Mapped massive hydraulic fractures in oil fields.

Stanford University, Stanford, CA, USA *(June 1981 – August 1984)*
Research on the dynamics of a particle laden flow in the freeboard of a fluidized bed.

Tata Consulting Engineers, Bangalore *(August 1977 – July 1980)*
Design and detailed engineering of systems and sub-systems for 110 MW, 210 MW and 500 MW fossil fired power stations.

Teaching Experience
Taught courses on thermodynamics, heat transfer, energy conversion, and thermal engineering laboratory.

Research
Guided several Ph.D., M.Tech. and B.Tech, projects related to heat transfer, combustion, particle-laden flows and energy systems.

Published several papers in journals and conferences.

Sponsored Projects and Consultancies
Consultant to public and private sector companies on aspects related to thermal engineering.

DINESH MOHAN **53 YEARS** **CITIZEN OF INDIA**

EDUCATION

1972-1975 The University of Michigan, Ann Arbor, Michigan.
Ph.D. and M.S. in Bioengineering.
Thesis: Passive Mechanical Properties of Human Aortic Tissue.

1967-1970 University of Delaware, Newark, Delaware
M.S. in Mechanical and Aerospace Engineering.
Thesis: Free Vibrations of Anisotropic Plates.

1962-1967 Indian Institute of Technology, Bombay.
B.Tech.(Hons.) in Mechanical Engineering
Project: Design of Single Seater Hovercraft.

1958-1962 The Doon School Dehra Dun.
Intermediate Science (UP Board).
General Certificate of Education (Cambridge).

WORK EXPERIENCE

Current Indian Institute of Technology, Delhi, Centre for Biomedical Engineering: Coordinator, Transportation Research and Injury Prevention Programme and Head, W.H.O. Collaborating Centre for Research and Training in Safety Technology. Research and Teaching: Transportation research (pollution and safety), Human tolerance biomechanics, motor-vehicle safety, biomechanical considerations in helmet design, road traffic injuries, agricultural injuries, rehabilitation aids for the disabled, childhood injuries.

1976-1978 Insurance Institute for Highway Safety, Washington, D.C., Research Department:Senior Bioengineer, responsible for the development and management of research projects of biological and biomechanical nature. Projects included: evaluation of injuries to humans falling from heights, biomechanics of children's head injuries, effectiveness of automobile child seat systems, effectiveness of automobile safety equipment, evaluation of injuries to cyclists and motorcyclists, motorcycle helmet design, head impact due to baseball balls, evaluation of airbags and seatbelts. Other duties included evaluation of U.S. Government's and motor-vehicle manufacturer's standards concerning motor-vehicle safety.

1972-1975 The University of Michigan, Ann Arbor. (i) Biomechanics Department, Highway Safety Research Institute. Experimental research on mechanical properties of blood vessels, lungs, diaphragm, ribs, pericardium, esophagus, femur and muscles. Mechanism of head and chest injuries, injury tolerance and vehicle safety design, low back pain. (ii) Department of Physiology. Assisted in the teaching of an introductory course on human physiology.

1970-1971 Robert's Technical and Trade School, New York. Instructor, taught science and automechanics to students on a rehabilitation programme. Wrote a guide for teaching automechanics.

1967-1970 The University of Delaware, Newark, Delaware.
Research Assistant - One Year, Teaching Assistant - One Year.

CONSULTANCIES

1. Escorts Ltd. India
2. World Health Organization
3. National Institute of Health Research and Development, Indonesia.
4. Tribhuvan University Teaching Hospital, Kathmandu.
5. Ministry of Health, Tripoli, Libya.
6. Delhi Police
7. TELCO
8. Ashok Leyland
9. Eicher Tractors
10. World Bank
11. Volvo Truck Corporation, Sweden

AWARDS

2000 American Public Health Association, 2000 International Distinguished Career Award in recognition of outstanding dedication and leadership in injury control and emergency health services.
1991 Association for Advancement of Automotive Medicine, 1991 Award of Merit for outstanding research in traffic safety.
1991 International Association for Accident & Traffic Medicine, International Award and Medal for Outstanding Achievement in the Field of Traffic Medicine.
1972 University of Michigan, Rakham School of Graduate Studies Fellowship.
1970 University of Delaware Summer Fellowship.
1969 E.I. Dupont Fellowship.
1968 University of Delaware Fellowship.
1967 Outstanding student at Indian Institute of Technology, Bombay.
1958-1962 Doon School- Prizes for Physics Essay, Chemistry Essay, Mathematics Test, Science Projects, Ishwar Chand Memorial Science Cup, General Knowledge Cup.

MEMBERSHIP

Professional Organizations:

(i) American Society of Biomechanics.
(ii) Institution of Engineers, India.
(iii) National Safety Council, India.
(iv) American Society for Mechanical Engineers.
(v) Burns Association of India.
(vi) Biomedical Engineering Society of India.
(vii) Indian Society of Technical Education.
(viii) International Association of Accident and Traffic Medicine.

International Committees and Boards:

(i) Member, Board of International Research Council on Biokinetics of Impacts.
(ii) Member, Board of International Society for Child and Adolescent Injury Prevention.

National Committees and Boards:

(i) Director, Sri Ram Industrial Enterprises Ltd.
(ii) Indian Roads Congress Traffic Engineering Committee.
(iii) Central Pollution Control Board.
(iv) Sub-Commission of Science, Indian National Commission for Unesco.
(v) Board Member, Footwear Design & Development Institute
(vi) President, People's Science Institute
(vii) Department of Science and Technology committee in Biomedical Engineering

Editorial Boards:

(i) Indian Journal of Physical Medicine and Rehabilitation.
(ii) Journal of Forensic Medicine and Technology.
(iii) Occupational Ergonomics
(iv) Injury Prevention
(v) Safety Science
(vi) Crash Prevention and Injury Control
(vii) Journal of Safety Research

PUBLICATIONS

Book

- L.Berger and D. Mohan "Injury Control : A Global View", Oxford University Press, 1996.
- Peter Barss, Gordon Smith, Susan Baker and Dinesh Mohan “Injury Prevention: An International Perspective”, Oxford University Press, 1998.
- Dinesh Mohan and Geetam Tiwari "Injury Prevention and Contorl", Taylor & Francis, 2000.

Reports and monographs

(i) S.N. Tandon and Dinesh Mohan: Status of Biomedical Engineering in India, 1982.
(ii) Dinesh Mohan: Motorcycle Safety Project, 1984.
(iii) Dinesh Mohan: Indian Issues in Science and Technology, 1984.
(iv) Dinesh Mohan and K.P. Kothiyal: Aids for the Visually Disabled, 1984.
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(viii) Dinesh Mohan: Aids for the Disabled : A Technology Assessment, 1988.
(ix) Dinesh Mohan and Imrana Qadeer: Safety of Agricultural Implements, 1990.
(x) Dinesh Mohan and Rajesh Patel: Safety Assessment of Motorcycle Helmets Being Sold in Delhi, 1992.
(xi) Dinesh Mohan and Geetam Tiwari: Development of a Recording System for Road Accident Data (Vol-I and II), 1995.
(xii) Dinesh Mohan, K.S. Bawa Bhalla and Sunil R. Kale: Research Study on Burn Properties of Fabrics in Use in India, 1995.
(xiii) Dinesh Mohan, Rajesh Patel and A.R. Ray: Development and Identification of Protective Fabrics for Agricultural Workers, 1995.
(xiv) Dinesh Mohan and Amit Deopura: Accidental Deaths in India: A Statistical Survey, 1996.
(xv) Dinesh Mohan and Nicole Muhlrad: Introduction to Road Traffic Safety: A Multidisciplinary Approach, 1996.
(xvi) Dinesh Mohan, Anoop Chawla, Janusz Kajzer: Safety of Front Seat Passengers in the Tata Sierra: Analysis of Vehicle Performance and Guidelines for Safe Design of the Car Interior, 1997.
(xvii) Dinesh Mohan, Geetam Tiwari, Rajeev Saraf, S.G. Deshmukh, Sunil R. Kale, S. Wadhwa and G.V. Soumitri: Delhi on the Move:2005-Future Traffic Management Scenarios, 1997.
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(xix) Dinesh Mohan and Nicole Muhlrad: Introduction to Road Traffic Safety: A Multidisciplinary Approach, 1998.
(xx) Dinesh Mohan and Ragnar Andersson: Introduction to Injury Control and Safety Promotion, 2000.

Papers Published in International Journals : 110

General articles published in Magazines & Newspapers: 120