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Greenhouse Gas Pollution Prevention Project
Climate Change Supplement
(GEP-CCS)

Reduced Rate of Growth of GHG Emissions from Vehicles
Task 7A
Report on Vehicle Technology Assessment

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Abbreviations

(D)	Diesel
(P)	Gasoline
2-W	Two Wheeler
3-W	Three Wheeler
ADB	Asian Development Bank
AFV	Alternate Fuel Vehicle
AINGV	Association of International Natural Gas Vehicle
AP	Andhra Pradesh
APSRTC	Andhra Pradesh State Road Transport Corporation
ARAI	Automotive Research Association of India
AQIRP	Air Quality Improvement Research Programme, US
Avl	Availability
BCM	Billion cubic Meter
BHU	Banaras Hindu University
BIS	Bureau of Indian Standard
BPCL	Bharat Petroleum Corporation Ltd
BSFC	Brake Specific Fuel Consumption
CARB	California Air Research Board
CAT	Catalyst
CI	Compression ignition
CII	Confederation of Indian Industry
CMIE	Centre for Monitoring Indian Economy
CMVR	Central Motor Vehicle Rule
CNG	Compressed Natural Gas
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CONCAWE	The oil companies' European organisation for environment, health and safety
CPCB	Central Pollution Control Board
Cr-Mo	Chromium – Molybdenum
CRT	Continuously regenerating trap
DI	Direct Injection
ECU	Electronic Control Unit
EGR	Exhaust Gas Re-circulation
est.	Estimated

ETBE	Ethyl Tertiary Butyl Ether
EUDC	Extra urban driving cycle
EV	Electric Vehicle
FBP	Final boiling point
g	Gram
GAIL	Gas Authority of India Ltd
GHG	Green House Gas
gms	Grams
GOI	Government of India
HC	Hydro Carbon
I&M	Inspection & Maintenance
IC	Internal combustion
IDI	Indirect injection
IEA	International Energy Agency
IIEC	International Institute for Energy Conservation
IIP	Indian Institute of Petroleum
IIT	Indian Institute of Technology
IPT	Intermediate Public Transport
kmpl	Kilometer per liter
Kmph	Kilometer per hour
Kms	Kilometers
kpa	Kilo Pascal
Kw	Kilowatt
LCV	Light Commercial Vehicle
LEV	Low emission vehicle
LNG	Liquefied natural gas
LPG	Liquefied Petroleum Gas
LPGV	Liquefied Petroleum gas vehicle
M&HCV	Medium & Heavy Commercial Vehicle
MCM	Million cubic meter
MON	Motor Octane Number
MoP&NG	Ministry of Petroleum & Natural Gases
MoRT&H	Ministry of Road Transport & Highways
MoST	Ministry of Surface Transport
MPFI	Multi point fuel injection
MTBE	Methyl Tertiary Butyl Ether
MUV	Multi Utility Vehicle
NCR	National Capital Region
NCT	National Capital Territory

NGV	Natural Gas Vehicle
No.	Number
NOx	Oxides of Nitrogen
OBD	On Board Diagnostic
OEM	Original Equipment Manufacturer
OIL	Oil India Ltd
ONGC	Oil & Natural Gas Corporation
Oxicat	Oxidation Catalyst
PAHs	Polycyclic Aromatic Hydrocarbons
PM	Particulate Matter
ppm	Parts per million
psi	Pounds per-square inch
PUC	Pollution Under Control
R&D	Research & Development
RON	Research Octane Number
rpm	Rotations per minute
RVP	Reid Vapour Pressure
SAE	Society for Automotive Engineers
SASEN	South Asia Environment Unit
SCR	Selective Catalyst Reduction
SI	Spark Ignition
SIAM	Society of Indian Automobile Manufacturers
SIAT	Symposium on International Automobile Tech.
SO_2	Sulphur Dioxide
SPM	Suspended particulate matters
Sq.	Square
T	Tonne
TA	Type Approval
TAME	Tertiary Amyl Methyl Ether
TC	Turbo Charger
Tech	Technology
TERI	Tata Energy Research Institute
TMS	Traffic Management Study
TSP	Total Suspended Particulates
ULEV	Ultra low emission vehicle
USAID	United States Agency for International Development
VAT	Value Added Tax
VCR	Variable Compression Ration
VMT	Vehicle miles traveled
VRDE	Vehicle Research Development & Establishment
VTA	Vehicle Technology Assessment
VVT	Variable Valve Timing

Executive Summary

EXECUTIVE SUMMARY

The Greenhouse Gas Pollution Prevention Project (GEP-CCS), which is being implemented by the Louis Berger Group, Inc. for USAID/India, includes a component focused on promoting demonstration projects that result in reduced greenhouse gas (GHG) emissions. GEP-CCS is working in a variety of sectors, including power, industry and municipalities for this purpose. In municipalities, GEP-CCS is working to promote the design and development of projects in the transportation sector and in the solid waste sector that illustrate methods of mitigating the generation of GHGs.

GEP-CCS has already initiated activities for developing a transportation demonstration project. The project is being designed to integrate both vehicle technologies and traffic management interventions in a selected city to serve as a model for reducing GHG emissions from vehicles. The project concept is to incorporate new applications of existing technologies or transportation management interventions and/or demonstrate new technologies or transportation management interventions that may not be well known in India. In this way, the project will promote new transportation interventions that might be replicated across India.

In the first phase of this transportation project, a city selection study was conducted to identify an optimal city in which to conduct the demonstration project. The City Selection Report is available from USAID on request. Hyderabad was selected as that city. This Vehicle Technology Assessment Report (VTA) represents the second step. Design of the demonstration project and preparation of documentation for financing the project are the next steps. The final step will be the preparation of guidelines for master plans of municipalities that can be used to facilitate integration of transportation interventions to reduce emissions and GHGs.

This VTA provides a foundation for selecting vehicle technology options that might be employed in the demonstration project. It contains an analysis of the type of vehicles in cities (two & three wheelers, four wheelers, buses, etc.), emissions per km/person from each, environmentally sound vehicle technology (VT) options for each category, likely scenario of emissions with replacement of existing vehicles with better technology, and alternate fuel options and their relative costs to users (for modification in vehicles and for recurring fuel costs).

The VTA was prepared by a team of experts working under LBG. The Society of Indian Automobile Manufacturers (SIAM) was the chief Indian technical member and prepared the bulk of this VTA. A transportation planning expert from LBG and a vehicle technology professional from the International Institute for Energy Conservation (IIEC) are also on the team. They reviewed the draft report and provided comments on its content and approach.

Framework Results

The current level of emissions generation from all vehicles in all categories under existing conditions is given in the table below for context:

Present Emissions in Hyderabad (Tonnes per day)

	2-W	3-W	Cars	Cars (D) (Taxis +MUVs)	Buses	Total
CO	128.49	36.42	45.63	32.08	11.09	**253.70**
HC	90.34	24.50	6.85	6.05	1.77	**129.52**
NOx	1.89	0.95	6.26	2.79	18.43	**30.32**
CO2	969.97	303.97	821.92	322.70	242.67	**2661.23**
PM	0.00	0.00	0.00	0.33	2.53	**2.86**

The above data helped to target technology options that have the most significant positive impacts on pollutant and CO_2 emissions reductions from various vehicle types.

A number of technology options were identified. Over the short term (1-5 years), CNG and LPG options are deemed to be the most practical. Other fuel alternatives including bio-diesel, electricity and alcohol derivatives may not be economically or technically feasible in large scale applications over the short term, but may be considered in a demonstration project context to illustrate emerging technology options that may become economically and technically feasible over the mid-term (5-10 years). Additional data on the CO_2 emissions characteristics of these fuels will be necessary as the demonstration project evolves.

Summary of Vehicle Technology Options

The table given in the next page summarises the various technology options identified for this study and their corresponding emissions reduction effects. Other options are discussed in the text and the details can be referred from Annexure I for Alternate Fuel Technologies and Annexure II for few case studies of the application of these technologies in different countries. Additional data on CO_2 emissions from some of these technologies are required.

Potential Vehicle Technology Options for Hyderabad

Vehicle Technology	Emission Benefits
Three wheelers going to the next stage of emission norm with improved technology/fuel quality	This is expected to reduce CO by 44%, while there will be no reduction in HC and NO_x. However, CO_2 emissions would be reduced by 46%.
Electronic fuel injection and higher compression ratio in cars will improve fuel consumption by 15-20%	This would reduce CO_2 by approximately 15-20%. As per estimates by IEA, CO would be reduced by 61%, HC by 55%, NOx by 43%.
For two wheelers, improved technology (going to Bharat Stage II) with matching fuel quality	This is expected to reduce HC by 25%, NO_x by 25%, CO_2 by 46%* and CO by 25%.
Modern diesel engines with higher compression ratio, turbo charging and better fuel quality will improve fuel efficiency by 20%	This would reduce CO_2 emission by 20%. This is also expected to reduce NOx by 9% and CO and HC emission by 26%.
Three wheeler is converted into CNG	CO emissions reduce by 71%, HC by 63%, NOx by 20% and CO2 by 42%.
Three wheeler is converted into LPG	CO emissions would decline by 40%, HC by 50% and CO_2 by 15% the Nox emission would not change appreciably.
Two Wheeler is converted to LPG	Reduction in CO emission by 48%, CO_2 by around 7%. However, HC and NO_x is expected to increase by around 15%.
Gasoline passenger cars converted to CNG	This would reduce CO by 93% and HC by around 24% as per Indraprastha Gas Ltd. World Bank report estimates that CNG reduces CO_2 by around 16% and NOx by 18%.
Gasoline driven passenger cars to be converted to LPG	This would reduce CO_2 by 30%, CO by 17%, and HC by around 14% compared to Gasoline. However, NOx is expected to grow by 33%

Vehicle Technology	Emission Benefits
Diesel Taxis to be converted to LPG	LPG car will lead to around 15% reduction in CO_2 on road. Similarly, particulates (PM) would reduce by 80%, NOx by 51%, but there would be an increase in HC by 15% and CO by around 695%.
Diesel buses to be converted to CNG	This would reduce HC by 17%, CO by 16%, NOx by 42% and PM by 98%. Brooklyn Union Gas study shows around 19% CO_2 reduction in buses on road.
Diesel Taxis to be converted to CNG	This would result in a 15% reduction in CO_2, 196% increase in HC and 76% increase in CO. However, there would be around a 53% reduction in NOx, and a 83% reduction in PM
Reduction of aromatics from 50 to 20% in gasoline	Decrease in CO_2 emissions by 5%.

The following sections describes the other technologies or fuel that may be considered for Hyderabad in the long run:

Gasoline vehicles when operated on ethanol.	Ethanol-run vehicles generate 20 to 30 percent less CO and roughly 15 percent less NOx compared to gasoline-fueled vehicles. Evaporative emissions from ethanol powered vehicles are significantly lower.

Ethanol can be blended into existing gasoline in a limited volume to achieve lowering of emissions. Blending of ethanol in gasoline is permitted in the BIS code and is being done selectively in some sections of India. Hyderabad can also consider blending ethanol with gasoline at the refinery stage.

Vehicle Technology	Emission Benefits
Hydrogen Vehicles	Hydrogen has the potential to be the cleanest burning motor fuel. With virtual elimination of CO and HC exhaust emissions, only NOx emissions from existing prototype hydrogen vehicles are similar to those from gasoline vehicles

Though there has been some selective trials of use of Hydrogen in vehicles, it is far from being commercially viable anywhere in the world. Though the CO_2 emissions are lower from the exhaust, it is estimated that the amount of CO_2 generated to produce hydrogen is significantly higher.

Vehicle Technology	Emission Benefits
Electric Vehicles	ZeroTail Pipe emissions from vehicles. Even though zero emission vehicles do not generate air emission at source, the generation of electricity needed to power the vehicles does create air emissions.The life cycle emission dynamics of this technology needs further assessment to determine the net benefit or impact on air emissions.

Electric Vehicle Technology can also be considered for small vehicles in Hyderabad city. Though through this technology the tail pipe emissions are eliminated, main issues like cost of vehicle, recharging facility, etc. have to be taken into consideration before implementation of the same. Small battery operated vehicles are operational in few countries but have not been commercialised on a large scale.

Vehicle Technology	Emission Benefits
Vehicles running on Bio Diesel	Engines running on neat Bio-diesel or blended with petroleum diesel tend to have lower black smoke and CO emissions but higher NO_x and possible higher emissions of particulate matter.

Vegetable oils considered as possible substitutes for diesel fuel can be produced from a variety of sources including rape-seed, sunflower, sesame, cotton, peanut, soya, coconut, and oil palm. Vegetable oils have been promoted as possible replacement for diesel fuel because of their good ignition quality. However, their high viscosity results in poor fuel atomization, fuel injector blockage, ring sticking, and contamination of lubricating oil, makes them best used as blends with diesel fuels in mixtures of up to 50 percent. As this product is derived from existing food products, it may difficult to implement the same in India. Moreover, no such trials has been done worldwide, on the long run, to see the effectiveness of bio-diesel.

Vehicle Inspection and Maintenance

This study also shows a significant reduction in emissions from vehicles if a good emission check system is enforced in the city. It is assumed that this kind of a system would be most cost effective measure to reduce emissions from vehicles as the preliminary infrastructure is already available. This would be a new system with computerisation of emission check Centres which would help the local Governments to track the grossly polluting vehicles. Preliminary estimate shows that by installing such a system would reduce CO_2 emission by about 16,000 tons per year as on 1999.

Vehicle Relocation

Air emission benefits can be achieved by relocating older vehicles outside of Hyderabad or retiring older vehicles. Relocation or retirement may be difficult due to socio-political reasons. If we consider a scenario, where vehicles more than eight years old are not allowed to ply in Hyderabad from the year 2000, it is estimated to result in daily reduction of 500 tonnes of CO_2 from 2 wheelers, 150 tonnes from 3 wheelers, 600 tonnes from cars and 100 tonnes from buses. If the vintage of vehicles is maintained as 8 years in Hyderabad, the daily CO_2 reduction in 2005 is estimated to be 2400 tonnes approximately.

Background & Introduction

INTRODUCTION AND BACKGROUND

The Louis Berger Group, Inc. is implementing The Greenhouse Gas Pollution Prevention Project (GEP-CCS) for USAID/India. GEP-CCS focuses on creating an enabling environment for the promotion of clean energy technologies that reduce greenhouse gas (GHG) emissions. GEP-CCS includes three primary components: capacity building, outreach and information dissemination, and project development.

As part of its project development activities, GEP-CCS is charged with designing a demonstration project in the transportation sector that illustrates approaches to reducing greenhouse gas emissions from vehicles in a selected city. The demonstration project is intended to illustrate how vehicle technologies and traffic management interventions can be integrated to reduce pollutant and GHG emissions from vehicles. The demonstration project should serve to illustrate new applications of existing vehicle technologies and traffic management interventions and/or new technologies or management interventions that are not well known in India. In this way, the demonstration project can be used to improve familiarity with innovative transportation approaches that can be replicated in other municipalities.

The experience gained through this process will subsequently be used to develop guidelines for master planning in cities. The guidelines will be used to inform city and transportation planners about transportation interventions that can be incorporated into master plans for the purpose of improving transportation conditions and reducing emissions, including GHGs, from vehicles.

To carry out the transportation demonstration project, LBG has assembled a team of specialists in transportation related disciplines whose work is being coordinated through LBG's India office. The team consists of International Institute for Energy Conservation (IIEC), a company which brings expertise in vehicle technology; LBG, which specializes in transportation planning and infrastructure development; and the Society of Indian Automobile Manufacturers (SIAM), which brings expertise in diverse automotive industry technical issues.

As a first step in the project development and master planning guideline activity, LBG worked in partnership with SIAM to prepare a City Selection report. Using a variety of screening criteria, LBG and SIAM evaluated a range of cities to identify one in which this project would be conducted. Hyderabad was ultimately selected as the location for the project. The City Selection Report is available upon request from LBG or USAID/India.

The second step in the demonstration project process has been to conduct this Vehicle Technology Assessment (VTA). The VTA is an in-depth analysis of current vehicle technologies in use in Hyderabad and of technology options that can be considered for integration into the demonstration project. As such, it serves as a foundation for making choices of vehicle technology options that could be designed into the project for the purpose of reducing vehicle emissions including GHGs.

METHODOLOGY

In light of the overall objective of reducing GHG emissions from vehicles, this report assesses a range of vehicle technology options for emissions reduction, including GHGs (CO_2)

For undertaking the VTA, an analysis of the type of vehicles in cities (two & three wheelers, four wheelers, buses, etc.), emissions per km/person from each type of vehicle, environmentally sound vehicle technology (VT) options for each category, likely scenario of emissions with replacement of existing vehicles with better technology, and alternate fuel options and their relative costs to user has been conducted. Also, an assessment of emissions from in-use vehicles and benefits of vehicle Inspection & Maintenance has been calculated.

Various Government Agencies, Institutions, Testing labs, Regulatory bodies provided data as follows:

- Reliable vehicle population statistics were obtained from (covering all segments of the population) Govt. agencies like Ministry of Road Transport and Highways (MoRT&H). Andhra Pradesh Transport Department provided the latest data on the vehicle population in Hyderabad. Projection of the growth rate of vehicular population is based on past trends which are done by SIAM regularly and accepted by the governmental agencies.

- Testing agencies for different types of vehicles provided data on emissions. SIAM has used test results published by ARAI as reference data.

- Data available on vehicle miles traveled and the occupancy rates was collected from published reports by TERI.

Technologies which result in reduced emissions for two wheelers, three wheelers, and four wheelers and which are in compliance with the upcoming emission standards stipulated by Indian regulatory agencies were identified and evaluated.

Data for replacing existing old technologies with newer options available was assessed to determine the effect of technology on emissions as a basis for identifying the suitability of technology options.

One of the important factors for reducing emissions from the transportation sector is to use the right fuel quality. Data that correlates fuel quality and alternative fuel to affect reduced emissions was generated based on data published by IIP (Dehradun) - "Evaluation of Various Alternative Fuels For Controlling Vehicular Emissions in Metropolitan Cities", World Bank Report - "Air Pollution From Motor Vehicles - Standards and Technologies for Controlling Emissions", Conference Papers at the International Conference & Exposition on Alternative Energy Driven Vehicles Programme in New Delhi in 2001, and in papers presented at ADB Conference on Fuel Quality & Alternative Fuels in New Delhi in 2001.

To analyse measures and control of emissions from vintage vehicles and to review the effects of inspection and maintenance programs on emissions reductions from such vehicles, data was collected using SIAM studies and programs on inspection and maintenance conducted in various locations in India.

A team of experts from IIEC and The Louis Berger Group along with SIAM met various State Government officials of Andhra Pradesh to ascertain their views regarding the study. The team met official from the Transport Department, Pollution Control Board, Environment Department and Municipal Commissioner. They welcomed the objective of the study and made initial recommendations on approaches and next steps.

Hyderabad

In this chapter, characteristics of Hyderabad, the city selected for the demonstration project to be undertaken as part of the study are described.

The background information of the city will provide a broad perspective under which the project has to be executed.

Hyderabad, one of the fastest growing cities of India being a state capital, has its own typical characteristics in terms of occupation and transportation requirement. Existence of a large number of people in Government services and a large Government fleet is one fact that should be kept in mind while developing any transportation plan for the city.

Hyderabad, the capital city of Andhra Pradesh and formerly the princely state of Nizam is today a prime centre of trade and commerce besides housing a large number of central and state government offices. The recent strides in Information Technology industry has prompted the state to develop infrastructure required by it. The presence of ancient monuments has become a source of tourist attraction. The present State Government is focusing on development of Information technology and the Tourism industry.

The city of Hyderabad is separated by Hussein Sagar from Secunderabad in north and bifurcated in the north-south orientation by Musa river, which flows along east-west direction. Further the south-central railways also passes through the city dividing it longitudinally.

The following table gives a statistical background of the city:

	Unit	1981	1991	1999 (est.)*
Area	Sq kms	217	217	217
Population '000 nos	2260.70	3145.94	4344.44	
Density	no/Sq km	10418	14497	20020
Urbanisation %	100	100	100	
Literacy	%	58.33	71.52	-
Main Worker '000 nos	626.94	819.73	-	
Primary Activity	%	-	-	4.0
Industrial Activity	%	-	-	32.0
Services Activity	%	-	-	64.0

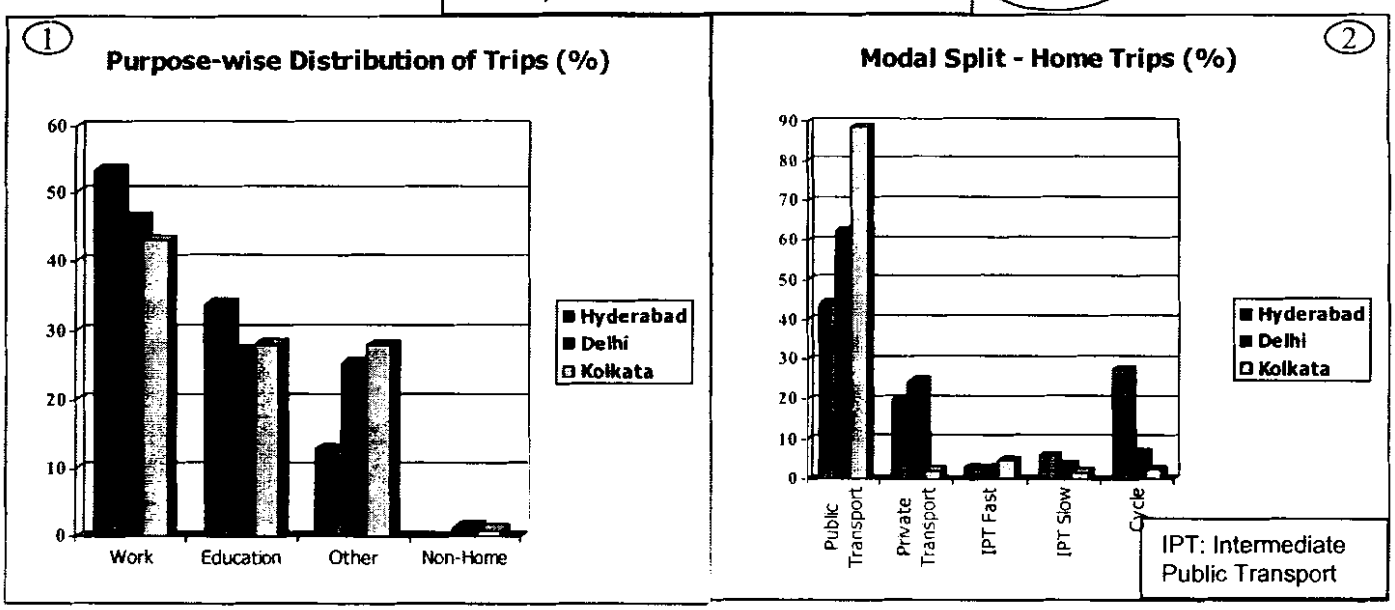
* CMIE Oct 2000 estimates

Hyderabad - Travel Characteristics

In the following graphs, travel characteristics of population of Hyderabad are illustrated.

Graph 1 depicts the purpose for which people normally use vehicles in different cities. It can be seen that in Hyderabad, people use vehicles mostly for going to 'work', and 'other use' of a vehicle is very limited compared to Delhi or Kolkata. Graph 2 depicts how people normally return home. As can be observed only around 40% people avail public transport and a very high proportion take cycle ride back home.

Compared to Delhi & Kolkata 1994



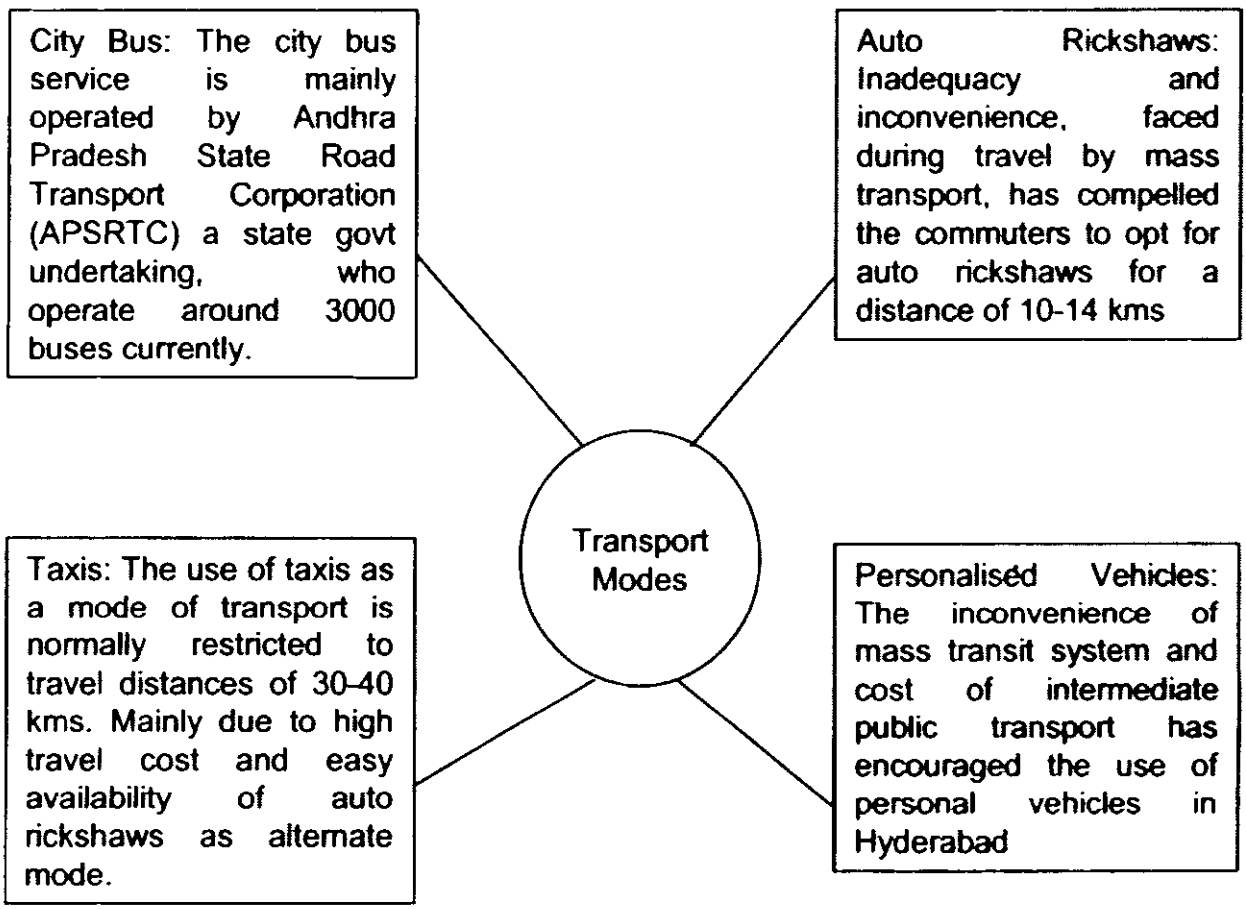
Source: Report of the subgroup on Urban Transport for the Ninth Five Year Plan, 1996

As can be observed, the public transport system in Hyderabad is very limited even compared to Delhi which is known for its grossly inadequate public transport facilities. Kolkata figures show how convenient public transport facility could carry most of the population back home.

Hyderabad - Transport Profile

Transport profile along with road network of a city always play a major role in air quality and level of living. In a city condition, mass transit system and public transport is always preferred from emissions point of view since per capita emissions contribution from such modes are generally lower compared to private modes of transport.

The transport network in Hyderabad consists of city buses, taxis, auto rickshaws and personalised vehicles like cars, two-wheelers and cycles. Also goods transport vehicles like trucks and multi-purpose vehicles.

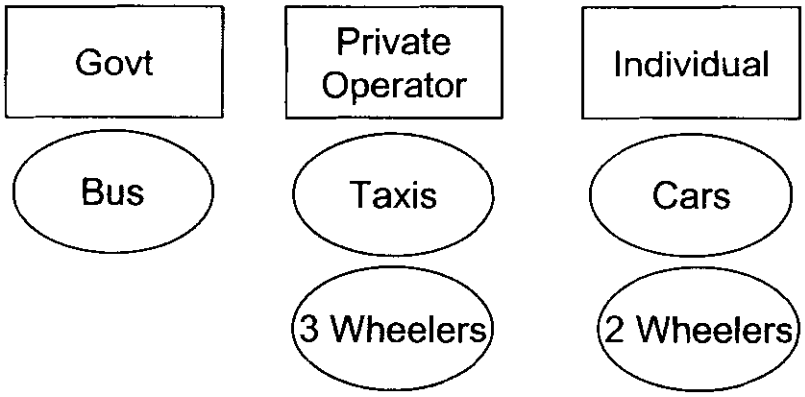


Hyderabad - Ownership and Vehicle Types

Ownership pattern of vehicles is very important from our study point of view where interventions are to be contemplated for reduction of emissions.

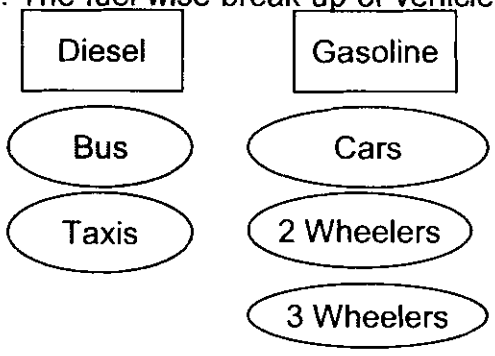
Any intervention at individual level will be very difficult in view of the large number and socio-political scenario in India. It has been noticed in several cities, particularly in Delhi that the Government has been able to initiate certain changes for commercial vehicles. However, in case of private vehicles, though Delhi Government had issued a notification banning, more than 15 year old two wheelers from the roads, they could not take any step to implement it. Even the Supreme Court of India has never initiated action against private vehicles.We can, therefore, conclude that it is be easier to implement interventions with Buses, Taxis and Three Wheelers - commercial vehicles.

Like most other cities in India, ownership of vehicles in Hyderabad shows the following pattern:



Source: SIAM Primary Investigation

The other important parameter from the point of view of this study is the type of vehicle in terms of its fuel usage. Diesel and gasoline has their own distinct emissions levels and each intervention will have its own impact depending on the current fuel and alternate technology/ fuel. The fuel wise break up of vehicles in Hyderabad is provided below:



Source: SIAM Primary Investigation

Vehicle Parameters used for Emissions Estimation: Reference Values

VEHICLE POPULATION

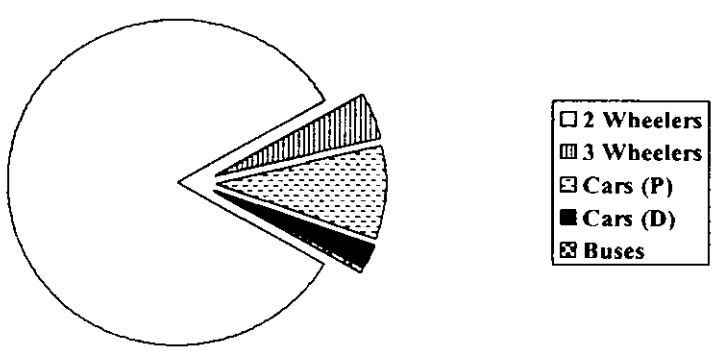
Vehicle population, composition including the vintage of vehicles is again an important criterion from the study point of view. The figures not only help us compute the magnitude of emissions from different types of vehicles but also give the level of emissions from different vintage. It has been observed that vehicle population in Hyderabad has been growing quite rapidly. The year wise compositions of different types of vehicle population in Hyderabad are given in the following table:

Year	2-W	3-W	Cars(P)	Cars (D) (Taxis +MUVs)	Buses
1992	384,490	20,015	40,163	12,796	2,919
1995	439,697	21,542	47,663	16,316	4,135
1996	621,237	29,906	58,282	16,633	4,261
1997	668,674	35,642	65,236	16,466	4,342
1998	711,977	41,588	75,059	17,530	5,196
1999	757,676	43,945	83,782	18,067	5,996

Source: MoRT&H

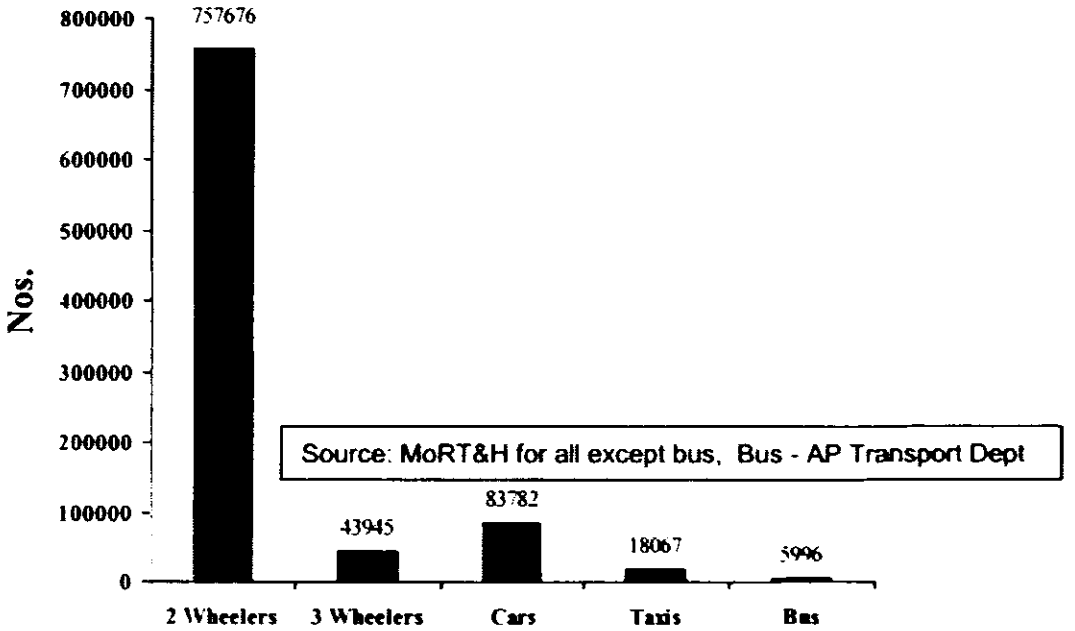
As can be observed there are about 1.1 million vehicles registered in Hyderabad. The two wheeler population in Hyderabad is quite substantial and growing at double digit rate during the last seven years. Gasoline driven passenger cars are also growing significantly in the city. Around 50% of all vehicles currently on road are pre 1992, except taxis for which the figure is over 70%.

Breakup of Types of Vehicles in 1999

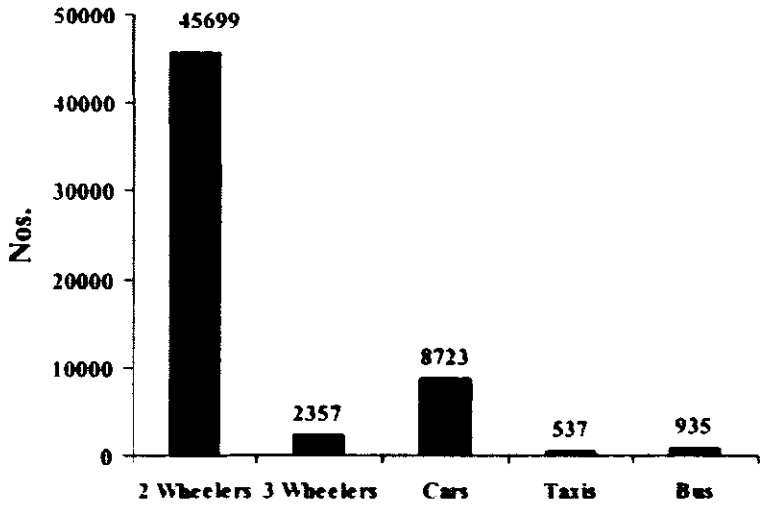


Population of Each Type of Vehicle in Hyderabad

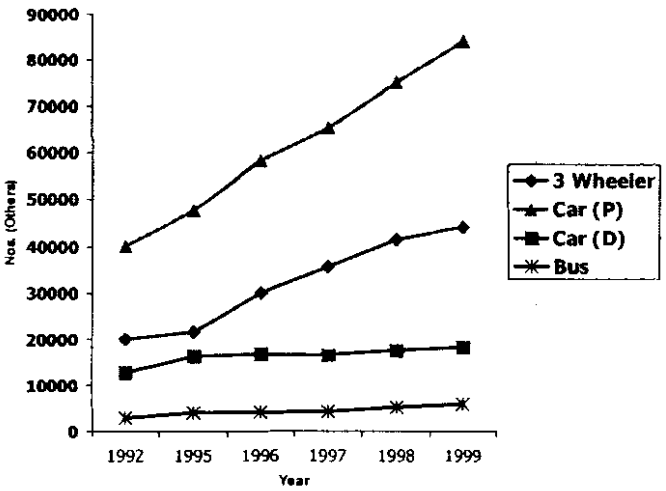
There are a total of around 1.1 million vehicles registered in Hyderabad currently. Composition of vehicles in 1999 was as given in the chart above. As can be observed, two wheelers are the single largest segment in the city.

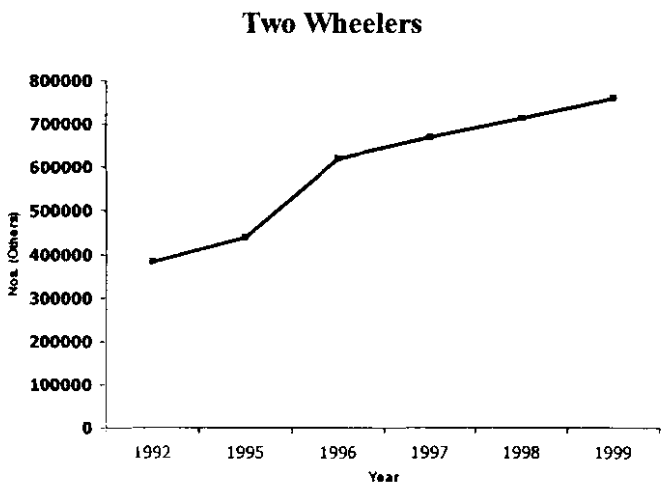


The following graph depicts the new vehicle registration in Hyderabad in 1999. It is important to note the magnitude of addition of vehicles in Hyderabad each year in recent times. This will have a clear implication on the level of emissions and intervention options on new vehicles.



The Graph below shows how different types of vehicles are growing in Hyderabad. Past trends are important for calculation of a future scenario for the city and make emissions estimations for the years to come.





It can be observed from the figures above that two wheeler population in Hyderabad is substantially above the other types of vehicles and also growing at a significantly high rate.

The table below shows the 1999 population of vehicles in Hyderabad in terms of vintage.

Estimated Vehicle Vintage

Year	2-W	3-W	Cars(P)	Cars (D) (Taxis +MUVs)	Buses
Pre-92	384,490	20,015	40,163	12,796	2,919
1992-95	55,207	1,527	7,500	3,520	1,216
1996	181,540	8,364	10,619	317	126
1997	47,437	5,736	6,954	167	81
1998	43,303	5,946	9,823	1,064	854
1999	45,699	2,357	8,723	537	800

The deterioration factor in vehicle according to the vintage plays a crucial role in overall emissions level in the city. As can be seen from the above table, all segments have significant numbers of old and more polluting vehicles in the parc.

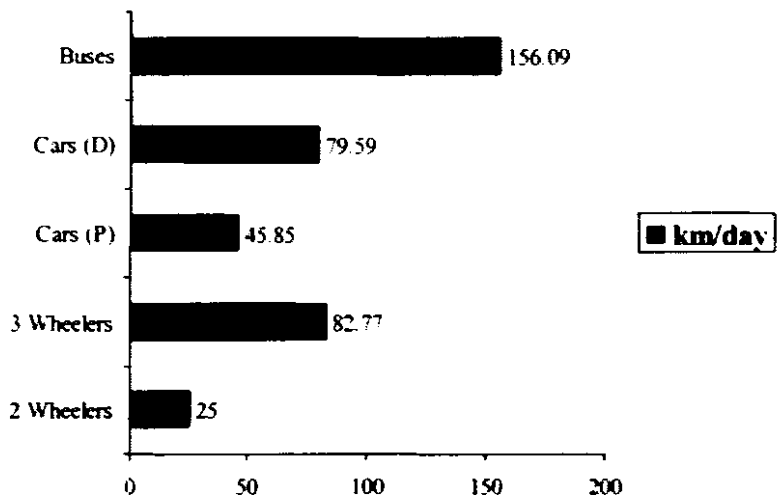
TYPEWISE AVERAGE VEHICLE KM PER DAY

The level of emissions, specially CO_2, is directly related to the distance traveled and the fuel efficiency of vehicles. The following table gives the figures for type wise average vehicle km per day.

Average Distance Traveled per Day

Type of Vehicle	Average Distance (km/day)
Two Wheelers	25.00
Three Wheelers	82.77
Cars (P)	45.85
Cars (D) Taxis & MUV	79.59
Buses	156.09

Source: Survey done on in-use vehicles by SIAM in various cities including Hyderabad.



As is expected the vehicles used for commercial purposes - buses, taxis and auto-rickshaws travel more per day than the personal vehicles. Thus from the point of view of emissions reduction, it is necessary that these vehicles run efficiently.

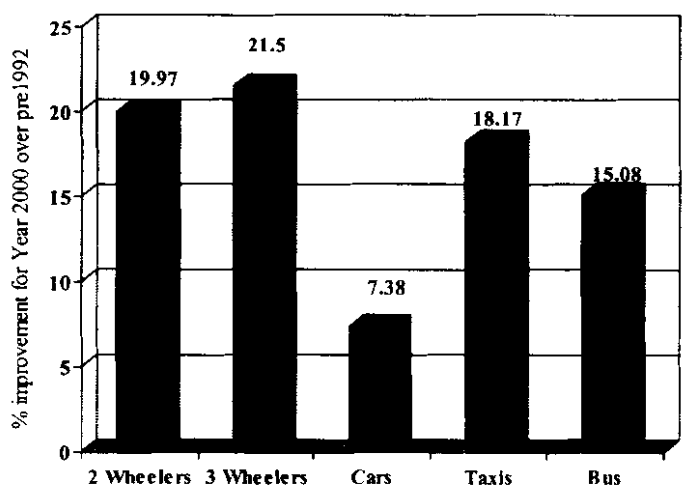
FUEL EFFICIENCY

CO_2 emission is directly correlated to fuel consumption and as such fuel efficiency plays an important role in determining CO_2 emissions. The following figures show the average fuel efficiency of different types of vehicles in Hyderabad over the years. The data has been generated by SIAM through a survey done in Hyderabad covering about 15,000 vehicles.

Fuel Efficiency of Different Types of Vehicles Over the Years

	Gasoline (KM/l)			Diesel (Km/l)	
Year	**2-W**	**3-W**	**Cars**	**Cars**	**Buses**
Pre-92	43.91	23.86	12.87	12.71	5.57
1992-95	45.48	24.12	13.39	13.42	5.7
1996	47.72	24.82	13.41	14.5	5.65
1997	48.19	25.73	14.12	13.25	5.96
1998	48.85	26.68	13.68	13.86	5.98
1999	51.73	27.23	14.18	13.61	6.14
2000	52.68	28.99	13.82	15.02	6.41

As can be seen from the above weighted average figures, the improvements in fuels efficiency over the last eight years have been significant. Average fuel efficiency gains for cars is relatively less because the share of midsize and larger cars in the population has increased significantly over the years. The following graph shows the type wise percentage increase in fuel efficiency from the pre-1992 to the Year 2000.



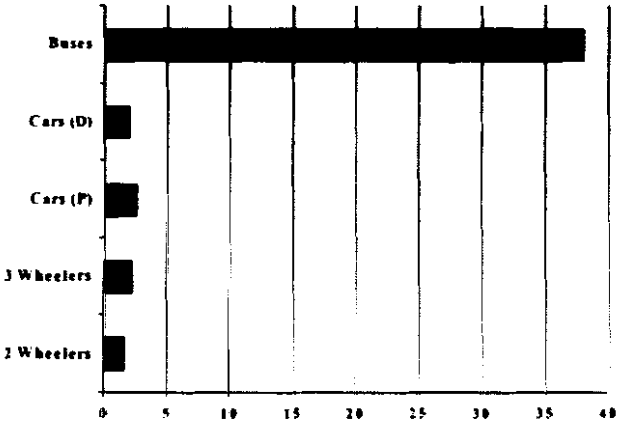
TYPEWISE AVERAGE OCCUPANCY

Average occupancy rate of vehicles play an important role in any emissions estimation study. A particular mode of transport may consume more fuel for a distance traveled, but because it is carrying more people, per capita emissions generation of that particular mode will be less. The following table gives the figures for type wise average occupancy of vehicles. It is to be noted that the driver is not included in these estimates in the cases of commercial vehicles (Three Wheelers, Taxis and Buses).

Average Occupancy per Vehicle

Type of Vehicle	Persons per Vehicle
Two Wheelers	1.6
Three Wheelers	2.0
Cars (P)	2.6
Cars (D) Taxis & MUV	2.0
Buses	38.0

Source: Impact of Road Transportation Systems on Energy and Environment- Analysis of Metropolitan Cities of India- Tata Energy Research Institute



Thus, in our subsequent analysis, we have shown that though a bus may produce more emission per km traveled, but the per capita emission would always be much less since more people travel in the bus at any point of time than in any other vehicle.

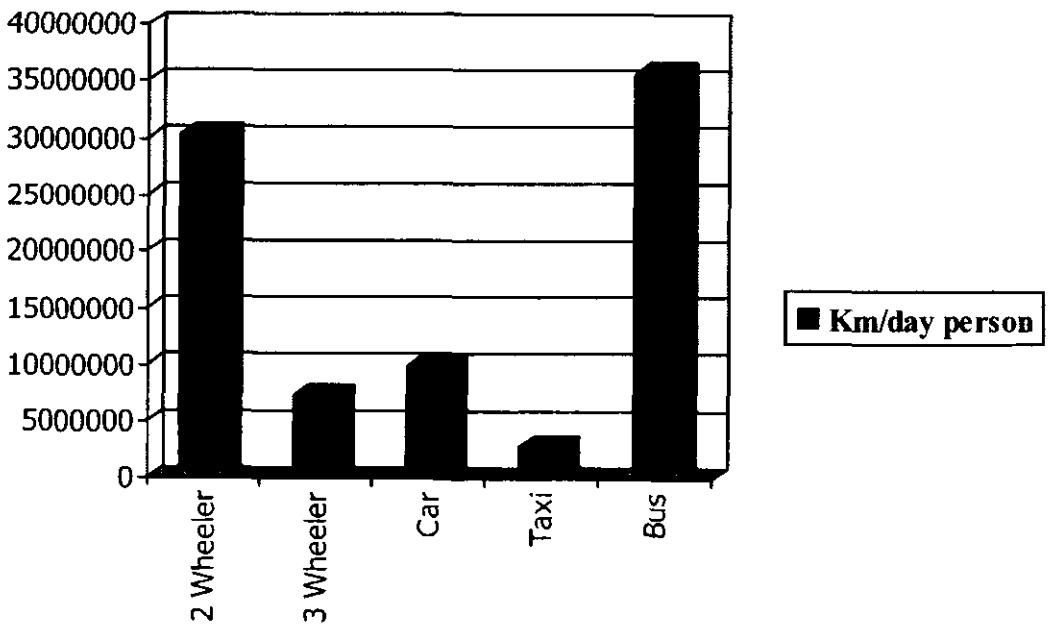
Vehicle Kilometre Person

Based on an analysis of the vehicle parameters, we have worked out how much people travel by each mode every day. This is important for this study from the point of view of selecting interventions that needs to be taken to reduce emissions through technology or through traffic management.

The equation used for this purpose:

Vehicle km traveled per day person = Vehicle population x Occupancy rate x Average distance traveled.

The following figure depicts vehicle km traveled per day person in Hyderabad if all vehicles run.



The graph reveals that though the population of Two Wheelers far exceed that of any other mode, maximum distance covered by people of Hyderabad daily is by bus (more than 35,000,000 km/day/person). This is because each bus travels a greater distance each day than any other mode and also carries more passengers per vehicle. Therefore, any step taken to reduce emission from buses will have better impact than any other modes of transport in Hyderabad.

Emissions Estimation - Current Status

Background

Growth in population of vehicles reflects growth in economy of any region. In Indian cities too, the population of vehicles has grown significantly in the last decade and there has been an increase in concern on environmental pollution. The deterioration in air quality in urban centres has been, to a large extent, attributed to automobiles.

The Ministry of Surface Transport notified mass emissions norms from newly produced vehicles since 1991 and in about 9 years, the limits were tightened three times in order to close the gap with the European Standards. Today, the Passenger Cars and MUVs in Delhi and Mumbai meet Bharat Stage II (i.e. Euro II equivalent) emission standards and shortly the same will be extended to other metro cities. The Heavy Commercial Vehicles currently meet India 2000 (i.e. Euro I equivalent) emission norms and are slated to meet Bharat Stage II by end of 2001 in metro cities. The Two-wheeler industry, on the other hand, is in the most advanced stage of emission regulations, meeting one of the tightest emission norms in the world. It is evident that the new vehicles produced by the automobile industry are very clean as compared to vehicles manufactured a few years earlier. The average emission reduction has been of the order of 70-80% in 2000 compared to the pre-control era.

The above initiatives, coupled with improvement in fuel quality, have led to considerable reduction in pollution loading, but there is very little improvement in air quality. Local emissions from vehicles on the road are of prime concern.

In this chapter we have estimated the emissions generation from different types of vehicles in Hyderabad including CO_2 emissions.

VEHICLE TYPE WISE AND YEAR WISE EMISSION

In this section we have discussed reference values of local pollutants for different types of vehicles.

Cars

In the following table, we have given the emission values (g/km) of cars/Jeeps/Station Wagons of different vintage in India.

Year	CO	NOx	SO_2	HC	TSP
1990	14.3	2	0.053	2.0	0.270
1991	14.3	2	0.053	2.0	0.147
1995	14.3	1.14	0.053	1.5	0.062
2000	3.16	0.56	0.053	0.56	0.030

Source: Decision Support System Approach to Vehicular Air Pollution Management, N. Harshadeep, South Asia Environment Unit (SASEN), The World Bank. For CO & HC the mass emission norms for the corresponding year has been taken for this study.

As can be seen the values for most of the local pollutants have decreased denoting improvement in both vehicle technology and fuel quality.

Two Wheelers

In the following table, we have given the emission values (g/km) of two wheelers of different vintage in India.

Year	CO	NO_x	SO_2	HC	TSP
1990	8.3	0.1	0.023	5.18	0.150
1991	6.49	0.1	0.023	4.5	0.130
1996	5	0.1	0.023	4.32	0.125
2000	2.4	0.1	0.023	2.4	0.069

Source: Decision Support System Approach to Vehicular Air Pollution Management, N. Harshadeep, South Asia Environment Unit (SASEN), The World Bank

As can be seen the values for CO has improved quite significantly.

VEHICLE TYPE WISE AND YEAR WISE EMISSION(Contd)

Three Wheelers

In the following table, we have given the emission values (g/km) of three wheelers (Auto Rickshaw) of different vintage in India.

Year	CO	NOx	SO_2	HC	TSP
1990	12	0.26	0.029	7.00	0.300
1994	12	0.26	0.029	7.00	0.079
1996	8.1	0.26	0.029	6.48	0.079
2000	4.8	0.26	0.029	2.40	0.006

Source: Decision Support System Approach to Vehicular Air Pollution Management, N. Harshadeep, South Asia Environment Unit (SASEN), The World Bank

As can be seen the values for most of the local pollutants like CO, HC and TSP have decreased quite significantly.

Taxis

In the following table, we have given the emission values (g/km) of diesel taxis of different vintage in India.

Year	CO	NO_x	SO_2	HC	TSP
1990	25	2	0.053	5	0.27
1994	19.8	2	0.053	2.73	0.14742
1995	6.45	1.14	0.053	1.14	0.06156
1999	6.45	1.14	0.053	1.14	0.06156
2000	3.16	0.56	0.053	0.56	0.03024

Source: Decision Support System Approach to Vehicular Air Pollution Management, N. Harshadeep, South Asia Environment Unit (SASEN), The World Bank

As can be seen the values for most of the local pollutants have decreased quite significantly denoting improvement in both vehicle technology and fuel quality.

VEHICLE TYPE WISE AND YEAR WISE EMISSION(Contd)

Bus

In the following table, we have given the emission values (g/km) of bus of different vintage in India.

Year	CO	NOx	SO_2	HC	TSP
1995	12.7	21	1.5	2.1	3.00
1996	9.96	16.8	0.75	1.44	2.06
2000	5.35	9.34	0.37	0.66	0.94

Source: Decision Support System Approach to Vehicular Air Pollution Management, N. Harshadeep, South Asia Environment Unit (SASEN), The World Bank

Values for most of the local pollutants have decreased quite significantly, especially since last year when the emission norms where tightened to align with Euro I.

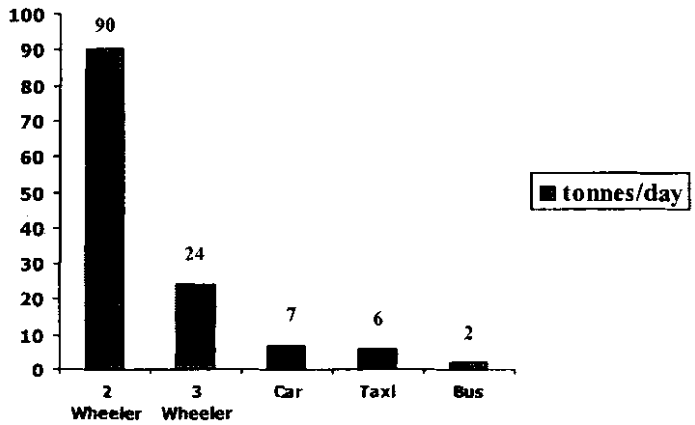
We have used the above emission values as reference values in subsequent analysis estimating emission loads for each pollutants from each type of vehicles.

Vehicular Emission in Hyderabad - Local Pollutants

In this section we have estimated the various pollution loads in Hyderabad from different types of vehicles. The estimated average emissions from various vintage and category of vehicles discussed in the previous section has been used to calculate the pollution load from each category of vehicles based on the present vehicle population of Hyderabad.

Hydrocarbons

Total HC emissions from vehicles in Hyderabad is around 129 tonnes per day. The vehicle type wise figures are given below.



As can be observed, two wheelers produce by far the maximum amount of HC in the city.

The following table gives an estimate of HC emission per kilometer per person from each category of vehicles:

HC Estimate per Km per person

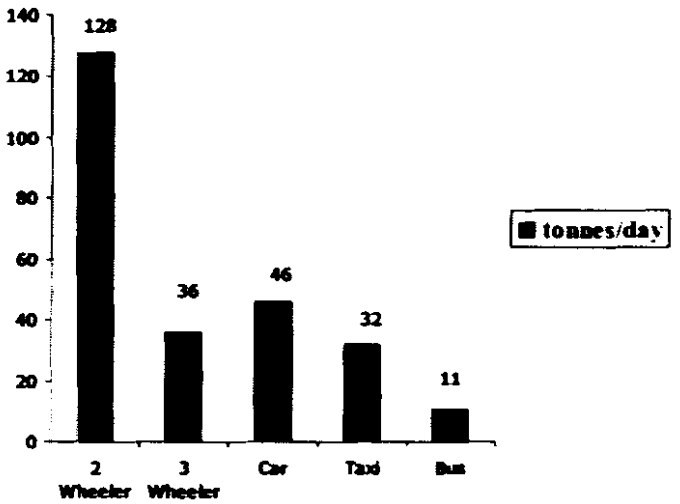
	2-W	3-W	Cars(P)	Cars (D) (Taxis +MUVs)	Buses
Occupancy (Persons per vehicle)	1.6	2	2.6	2	38
Total HC Emission (T/day)1999	90	24	7	6	2
HC Emission in gms/km/person	**2.98**	**3.37**	**0.69**	**2.09**	**0.05**

From the above table we understand that the contribution to HC emission by Two-Wheelers is quite high and the per person emission of HC per kilometer is also very high for Two-Wheelers, only next to Three-Wheelers. Buses have the lowest per capita HC emission.

Vehicular Emission in Hyderabad - Local Pollutants

Carbon Monoxide

Total CO emissions from vehicles in Hyderabad is around 253 tonnes per day. The vehicle type wise figures are given below.



As can be observed, two wheelers again produce the maximum amount of CO in the city. The second largest CO emitters are the private cars.

The following table gives an estimate of CO emission per kilometer per person from each category of vehicles:

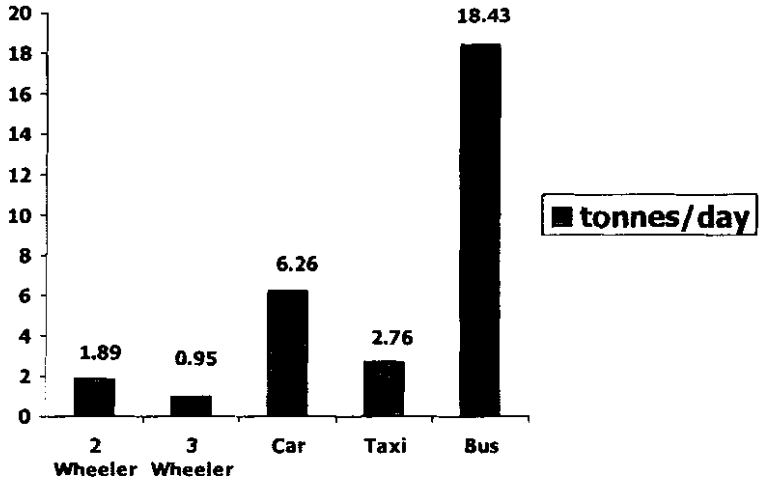
	CO Estimate per Km per person				
	2-W	3-W	Cars(P) (Taxis +MUVs)	Cars (D)	Buses
Occupancy (Persons per vehicle)	1.6	2	2.6	2	38
Total CO Emission 1999 (Tons/day)	128	36	46	32	11
CO Emission in gms /km/person	**4.24**	**5.01**	**4.57**	**10.95**	**0.31**

From the above table we understand that though the contribution to CO emission by Two-Wheelers is quite high but the per person emission of CO per kilometer is highest for Diesel Cars. Buses have the lowest per capita CO emission.

Vehicular Emission in Hyderabad - Local Pollutants

Oxides of Nitrogen NOx

Total NOx emissions from vehicles in Hyderabad is around 30 tonnes per day. Vehicle type-wise figures are given below.



As can be observed, buses produce the maximum amount of NOx in the city. The second largest NOx emitters are again the private cars.

The following table gives an estimate of NO_x emission per kilometer per person from each category of vehicles:

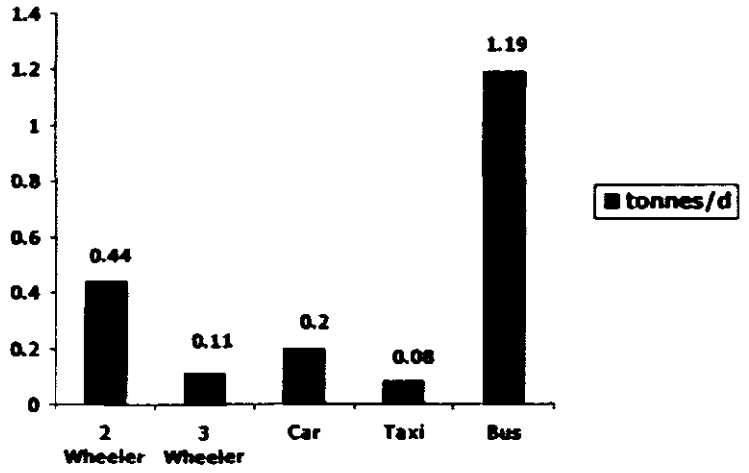
	NO_x Estimate per Km per person				
	2-W	**3-W**	**Cars(P)**	**Cars (D) (Taxis +MUVs)**	**Buses**
Occupancy (Persons per vehicle)	1.6	2	2.6	2	38
Total NO_x Emission 1999 (Tons/day)	1.89	0.95	6.26	2.76	18.43
NO_x Emission in gms/km/person	**0.06**	**0.13**	**0.63**	**0.96**	**0.52**

Here we can see that the contribution of NO_x is highest by buses and diesel vehicles per say seem to have higher NO_x emission compared to Gasoline vehicles.

Vehicular Emission in Hyderabad - Local Pollutants

Sulphur Dioxide SO_2

Total SO_2 emissions from vehicles in Hyderabad is around 2 tonnes per day. Vehicle type-wise figures are given below.



As can be observed, buses produce the maximum amount of SO_2 in the city. The second largest SO_2 emitters are again the private cars.

The following table gives an estimate of SO_2 emission per kilometer per person from each category of vehicles:

	SO_2 Estimate per Km per person				
	2-W	**3-W**	**Cars(P)**	**Cars (D) (Taxis +MUVs)**	**Buses**
Occupancy (Persons per vehicle)	1.6	2	2.6	2	38
Total SO_2 Emission 1999 (T/day)	0.44	0.11	0.20	0.08	1.19
SO_2 Emission gms/km/person	**0.01**	**0.01**	**0.02**	**0.03**	**0.03**

Here we can see that the contribution of SO_2 is highest by buses followed by Two-Wheelers but the per capita contribution is insignificant compared to other pollutants.

Estimate of CO_2 Emission from Vehicles

In this section we have estimated CO_2 emissions from vehicles. In India CO_2 is a non regulated pollutant and as such tailpipe emissions data is not available from in use vehicles. However, for new vehicles, CO_2 is recorded at the time of giving Type Approval (TA) certificate. Our objective is to estimate CO_2 from vehicles in Hyderabad. Since the data is not readily available, we have used the following methodology.

Based on the data published by Automotive Research Association of India (ARAI), the premier Government recognised testing agency in India (Source: SAE Paper) the following data on CO_2 emission from new vehicles was obtained:

Vehicle Type	Mileage (Kmpl) (Range)	CO_2 (g/km) (Range)
Two-Wheeler	95-40	20-55
Three-Wheeler	45-27	50-80
Cars (Gasoline)	19-7.5	130-300
Cars (Diesel)	22-10	100-260

To estimate the CO_2 emission for every kilometer covered by a vehicle we have taken the value of the mileage of each type of vehicle and its corresponding value of CO_2 emission:

e.g. :**Vehicle type - Two-Wheeler**

Mileage (Kmpl) (Range)	95 - 40
CO_2 (g/km) (Range)	20 - 55

The above values have been used to derive an equation which would help in estimating the CO_2 emission from vehicles based on average kilometer per litre of Two-Wheelers and assuming that the mileage and CO_2 emission has a linear trend.

X_1 = 20 g/km $\quad$ X_2 = 55 g/km

Y_1 = 95 Kmpl $\quad$ Y_2 = 40 Kmpl

Slope (M) = $(Y_2 - Y_1) / (X_2 - X_1)$

$\Rightarrow$ M =(40 - 95) / (55 - 20) ___=-55/35

$\Rightarrow$ **M= -11/7**

Straight line formula= $(Y - Y_1) = M (X - X_1)$ — 1

Substituting the value of M, Y_1 & X_1 in 1

X= (885 - 7Y) / 11

The above expression was used to calculate the average CO_2 emission from the fuel efficiency data of Two-wheelers shown in the previous table.

Similarly the expression to calculate CO_2 emission from fuel efficiency was worked out for Three-Wheelers, Gasoline Cars and Diesel cars as given below:

Vehicle type: **Three-Wheeler**

Mileage (Kmpl) (Range) 45 - 27

CO_2 (g/km) (Range) 50 - 80

Expression **X= (375 - 5Y) / 3**

Vehicle type: **Gasoline Cars**

Mileage (Kmpl) (Range) 19 - 7.5

CO_2 (g/km) (Range) 130 - 300

Expression **X= (47250 - 1700Y) / 115**

Vehicle type: **Diesel Cars**

Mileage (Kmpl) (Range) 22 - 10

CO_2 (g/km) (Range) 100 - 260

Expression **X= (1180 - 40Y) / 3**

The earlier equations were used to calculate the average CO_2 emission and the same has been calculated and given in the table below. We have taken the deterioration factor of different vintage based on fuel efficiency to arrive at the emissions load from vehicles of different vintage.

	Gasoline (CO_2-g/km)		Diesel (CO_2-g/km)		
	2-W	**3-W**	**Cars**	**Cars**	**Buses**
Pre-92	52.51	85.23	220.62	223.87	299.32
1992-95	51.51	84.80	212.93	214.40	268.30
1996	50.09	83.63	212.63	200.00	280.23
1997	49.79	82.12	202.14	216.67	206.25
1998	49.37	80.53	208.64	208.53	201.47
1999	47.54	79.62	201.25	211.87	163.29

The data for Buses 1992 has been taken from an estimate done by the Decision Support System Approach to Vehicular Air Pollution Management, N. Harshadeep, South Asia Environment Unit (SASEN), The World Bank, as CO_2 emission in g/km is not available for Buses from the Test Agencies. As mentioned earlier for other types of vehicles, the CO_2 emission from buses for the following years has been calculated based on the ratio derived from Fuel efficiency improvement.

As per SIAM survey the average distance traveled by various types of vehicles in Hyderabad is given below:

			Gasoline	Diesel	
	2-W	**3-W**	**Cars**	**Cars**	**Buses**
Av. Distance Traveled per Day (Km)	25	82.77	45.85	79.59	156.09

The product of CO_2 emission, vintage wise population and vehicle kilometer traveled per day for each category of vehicle resulted in the total CO_2 emission generated per day as shown below:

Total CO_2 Emissions (Tons/ Day) as on Year 1999

	2-W	3-W	Cars	Taxi(D)	Buses	Total	Cumulative
Pre-92	505	141	406	228	136	1,417	1,417
1992-95	71	11	73	60	51	266	1,683
1996	227	58	104	5	6	399	2,082
1997	59	39	64	3	3	162	2,244
1998	53	40	94	18	27	232	2,476
1999	54	16	80	9	20	180	2,655
Total (Category-Wise)	969	305	821	323	243	**2,655**	

The above table shows that vehicles in Hyderabad contribute to 2,655 Tons of CO_2 per day, with maximum contribution by Two-Wheelers followed by Cars.

The following table gives an estimate of CO_2 emission per kilometer per person from each category of vehicles:

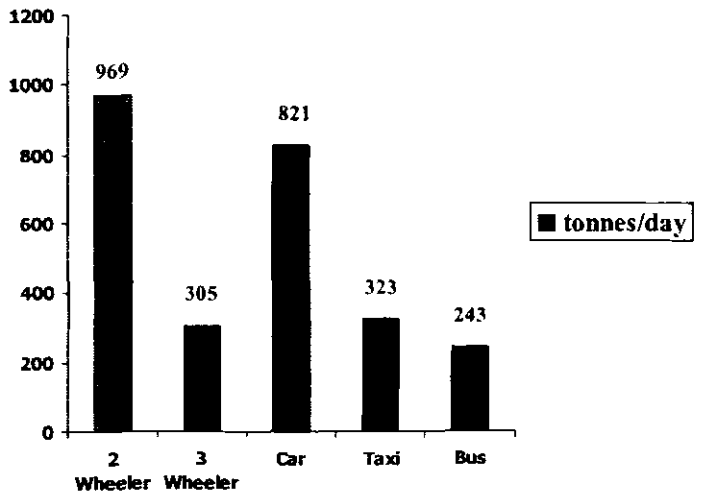
CO_2 Estimate per Km per person

	2-W	3-W	Cars(P)	Cars (D) (Taxis +MUVs)	Buses
Occupancy (Persons per vehicle)	1.6	2	2.6	2	38
Total CO_2 Emission 1999 (Tons/day)	970	304	822	323	243
CO_2 Emission in gms Per Km per Person	**32.00**	**41.78**	**82.29**	**110.21**	**6.82**

From the table it can be seen that the contribution to CO_2 emission by Buses is quite low, the per person emission of CO_2 per kilometer, is much lower than any other vehicles. Cars & Taxis show a very high per capita CO_2 emission.

Vehicular Emission - Carbon Dioxide

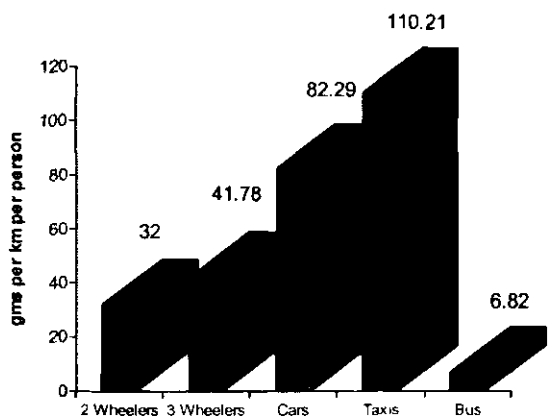
Total CO_2 emissions from vehicles in Hyderabad is estimated to be around 2,655 tonnes per day. The vehicle type wise figures are given below.



As can be observed, two wheelers produce the maximum amount of CO_2 in the city followed by cars.

Per Capita CO_2 of Each Type of Vehicle: Hyderabad

As depicted in the graph below, buses in Hyderabad emit only around 7 gms of CO_2 per km per person.



In contrast all other vehicles emit more than 4 times CO_2 per km per person. Since we have seen in previous chapters that Hyderabad has very limited bus facility, a modal shift in its favour will have positive impact on GHG emissions.

Background

Several alternative fuels have been considered from time to time all over the world as low cost substitute for gasoline and diesel and lately as clean air fuel.

Primary alternative fuels for the transportation sector include

- ⇨ Gaseous fuels : Compressed Natural gas (CNG), Liquefied Petroleum Gas (LPG), Hydrogen,
- ⇨ Alcohol fuels : Methanol, Ethanol and other alcohols, in pure form or in mixtures with gasoline
- ⇨ Electricity (including solar energy)
- ⇨ Fuels other than alcohol derived from biological materials: like soya bean, rape-seed or other vegetable oil-based fuels - Bio Diesel

The alternative fuels to be considered for use should meet the following criteria :

- •Technically acceptable
- •Economically competitive
- •Environmentally friendly
- •Easy availability and accessible

Preliminary Findings and Information on Alternative Fuels

⇨CNG/LPG is available in the Krishna Godavari basin of Andhra Pradesh and the Government of Andhra Pradesh is considering to bring this gas through pipelines to the city of Hyderabad. Once the pipeline is in place, the time frame for setting up of dispensing infrastructure should not be significant. Hence, CNG is viable for implementation in Hyderabad in the next few years. LPG is also being pursued by the Central Government for use in automobiles and the the oil companies also plan to set up LPG dispensing units across the country, this technology also has a good potential for Hyderabad.

⇨Electric vehicles although technically feasible and environmentally friendly are still not financially competitive for mass scale use and can be considered for niche market like Airports, etc. because of their environment friendliness.

⇨ Fuel cells are considered as the possible future environmentally friendly technology to power the automotive vehicles and considerable research is being carried out, with prototypes already being built. Inclusion of a fuel cell technology in the demonstration project must consider that fuel cells have not yet proven commercial viable anywhere in the world, including India and are not anticipated to be economically viable within the next ten years.

⇨Bio-diesel is another promising fuel which is environmentally friendly. Biodiesel is a mono alkyl ester produced from natural sources such as vegetable oils and can be used directly in diesel engines. At present about 245,000 tonnes per year of biodiesel are used in some 100,000 vehicles in Europe, predominantly in Germany and to a lesser extent in Sweden and Holland. A similar quantity is blended into diesel fuel in France, Italy and Belgium. Compared to diesel fuel, the cost of biodiesel is high, resulting in very limited use in America. There is no known usage in Asia. As per the present technology for production it is prohibitably costly and also it is not abundantly available. These existing limitations must be considered as must the potential change in economic viability and availability over the next 5–10 years.

⇨Alcohol, both methanol & ethanol are easily available but with the current cost structure, these are not currently economically viable for use on a large scale. Methanol is considered as toxic and as oxygenate MTBE is considered as potentially dangerous for under water contamination in case of leak. Ethanol produced from sugarcane is being considered as a potential admixture with gasoline fuel for use in gasoline vehicles.

Ethanol from sugarcane is one of the best tools to fight urban air pollution from motor vehicles. As an oxygenate (ethanol contains 35 percent oxygen by weight), fuel ethanol enhances the combustion of gasoline, resulting in a more efficient burn and greatly reduced emissions. It helps reduce all pollutants, including hydrocarbons, NOx, CO_2 fine particulates and toxics. 10 percent ethanol blends reduce carbon monoxide better than any other reformulated gasoline blend - more than 25 percent. Ethanol is low in reactivity and high in oxygen content, making it an effective tool in reducing ozone pollution. Ethanol is a safe replacement for toxic octane enhancers is gasoline such as benzene, toluene and xylene. ETBE lowers gasoline volatility and is particularly effective in reducing VOC emissions from automobiles. Because ethanol is produced from renewable agricultural wastes and feedstock such as corn, sugarcane, wheat, barley, oat and wastes, it reduces greenhouse gas emission.

Ethanol gasoline blends are widely used in Brazil as gasohol which contains 20 - 22 percent ethanol. In Indian standards IS 2796, 5 percent ethanol gasoline blends are permitted. A pilot trials are in progress in Maharashtra by the Oil companies, using 5 percent anhydrous ethanol gasoline blends. The Indian government is planning to extend the same to some locations and has proposed to set up a committee to look into all the aspects including financial aspects for its likely introduction in the country. However, because of restricted availability large scale use of Ethanol in India is not expected in the next ten years.

Hybrid Passenger Cars represent a "Spin-off" of technology developed for Electric Vehicles. The attraction for Hybrid Vehicles is its good potential for Petroleum conservation and potential for low emissions. Two models currently available - Toyota Prius (48 mpg), Honda Insight (64 mpg)

Expected other Hybrid Vehicle Commercialization prospects internationally are:

Ford Escape	Small SUV	2003
Dodge Durango	Large SUV	2003
GM Sierra	Large Pickup	2004
GM	Medium SUV	2004
Toyota	Minivan	?

It is very unlikely that these vehicles will be commercially available in India in the next ten years. Nevertheless, they might be considered for the demonstration project depending on its desired outcome.

Annexures I and II contain extensive background data on the fuel technologies described above. The reader should refer to them for additional information.

Information on Alternative Fuels

The following section also contains background data on the various alternative fuels described in this VTA. As noted previously, supplemental data on these technologies may need to be generated as the demonstration project evolves.

Electric Vehicles

Electric vehicles are often classified as zero emission vehicle because no pollutants are emitted directly from the vehicle. This does not imply they are zero emissions overall, for only that the emissions are displaced from congested urban areas to (hopefully) remote locations. In case of rechargeable batteries, this applies to power plant emissions; in case of fuel cells commercial hydrogen production results in substantial copious CO_2 emissions.

Electric Passenger cars have been introduced for the first time in our country. Mahindra & Mahindra, Bharat Heavy Electricals Ltd, Eddy Current Controls India Ltd, Cheetlec Vehicles India Ltd, etc. are producing electric vehicles over the last few years. Bajaj Auto Ltd has also developed a Three Wheeler to run on Electricity. The technologies developed so far have reached a level to meet the basic operational requirements of urban road transport and industrial sector in a limited way. The manufacturers are prepared to commercialise various models developed. This technology can be considered for Hyderabad for use in selected traffic segments of Hyderabad

Government of India has shown an interest in supporting the development of battery operated vehicles to contain the menacing vehicular emissions polluting the environment and also because India will have limited access to oil in the near future.

However, EVs have not yet been successful in competing with IC engines vehicles due to:

- Short Range operation,
- Inferior on Road Performance,
- Need for regular charging requiring several hours,
- Logistics for charging batteries and
- High initial capital cost.

The problem related to short range of current EVs is mainly due to non-availability of high-energy batteries with quick charging. The battery is thus an important factor for commercialisation of EVs.

Natural Gas

Low-priced and abundant in supply, natural gas represents a growing market. Natural gas is an inflammable gas (mainly methane) that is found in the Earth's crust. Natural gas reserves are found all over the world in sandstone and carbonate reservoirs.

When used in a properly prepared engine, natural gas could combust more completely than gasoline. This would result in lower levels of the exhaust emissions that contribute to urban pollution and global warming. Natural gas contains no aromatic compounds and produces no benzene emissions. Also, when used to replace diesel fuel in a compression ignition engine, natural gas does not produce any particulate matter. Natural gas has a higher octane rating than gasoline, which means engines optimised to use this alternative fuel could improve energy efficiency and reduce carbon dioxide, the main greenhouse gas.

In India many commercial vehicle operators especially the Three-Wheeler owners see natural gas as a plausible alternative because it is virtually less than half the price of Gasoline. Since natural gas three-wheelers are operating successfully in Delhi the same can be considered for Hyderabad provided supply of CNG is assured to the Three-Wheeler owners. Vehicles running on Gasoline are most suitable for conversion to natural gas or dual as no modifications are required on the existing engine.

Conversion costs for three-wheelers can range upwards from 15,000 provided the vehicle is technically suitable for conversion. Cost of conversion of cars to CNG ranges from Rs 25,000 to Rs 35,000 depending upon the make of the vehicles. Heavy vehicles are generally not converted but a new vehicle cost depends upon the size and number of storage tanks that are fitted on the vehicle. Today there are several options for conversion, including a system that can run both on gasoline and natural gas for smaller vehicles.

Liquefied Petroleum Gas

Liquified Petroleum Gas (LPG) is another Alternate fuel option on which large number of vehicles operate worldwide. It is estimated that number of vehicles plying on LPG is more as compared to natural Gas. In India the Government has recently approved LPG as an automotive fuel, which till recently was used only for domestic cooking purposes. Vehicle manufacturers in the country have started their trials on newly developed LPG vehicles. However, with de canalising of the imports, its use is being considered for transport sector for auto rickshaws, taxis and cars in the metropolitan cities. The Safety Code of Practice for use as automotive fuel is being drawn and the specification of automotive LPG to be used in India is being prepared.

Like natural gas, LPG comprising of largely propane, is a clean burning, low polluting engine fuel. It can be used as a substitute or sole fuel in place of diesel or gasoline. LPG vehicle (LPGV) uses LPG as a sole fuel in spark ignition (SI) engines fully replacing gasoline or as a supplementary fuel in compression ignition (CI) engines in dual-fuel mode partly replacing diesel. In either case, option of switch back to gasoline or diesel operation is possible.

LPG fuel-system technology is well developed, and is mostly mechanical based and designed as 'Second Fuel Systems', to be added onto gasoline fuel systems, for dual-fuel operation in either/or mode.

Exhaust emissions of unburned hydrocarbons for LPG vehicles are about the same as or higher than those of gasoline vehicles, depending upon the interaction with the emission controls of the original gasoline fuel system. Carbon monoxide is normally lower, while oxides of nitrogen show no change. In diesel engines, nitrous oxides emission is lower at part-loads and higher at full load and is expected to be lower than diesel operation over the duty cycle of the engine.

Fuel Cells

Fuel cells have several advantages over batteries. First of all, the energy density can be increased by increasing the size of the fuel tank, since the specific weight (kg/W) of the fuel plus fuel tank are typically much less than the fuel cell itself. Secondly, fuel cells can be quickly 'recharged' by refilling the fuel tank. Because of the difficulty of on-board hydrogen storage, a good deal of work has gone into developing reformers to convert methanol or other liquid hydrocarbon fuels into mostly H_2 and CO_2.

Phosphoric acid fuel cells (PAFC) are fairly well developed and are being demonstrated as part of a hybrid PAFC-battery electric power plant for a small bus. This is the only fuel cell technology, which has demonstrated the ability to run on hydrogen from reformed hydrocarbon fuels for long periods without degradation. Disadvantages include the use of noble metal catalysts, slow start-up (200°C operating temperature), large volume, and weight. Proton exchange membrane (PEM) fuel cells (also known under the trademark of solid polymer electrolyte, or SPE, fuel cells) require purer grades of hydrogen (typically in excess of 95% H_2), and only ppm concentrations of CO, which can poison the noble metal catalyst. Noble metal loading are currently about ten times higher than those required for PAFCs, which adds a significant cost to the cell. However, PEM fuel cells offer fast start up, rapid response, good power density (relative to other fuel cells), long life, and good low-temperature performance. Ballard Power Systems of Canada is participating in a 9.8 m (32 ft) bus demonstration project in which 120 kW will be supplied by a group of 5 kW PEM stacks. The current cost of such a system is not commercially viable ($10,00/kW), but costs should fall dramatically if a significant market develops and mass production becomes possible. Therefore this technology is still some years away from large-scale use.

Other promising fuel cell technologies have also been proposed for electric vehicles, but have not yet been proven. Alkaline fuel cells (AFC) have power densities (60-250 W/kg), can be made without noble metal catalysts, and have rapid response and start up capabilities, but are sensitive to poisoning by CO_2. Thus, operation on reformed fuels is not possible. Several vehicle demonstrations were carried out in the 1960s, and the technology has found fairly extensive application in spacecraft power generation. Finally, high temperature (800-1000°C) solid oxide fuel cells (SOFC) similar to those being developed for stationary utility applications, are also being considered for vehicle use. This technology is still many years away: safety hazards, warm up time, and start/stop operation difficulties associated with vehicle applications have not yet been addressed.

Ethanol

Ethanol has attracted considerable attention as a motor fuel due to the success of the Brazilian Pro-alcohol program initiated in 1975 as a response to the global oil crisis of the 1970s. Despite the technical success of this program-around one-third of Brazil's 12 million cars are powered by ethanol fuel- the high cost of producing ethanol (compared with hydrocarbon fuels) has required large direct and indirect subsidies amounting to over U. S $ 1.0 billion per annum.

Ethanol or grain alcohol can be produced by processing agricultural crops such as sugar cane or corn but it is more expensive to produce than methanol and requires large harvest of these crops and large amounts of energy for its production. This can lead to environmental problems, particularly soil degradation (OECD 1995).

When ethanol is blended with ordinary gasoline in proportions up to 22 percent, the resulting mixture known as gasohol, may be burned in ordinary spark-ignition automobile engines. Pure ethanol is used extensively as a blend stock for gasoline in Brazil, South Africa, and the United States.

The fuel economy of vehicles using gasohol is dependent mostly on the engine type and driving conditions Dynamometer test results and road trials on non-catalyst cars show no change in fuel economy for ethanol content up to 5 percent volume. For closed loop catalyst-equipped cars there is a noticeable reduction in fuel economy associated with gasohol (Hutcheson 1995).

A special engine is required to burn mixtures richer than 22 percent ethanol. "All alcohol" cars bearing such engines normally burn hydrates ethanol and require special adaptations mainly to prevent corrosion. These adaptation costing about US$500 per vehicle, include coating the insides of the fuel tank with tin, the fuel lines with copper and nickel, and the carburetor with zinc. The pistons also have to be strengthened to permit the use of higher compression ratios possible with the use of alcohol.

Such engines cannot compensate for the lower energy content of a given volume of ethanol compared to gasohol, even though their higher compression ratios achieve even higher thermal efficiency than those with gasohol in an ordinary engine. About 1.25 litres of pure hydrated alcohol give the same mileage as one litre of gasoline- a significant fuel economy penalty. Ethanol-powered cars tend to be poor starters in cold weather (Homewood 1993; Weiss 1990). To ease this problem, flexible-fuel vehicles have been developed in the United States to operate on any blend of gasoline and ethanol up to 85 percent ethanol by volume. Emissions, By blending 22 percent anhydrous ethanol with gasoline to produce gasohol, Brazil has been able to eliminate completely the requirement for lead as an octane enhancer.

Emissions from ethanol-powered vehicles are not as well characterized as for other alternative fuels, but are believed to be high in unburnt ethanol, acetaldehyde (more than 12 times compared to gasoline vehicles), and formaldehyde. These emissions, however, can be effectively controlled with a catalytic converter. Ethanol-run vehicles generate 20 to 30 percent less CO and roughly 15 percent less NOx compared to gasoline-fueled vehicles. As the vapor pressure of pure ethanol is much lower than gasoline, evaporative emissions from ethanol powered vehicles are significantly lower. The low vapor pressure of ethanol, however, could cause cold-starting problems in colder climates and result in higher cold start exhaust emissions. Emissions of benzene 1.3 butadiene and particulate matter are also substantially lower for ethanol-powered vehicles (Homewood 1993; Pitstick 1993).; Limited ozone modeling of speculated emissions from ethanol-fueled vehicle suggests that the ozone-forming potential of neat ethanol is less than that of gasoline and diesel, about the same as that of reformulated gasoline, and higher than that of LPG, methanol, and CNG.

Some of the limitations of pure ethanol such as cold start problems and the need for dedicated OEM vehicles can be addressed by blending ethanol with gasoline to form E85 fuel (85 percent ethanol and 15 percent gasoline) for use in dedicated variable fuel vehicles (VFVs)/ Flexible Fuel Vehicles (FFVs). But ethanol blended with gasoline diminishes some of the inherent such as low volatility; no benzene in fuel, and lower CO emissions. FFV/VFVs running on ethanol-gasoline blends are likely to have higher evaporative emissions (with greater ozone-forming potential) than gasoline vehicles as well as increased emissions of CO and benzene (Pitstick 1993; OECD 1995).

As an intoxicating beverage, ethanol presents a special supervisory challenge. Supplies of ethanol must be carefully monitored (Maggio and other 1991).

Fuel prices and supply: Ethanol is produced primarily by fermentation of starch from grains or sugar from sugar cane. As a result the production of ethanol for fuel competes directly with food production in most countries. The resulting high price of ethanol (ranging from US$0.26-0.41) per liter equivalent to US &0.40 - 0.65 per liter of gasoline on an energy basis) has effectively ruled out its use as a motor fuel except where (as in Brazil and the United States) it is heavily subsidized.

The Brazilian pro-alcohol program has attracted worldwide attention as the most successful example of implementing an alternative fuel program. Despite the availability of a large and inexpensive biomass resource, this program has required massive government subsidies for its viability. To address a severe shortage of ethanol in 1990, a blend of methanol, ethanol, and gasoline was developed for use in dedicated alcohol vehicles. Because of earlier disruptions in supply of fuel alcohol and reductions in direct, the share of ethanol-powered cars in new car sales in Brazil dropped to less than one percent in 1996.

Bio-diesel

Vegetable oils considered as possible substitutes for diesel fuel can be produced from a variety of sources including rape (also known as canola or colxza), sunflower, sesame, cotton, peanut, soya, coconut, and oil palm. Vegetable oils have been promoted as possible replacement for diesel fuel because of their good ignition quality. However, their high viscosity (about 20 times that of diesel), which results in poor fuel atomization, fuel injector blockage, ring sticking, and contamination of lubricating oil, makes them best used as blends with diesel fuels in mixtures of up to 50 percent.

When used in blends, vegetable oils produce higher emissions of CO, HC, and PM as compared to pure diesel fuels (OED 1995; IEA 1993). Biodiesel is produced by reacting vegetable or animals fats with methanol or ethanol (trans-esterification to produce a lower viscosity fuel (oil ester) than is similar in physical characteristics to diesel, and can be used neat or blended with Petroleum diesel. Care must be exercised to completely remove the glycerin residues produced as a by-product. Engines running on neat Biodiesel or blended with Petroleum diesel tend to have lower black smoke and CO emissions but higher NOx and possible higher emissions of particulate matter. These differences are not large, however. Other advantages of biodiesel include high cetane number, low viscosity, very low sulfur content, and the fact that is a renewable resources. Disadvantages include high cost (U.S $ 0.39 – 0.91 per liter before tax) and reduced energy density (resulting in lower engine power output). The effects of bio-diesel on engine performance and emissions over a long period in actual service are not well documented.

Although the use of vegetable oils in diesel engines dates to 1900, the modern use of biodiesel fuel started in the early 1980's which vegetable oils – soybean oil, sunflower oil, corn oil, cottonseed oil, and rapeseed oil – were first used as experimental substitutes for diesel fuel in farm tractors. Interest in bio-diesel plunged along with the price of oil in 1983. Recently, interest in cleaner air and renewable energies has led to renewed private and public focus on bio-diesel fuel.

Owing to the high price of conventional diesel fuel in Europe (U.S $ 3 to U.S $ 4 a gallon including taxes), a sizeable number of diesel vehicles in Austria, Belgium, France, and Italy run on bio-diesel fuel made primarily from rape-seed oil (U.S DOE 1994). In the United States bio-diesel fuel has been used mostly in demonstration projects in which it is blended with conventional diesel fuel to reduce sulfur and particulate emissions from diesel vehicles Some limited demonstration projects using neat bio-diesel in diesel vehicles have also been initiated.

Results from laboratory studies (Alfuso and others 1993; Pagowski and others 1994; Scholl and Sorenson 1993; Tritthart and Zelenk 1990; Ziejewski, Gettler, and Pratt 1986) generally agree that blended or neat bio-diesel has the potential to reduce diesel CO emissions (although these are already low), smoke opacity, and HC emissions particularly polycyclic aromatic hydrocarbons. But these studies show an increase in NOx emissions for bio-diesel fuel compared with diesel fuel at normal engine conditions. Generally lower particulate emissions particularly under high-speed and moderately high-load conditions but a dramatic increase under low-speed and light-load conditions.

As for the HC emissions, research by School and Sorenson (1993) shows a reduction in HC emission when biodiesel is used. There is some concern, however, that the organic acids and oxygenated compounds in bio-diesel may affect the response of the flame ionization detector, thus understanding the actual HC emissions. Scholl and Sorenson also mention that the behavior of these compounds with respect to adsorption and desorption on the surfaces of the vas sampling system is unknown. Thus more studies are needed to understand the organic constituents in the exhaust from bio-diesel fueled engines before firm conclusions can be drawn regarding the effects on HC emissions.

There is controversy concerning effect of bio-diesel on particulate matter emissions. Alfuso and others (1993) report that some studies claim a reduction of particulate emissions when bio-diesel is used, while some studies show an increase.

The production of vegetable oil based bio-diesel fuel involves plowing the ground (tillage), planting the crops (rape, soybean, sunflower, corn), and fertilizing and harvesting the crops. These processes require the use of motorized farm equipment, which produce exhaust emissions and use fossil energy. In addition, methanol or ethanol are needed in the transesterification process, and the emissions emitted to produce these compounds should be taken into account. In a life cycle study on rape seed oil and its esters, the German Federal Environmental Agency has noted that other factors such as odor generated by fuel combustion and large emissions of nitrous oxide (N_2O) in the production cycle render the use of this fuel less attractive (OECD 1995). Therefore the overall energy consumption and full fuel cycle emissions for biodiesel fuel might be as high as those from conventional diesel fuel. Thus biodiesel fuel might not be as attractive as other alternative fuels, such as natural gas, as a substitute for conventional diesel fuel.

The cost of biodiesel fuel is one of the principal barriers making it less attractive as a substitute for diesel. The cost of vegetable oils in US is U.S.$2-3 a gallon. If the credit for glycerol, which is a by-product of the biodiesel transesterification process and a chemical feedstock for many industrial processes, is taken into account, the cost of converting vegetable oils to biodiesel is approximately U.S $0.50 a gallon (Reed 1994). Thus the total cost for biodiesel fuel is U.S $ 2.50 – 3.50 a gallon. This is substantially higher than the cost of conventional diesel, about U.S $ 0.75 – 0.85 a gallon before tax. If waste vegetable oil is used, the cost of biodiesel could be reduced to about U.S $ 1.50 a gallon (Reed 1994). Since the heating value for biodiesel is less than that for diesel, more fuel must be burned to provide the same work output as diesel. This adds further to the cost disadvantage of biodiesel. Considering these limitations and the availability of less greenhouse gas intensive alternatives at similar cost, the use of rape-seed oil or its derivative cannot be justified from the standpoint of environmental protection.

Hydrogen

Although hydrogen has the potential to be the cleanest-burning motor fuel, it has many properties that make it extremely difficult to use in motor vehicle. Hydrogen's potential for reducing exhaust emissions stems from the absence of carbon atoms in its molecular structure. Because of the absence of carbon, the only pollutant produced in the course of hydrogen combustion is NOx (of course in the absence of carbon, the only pollutant produced in the course, the lubricating oil may still contribute small amounts of HC, CO and PM). Hydrogen combustion also a produces no direct emissions of CO_2 Indirect CO_2 emissions depend on the nature of the energy source used to produce the hydrogen. In the long-term event of drastic measures to reduce CO_2 emissions (to help reduce the effects of global warming), the use of hydrogen fuel produced from renewable energy sources would be a possible solution.

Hydrogen suffers from two major problems; production and storage. Hydrogen is not a fossil fuel, and is not found in significant quantities in nature. It, therefore, must be manufactured. Hydrogen can be produced by a number of methods, of which the most common are electrolysis of water, reforming natural gas, or partial oxidation and steam reforming of other fossil fuels. (It should be noted that hydrogen produced by reforming fossil fuels does not reduce greenhouse emissions because the CO_2 emitted in the reforming process in comparable to that what which would have been emitted if the fossil fuels were used directly in a vehicle). The most economical source of hydrogen is from reforming natural gas. Hydrogen is currently manufactured in limited quantities as an industrial chemical, as rocket fuel. And in larger quantities for use in Petroleum refineries and chemical plants. Electrolysis is sometimes used to produce high-purity hydrogen for special purposes but cannot compete economically with natural gas reforming for large-scale production. The potential future sources include electrolysis of water using large-scale, cheap photoelectric or solar-electric systems, or cheap abundant, and environmentally benign hydroelectric or nuclear-electric plants.

In the nearer term, renewable hydrogen could be produced from biomass. Hydrogen could also be produced on a large scale through in-situ gasification of coal, but this would result in large emissions of CO_2, as well as localized environmental damage due to subsidence, possible groundwater contamination.

In order for hydrogen to become available as a motor fuel, significant investments would be needed in the infrastructure for the delivery, storage, and dispensing of the fuel. These investments are unlikely to occur as long as the costs of hydrogen production and use exceed those of other available motor fuels.

Hydrogen can be stored on-board a vehicle as a compressed gas a liquid, or in chemical storage in the form of metal hydrides. Hydrogen also can be manufactured on-board the vehicle by reforming natural gas, methanol, or other fuels, or by the reaction of water with sponge iron. In the latter case the sponge iron is oxidized and must be regenerated periodically. Compressed hydrogen occupies roughly fourteen times the space of an equivalent amount of gasoline. Thus compressed gas storage would add significant bulk and weight to a vehicle – about three times the bulk and weight of a equivalent volume of compressed natural gas. Vehicle range and refueling frequency would be significant constraints.

Even as a liquid, however, hydrogen would still occupy roughly four times the volume of an equivalent amount of gasoline. Furthermore, the energy required for refrigeration to liquefy the hydrogen could easily exceed the energy value of the fuel itself, resulting in an extremely inefficient system.

The third option for hydrogen storage is in the form of metal hydrides. Current metal hydride storage systems are heavy and bulky, but less so than the storage cylinders required for compressed hydrogen. This is considered the leading technology for storing hydrogen for vehicular use. Research is under way in several countries to improve these characteristics, and some vehicle manufacturers in Germany and Japan are developing prototype vehicles.

The most promising approach to the use of hydrogen for vehicular propulsion is to react it with oxygen in a fuel cell to supply electric energy to a hybrid-electric vehicle. Fuel cells are extremely efficient compared with internal combustion engines and hydrogen-air fuel cells produce no pollutant emissions. Thus this system would be similar to a battery-electric propulsion system, except that the fuel cell and fuel supply would require significantly less weight and bulk than a battery system for the same energy storage. The fuel could be supplied and stored as hydrogen or could be produced on-board by the reformation of methanol, natural gas, or by the reaction of water with sponge iron. Producing hydrogen for the fuel cell by reforming hydrocarbon fuels may be especially attractive – both because of the increased case of handling compared with pure hydrogen and because this approach could continue to use the fuel supply infrastructure already in place.

Research and development work on hydrogen-powered vehicles is progressing in several countries including Canada, Germany, Japan and the United States. One of the most promising developments is a prototype 60 passenger hydrogen bus produced by Canada's Ballard Power Systems, a leader in fuel cell technology. The proton-exchange-membrane (PEM) fuel-cell bus has been put in service in Vancouver, Canada. It travels at normal operating speeds and can go more than 400 km on a single hydrogen charges. The Ballard prototype, however, costs three times as much to operate as a comparable diesel bus. Economies of scale and improved fuel cells might make it competitive with conventional diesel buses beyond 2000.

Hydrogen has the potential to be the cleanest – burning motor fuel. With the virtual elimination of CO and HC exhaust emissions, only nitrogen oxide emissions would be present in any significant quantify in the vehicle exhausts; NOx emissions from existing prototype hydrogen vehicles are similar to those from gasoline vehicles.

Due to the high cost of production, lack of storage reserves, and the large quantities required for hydrogen to be used as a motor fuel, it is unlikely that hydrogen will be as cost-effective fuel in the near future. New production and storage techniques will be required before hydrogen fuel becomes economically – much less technology – feasible.

Potential Alternative Fuel Technology Options

This section describes eight CNG/LPG technology options for different vehicle types that might be incorporated into the demonstration project. The focus is on CNG/LPG because they are deemed to be potentially feasible for use on a large scale, commercial basis within India in the next several years. The other alternative fuels noted previously may also be considered for the demonstration project, but with the recognition that they will be used to promote technologies and fuels that could become feasible in India over the mid-term of 5-10 years. The following is a summary of the CNG/LPG related options:

Alternate Fuel Option : Two & Three Wheelers

While vehicle technology for conventional fuel is being continuously upgraded for tighter emission standards, active work is also being pursued for use of alternate fuels in this category of vehicles.

Status/ Availability

- CNG Expected from coastal AP. State Transport Minister has, in a press statement, indicated launch of CNG bus in Hyderabad from September 2001.
- Trials are on for LPG 3 Wheelers - Fuel available.
- Electric vehicle technology for 3 Wheelers is available. Charging infrastructure required.
- LPG Two Wheelers have been developed with replaceable cylinders to avoid refuelling problem.
- Banaras Hindu University, India has been using Hydrogen as fuel in 10 prototype 2 Wheelers.

While CNG and LPG can be considered as an immediate measure, Electric vehicle in hot-spots can be considered provided desired charging infrastructure can be built in that area. Hydrogen may be the best possible solution in the long run from the point of view of emissions, however, its development is still in a very nascent stage. Commercial utilisation of Hydrogen has not been reported from anywhere in the world and as a result commercial estimates are not available. Cost of running alternate fuel Two & Three Wheelers is expected to be much less than that of Gasoline.

Commercial Implications

- CNG 3 Wheeler cost Rs 94,000/- compared to a Gasoline 3 Wheeler costing Rs 76,000/- that is around 23% higher. However, the running cost less by almost 70%.
- LPG 2 Wheelers cost 20% more. However, the running cost is less by 40%.
- Very high cost implications for electric and Hydrogen fuel now. No commercial information is available for comparison.

CNG and LPG though require some initial investments, they are quite competitive in terms of running cost. Depending on the section of vehicles that would be targeted for running on CNG, the State Government will have to set up CNG dispensing stations across the city to cater to the vehicles of Hyderabad.

Emission Implications

Emissions performance of CNG and LPG in Two & Three Wheelers will be significantly lower than Gasoline

- CNG 3 Wheeler to reduce CO by 71%, HC by 63%, NO_x by 20% and CO_2 emissions by around 42% as per the test results published by GAIL.
- LPG 3 Wheeler may reduce CO by 40% and HC by 50% and CO_2 by 15%**, while there is may not be any change in NO_x emissions as compared to conventional Gasoline three wheelers based on the estimates done by Decision Support System Approach to Vehicular Air Pollution Management, N. Harshadeep, South Asia Environment Unit (SASEN), The World Bank.
- As per tests done by SIAM member company, LPG 2 Wheeler, in Indian condition, to reduce CO emission by 48%, CO_2 by around 7%. However, HC and NO_x is expected to increase by around 15%.

** Paper by Mr Michael P Walsh at ADB Workshop 2001

Introduction or conversion of Three Wheelers to CNG is a good option from the point of view of reducing both local pollutants including HC, CO and NOx and global emissions viz. CO_2.

Alternate Fuel Option : Gasoline Cars

Both CNG and LPG can be considered for converting Gasoline cars without much problem.

Status / Availability

- CNG/LPG conversion technology is available. However, after notification of LPG safety norms for fixed cylinder system, infrastructure in terms of LPG dispensing centres is not in place yet.

Commercial Implications

- CNG conversion to cost around Rs 30,000-35,000/-. However, there will be a 70% reduction in fuel cost.
- LPG conversion to cost Rs 6,000-10,000. There will be approximately a 35% reduction in fuel cost.

Emission Implications

Conversion of Gasoline driven cars to both CNG and LPG will reduce vehicle emissions significantly.

- Use of CNG will reduce CO by 93% and HC by around 24% as per Indraprastha Gas Ltd. World Bank report estimates that CNG reduces CO_2 by around 16% and NOx by 18%.
- As per World Bank publication (Hutcheson -1995) LPG cars to reduce CO_2 by 30%, CO by 17%, and HC by around 14% compared to Gasoline. However, NOx is expected to grow by 33%

Initial investment of CNG conversion is more than that of LPG but running cost of CNG offsets the disadvantage. Supply of CNG in Hyderabad is not yet available.

CNG is a preferred option to LPG as far as CO emissions are concerned, but when CO_2, is considered LPG will have a better impact, when compared to the present gasoline vehicles.

Alternate Fuel Option : Diesel Vehicles

Diesel cars and buses can be converted to CNG through both conversion or retrofitment route.

Status / Availability

- Conversion Technology and Retrofitment of new CNG engine from diesel mode is available. LPG conversion technology for diesel passenger cars is available.

Commercial Implications

- Cost of a CNG bus chassis is around Rs 11,65,000/- compared to a similar diesel bus costing Rs 6,45,000/-. That is, CNG buses to cost around 80% more than conventional diesel buses. Conversion of cars to CNG will increase cost by around 10%. However, the rate of increase in cost will depend on the price of the original car.

Conversion of diesel bus to CNG will require only around 25% of a new CNG bus.

Particulate matter, which is of great concern to local authorities from vehicular emissions point of view, will be reduced to a great extent by conversion of diesel vehicles to both CNG and LPG.

Emission Implications

- As per the Paper by Mr Michael P Walsh at ADB Workshop 2001 in Delhi, LPG car will lead to around 15% reduction in CO_2 on road. The reduction in other pollutants may be PM by 80%, NOx by 51%.However, there will be an increase in HC by 15% and CO by around 695%.
- As per tests done on Indian buses (GAIL-data on Mass Emission test with CNG as certified by ARAI/VRDE), reduction in buses is estimated to be 17% HC, 16% CO, 42% NOx and 98% PM. Brooklyn Union Gas study shows around 19% CO2 reduction in buses on road.
- World Bank report states that for CNG cars there will be around 15% reduction in CO_2, 196% increase in HC and 76% increase in CO. However, there will be around 53% reduction in NOx, and 83% reduction in PM

Alternate Fuel Option : Diesel Vehicles (Contd.)

However, as per the World Bank Report - "Air Pollution From Motor Vehicles - Standards and Technologies for Controlling Emissions", life cycle analysis of CNG / LPG will increase CO_2 emission by around 6%. Life Cycle Analysis estimates cradle to grave situation where emissions generated from mining of fuel, transportation, purification/ refining, distribution, dispensing, utilisation, etc. are taken into account.

From the point of view of CO or CO2 emissions, conversion of diesel vehicles to CNG or LPG will not be so encouraging.

Emission Reduction Through Technology Changes

In the following pages we have described present level of emissions from vehicles in Hyderabad and emissions reductions by using CNG/LPG related alternate fuel options. As has been previously noted, additional data on the emissions character of other alternative fuels, especially in regard to CO_2 emissions may be needed to enable "across the board" comparisons of all technology/fuel options. The following table gives the contribution of CO, HC, NOx, CO_2 & PM in tons per day for each type of vehicle in Hyderabad.

	2-W	3-W	Cars	Cars (D) (Taxis +MUVs)	Buses	Total
CO	128.49	36.42	45.63	32.08	11.09	**253.70**
HC	90.34	24.50	6.85	6.05	1.77	**129.52**
NOx	1.89	0.95	6.26	2.79	18.43	**30.32**
CO2	969.97	303.97	821.92	322.70	242.67	**2661.23**
PM	0.00	0.00	0.00	0.33	2.53	**2.86**

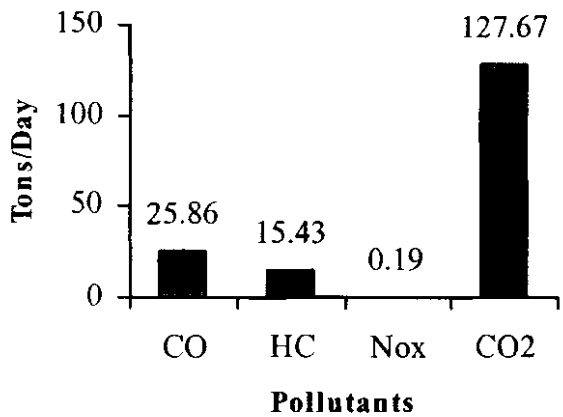
It can be seen that in terms of quantity, contribution of vehicles to Particulate Matters is minimum while CO_2 emitted from vehicles is excessively higher than any of the pollutants.

The above data has been used as a base to arrive at the benefits of various technological options to reduce pollution load per day. Though the following section describes the various technology options and its corresponding reduction in emissions. The actual impact of the same on the environment or health is beyond the scope of this study.

Option 1:

We have seen from the previous sections that when a three wheeler is converted into CNG the CO emissions reduce by 71%, HC by 63%, NOx by 20% and CO2 by 42%. Considering a scenario where all the Three-Wheelers are converted to CNG we get the following reductions per in tons of pollutants per day.

	Reduction (Tons per Day)
CO	25.86
HC	15.43
NOx	0.19
CO2	127.67

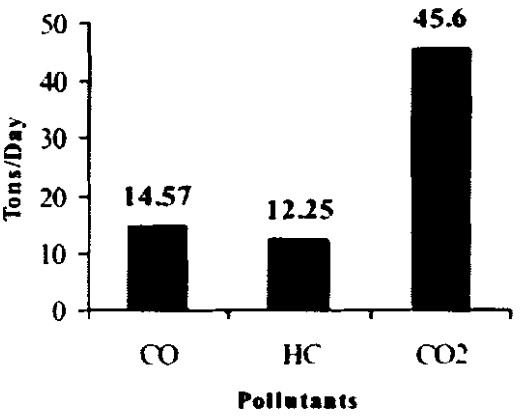


This scenario helps in reducing all types of pollutants considered for the study. There is a significant reduction in CO_2 emission and good reductions in CO & HC emissions. It is also estimated to reduce NOx marginally by 0.19 Tons.

Option 2:

Similarly, when a three wheeler is converted into LPG the CO emissions reduce by 40%, HC by 50% and CO_2 by 15% the NOx emission wont change appreciably. Considering a scenario where all the Three-Wheelers are converted to LPG we get the following reductions per in tons of pollutants per day.

	Reduction (Tons per Day)
CO	14.57
HC	12.25
CO2	45.60

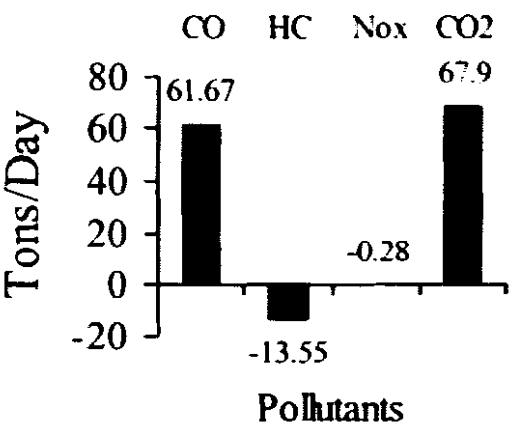


This option would help in reducing CO, HC & CO_2 but the magnitude of CO_2 emission reduction is less as compared to when a vehicle is converted to CNG.

Option 3:

In this section we have considered technology change for two-wheelers. As previously noted, there are constraints to converting two-wheelers to CNG due to operational problems. Therefore, conversion to LPG is considered. The following estimates is a hypothetical scenario where all two-wheelers are converted to LPG.

	Reduction (Tons per Day)
CO	61.67
HC	-13.55
NOx	-0.28
CO2	67.90

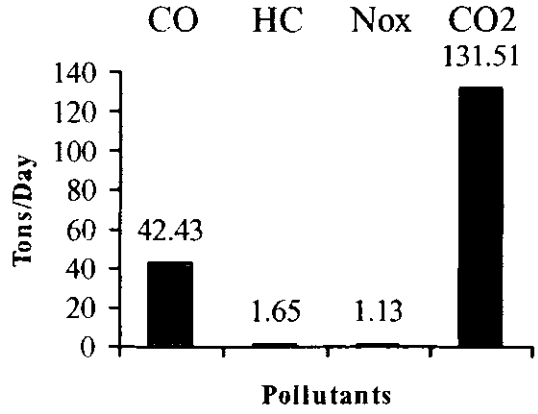


From the above table it is evident that converting two-wheelers to LPG will reduce CO & CO_2 emission significantly but there would be an increase in HC & NOx emissions. However, the reactive Hydrocarbon, which are normally considered as 50% of total would be less.

Option 4:

Conversion of cars to CNG is being done extensively in India especially in Delhi & Mumbai due to availability of CNG. As Hyderabad is also contemplating to bring CNG from Krishna Godavari basin there would be a scope for converting passenger cars to CNG. The benefits achieved in terms of reducing each of the pollutants if all cars are converted to CNG is given below:

	Reduction (Tons per Day)
CO	42.43
HC	1.65
NOx	1.13
CO2	131.51

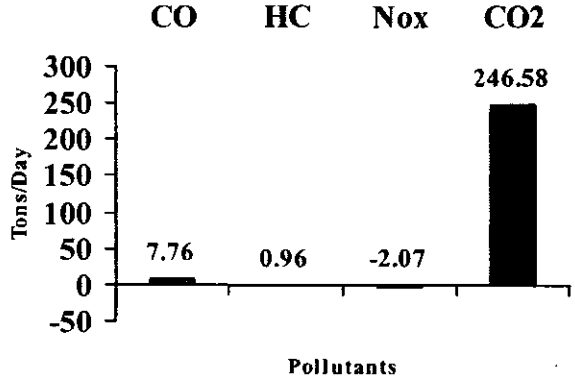


The above results clearly indicate that conversion to CNG is a very good option with reduction of all types of pollutants. CO & CO_2 is reduced by a large margin.

Option 5:

Conversion of cars to LPG is can also be done as the safety standards for LPG vehicles are in place now. Following are the impact on pollution loading if al the passenger cars are converted to LPG.

	Reduction (Tons per Day)
CO	7.76
HC	0.96
NOx	-2.07
CO2	246.58

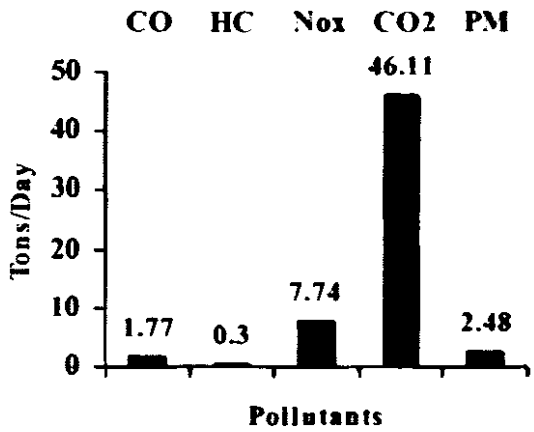


The results shown in the previous page clearly indicate that conversion to LPG is a good option as far as reduction of CO_2 if concerned. There is not much change in the emissions of HC and NOx when vehicles are converted to LPG.

Option 6:

Another vehicle category which can be considered for conversion to Alternate fuel is buses. As buses of Delhi are changing over to CNG in a large scale, the same experience can be considered for Hyderabad. For example the older buses may be considered for replacement with a new CNG bus to begin with, provided CNG is widely available for dispensation before introduction of this technology in the city. If all the buses are converted to CNG following reduction is estimated to be achieved.

	Reduction (Tons per Day)
CO	1.77
HC	0.30
NOx	7.74
CO2	46.11
PM	2.48

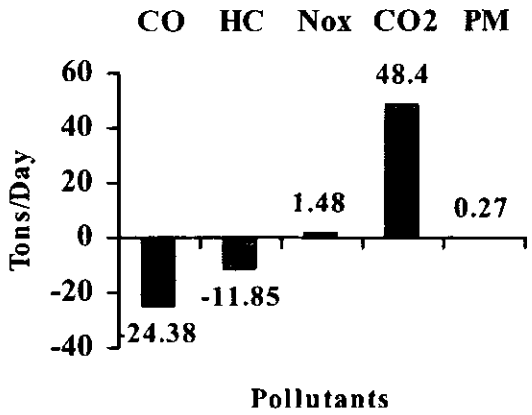


As has been seen from the previous sections, conversion to CNG reduces all the pollutants that are considered for this study.

Option 7:

In a scenario, if all the Diesel taxis are either converted into CNG the following would be the effect on emissions.

	Reduction (Tons per Day)
CO	-24.38
HC	-11.85
NOx	1.48
CO2	48.40
PM	0.27

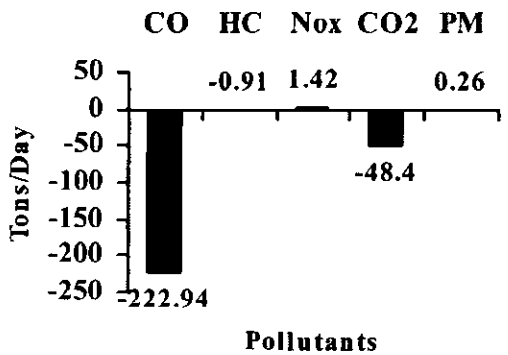


Though conversion to CNG mode from Gasoline option reduces all the pollutants, the conversion from Diesel to CNG shows that there is a marked increase in CO & HC emissions. PM & NOx reduce marginally and there is a good reduction of CO_2.

Option 8:

In a scenario, if all the Diesel taxis are either converted into LPG the following would be the effect on emissions.

	Reduction (Tons per Day)
CO	-222.94
HC	-0.91
NOx	1.42
CO2	-48.40
PM	0.26



From the above results that focus on CNG/LPG options, it appears that converting Diesel Taxis to LPG is not a better proposition if only pollutants like CO, HC & CO_2 are considered. But, definitely there is a gain by reduction of PM which is of prime concern for most of the cities.

These options, as well as a host of others such as electric vehicles, bio-diesel, alcohols, etc., must be evaluated by the State Governments and the actual path to be taken for implementation has to be decided taking into consideration various parameters like availability, feasibility, cost, etc.

Effect of

Fuel Quality
Vehicle Technology
Relocation of Vehicles

on Emission Reduction in Hyderabad

Introduction

This section deals with various technology options and their assessment of the same for reducing emissions from vehicles both in terms of reducing local pollutants like CO, HC, NOx & PM and Green House Gases (GHG) like CO_2.

Best Technology for vehicle is difficult to define as Cars running on Solar cells have been used in Australia and the United States for years, but not commercially or for day-to-day work. Very efficient diesel engines using direct injection of fuel are now very popular in Europe, and reduce fuel use compared to ordinary diesel of the same power by as much as 30%, although there are problems of NOx emissions. Companies like Chrysler, Daimler Benz and Ford Motor Co. are developing vehicles with fuel cells, which would be discussed in details in the Alternate fuel section. Since this device does not have on-board combustion so there is no thermal losses associated with this system. Some also advocate use of battery based electric drive, combined combustion/ electric Hybrid. Companies like Mitsubishi, Honda and Nissan also place a great deal of hope on direct injection gasoline engines that would reduce fuel use to nearly parity with diesel for the same (or better) performance. A Honda lean burn gasoline engine reduces CO_2 emissions/ km 25 percent over those of a similar Honda but NOx emissions are higher. In other words it is very difficult to define "best" for most kind of vehicle technology technologies because the vehicles themselves have so many technical, environmental, and market requirements.

To begin with this section will deal in the effect of fuel quality on emission reduction in vehicles in Hyderabad.

Further the vehicle technology options available for meeting the next stage of emission norms for two & three wheelers, cars and diesel vehicles is discussed in detail with it implementation schedule and the reduction gained in terms of reducing pollutants by each category of vehicle.

The population growth of the vehicle has been projected and then various scenarios of implementing new technology has been discussed and then the reductions are estimated.

EFFECT OF CHANGES IN FUEL QUALITY

In India the fuel is distributed primarily by four large Oil Companies viz.: Indian Oil Corporation, Bharat Petroleum, Hindustan Petroleum and Indo-Burma Petroleum. Recently Reliance Petroleum has come up with one of the largest grass root refineries in Asia. The quality of fuel to be supplied should be as per the specifications of Bureau of Indian Standards (BIS). The standards are revised periodically as per the requirement of vehicle technology and/or environmental imperatives. The key fuel parameters is given at the following section with a comparison of present fuel specs to that of European specs. The comparison of Indian Fuel is done with European specifications because the emission norms in India follow the European pattern and therefore the fuel quality should ideally follow the European trends.

Some of the critical fuel parameters has been improved in the last few years for select areas to meet the requirement of better vehicle technology being introduced in cities like Delhi, Mumbai, Chennai & Kolkata. Since the benefit of improved vehicle technology in terms of reduction in emissions can be achieved only if the matching fuel is available, the Sulphur content in both Gasoline and Diesel has been reduced to 500 PPM in the above cities.

The benefit of improving the fuel quality has a wider impact and can spread to the entire cross section of vehicles plying on the roads of Hyderabad. The following sections describes the effect on emissions by change in fuel quality.

Gasoline Specifications

PARAMETER	INDIA 1971	INDIA IS2796 :1995	INDIA 2000	EURO EN228 1993	EUR3 2000	EUR4 2005
RVP, kpa	70	70	60	-	60	-
Aromatics, %v/v		-	-	-	42	35
Benzene, %v/v		-	5(3)	5	1	-
Olefins, % v/v		-	-	-	18	-
Oxygen, % v/v		-	-	-	2.7	-
Sulphur, ppm	2500	2000	1000	500	150	50
Washed gum, mg/100ml		5	5	5	-	-
Lead, g/l		0.013	0.013	0.013	-	-
RON, min	87	87	84*	95	95	-
MON, min		-	-	85	85	-
Density @ 15^0 C Kg/m^3		710-770	710-770	725-780	-	-

Diesel Specifications

PARAMETER	INDIA 1980	INDIA 1995	INDIA 2000	EURO EN590 1993	EUR3 2000	EUR4 2005
Cetane no. min	42	45	48	49	51	-
Cetane Index, min		-	-	46	-	-
Sulphur, % max	1.0	1.0	0.25	0.20	0.035	0.005
Sediments, mg/100ml	1.0(DEF2000-16T)	1.6	1.6	-	-	-
Aromatics, % m/m	-	-	-	-	-	-
Polyaromatics, % m/m	-	-	-	-	11	-
Viscosity @ 40^0 C, m/m^2/s	-	1.8-5	2-5	2-4.5	-	-
@38^0 C	2-7.5					
Density @ 15^0 C, kg/ m^3		880	860	860	845	-
T85. ^{0} C						
T90. ^{0} C	366	-	350	350	-	-
T95, ^{0} C		366	-	-	-	-
FBP, ^{0} C		-	370	370	360	-
		-	-	-	-	-

Source: BIS Specification & Concawe Report

Fuel characteristics affects the fuel quality directly as well as indirectly. Effect on emissions due to change in quality of Gasoline and diesel are discussed below.

Changes in fuel quality alone helps in reduction of local pollutants but will not help in any significant reduction of CO_2 emissions. If the octane number of Gasoline in increased it will give an opportunity for the vehicle manufacturers to redesign their engines thereby improve fuel efficiency by increasing the compression ratio and in turn reduce CO_2 emissions. Similarly, increase in Cetane number could indirectly improve the fuel efficiency of Diesel vehicles. Reduction in sulphur content reduces particulate emissions from vehicles and also enables effective working of electronic engine control systems. The following sections discusses some of the key Gasoline and Diesel parameters and their effect on various pollutants.

Gasoline

Sulfur

Sulfur naturally occurs in crude oil. If the sulfur is not removed during the refining process it will contaminate vehicle fuel. Sulfur has significant impact on vehicle emissions by reducing the efficiency of catalysts. Sulfur also adversely affects heated exhaust gas oxygen sensors. Reductions in sulfur will provide immediate reductions of emissions from all catalyst-equipped vehicles on the road.

There has been extensive testing does on the impact of sulfur on vehicle emissions. The following table indicate the emission reductions that occur with different vehicle technologies as sulfur is reduced from the 'high' sulfur gasoline to the 'low'.

Study:Vehicle Technology Sulfur Range (ppm) Emission Reduction % (high to low sulfur)

	High	Low	HC	CO	NOx
AQIRPTier0	450	50	18	19	8
EPEFEStage2+	382	18	9(43*)	9(52*)	10(20*)
LEV&ULEV	600	30	32	55	48

(*Reduction achieved during hot EUDC (extra-urban)portion of test).
LEV- Low Emission Vehicles
ULEV- Ultra Low Emission Vehicles

Future Technology

Manufacturers are working towards ambitious goals for improved fuel consumption/reduced CO_2 emissions. Operation at lean air-fuel ratio is the most promising means to achieve these reductions in gasoline-powered vehicles. However, lean operation introduces a new challenge for exhaust emissions control. While unburned HC and CO are effectively removed by existing catalysts during lean operation, NOx is removed only during stoichiometric or rich operation.

Many manufacturers are developing and introducing lean-burn technology. These technologies have the potential to reduce fuel consumption by up to 15 to 20%, but require NOx control technologies which can function under lean conditions. These technologies are very sensitive to fuel sulfur.

Oxygenates

Oxygenated organic compounds, such as MTBE and ethanol, are often added to gasoline to increase octane, to extend gasoline supplies, or to induce a lean shift in engine stocihiometry to reduce carbon monoxide emissions. The leaner operation reduces carbon monoxide emissions, especially with carburetor vehicles without electronic feedback controlled fuel system.

These emission benefits are not realised as much in modern electronic feedback controlled vehicles because the leaning effect only occurs during cold operation or during rapid accelerations. In fact, fuel leaning caused by oxygenates can degrade driveability depending on the leanness of the engine's base calibration with all-HC (i.e.., non-oxygenated) gasoline. This over-leaning can also cause emissions to increase. Because ethanol has a higher heat of vaporisation than ethers, some of the driveability degradation of gasoline oxygenated with ethanol can be attributed to the additional heat needed to vaporise the gasoline.However, blending of ethanol in gasoline is permitted in the BIS code and is being done selectively in some sections of our country. Hyderabad can also consider blending ethanol to gasoline at the refinery stage

The California Air Resources Board (CARB) conducted emission tests on 14 1990-1995 vehicles using 2 gasoline blends, i.e. with 10% ethanol and 11% MTBE. When the ethanol fuel was compared to the MTBE fuel, it decreased toxic emissions by 2% and CO by 10% but it increased NOx by 14% total HC by 10% and Ozone Forming Potential by 9%.

Aromatics

Aromatics are fuel molecules that contain at least one benzene ring. In general, aromatics are good octane components of gasoline and high-energy density fuel molecules. Fuel aromatic content can increase engine deposits and increase tailpipe emissions, including CO_2

Influence of Aromatics on Engine Deposits

Heavy aromatics, and other molecular weight compounds, have been linked to engine deposit formations, particularly combustion chamber deposits. As discussed below ('Deposit Control Additives'), these deposits increase tailpipe emissions, including HC and NOx. Since it is not feasible to specify limits for individual hydrocarbon compounds in the fuel, the total aromatics limit in Category I and the final boiling point limits in Categories 2 and 3 provide the best means to limit heavy aromatics.

Influence of Aromatics on Tailpipe Emissions

Combustion of aromatics can lead to the formation of carcinogenic benzene in exhaust gas and increased combustion chamber deposits which can increase tailpipe emissions. Lowering aromatic levels in gasoline significantly reduces toxic benzene emissions in exhaust from vehicles.

Findings from the US AQIRP programme showed that of all the fuel properties tested, aromatic level had the largest effect on total toxics, largely due to its effect on exhaust benzene emissions as shown in the above figure. Reducing total aromatics from 45% to 20%, caused a reduction in total exhaust air toxics of 28% (74% of the total toxic emissions was benzene)

Influences of Aromatics on CO_2 Emissions

Gasoline aromatic content also has a direct effect on tailpipe CO_2 emissions. The European EPEFE programme demonstrated a linear relationship between CO_2 emissions and aromatic content. The reduction of aromatics from 50 to 20% was found to decrease CO_2 emissions by 5%.

Fuel specifications to meet stringent emission norms in India is being upgraded to Euro II level to meet the technology requirements of Bharat Stage II (Euro II equivalent) emission norms.

The key parameters of matching gasoline fuel quality that may be required for Hyderabad are:

•Benzene	% v/v	3
•Sulphur	ppm	500
•AKI min		84

AKI is Anti Knock Index which is the average of Research Octane Number (RON) and Motor Octane Number (MON). Octane Number is a measure of antiknock performance of a gasoline or gasoline component; the higher the octane number, the greater the fuel's resistance to knock. There are two main types of octane number RON & MON, which are based on different engine operating conditions and, therefore, relate to different types of driving mode.

Status/ Availability

•Euro 2 Compliant fuel is available in select cities and if Hyderabad proposes to introduce Bharat Stage II vehicles the same can be made available depending upon the suitability of the Oil companies. Euro 3 fuel planned for 2005 in select cities including Hyderabad.

Diesel

Influence of Cetane on Exhaust Emissions and Fuel Consumption

The influence of Cetane on NOx emissions and fuel consumption is a functions of engine. Cetane has a significant effect on NOx, particularly at low loads, where reductions of upto 9% are achieved. The Cetane increase also demonstrated a 30-40% reduction in HC emissions.

An increase in natural Cetane has shown to reduces fuel consumption. The increase in natural Cetane (from 50 to 58) improved brake specific fuel consumption (BSFC) at every load level tested.

Density and Viscosity

The diesel fuel injection is controlled volumetrically or by timing of the solenoid valve. Variations in fuel density (and viscosity) result in variations in engine power and, fuel consumption. The European EPEFE programme has found that fuel density also influences injection timing of mechanically controlled injection equipment, which has further effects on emissions and fuel consumption. Therefore, in order to optimise engine performance and tailpipe emissions, both minimum and maximum density limits must be defined in a fairly narrow range.

Effect of Density on Emissions and Fuel Consumption

Emission testing has demonstrated that reduced density will reduce PM emissions from heavy duty vehicles.

However, due to the volumetric fuel injection of diesel engine, reduced density will also increase fuel consumption and reduce power output. EPEFE testing has shown that reductions in fuel density decreases engine power output and increase volumetric fuel consumption. Variations in fuel viscosity (i.e. reduced density generally reduces viscosity) may accentuate the density effects on power (not necessarily fuel consumption), particularly in combination with distributor-type injection pumps.

Despite the increase in fuel consumption, EPEFE found that reduced density actually decreased CO_2 emissions slightly (about 1%). This is explained by the higher hydrogen/carbon ratio in low density fuels when other fuel parameters (most importantly Cetane number/index) are kept constant.

Influences of Fuel Density on Emission Control System

Production diesel engines are set to a standard density which determines the amount of fuel injected. The (volumetric) injection is a control parameter for other emission control systems like the exhaust gas recirculation (EGR). Variations in fuel density therefore result in non-optimal EGR-rates for a given load and speed point in the engine map and, as a consequence, influence the exhaust emission characteristics.

Influence of Fuel Viscosity on Injection System Performance

Fuelling and injection timing are also dependent on fuel viscosity. High viscosity can reduce fuel flow rates, resulting in inadequate fuelling. A very high viscosity may actually result in pump distortion. Low viscosity, on the other hand, will increase leakage from the pumping elements, and in worse cases (low viscosity, high temperature) can result in total leakage. As viscosity is impacted by ambient temperature, it is important to minimise the range between minimum and maximum viscosity limits to allow optimisation of engine performance.

Sulfur

Sulfur naturally occurs in crude oil. If the sulfur is not removed during the refining process it will contaminate vehicle fuel. Diesel fuel sulfur contributes significantly to fine particulate matter (PM) emissions, through the formation of sulfates both in the exhaust stream and, later in the atmosphere. Sulfur can lead to corrosion and wear of engine systems. Furthermore the efficiency of some exhaust after-treatment systems is reduced as fuel sulfur content increase, while others are reduced permanently ineffective through sulfur poisoning.

Effect of Sulfur on PM Emissions

The impact of sulfur on particulate emissions understood and known to be significant. In the European Auto Oil programme it was predicted that a reduction from 500 ppm to 30 ppm will result in PM emission reductions of 7% from light duty vehicles and 4% from heavy duty trucks. However, the predictive equations do not take into account the absolute PM level nor the fuel consumption.

Testing performed on heavy duty vehicles using the Japanese diesel 13 mode cycle have shown that significant PM emission reductions can be achieved with both catalyst and non-catalyst equipped truck running on 400 ppm sulfur fuel. Reductions were shown to be reduced by half when operated on 2 ppm fuel.

Effect of Sulfur on Diesel After-Treatment

Future regulations will require lower NOx and particulate emissions in combination with lower fuel consumption and CO_2 emissions. De-NOx catalyst systems, which can remove NOx emissions from the diesel's oxygen-rich exhaust, could be the solution to break the trade-off between NOx, PM and fuel consumption. However these system are very sensitive to fuel content. The level of sulfur in diesel fuel (and gasoline) is an important factor in the performance of De-NOx systems. The catalyst performance is better with lower sulfur fuel.

Aromatics

Aromatics are fuel molecules which contain at least one benzene ring. The fuel aromatic content will affect combustion and the formation of particulate and PAH emissions.

The diesel fuel aromatic content in the fuel will increase the flame temperature during combustion which results in increased NOx emissions. Testing in Europe (ACEA follow-up programme to EPEFE) demonstrated that a reduction of the total aromatic content from 30 to 10% yields significantly lower NOx emission.

The light duty data is based on the combined ECE/EUDC cycle, the heavy duty on the 88/77/EEC 13-mode cycle.

Cost Implications

Any technological change will have its own commercial implications. To have a better quality of fuel changes or additions may be required in the existing refineries like installation of desulphurisation unit for reducing sulphur from fuel. Investment required for better fuel in refineries and higher distribution cost for Hyderabad may increase price by 2-3%. It has been estimated that refineries require about Rs 25,000 crores to achieve Euro II fuel quality across the country and an additional Rs 10,000 crores to achieve Euro III fuel quality across the country.

VEHICLE TECHNOLOGY

Gasoline Vehicles:

The Gasoline vehicles in India were based on Carburetor technology and for the first time the Catalytic converter fitted passenger cars was introduced in 1995 in Four metro cities viz.: Delhi, Mumbai, Chennai and Kolkata. Later in 1998 it was extended to 42 cities in our country. Now, since only unleaded gasoline is available all new passenger car should have a catalytic converter fitted on them. Subsequently to meet the tight emission regulations vehicle manufacturers started introducing Gasoline Fuel injected engines with electronic engine management systems. Further as done in Europe the passenger cars may have On-Board Diagnostics (OBD) to continuously monitor the emission performance of the vehicle. The evolution of gasoline vehicle technology is given below:

- CARBURETTOR ENGINES
- OXIDATION CATALYTIC CONVERTER WITH OPEN LOOP
- EXHAUST GAS RECIRCULATION (EGR)
- SECONDARY AIR INJECTION
- THROTTLE BODY /PORT INJECTION
- 3-WAY CATALYTIC CONVERTER WITH CLOSE LOOP
- MULTIPOINT FUEL INJECTION SYSTEM (MPFI)
- ELECTRONIC ENGINE MANAGEMENT
- ON-BOARD DIAGNOSTICS (OBD)

Diesel Vehicles

Similarly, for Diesel vehicles the evolution of engine technology was in line with the changes in emission regulation. The emission regulation for Diesel vehicles was introduced for the first time in 1992, I.e. one year after the introduction of emission norms for gasoline vehicles. Following are some of the technology changes that would be made/ being made to met the next stage of emission norms.

- OXIDATION CATALYSTS
- DeNOx CATALYSTS (PASSIVE & ACTIVE)
- NOx TRAP CATALYST
- OPTIMUM FIE +COMB. CHAMBER + AIR MOTION
- TURBO CHARGER (TC) + VARIABLE NOZZLE TURBINE
- SELECTIVE CATALYST REDUCTION (SCR)
- CONTINOUSLY REGENERATING TRAP (CRT)

The effect of each of the after Treatment technology on emissions is shown in the following section.

	HC	CO	NOx	PM
Oxidation Catalyst	***	***	0	*
Oxicat with passive NOx redn.	***	***	*	*
Oxicat with active NOx redn.	***	***	**	*
CRT	***	***	*	***
SCR	*	*	***	*
NOx Trap	**	**	***	0

0=no effect, *=small effect, **=medium effect, *** = High Effect

The above table shows that there is a significant reduction of local pollutants like CO & HC by use of oxidation catalyst, while CRT reduces PM emissions appreciably as compared to other after treatment devices.

To meet future emission norms some of the technology changes that may be required is tabled below:

NORMS	PETROL ENGINE	DIESEL ENGINE
EURO I	PROPERLY DESIGNED COMBUSTION CHAMBERS & PORTS, CARBURETTOR/ TBI UNDER FLOOR CATALYST SECONDARY AIR INJECTION EGR	IDI (1992-93), DI (1994) INJECTION PR. LESS THAN 1000 BAR EGR TURBOCHARGER/INTERCOOLER
EURO II	MULTI POINT FUEL INJECTION (MPFI) WITH ELECTRONIC ENGINE MANAGEMENT WITH KNOCK SENSED IGNITION CONTROL, A/F CLOSED LOOP CONTROL, THREE WAY CATAYTIC CONVERTER, , EGR CONTROL(ON/OFF DYNAMIC	DI 2V/CYL SIMPLE EGR, STANDARD RORATY PUMP, ELECTRONIC CONTROL, OXICAT IDI 2V OR 4V/CYL, DYNAMIC MODULATED EGR, HIGHER INJECTION PRESSURE, MASS FLOW RATE (WASTE GATE), ELECTRONIC CONTROL, OXICAT
EURO III	IN ADDITION TO EURO II CLOSED COUPLED CATALYST IN ADDITION TO UNDERFLOOR CAT. CLOSE CONTROL OF LAMBDA(A/F RATIO) , ON BOARD DIAGONOSTICS(OBD)	4V/CYL NEW FIE COOLED EGR OXICAT, DeNOx CAT, PARTICULATE TRAP
EURO IV,V, & FUTURE	HEATED CATALYST, ADVANCED CATALYST FORMULATION, EXHAUST TRAP/COLLECTER BAG SYSTEM, GASOLINE DIRECT INJECTION, NOx ADSORBERS, VARIABLE VALVE TIMING(VVT) AND VARIABLE COMPRESSION RATIO (VCR)	IN ADDITION TO EURO III PILOT INJECTION PARTICULATE TRAPS, DeNOx CAT, NOx ABSORBERS, WATER INJECTION

SIAM Emission Road Map

The following sections gives the details of SIAM road map laid down for future emission legislation in the country. This road map is being generally used as the guideline to decide on the next stage of emission norms and their implementation time. The road map has been used to project the contribution to pollution by new technology vehicle in future.

Future Norms proposal for Petrol 2-Wheeler Segment				
Norms		India Norms	SIAM Proposal	Principal fuel specification
CO g/km	HC+NOx g/km			
4.5	3.6	1996		
2	2	2000		
1.5	1.5	Stage II	1/4/2005	Sulphur ppm max=150
1.25	1.25	*Stage III	1/4/2009	Sulphur ppm max=50

* The stage III norms need to be reviewed in 2005 for technical feasibility

Future Norms proposal for Three Wheeler Segment & Diesel Two Wheelers

Norms	SIAM Proposal					
	Year	For all 3-wheelers GVW less than 1.5 tonnes g/km and Diesel Two-Wheelers				
		Diesel (2&3W)			Petrol (3W)	
		CO	HC+NOx	PM	CO	HC+NOx
Stage I (2000)	1.4.2000	2.72	0.97	0.14	4.0	2.0
Stage II	1.4.2005	1.00	0.85	0.11	2.25	2.0
Stage III*	1.4.2009	0.64	0.70	0.09	1.88	1.88
Principal fuel Specification	Stage-II	Sulphur ppm max 350			Sulphur ppm max=150	
Principal fuel Specification	Stage-III	Sulphur ppm max= 50			Sulphur ppm max =50	

* The stage III norms need to be reviewed in 2005 for technical feasibility

Future Norms proposal for Passenger Car Segment

Norms Level	India Norms	Europe Norms		SIAM Proposal		
		New TA	All Production	New TA	All Production	Principal parameters of fuel specification (per EU)
Euro 0	1996	1983				
Euro 1	2000	1992				
Euro 2	-	1996/1997		2000 *		Petrol & Diesel Sulphur max = 0.05%
Euro 3		1/1/2000	1/1/2001	1/4/2003	1/4/2004	Petrol: Sulphur ppm max 150 Diesel: Sulphur ppm max 350
Euro 4		1/1/2005	1/1/2006	1/4/2006	1/4/2007	Petrol: Sulphur ppm max 50 Diesel: Sulphur ppm max 50

* NCR; Rest of the country - 6 months from date of notification

Future Norms proposal for MUV Segment

Norms Level	India Norms	Europe Norms		SIAM Proposal		
		New TA	All Production	New TA	All Production	Principal parameters of fuel specification (per EU)
Euro 0	1996	1983				
Euro 1*	2000	1993/94				
Euro 2*						
Class I	-	1/1/1997	1/1/1998	1/4/2002#		Petrol & Diesel
Class II&III	-	1/10/1997	1/10/1998	Do		Sulphur max = 0.05%
Euro 3**						
Class I	-	1/1/2000	1/1/2001	Skip		Petrol: Sulphur ppm max 150
Class II&III	-	1/1/2001	1/1/2002	Skip		Diesel: Sulphur ppm max 350
Euro 4**						
Class I	-	1/1/2005	1/1/2006	1/4/2007	1/4/2008	Petrol: Sulphur ppm max 50
Class II&III	-	1/1/2006	1/1/2007	1/10/2007	1/10/2008	Diesel: Sulphur ppm max 50

Light Duty Vehicles are classified as:

** In Europe for Euro 1 and Euro 2*

Class I (rw ≤ 1250 kgs)

Class II (1250 <rw ≤ 1700 kgs)

Class III (rw > 1700 kgs)

 # NCR : 1/04/2000. Other Metros : 1/10/2000

*** In Europe for Euro 3 and Euro 4*

Class I (rw ≤ 1305 kgs)

Class II (1305 <rw ≤ 1760 kgs)

Class III (rw > 1760 kgs)

Future Norms proposal for Commercial Vehicles Segment

Norms Level	India Norms	Europe Norms		SIAM Proposal		
		New TA	All Production	New TA	All Production	Principal parameters of fuel specification (per EU)
R 49	1992					
Euro 0	1996	1983				
Euro 1	2000	1/7/1992	1/10/1993			
Euro 2	-	1/10/1995	1/10/1996	1/4/2002	1/4/2003	Diesel Sulphur max [illegible]
Euro 3	-	1/10/2000	1/10/2001	Skip		Diesel Sulphur ppm max 35[illegible]
Euro 4	-	1/10/2005	1/10/2006	1/10/2007	1/10/2008	Diesel Sulphur ppm max 5[illegible]

The technology required to go as per the above road map has been discussed in the following sections for each category of vehicles.

Two & Three Wheelers

Two and three wheelers form an important means of mobility of Indian transportation sector. They serve the mobility needs of over 26 million people in the country. As per a TERI study, (1993) out of total travel demand of 334 billion passenger km, 19% is satisfied by two wheelers and 3% is satisfied by three wheelers.

Various technology options for reducing exhaust emission from Two & Three Wheelers are:

•Improvement in Engine Design for Better Scavenging and Combustion

•Electronic Engine Management

•Advanced Catalytic Converters

•4 Stroke Gasoline

•2-Stroke Direct Injection

The technology mix will depend upon the each vehicle model. In order to achieve higher air quality benefits it shall be desirable to phase out pre - 1985 Two & Three Wheelers.

In India, the Two-Wheeler technology is in the advanced stage and the emission norms being met by the present two wheelers are one of the tightest in the world. Immense in-house research and development is required before the vehicles meet the next stage of emission norms and similar vehicle technology is not readily available world-wide. Indian manufacturers have indicated that the introduction dates for Stage III emission norms can only be reviewed once the stage II emission norms are well in place in the year 2005. Changes in engine technology along with matching fuel quality is expected to yield substantial benefit in terms of emission reduction.

The implication on emissions by improving the technology for two & three wheelers are:

For two wheelers, improved technology (going to Stage II of India Emission norms as proposed in SIAM Roadmap) with matching fuel quality is expected to reduce HC by 25%, NO_x by 25%, CO_2 by 46%* and CO by 25%.

For three wheelers, going to the next stage of emission norm as proposed by SIAM through improved technology and matching fuel quality is expected to reduce CO by 44%, while there will be no reduction in HC and NO_x. However, CO_2 will be reduced by 46%*.

Further reduction can be achieved by changing engine technology along with matching fuel quality and is expected to yield substantial benefit in terms of emission reduction

The Automobile Industry recognising the importance of setting an agenda for future emission norms so that there is adequate lead time given to all stakeholders, including Government to frame necessary legislation, Oil Industry- to provide matching fuel quality and Vehicle manufacturers- to develop appropriate technology.

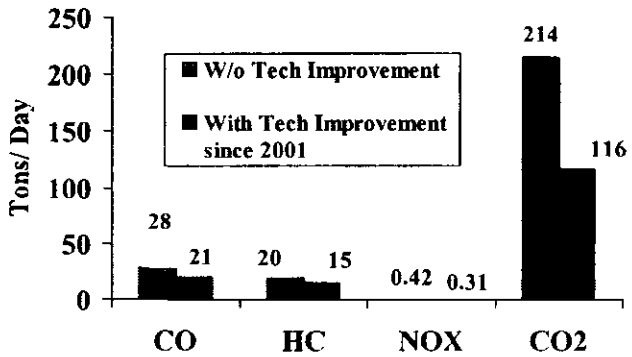
As a pro-active initiative to improve emission standards in India, SIAM has submitted to the Government, a calendar for implementing next stage of emission norms.

For Two & Three wheeler segment, India 2000 norms are far stricter than Euro II norms, and one of the most stringent in the World. These norms have already been implemented from April 1, 2000, throughout the country. Though the Stage II (India) norms is proposed to be applicable from April 1, 2005, the stage III (India) norms will only be implemented in 2009 after a technical feasibility review in 2005.

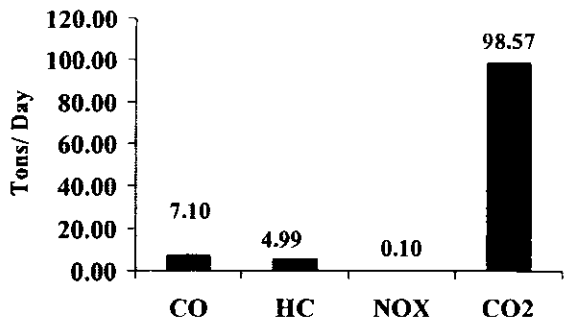
* SAE paper by Mr B Bhanot, Director ARAI at SIAT 2001

If next stage of emission norms for two-wheelers is introduced in 2005 as per SIAM road map, the following graph shows a comparison of emissions in tons per day of two-wheelers as on the year 2006, if no technology changes are done and they do not meet the next stage of emission norms vis-à-vis if from 2005 onwards all new two wheelers meet the next stage of emission norms.

Contribution to Pollution by Two-Wheelers sold in 2005-2006

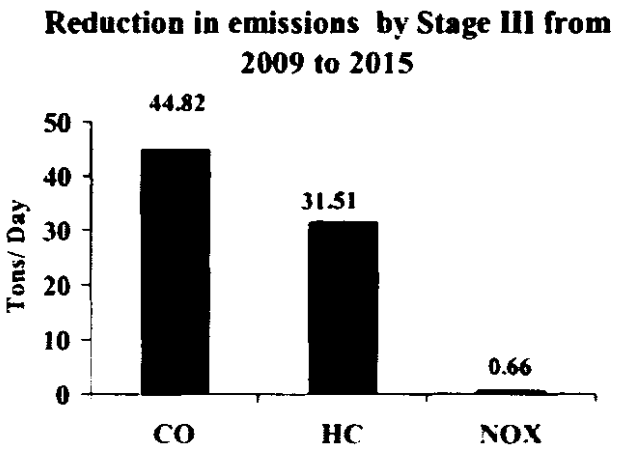


Reduction by New Tech. Two-Wheelers as on 2006



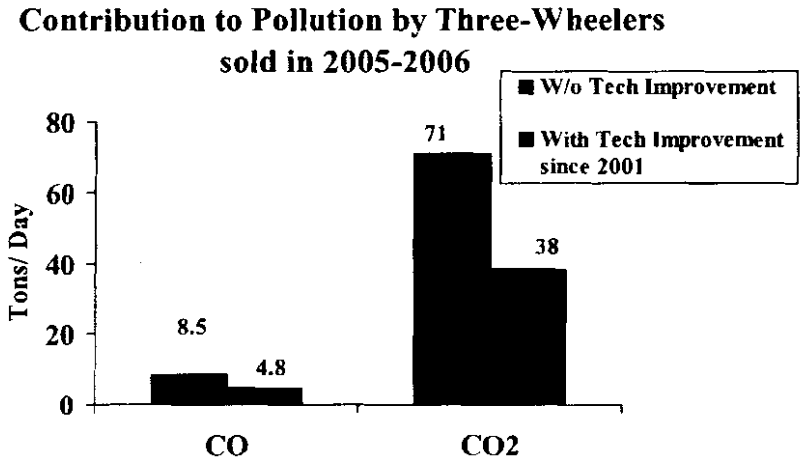
It is seen from the above graphs that there is a significant reduction in CO_2 as compared to other pollutants.

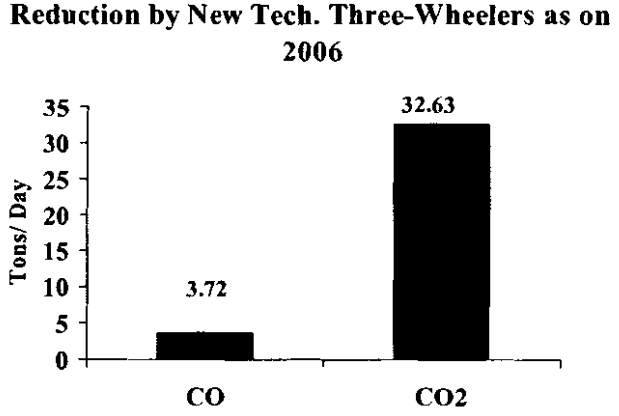
Further if next stage of emission norms are introduced in 2009 (Stage III) then, in the year 2015, the reductions of various pollutants achieved due to introduction of new emission norms are given below. Though the reduction in pollutants is 17% approximately for CO, HC & NOx but the reduction in CO2 emission has not yet been estimated.



It is seen from the above graph that there is a significant reduction in CO and HC as compared to NOx.

Similarly, when next stage of emission norms for three-wheelers is introduced in 2005 as per SIAM road map, the following graph shows a comparison of emissions in tons per day of three-wheelers as on the year 2006, if no technology changes are done and they do not meet the next stage of emission norms vis-à-vis if from 2005 onwards all new three wheelers meet the next stage of emission norms.

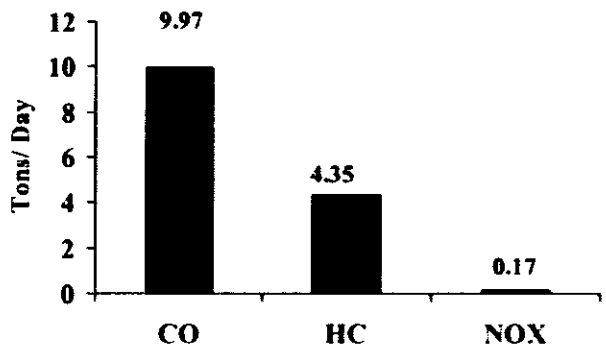




It is seen from the above graphs that there is a significant reduction in CO_2 as compared to CO.

Further if next stage of emission norms are introduced in 2009 (Stage III) then, in the year 2015, the reductions of various pollutants achieved due to introduction of new emission norms are given below. Though the reduction in pollutants is 17% approximately for CO and 6% reduction of HC & NOx but the reduction in CO_2 emission has not yet been estimated.

Reduction in emissions by Stage III from 2009 to 2015



It is seen from the above graph that again there is a significant reduction in CO and HC as compared to NOx.

Gasoline Cars

Currently Euro II equivalent, Bharat Stage II, vehicles are not introduced in Hyderabad due to non availability of Euro II equivalent fuel in the city. The following technology changes would be required to meet the Bharat Stage II norms:

•Electronic Fuel Injection - Lean burn charge

•Engine with high Compression Ratio

•Electronic engine management systems

To get optimum benefit in terms of emission reduction, matching fuel quality is a necessary pre-requisite. All modern Euro II equivalent cars which have been introduced in major metropolitan cities in India are equipped with such modern technologies.

Status / Availability

•Electronic Fuel Injection - Lean burn charge, Engine with high Compression Ratio, Electronic engine management systems: Currently existing in Bharat Stage II (Euro 2) Compliant vehicles

•Technology is available, engines to be adjusted to accommodate fuel with higher Octane Number, if available.

•Modern engines equipped with Electronic Control Unit (ECU).

Hyderabad can on environmental considerations, ask for matching fuel quality for the oil companies.

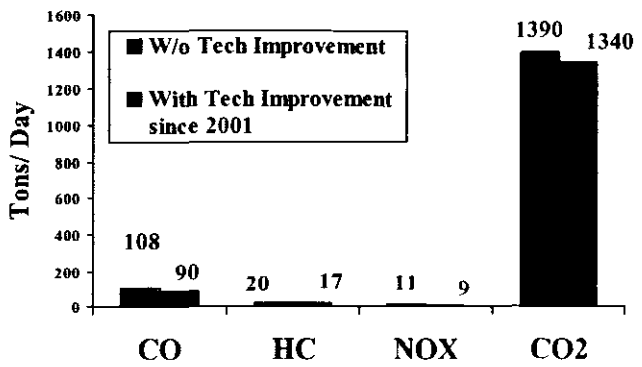
Electronic fuel injection and higher compression ratio will improve fuel consumption by 15-20% thereby reduce CO_2 by approximately the same proportion. As per estimates by IEA, CO will be reduced by 61%, HC by 55%, NOx by 43%. Hyderabad will have to select optimum mix of technologies to derive the maximum benefit of emission reduction

Commercial Implication

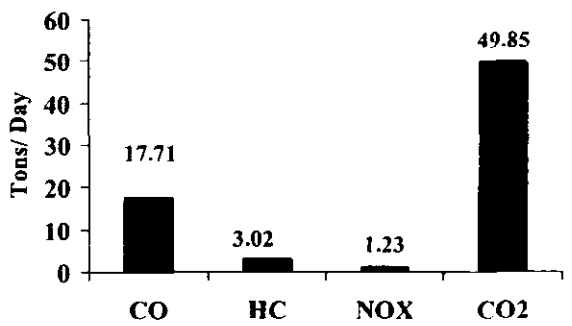
Only marginal cost increase for all the upgradations - Maximum around 2% in case of lower end vehicles. At the higher end the increase will be insignificant. This upgraded version of new vehicles can be made available for Hyderabad with sufficient lead time. The technology for going to the Bharat II Stage is readily available with vehicle manufacturers.

Similarly, when next stage of emission norms for Cars is introduced with immediate effect but with sufficient lead time to phase in the vehicles and available of appropriate fuel quality as per SIAM road map, the following graph shows a comparison of emissions in tons per day of Cars as on the year 2004, if no technology changes are done and they do not meet the next stage of emission norms vis-à-vis if from 2001 onwards all new Cars meet the next stage of emission norms.

Contribution to Pollution by Cars in 2004



Reduction by New Tech. Cars as on 2004



It is seen from the above graphs that there is a significant reduction in CO_2 as compared to CO. Further reduction can will be achieved from various pollutants further tightening of emission norms take place in 2004 when Euro III equivalent norms are introduced and in 2007 Euro IV norms are introduced.

Diesel Vehicles

Changes in engine technology along with matching fuel quality is expected to yield substantial benefit in terms of emission reduction in Diesel vehicles too. Some of the technologies that can be adopted for diesel vehicles are:

•Engine with Higher Compression Ratio

•Turbo-Charging and Retarded Timing

•Exhaust Gas Re-circulation

Euro II equivalent technology as well as CNG and LPG technologies are available with the manufacturers for both diesel passenger cars as well as buses.

•Engine with Higher Compression Ratio, Turbo-Charging and Retarded Timing is currently available with Euro II equivalent vehicles

•Exhaust Gas Re-circulation technology is yet to be tested in Indian conditions

•Conversion Technology through spark ignition mode for CNG(both Lean Burn and Stoichiometric).

•LPG conversion for diesel passenger cars has been approved by GOI from April 2001 and technology is available.

Currently no regulatory provisions for LPG usage in buses. In case of conversion of CNG buses, adequate care needs to be taken with respect to safety features while introducing in Hyderabad.

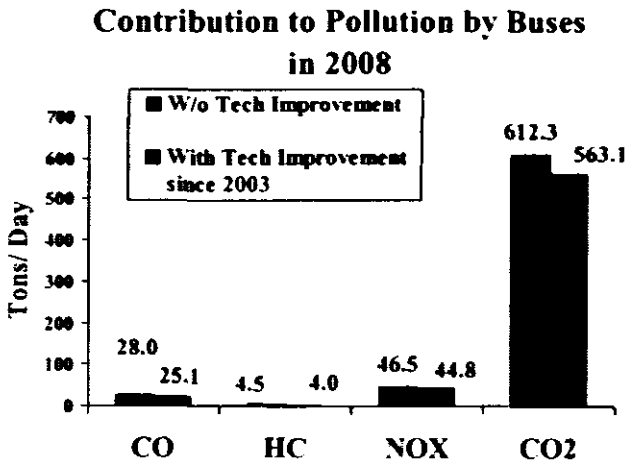
Diesel vehicles mostly used for commercial purposes and adequate policy instruments need to be adopted to achieve maximum benefit in emissions.

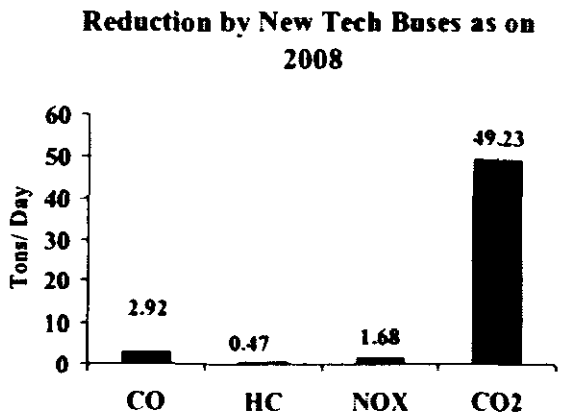
Emission Implications

As per the World-wide Fuel Charter (April 2000) Modern diesel engines with higher compression ratio and turbo charging and better fuel quality will improve fuel efficiency by 20% and thereby reduce CO_2 emission proportionately. This is also expected to reduce NOx by 9% and CO and HC emission by 26%.

Keeping in view the fuel availability and dispensing infrastructure, Hyderabad needs to implement various combinations of diesel vehicle technologies along with LPG and CNG.

Similarly, when next stage of emission norms for Buses is introduced in 2003 as per SIAM road map, the following graph shows a comparison of emissions in tons per day of Buses as on the year 2008, if no technology changes are done and they do not meet the next stage of emission norms vis-à-vis if from 2003 onwards all new Buses meet the next stage of emission norms I.e. Euro II equivalent.





It is seen from the above graphs that there is a significant reduction in CO_2 as compared to CO and other pollutants.

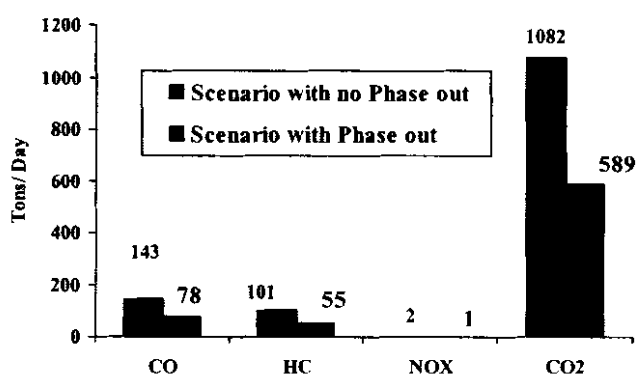
Relocation of Vehicles

In India, there is no life indicated for vehicles plying on the road and a vehicle once bought is used for many year even if the emission performance of these vehicles deteriorate significantly. Primary reason why it is difficult for various State Governments to implement these measures is because of the socio-political reasons. The vehicle, especially the commercial vehicle is a bread earner for the family and people generally have only one vehicle on which their livelihood depends.

The Government of National Capital Territory of Delhi under the orders of Hon'ble Supreme Court has restricted the plying of commercial vehicles which are more than eight years old. Considering a scenario where the Government of Andhra Pradesh restricts plying of more than eight year old vehicles in Hyderabad city, we have estimated the reduction in various pollutants from all the vehicle category.

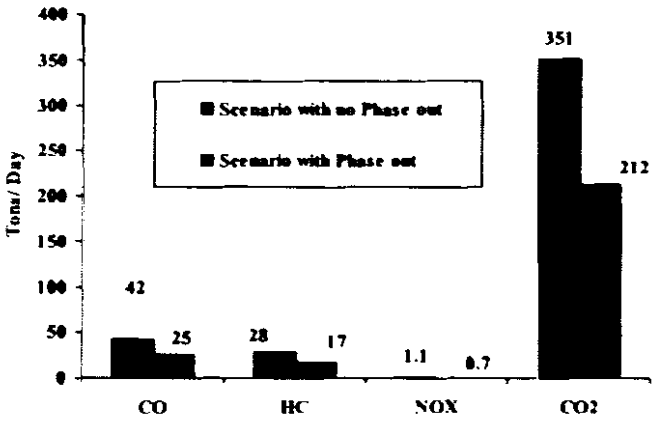
The following graph shows a comparison of emissions in tons per day of two-wheelers in the scenario with no phase out as against one in which, vehicles older than 8 years are phased out, estimated for 2000. It is clearly visible that that all emissions are reduced to almost 50%, if eight year old vehicles are phased out. Also, the absolute reduction in CO_2 from 1081.50 tons per day to 589.28 tons per day is a substantial one

Contribution to Pollution by Two-Wheelers in 2000 with and without Phase out



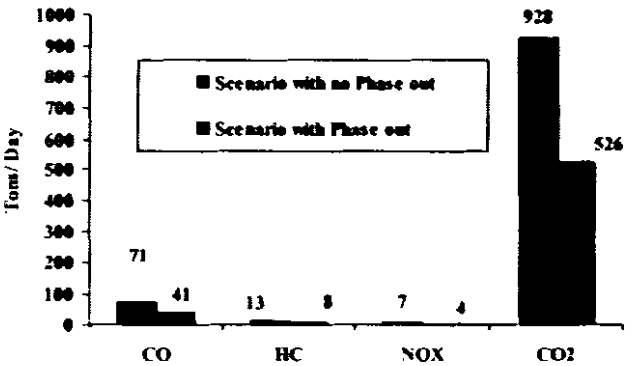
The following graph shows a comparison of emissions in tons per day of three-wheelers in the scenario with no phase out as against one in which, vehicles older than 8 years are phased out, estimated for 2000. It is clearly visible that that all emissions are reduced to almost 60%, if eight year old vehicles are phased out.

Contribution to Pollution by Three-Wheelers in 2000 with and without Phase out



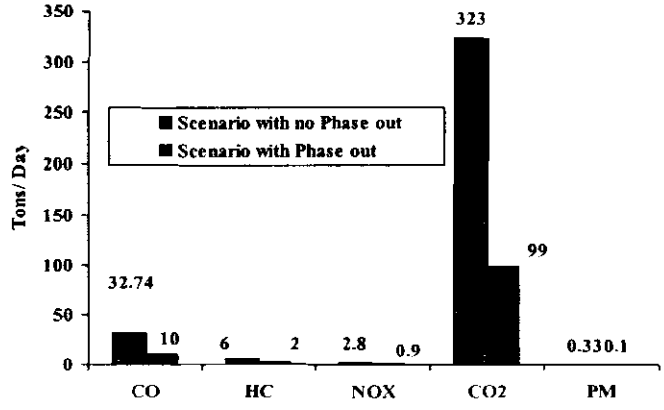
The following graph shows a comparison of emissions in tons per day of Gasoline cars in the scenario with no phase out as against one in which, vehicles older than 8 years are phased out, estimated for 2000. It is clearly visible that that all emissions are reduced to almost 60%, if eight year old vehicles are phased out. Also, the absolute reduction in CO_2 from 928.08 tons per day to 526.07 tons per day is a substantial one

Contribution to Pollution by Petrol Cars in 2000 with and without Phase out



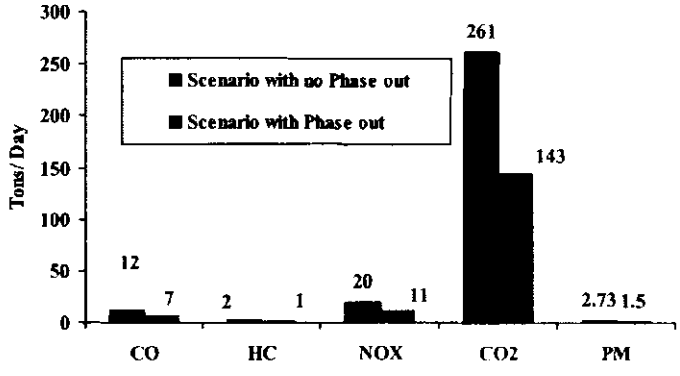
The following graph shows a comparison of emissions in tons per day of Diesel Cars in the scenario with no phase out as against one in which, vehicles older than 8 years are phased out, estimated for 2000. It is clearly visible that that all emissions are reduced to almost 30%, if eight year old vehicles are phased out. There is a marked reduction of almost 225 tons per day in CO_2 emission in the new scenario.

Contribution to Pollution by Diesel Cars in 2000 with and without Phase out



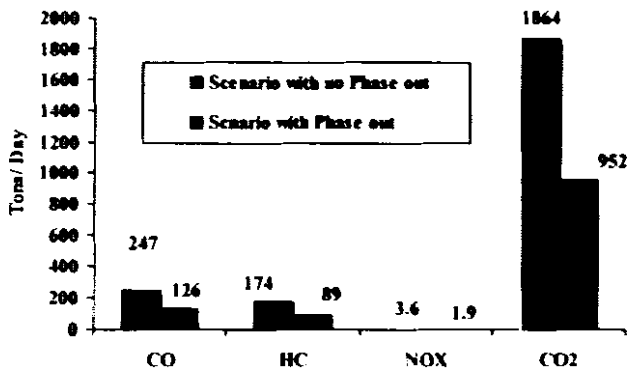
The following graph shows a comparison of emissions in tons per day of buses in the scenario with no phase out as against one in which, vehicles older than 8 years are phased out, estimated for 2000. It is clearly visible that that all emissions are reduced to almost 55%, if eight year old vehicles are phased out. Also, There is a marked reduction of almost 118 tons per day in CO_2 emission in the new scenario.

Contribution to Pollution by Buses in 2000 with and without Phase out



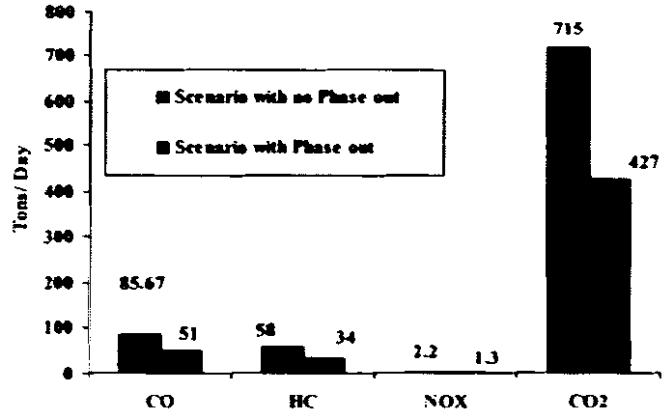
The following graph shows a comparison of emissions in tons per day of two-wheelers in the scenario with no phase out as against one in which, vehicles older than 8 years are phased out, estimated for 2005. It is clearly visible that all emissions are reduced to almost 50%, if eight year old vehicles are phased out. Also, the absolute reduction in CO_2 from1863.61 tons per day to 952.14 tons per day is substantial.

Contribution to Pollution by Two-Wheelers in 2005 with and without Phase out



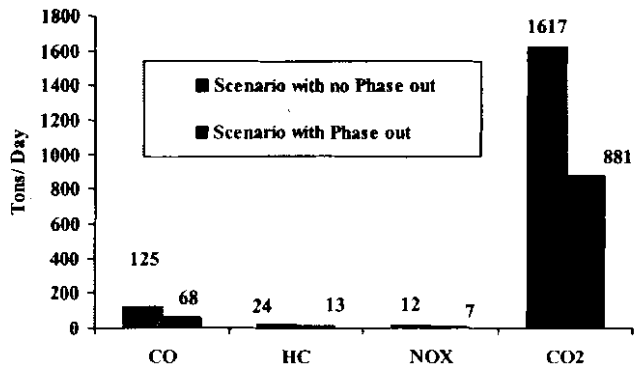
The following graph shows a comparison of emissions in tons per day of three-wheelers in the scenario with no phase out as against one in which, vehicles older than 8 years are phased out, estimated for 2005. It is clearly visible that that all emissions are reduced to almost 60%, if eight year old vehicles are phased out.

Contribution to Pollution by Three-Wheelers in 2005 with and without Phase out



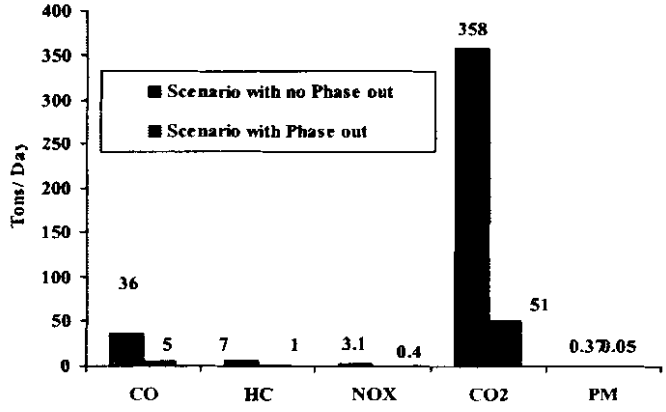
The following graph shows a comparison of emissions in tons per day of Gasoline cars in the scenario with no phase out as against one in which, vehicles older than 8 years are phased out, estimated for 2005. It is clearly visible that that all emissions are reduced to almost 60%, if eight year old vehicles are phased out. Also, the absolute reduction in CO_2 from 1617.31 tons per day to 880.96 tons per day is a substantial one

Contribution to Pollution by Petrol Cars in 2005 with and without Phase out



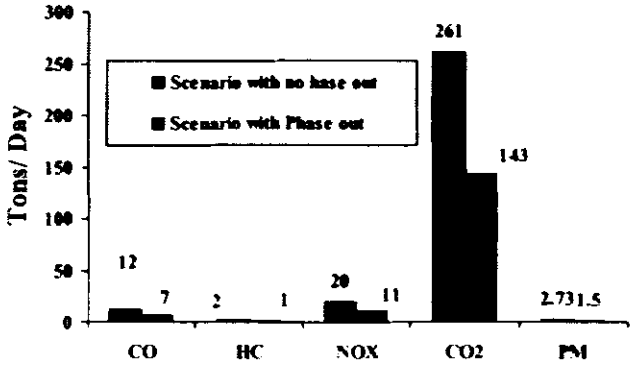
The following graph shows a comparison of emissions in tons per day of diesel cars in the scenario with no phase out as against one in which, vehicles older than 8 years are phased out, estimated for 2005. It is clearly visible that that all emissions are reduced to almost 15%, if eight year old vehicles are phased out. There is a marked reduction of almost 307 tons per day in CO_2 emission with the phase out.

Contribution to Pollution by Diesel Cars in 2005 with and without phase out



The following graph shows a comparison of emissions in tons per day of buses in the scenario with no phase out as against one in which, vehicles older than 8 years are phased out, estimated for 2005. It is clearly visible that that all emissions are reduced to almost 45%, if eight year old vehicles are phased out. Also, There is a marked reduction of almost 118 tons per day in CO_2 emission with phase out.

Contribution to Pollution by Buses in 2005 with and without Phase out



Effect of I&M on Emissions Reduction in Hyderabad

Introduction

Several cities in the country today are facing severe pollution problems–a challenge for sustainable development, which is not peculiar to any state or country but is faced even by the developed economies.

Increase in population of vehicles and absence of maintenance culture has added to the problem of pollution and safety. While emission standards for new vehicles is being progressively tightened, there has not been an improvement in air quality.

We now need proper infrastructure to -

- ⇒ Reduce exhaust emission from in-use vehicles and thereby reduce atmospheric pollution load.
- ⇒ Ensure that more number of vehicles undergo the periodic emission check.
- ⇒ Establish a strong data bank of the emission performance of in-use vehicles and reduce CO_2 emissions.

Presently all vehicles require Pollution Under Control (PUC) certificate once in six months. But lots of vehicles do not undertake this test and there is very little data bank, through which one could establish the number of vehicles tested and number of vehicles due for the test. If pollution checking is in proper perspective it will definitely lead to reduction of emissions from in-use vehicles.

It has been found that periodic emission check of in-use vehicles is the single most cost effective method for controlling vehicular pollution. An effective upgraded PUC system will help identify polluting vehicles and enable remedial steps. It has been observed that the there is a direct impact in reduction of air pollution through proper Inspection & Maintenance of vehicles, some of the data generated on this aspect is explained below.

It is widely recognised, based on several studies conducted in the various parts of the world that the oldest vehicles are the gross polluters that can constitute upto 80% of the pollution in the major cities. The Govt. of National Capital Territory (NCT) of Delhi under directions of the Hon'ble Supreme Court phased out more than 15 year old transport vehicles in 1998. Now only vehicles less than 8 years old are allowed to operate in Delhi. There is no doubt that such a drastic step will help improve air quality very significantly. However phase out or scrappage can form only a small component of the package to control pollution in view of the socio-economic implications and can at best be a one-time exercise considering the costs involved.

It must be remembered that even new vehicles with the state-of-the-art-technologies, will deteriorate in service and must be maintained properly if they are to continue to operate at the emission levels for which they are designed and manufactured. Considering that a large percentage of the vehicle population in India belongs to the pre-emission control period, i.e. prior to 1991, and that most of these vehicles are poorly maintained, it is apparent that these vehicles are the gross polluters and need to be tackled on priority for emission - abatement.

Studies conducted by ARAI in India has shown that on a batch of 34 vehicles of various ages, comprising of 2 and 3 wheelers and passenger cars, simple and relatively inexpensive maintenance action, consisting of cleaning and tuning and adjusting of carburettors and ignition system, reduced the HC and CO emissions by upto 60%. As a result of the maintenance work there was improvement in fuel consumption by upto 20%. This will provide the motivation and incentive for the vehicle users to incur the expenditure on maintenance once a year. What is important is that the maintenance must be carried out according to the instructions of vehicle manufacturers, by skilled and trained mechanics and not by the "fiddling" resorted to by some.

It has also been seen in Finland that an average I/M programme reduces CO, HC, NOx by 25%, 5%, and 13% respectively. Similarly a report from Michael P Walsh, Environmentalist and Consultant to World Bank, indicates that there was an reduction of 25% of HC & CO and a reduction of 10% of NOx by introducing I/M programme in the in-use vehicles.Studies done by SIAM reveal that there is 15-20% improvement in fuel efficiency by minor maintenance.

Upgraded PUC Check Centre

Since Pollution Under Control (PUC) checking is the only system existing in India for checking emission from vehicles it is suggested that this system should be upgraded to make it more effective. An Upgraded PUC Centre will have an emission test equipment connected to a computer. It will also have a digital Camera to capture the registration number of the vehicle being subjected to test. A printer will be attached for printing out the certificate which would include all particulars of the vehicle in addition to the recorded emission values and a photograph of the number plate. A typical schematic layout of the upgraded PUC set up is shown below.

Details of the PUC Centres

Cabin

The upgraded PUC centre to be a cabin with 2 compartments, separated by a glass partition. One compartment will be an open passage for motorcycle or car to pass through and the second one will be a Control room with test facilities and for operation of the inspectors.

Equipment

The equipment that is proposed to be installed will be the state of art technology; that is, it will be to the same specification and accuracy as they are used presently in similar Centres abroad. The equipment will be automated wherever possible, with computer printout of results so that there is no influence due to error or interference. The equipment will be tamper proof and calibrated periodically as recommended by the equipment manufacturers.

The list of equipment required to be installed are:

1. Emission measurement instruments (If not available already)

2. Digital camera
3 Computer System with printer

Operation

At the registration counter the customer would be given a card which has to be duly filled in giving details of vehicle no., make, model, date of registration, owner's name and address etc. This information will then be entered into the computer at the counter. After warming up, the vehicle is moved into the test cabin. Certificate is printed with the emission values recorded from the analyser eliminating handwriting on the certificate.

Test Certificate

The test certificate issued will contain the following legends:

- Serial Number generated by the computer
- Registration No., year of registration, speedometer reading, make, model, type of engine, type of vehicle are entered manually.
- The test station code and the date and time of test are automatically recorded and no manual entry is possible
- Reference to relevant CMVR regulation.
- Validity date of the certificate is automatically generated by the computer
- Image of the Number Plate

Similar PUC centres in an area/city/district etc will be connected through a network and on-line data will be available for further studies. By adopting the above procedure in general, the system would be rid of manual intervention and mis-use. A system with computer facility will assist the Transport Department to track vehicle which have not undergone the periodic emission check, thereby increasing the turnout of vehicles. As this system will have the capability to record values of their pollutants like HC, CO_2 etc., this will help the local Government to evolve policy decision for various categories of vehicles.

SIAM study on in-use vehicles

The following data is based on the extensive study done on in-use vehicles by SIAM in Hyderabad and other cities. SIAM has organised mega Inspection & Maintenance Camps in prime locations of Hyderabad along vehicle manufactures. The clinics helped in determining the current condition of the vehicles, the characteristics of the driver, tested vehicle emissions, minor repairs were done for those vehicles needing it, and then retested again.

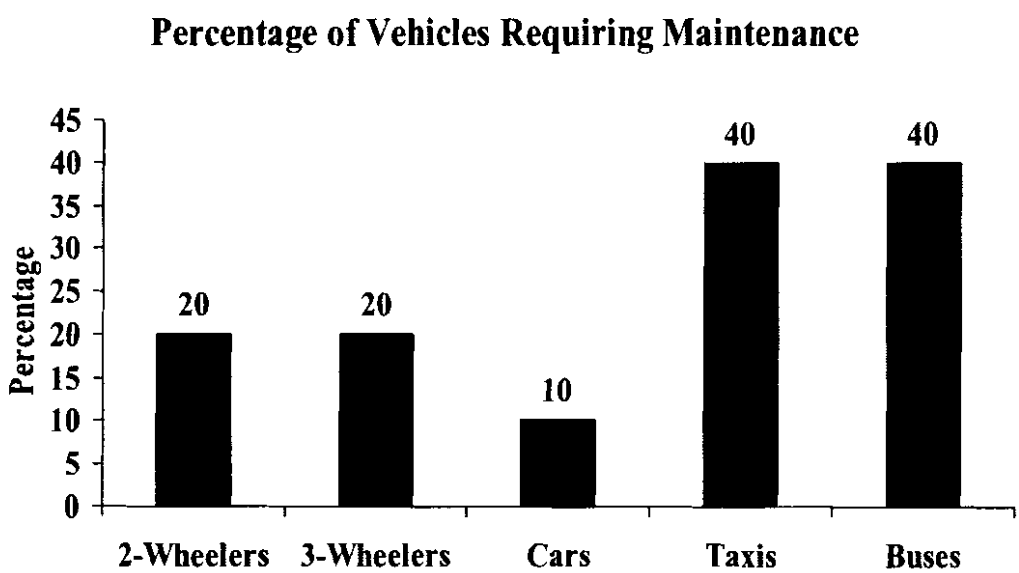
Initial data collected at the clinic site for each vehicle was on the driver, vehicle condition, and current state of HC, CO and smoke emissions. Similar database of this size and quality has never been generated in India.

A subset of the vehicles needing repair were tested on a before and after repair basis to determine the change in fuel efficiency, as well as, the change in emissions resulting from the repairs. The fuel efficiency test were done using a flask with a specified amount of fuel connected to the carburetor of the vehicle. The vehicle was then be driven over a specific course and the fuel use was measured for each case. An opacity test may also be done on a selected number of these vehicles that are being tested for fuel efficiency in few cities.

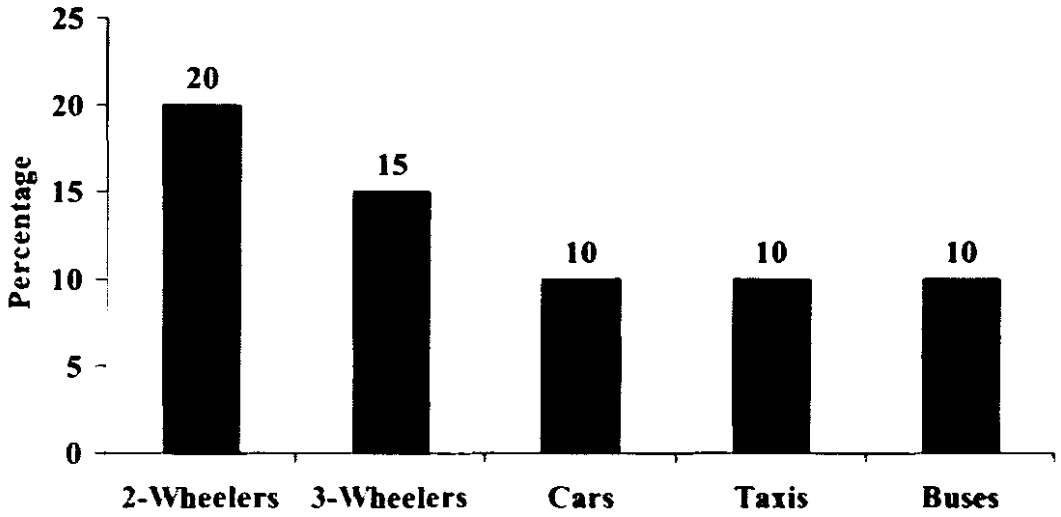
Drivers passing the emission test without any need for adjustments or repairs were issued a PUC certificate, and given a booklet on fuel-efficient driving and simple maintenance tips and a green sticker. The waiting period for these drivers was limited to no more than 5 minutes.

Drivers who failed the idle emission test were sent to a repair booth where a mechanic did minor repairs on the vehicle in order to bring down the emission value. Drivers passing the retest were issued a PUC certificate, and given a booklet on fuel-efficient driving tips and a green sticker. The waiting period for these drivers was about 20 minutes.

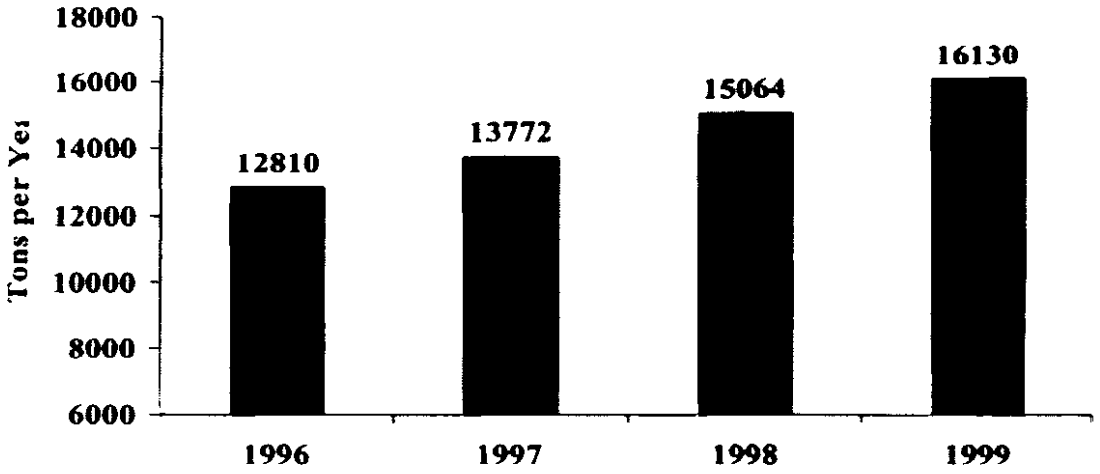
From the data generated by SIAM the following results were obtained:



The following Fuel Efficiency Improvement were achieved by I&M:



Based on the above Fuel Efficiency Improvement the estimated reduction in CO_2 are given below for each year. If the same trend is to be followed then it is estimated that in the year 2005 about 28,000 tons of CO_2 could be reduced annually:



To Create an infrastructure to realize the benefits of periodic emission check the following investment is estimated:

Cost of Upgrading 100 PUC Centres in Hyderabad

- Rs 25,200,000

($ 550,000)

Revenue that is expected to be generated by these Centres is also given below:

	Revenue Generated:			
	Vehicles	**Fee**	**Half Yearly Revenue***	**Annual Revenue**
Two-Wheeler	757,676	10	6,819,084	13,638,168
Three-Wheelers	43,945	15	593,258	1,186,515
Cars	83,782	15	1,131,057	2,262,114
Cars (Diesel)	18,067	20	325,206	650,412
Buses	7,431	20	133,758	267,516
		Total	9,002,363	**18,004,725**

ANNEXURE I

ALTERNATIVE FUELS FOR TRANSPORTATION

Several alternative fuels have been considered from time to time all over the world as low cost substitute for gasoline or diesel and lately as clean air fuels.

The possible alternate fuels for transport sector are:

- Gaseous fuels: Liquified Petroleum Gas (propane), Natural Gas (CNG, LNG) and Hydrogen.
- Electricity: Battery and Fuel Cells.
- Liquid fuels: Alcohol both Methanol and Ethanol.

Methanol is being primarily used today in the USA for production of MTBE, which is an oxygenate of high octane number. MTBE is used as a gasoline fuel component, particularly for the reformulated gasoline. Ethanol although, used widely during 80's in Brazil in the form of blends with gasoline, but elsewhere it did not pick up very much due to lack of availability and costs. Currently ethanol also is being considered as a raw material for production of ETBE, a substitute of MTBE.

The natural gas is gaining prominence as a low pollution fuel for application in commercial transportation e.g.. Taxies, buses etc. in urban areas. In case of natural gas, supply and distribution are the main constraints, which tend to localise the use of natural gas.

The alternatives to Petroleum based fuels must meet the following criteria, if they are going to be used widely for transportation.

Technically acceptable
Economically competitive
Environmentally acceptable
Available and accessible

Available Options

Modifications and Improvements to Diesel Fuels

Improvements to diesel fuels will result in lower emissions of particulate matter and nitrogen dioxide from trucks and other diesel engines. Nitrogen dioxide is an important component of smog and particulate matter may contribute to respiratory problems in people.

Low-sulphur diesel and diesel exhaust emissions

The two main pollutants emitted by heavy-duty diesel vehicles are nitrogen oxides and particulate matter. Nitrogen oxide emissions contribute to environmental problems such as acid rain and ground-level ozone. Particulate emissions from diesel engines can be harmful to human health. Particulate matter can be divided into two categories: primary and secondary particulate. Primary particulate is formed during the fuel combustion process in the engine, and is released as exhaust from the tailpipe. Primary particulate includes soot, the soluble organic fraction, which contains polycyclic aromatic hydrocarbons (PAHs), and sulphate.

Secondary particulate is formed when sulphur dioxide (SO_2) emissions from diesel exhaust are converted to sulphate particulate in the atmosphere

Since diesel particulate is released at levels that result in direct exposure, it can be especially harmful to human health. Particulate matter can be inhaled deep into the lungs and may build up over time, leading to increased susceptibility to lung infections, aggravated respiratory conditions such as asthma, and chronic lung disease. In addition, preliminary data suggests some PAHs in diesel particulate are potentially carcinogenic to humans. As well as these health effects, particulate matter from diesel engine exhaust absorbs and scatters light, reducing visibility. Its black colour and oily nature result in the formation of a soil sediment when exhaust fumes are deposited on a surface. Diesel exhaust also has an unpleasant odour.

Reformulated Gasoline

As air pollution and vehicle use increase, researchers are modifying conventional fuels to produce alternatives, such as reformulated gasoline, which reduce harmful emissions.

Conventional gasoline is a complex mixture of various chemical compounds known as hydrocarbons. Reformulated gasoline is simply gasoline that has undergone some change in its composition, while still maintaining acceptable performance. The reformulation process can range from mild changes in composition (such as removing some of the butane), to substantial alteration of the fuel's make-up. Currently, this kind of gasoline is only available to limited markets, because of the cost of refinery modifications needed to produce this specialised fuel.

Individual refineries can produce reformulated gasoline that meets specific performance requirements. This is accomplished by manipulating certain components of the gasoline to reduce carbon dioxide and other emissions.

In general, reformulated gasoline produces lower evaporative emissions and also reduces the emissions of ozone precursors and toxic pollutants compared to conventional fuels. The following are specific examples of what various kinds of reformulated gasoline can do for the environment:

- ✓ By lowering volatility (rapid evaporation), evaporative emissions are reduced.
- ✓ By lowering sulphur content, catalytic converters will operate more efficiently and therefore exhaust hydrocarbons, nitrogen oxides and carbon monoxide emissions are reduced.
- ✓ By lowering levels of aromatics (organic compounds with an unsaturated ring, such as benzene), exhaust toxins are reduced.
- ✓ By adding oxygen containing compounds (known as oxygenates) such as alcohols or ethers, exhaust hydrocarbons and carbon monoxide emissions are reduced.

Alternative Fuels

Alternative fuels, such as liquefied Petroleum gasoline (propane), natural gas, methanol and ethanol, have the potential to reduce emissions of hydrocarbons, hazardous pollutants and greenhouse gases.

Serious interest in alternative fuels began during the energy shortages of the mid-1970s. Scientists investigated other forms of fuels, which could be used in spark ignition engines. More recently, interest in alternative fuels has been renewed because they may have environmental benefits.

The most common alternative fuels today are propane, natural gas, methanol and ethanol. In general, these fuels have the potential to reduce hydrocarbon emissions, air toxic such as benzene, and global warming effects. However, it is important to understand the complete life cycle of each fuel. The life cycle concept is a "cradle to grave" systems approach for thinking about products and services. This approach recognises that all life-cycle stages (raw material acquisition, manufacturing, transportation and distribution, use and disposal) have associated environmental and economic impacts. This means, for example, that the amount of energy used to make and store fuels, and the pollution generated in doing so, would have to be considered when evaluating the benefits of alternative fuels.

Although these fuels have the potential to offer environmental benefits over conventional gasoline and diesel, the benefits can only be realised if the technology of the vehicle has been properly adapted to the new fuel. At first, most natural gas and propane fuels were used in conventional vehicles that were adapted for the new fuel. While the vehicle might perform satisfactorily, fuel efficiency and emissions were not optimal. In many cases these conversions produced more pollution than the original gasoline engine. In the last few years, a limited selection of vehicles powered by propane and natural gas have been available directly from major manufacturers. Known as Original Equipment Manufacturer (OEM) vehicles, they are researched, engineered and certified to meet all emissions and safety regulations that apply to the equivalent gasoline vehicle.

Propane

Propane fuel has the potential to burn more cleanly than gasoline and could therefore be less damaging to the environment. In addition to improving engine efficiency, propane is a practical and low-priced alternative to conventional fuels because the infrastructure for its use already exists.

Chemically speaking, propane is a gaseous hydrocarbon of the alkane series. As a fuel, propane — or, more accurately, liquified Petroleum gas (LPG) — is composed mainly of propane with small amounts of ethane, propylene and butane. Propane has been used for decades as a heating and cooking fuel supplied in the familiar pressurised steel bottles. It has also been used as an internal combustion engine fuel in forklifts and other machinery, but has only been seriously considered as a transportation fuel since the early 1980s.

When used in a properly prepared engine, propane could combust more completely than gasoline. This would result in lower levels of exhaust and evaporative emissions that contribute to urban pollution and climate change. Propane contains no aromatic compounds, and produces no benzene and particulate emissions.

Propane has a higher octane rating than gasoline, which means engines optimised to use this alternative fuel could improve energy efficiency and reduce emissions of the main greenhouse gas, carbon dioxide.

In certain locations, propane can offer a price advantage over gasoline. Many organisations have already recognised the cost advantages of switching to an alternative fuel like propane. For example, United Parcel Service (UPS) Canada is a courier company operating 1,300 delivery vehicles that consume over 12 million litres of fuel annually. After extensive research and planning, UPS decided that converting 70 percent of its Canadian fleet to an alternative fuel made environmental and economic sense. Pilot tests showed that the new fuels reduced the fleet's emissions while still maintaining acceptable vehicle performance.

Recent developments in "liquid fuel" injection for this alternative fuel will significantly improve the performance of propane vehicles, while reducing the cost and complexity of the fuel system. New self-serve propane refuelling should further increase the marketability of propane vehicles. Propane is, however, a less concentrated source of energy than gasoline, placing some limits on the range of the vehicles between refuelling.

Natural Gas

Low-priced and abundant in supply, natural gas represents a growing market exporting countries. Natural gas is an inflammable gas (mainly methane) that is found in the Earth's crust. Natural gas reserves are found all over the world in sandstone and carbonate reservoirs.

When used in a properly prepared engine, natural gas could combust more completely than gasoline. This would result in lower levels of the exhaust emissions that contribute to urban pollution and global warming. Natural gas contains no aromatic compounds and produces no benzene emissions. Also, when used to replace diesel fuel in a compression ignition engine, natural gas does not produce any particulate matter. Natural gas has a higher octane rating than gasoline, which means engines optimised to use this alternative fuel could improve energy efficiency and reduce carbon dioxide, the main greenhouse gas.

Many commercial vehicle operators see natural gas as a plausible alternative because it is virtually half the price of Petroleum-based fuels. In fact, natural gas is a proven technology — vehicles have been running on it for the last 20 to 30 years. As well, adapting traditionally fuelled vehicles to natural gas is straightforward, although expensive.

Conversion costs can range upwards of $2,600, depending on the vehicle type and the number and size of storage tanks for the natural gas itself. Conversions make the most economic sense for highly used vehicles such as taxis, delivery trucks and utility vehicles, which will recover the cost of conversion quickly. Today there are several options for conversion, including a system that can run both on gasoline and natural gas.

Many organisations have already recognised the economic advantages of switching to alternative fuels such as natural gas. For example, after extensive research and planning, the American Division of the United Parcel Service (UPS) decided that converting its entire fleet to natural gas made economic sense. Pilot tests showed that the new fuel reduced the fleet's emissions while still maintaining acceptable vehicle performance. While the price of natural gas at the pump is the lowest of the alternative fuels, it must be remembered that in many countries there is no federal excise applied to natural gas as a vehicle fuel. The economic incentive for using natural gas could disappear if these taxes are applied to the pump price.

Electronically controlled gaseous fuel injection systems for this alternative fuel were developed in 1992, which improved the performance and reduced the emissions of natural gas vehicles. Auto manufacturers are planning to produce a wider selection of dedicated natural-gas vehicles by the late 1990s.

Methanol

When used in a specialised factory produced vehicle, methanol could combust more completely than gasoline.

Methanol is a type of alcohol, currently made from natural gas but which can also be made using biomass (wood waste or garbage) or coal. Unlike Petroleum based hydrocarbon fuels like gasoline, that are made up of only hydrogen and carbon, methanol is an oxygen-containing fuel. This bound oxygen results in methanol having significantly different physical and chemical properties from typical hydrocarbon fuels. Methanol has been used for decades in a wide variety of industrial and consumer applications, and has been used as a fuel in racing cars and other high power applications. Only recently has methanol been investigated for use in ordinary cars and light trucks, and as a replacement for diesel fuel in heavy-duty trucks and buses.

When used in a properly prepared engine, methanol could combust more completely than gasoline. This would result in lower levels of the exhaust emissions that contribute to urban pollution and global warming. Methanol contains no aromatic compounds and therefore produces no benzene emissions. Full analysis of all of the energy and materials required to produce and distribute methanol must be done, however, before the true environmental impact of large scale methanol use can be determined.

Methanol is one of two currently available alcohol fuel alternatives to gasoline or diesel fuels: the other being ethanol. Methanol and ethanol have similar, but not identical, properties and both are different in many ways from conventional hydrocarbon fuels.

Alcohol fuels such as methanol can be used in two ways in transportation applications:

Neat Fuels - vehicle and engine systems can be altered to run exclusively on methanol as opposed to gasoline (the most advanced technology, known as flexi-fuel or variable fuel, allows an engine to operate on straight methanol or straight gasoline — or any mixture of the two — without re-tuning the engine). For safety reasons, the content of methanol is limited to 85% maximum of methanol (referred to as M85). Methanol has a higher octane rating than gasoline, which means engines optimised to use this alternative fuel could improve energy efficiency and reduce emissions of the main greenhouse gas, carbon dioxide.

Fuel Blends - methanol can be mixed in small amounts (up to 5%) with gasoline to extend or improve the performance of conventional fuels for use in vehicles that have not been modified in any way. Methanol is more corrosive than gasoline and requires additives to reduce this effect.

Unfortunately, methanol also separates from gasoline in the presence of water and therefore requires a co-solvent such as ethanol, isopropanol, isobutanol or tertiary butyl alcohol, along with stringent handling procedures, to avoid water contamination.

The greatest obstacle facing alcohol fuels, however, is availability. Methanol is currently distributed widely as a chemical commodity with very strict controls on quality. Wide distribution and availability of fuel methanol will be required before this alternative fuel can play a role in the transportation sector. Research is currently under way to reduce the cost of methanol production.

In the United States, methanol fuelling stations are available in California. The famous Indy 500 auto racing circuit continues to require methanol as the only fuel that can be used at Indy races.

Ethanol

Ethanol blended with gasoline may be less damaging to the environment than conventional fuel. Fuel ethanol is a high-octane, water-free alcohol produced from the fermentation of sugar or converted starch. In some countries, ethanol is made primarily from lower value grains, such as barley, feed wheat, and corn. Poor quality grains (weather-damaged or immature) and forestry wastes (sawdust, etc.) are also excellent feedstock for ethanol production.

Alcohol fuels, like ethanol, are a series of organic compounds that contain the hydroxyl group — an atom of oxygen bonded to an atom of hydrogen. Ethanol is different than conventional transportation fuels like gasoline and diesel because it contains oxygen as well as carbon and hydrogen (the conventional fuels lack the oxygen component), which permits the fuel to burn more completely than non-oxygenated fuels.

Ethanol is one of two currently available alcohol-fuel alternatives to gasoline. Alcohol fuels such as ethanol can be used in two ways in the transportation industry:

Neat Fuel - vehicle engines can be altered to run exclusively on ethanol as opposed to gasoline. These vehicles are presently being demonstrated as a viable alternative to conventional vehicles and fuels; or

Fuel Blends - up to 10% ethanol can be mixed with gasoline to extend or improve the performance of conventional fuels, and since ethanol has a much higher octane number than gasoline, it is considered to be a viable octane enhancer.

Usually, ethanol is blended with gasoline to produce "gasohol", commonly called E5 (five percent ethanol) or E10 (ten percent ethanol). The Environmental Choice™ Program (ECP) granted an EcoLogo™ to these low-level blends. Low-level ethanol blends can be considered an alternative to conventional transportation fuel because they may have a potentially less harmful impact on the environment. Ethanol, if it is blended properly, can reduce carbon monoxide and benzene emissions. However, the carbon monoxide benefit of ethanol over regular gasoline will diminish as the emission control technologies on cars become more sophisticated.

Carbon dioxide emissions can also be reduced when ethanol is derived from some biomass sources. While producing fuel ethanol by fermentation helps reduce greenhouse gas production, it has some disadvantages. Not only is the process to produce ethanol expensive, the energy required for distillation comes from burning natural gas or coal. These fuels produce greenhouse gas emissions and, therefore, decrease the net environmental advantage of using ethanol as a fuel. Furthermore, ethanol may increase aldehyde emissions.

Tests of pure alcohol fuels have also proven successful even in severe cold winter and hot summer conditions.

Ethanol became popular in the American mid-west in the 1970s, and its popularity spread to Western Canada and continued eastward into South-western Ontario by 1991. The greatest obstacle facing alcohol fuels like ethanol, however, is one of economics. Ethanol is more expensive to produce than methanol, which in turn is more expensive to produce than gasoline. However, researchers are closer to finding cost-effective ways to convert plant cellulose to sugar, and there may even be ways to use the material left over after the ethanol has been removed.

Electricity and Hydrogen

Zero emission vehicles powered by electricity or hydrogen may be a key to reducing consumption of non-renewable resources. However, several issues need to be resolved before these vehicles can be integrated on a large scale into the present transportation network

Hydrogen gas (H_2) is being explored for use in combustion engines and fuel-cell electric vehicles. It is a gas at normal temperatures and pressures, which presents greater transportation and storage hurdles than exist for the liquid fuels. Storage systems being developed include compressed hydrogen, liquid hydrogen, and chemical bonding between hydrogen and a storage material (for example, metal hydrides).

While no transportation distribution system currently exists, for hydrogen transportation use, the ability to create the fuel from a variety of resources and its clean-burning properties make it a desirable alternative fuel.

Chemical Properties: The simplest and lightest fuel is hydrogen gas (H_2). Hydrogen is in a gaseous state at atmospheric pressure and ambient temperatures. Fuel hydrogen is not pure hydrogen gas. It has small amounts of oxygen and other materials.
Two methods are generally used to produce hydrogen: (1) electrolysis and (2) synthesis gas production from steam reforming or partial oxidation.

Electrolysis uses electrical energy to split water molecules into hydrogen and oxygen. The electrical energy can come from any electricity production sources including renewable fuels. DOE has concluded that electrolysis is unlikely to become the predominant method for large quantities of hydrogen production in the future.

The predominant method for producing synthesis gas is steam reforming of natural gas, although other hydrocarbons can be used as feedstock. For example, biomass and coal can be gasified and used in a steam reforming process to create hydrogen.

A distribution system for hydrogen as a transportation fuel does not exist. While pipeline transportation is generally the most economic means of transporting gaseous fuels, a pipeline system is currently not in place. Transportation of Hydrogen is typically in canisters and tanker trucks.

Hydrogen as a fuel holds great promise for the environment. It burns quickly and cleanly. Since hydrogen contains no carbon, it does not produce CO, CO_2 and VOC and the only exhaust it produces is water vapour. However, because it does not exist in nature in pure form, hydrogen has to be extracted from other substances.

The most energy-efficient source of hydrogen for transportation uses is water. Hydrogen can be extracted from water using electricity, a process known as electrolysis.

Electricity is unique among the alternative fuels in that mechanical power is derived directly from it, whereas the other alternative fuels release stored chemical energy through combustion to provide mechanical power. Motive power is produced from electricity by an electric motor. Electricity used to power vehicles is commonly provided by batteries, but fuel cells are also being explored. Batteries are energy storage devices, but unlike batteries, fuel cells convert chemical energy to electricity.
A large number of various types of batteries are being tested for use in EVs. Some of the technologies being used or evaluated include lead-acid, nickel cadmium, nickel iron, nickel zinc, nickel metal hydride, sodium nickel chloride, zinc bromine, sodium sulphur, lithium, zinc air, and aluminium air.

Electricity is produced from power plants located throughout the country, transmitted to substations through high voltage transmission systems, stepped down to lower voltages, and carried to homes and businesses through distribution systems. Similarly recharging of vehicles can be done from the grid.

Electricity fuelling costs could be quite reasonable, especially if off-peak rates are taken advantage of. However electricity cost varies across the country depending on location, type of generation, and time of use.

The main benefit from EV is no tailpipe emissions! This is the number one benefit of owning an EV. Although, some people argue that there are some emissions that can be attributed to EVs — the emissions that are generated in the electricity production process at the power plants.

The economy of using EVs, once the relatively high initial capital cost is made comes with the lower "fuel" and maintenance costs. The cost of an equivalent amount of fuel for EVs is less than the price of gasoline. Also, maintenance for EVs is less—EVs have fewer moving parts to service and replace.

Electricity is derived from a number of sources such as coal, oil, gas, wood, nuclear power, water, wind and solar energy. Even though zero emission vehicles do not give off any harmful contaminants at source, if the electricity to power them results in environmental damage or releases harmful emissions, the environmental benefits may be negated. Electric - and hydrogen-powered vehicles are "cleanest" when renewable resources are used to generate the electricity.

With widespread electric vehicle use, other environmental repercussions such as battery production, transport, use and disposal will come under consideration. As well as reducing greenhouse gases, urban smog and other air pollution problems aggravated by conventionally fuelled vehicles, zero emission vehicles are quieter and more energy efficient.
Vehicles operated by electricity from a battery or a fuel cell using hydrogen are known as zero emission vehicles. The name comes from the fact that such vehicles do not directly emit any pollutants during their operation.

Electricity has been used for over a century to power public transit vehicles such as streetcars and subway trains. These vehicles run on a set track or cable that provides a constant source of electricity. Companies are developing self-contained, battery-powered light-duty vehicles, which will be practical for urban, short-range commuting.

Another option for powering electric vehicles is the **hydrogen fuel cell**. Fuel cells generate electricity and water on board the vehicle by combining compressed hydrogen gas with oxygen from the air. This eliminates battery weight and recharging problems faced by other electrically powered vehicles. Recent technologies can also produce hydrogen on board the vehicle using fuels such as natural gas, propane, methanol and even gasoline.

Manufacturers are investigating ways to expand the electric vehicle market to sustain the transportation industry. Conventional lead-acid battery technology must be improved to increase the vehicle driving range, lower the cost, and shorten the time needed for recharging. New battery types such as sodium-sulphur, lithium-aluminium and iron-sulphide batteries are also being developed. Hybrid vehicles that can run on electricity as well as other fuels such as gasoline, natural gas, propane, or methanol, are also being considered as an alternative to vehicles that run by battery only.

As electricity prices rise, manufacturers must find cost-effective methods to maintain and operate zero emission vehicles without increasing demand on the source of electric power.

Developments in the electric-and hydrogen-powered vehicle field are stimulated by increasingly stringent emissions regulations. Electric vehicles, including hybrid electric vehicles, are already being produced in limited numbers. Hydrogen-powered buses, using technology developed in Canada, are being tested on the streets of Vancouver and Chicago. Mass use of hydrogen-powered vehicles, however, will require the development of a safe and economically viable way of producing, distributing and storing hydrogen.

MTBE/ETBE as Fuel Additives

Oxygen-containing gasoline additives such as methyl tertiary butyl ether (MTBE) or ethyl tertiary butyl ether (ETBE) reduce certain emissions. They also function as octane enhancers.

There are several different types of fuel additives, including alcohols, ethers and metals. Oxygenates, which refers to oxygen-containing compounds such as alcohols or ethers, can be blended with gasoline in small amounts (usually 5 to 15 percent) to improve fuel quality. Some oxygenates can be used as fuel extenders, allowing other resources such as natural gas and biomass to replace part of the crude oil used to manufacture gasoline. This helps to conserve diminishing oil supplies. Fuel additives also act as octane enhancers, preventing the fuel from igniting prematurely and causing engine damage. Lead was a fuel additive, used for over 60 years as an octane enhancer, before being banned in 1990 because of its adverse health effects. Since then, researchers have developed other, less-harmful alternatives that have the same fuel-improving qualities.

This base paper covers only two ethers, MTBE and ETBE, that are used as fuel additives.

Methyl Tertiary Butyl Ether

Methyl tertiary butyl ether (MTBE) is made from a mixture of methanol and isobutylene from oil refineries. It has a high octane value and a low volatility, and is thus an effective octane enhancer. It has an advantage over alcohol-blend fuels because it does not separate out in the presence of water. A research program on fuels, underway in the United States, revealed that adding 15 percent MTBE to gasoline reduced hydrocarbons and carbon monoxide, but had no effect on nitrogen oxides or hazardous pollutants.

Gasoline containing MTBE has been sold in the United States since 1979, and MTBE is currently the most popular oxygenate on the US market. There has been concern in the United States over the contamination of surface and ground water with MTBE. MTBE is extremely persistent in water and may carry chemicals from gasoline along with it into drinking water supplies.

Ethyl Tertiary Butyl Ether

Ethyl tertiary butyl ether (ETBE) is similar to methyl tertiary butyl ether except it is made from ethanol and isobutylene. ETBE also has a high octane value and offers a lower volatility than MTBE. Presently, ETBE is more expensive to produce than MTBE.

ALTERNATIVE FUEL VEHICLES

Compressed Natural Gas

Compressed Natural Gas (CNG) is a mixture of hydrocarbons consisting of approximately 80-90% methane in gaseous form. Due to the low energy density of Natural Gas, it is compressed at a pressure of 200 to 250 kg/sq. cm to increase the storage quantity in a cylinder.

Natural gas availability in India is quite high. The supply potential for 2000-1 is 23-30 billion cubic meters (BCM). Though natural gas has a committed use for fertiliser, power plants and process industry but still large quantities would be available for miscellaneous use including transport sector which otherwise would go waste as flared gas. Even a 3 MCM of gas used in transport sector would result into replacement of 1 Million Ton of diesel or gasoline per annum. A substantial penetration of market by natural gas in the transport sector will improve the overall energy availability and environment in large metropolis.

In India, studies on use of natural gas as fuel for internal combustion engines is being pursued by the research and academic institutes as well as oil, gas and vehicle industries. The Ministry of Petroleum and Natural Gas (MOP&NG) has also put in its efforts to demonstrate use of compressed natural gas as alternative fuel for automobiles and its potential to abate vehicular emissions. The Gas Authority of India (GAIL) has already started vending CNG at certain retail outlets in Delhi, Gujarat and Mumbai. Some CNG kit suppliers/manufactures have also started getting their kits/vehicles type approved by Automotive Research Association of India (ARAI), Pune and Indian Institute of Petroleum (IIP), Dehradun.

Abroad, in Italy, New Zealand, Canada, USA, Australia, Russia and former USSR, etc. natural gas vehicles technology is well established. USA's Alternative Motors Fuels Act of 1988, Clean Air Amendments Act of 1990 and Energy Policy act of 1992 encourages use of natural gas as a low polluting fuel in motor vehicles.

Natural gas, comprising of largely methane, is a clean burning, low polluting engine fuel. It can be used as a substitute or sole fuel in place of diesel or gasoline. Major problem in using natural gas in transport sector besides lack of country wide CNG filling facility, is its limited on-board storage on vehicles,

which is due to its low volumetric energy content at normal pressure and temperatures. Compression of natural gas to higher pressures (164-200 bar) is essential to store adequate quantity of the fuel on-board a vehicle. Liquefaction of natural gas enhances its storage density but requires expensive cryogenic (-162^{0}C) containers. From the engine's stand point both compressed natural gas (CNG) and liquefied natural gas (LNG) are same it is only the on-board storage medium that is different. For automotive purpose use of CNG is more common than LNG.

Natural gas vehicle (NGV) uses CNG either as a sole fuel in spark ignition (SI) engines fully replacing gasoline or as a supplementary fuel in compression ignition (CI) engines in dual-fuel mode partly replacing diesel. In either case, option of switch back to gasoline or diesel operation is possible.

In gasoline engines, use of natural gas lowers carbon monoxide and reactive hydrocarbon emissions and eliminates lead emissions. In diesel engines, it reduces smoke and particulate emissions and also reduces nitrous oxides emissions over the duty cycle of the engine.

Natural Gas Vehicles

About 0.18% of the world's transport fleet is now fuelled on natural gas. In a total world vehicle population of about 650 million there are approximately 1.2 million NGVs; the bulk of these has been converted from gasoline fuelling.

Internationally, the manufacture and marketing of NGVs to the private and public transport sectors is in the process of transition. Until the late 1980s the number of vehicles produced by the original equipment manufacturers (OEMs) was very limited. This situation is changing. The OEMs are offering a wider choice of types and styles of models. Over the coming years the OEM supply will gradually take over from the existing conversion options. This is likely to be a slow process, extending over 10 years or more.

The conversion (or retrofit) programme was necessitated by the lack of sufficient demand to encourage direct involvement of the OEMs. The programme has over a period of 10 years publicised the concept of the NGV, built up valuable operating experience and stimulated a knowledge of and demand for CNG fuel. The refuelling network built up in many countries is now available to supply growing fleets of OEMs.

NGV refuelling facilities rely to a large extent on the existing natural gas supply network. This provides a safe and reliable distribution system, avoiding the road and rail handling required for conventional liquid fuels. But equipment is still needed to compress and dispense gas at the high pressures (in the range 200 to 300 bar) required at refuelling stations. The addition of large numbers of these stations to the network has been one of the main achievements of the past five years. Increasing emphasis is being placed on improving the efficiency and lowering the cost of refuelling.

Over the past 15 years the industry has built up a wide experience of manufacturing and operating NGVs. This growth has taken place in many different countries; so has the development of standards and codes needed for efficient and safe operation of vehicles. The time has come for a rationalisation of these standards. Much effort by representatives of the industry has gone into this work, which will continue for some years. It will result in improvements in quality, safety and operational efficiency of vehicles and refuelling stations.

Apart from the central role played by the gas supply authorities, other important stakeholders in the industry are the equipment and vehicle manufacturers and vehicle converters. Government bodies and local authorities play an important role in setting a supportive environment for the operation of NGVs; they benefit in turn from the use of a widely available fuel with favourable environmental properties.

The present superiority of natural gas as a fuel has been amply demonstrated by the NGV industry. But there are significant gains being made in the development of new formulations of Gasoline and diesel fuels. At the same time very large R&D funding is being devoted to the development of electric cars. The NGV industry can prosper only if its stakeholders work to eliminate the barriers to NGVs and to foster the economic, strategic and emissions advantages of natural gas as a fuel.

There has been a long history dating back to the 1920s of using natural gas as a vehicle fuel. The two oil shocks in the 1974 and 1979 and the possibility of renewed fuel shortages brought a strong interest in natural gas for vehicles. It provided economic benefits that sustained the programmes after the strategic benefits became of less immediate importance. And it became clear, at a time when urban and global pollution was being highlighted as a serious problem, that natural gas provided emissions reductions not readily attained with liquid fuels.

The path to the present level of progress has not been an even one. It is interesting to compare the varying success in different countries. France had a thriving NGV programme in the 1930s; by the 1960s low cost liquid fuels were widely available and interest in NGV almost totally disappeared. It is only now being revived. Italy developed its NGV industry steadily from the 1930s onwards and it is still thriving.

In New Zealand the industry grew over eight years to the stage where in 1987 11% of passenger cars had been converted; a change in government attitude and in liquid fuel prices has cut progress and more than halved vehicle and refuelling station numbers. This programme still runs downhill.

Strong and rapid progress has been made in the USA, driven mainly by emissions legislation and government incentives. The testing time for the industry will come if and when mandates and incentives are phased out. Argentina has over a period of 10 years overtaken the growth rate of all other countries in the conversion of passenger cars and taxis. It has a very favourable price differential driving the conversion of Gasoline vehicles to natural gas; conversely there is little incentive to convert diesel vehicles.

The past decade has been one of consolidation, with far-reaching technical and infrastructure developments only coming to fruition at the end of the period. Recent achievements are a higher awareness of the improvements in emissions that NGV can bring - especially those not at present regulated. A better understanding of the approaches that need to be made to governments and regulatory authorities foreshadows an improved operating environment for the industry.

The quality and availability of engine management systems has increased rapidly. And an awakening of interest on the part of the OEMs promises the availability of vehicles tailored to take full advantage of the superiority of natural gas as a fuel.

Advances in the industry have not been made uniformly around the world. This can be ascribed to such diverse factors as the availability of energy resources, government attitudes, pollution awareness, differences in fuel taxes and expectations of motorists.

Concerns regarding resources have led to a range of development and demonstration programmes using new sources of transport energy. Although a great deal of this effort has been associated with electric vehicles, the progress of NGVs has outstripped any of the alternative fuels, with the exception of LPG. Natural gas is seen no longer as merely a possible alternative. It is accepted as a fuel with a long-term future. This view is supported by the action of the World Energy Council at its 1995 meeting in Tokyo declaring natural gas as the favoured alternative transport fuel.

Over the past 10 years it has been shown that, where emissions advantages are combined with economies in operation, very rapid progress can be achieved. The different national programmes have encountered market and technical pressures that encourage growth - and also pressures that could constrain it. It is important that the industry takes note of these experiences.

Another noteworthy advance made recently has been the increase in availability of OEM cars and in particular heavy-duty vehicles. Many of the latter have targeted carefully selected urban applications such as transit buses, refuse collection and other service vehicles. Hand in hand with this has gone a strengthening of the regulatory structure for vehicles, components and fuels. In particular the development of an international standard for high-pressure gas storage cylinders is coming to fruition.

The number of vehicles and refuelling stations in use in some countries is illustrated in the Table overleaf. It can be seen that there are at present only 7 countries with 14,000 vehicles or more.

World status of CNG Vehicles and Refuelling Stations

COUNTRY	CNG Vehicles	CNG Refuelling stations
Argentina*	3855	504
Italy*	300000	280
Russia*	205000	187
NZ*	25000	245
USA*	68000	1102
India (Oct 2000)	36000	75
Canada*	36000	130
Brazil*	14000	39
Colombia	4600	22
Indonesia*	3000	12
Pakistan*	2500	12
Germany*	2415	55
China	2000	10
Venezuela	1500	20
Australia*	1600	70
Malaysia*	975	8
France*	869	9
Iran	800	1
Japan*	798	37
Holland*	535	15

Source: AINGV and GAIL

Notes:
1. Updated Sept 1996 (at least in part) for countries marked *
2. Where no new data available, previous information (1994) remains

Europe is small if the Italian fleet is omitted. This slow growth is attributable to the fuel price differentials, which have so far been insufficient to encourage the use of NGV. It is noted that there are now moves to alter the European fuel tax structure to provide a differential that will foster growth; they are already meeting with success.

Another factor that has hampered a shift to NGVs in Europe is an emissions regulation that counts exhaust methane as a hydrocarbon. The industry in Europe is arguing strongly for NMHC as a measure for photochemically reactive hydrocarbons.

There is no reliable measure of the division of NGVs into OEMs and converted vehicles. It is estimated that a very high proportion of the cars - perhaps 95% - is converted. An increasing proportion of the HD vehicles will be OEM buses - a sector of the industry that is currently making rapid progress.

The numbers of NGV in Russia are very impressive, although there appears to be some question as to whether the statistics quoted may include some LPG vehicles.

In Italy over 300,000 converted vehicles are on the road after a programme spanning 50 years. A distribution network of 295 refuelling stations has been created - mainly in north and central Italy. Annual fuel sales amount to about 310 billion cubic metres. The percentage of vehicles converted over the whole country is only 1%, but in some areas it is as high as 10%. CNG makes up about 0.5% of total vehicle fuel sales.

Perhaps the figures that best reveal the way in which an NGV programme can progress are those for Argentina. In 1990 the NGV fleet was numbered in hundreds. There are now more than 400,000 vehicles and over 500 refuelling stations. The present monthly increase in vehicle numbers is about 4,000. This provides an interesting statistic on the very rapid increase in numbers that can be achieved with a programme based largely on conversions and driven by both a large fuel cost differential and an environmental concern.

One issue regarding the collection of statistics has not been resolved by the industry. This relates to the meaning of the term number of vehicles converted. In New Zealand about 250,000 vehicles have been converted over a period of about 12 years. Currently there are only 25,000 NGVs there.

NGV industry in these countries is commercial with an adequate supporting infrastructure. Use of CNG as motor fuel is being promoted in India too. There are about 75 refuelling stations and around 31350 cars and 4500 three wheelers on CNG in Delhi, Mumbai, Vadodra, Surat and Ankleshwar. Around 150 CNG buses of DTC are also currently plying in Delhi. Though there is a wide scope of CNG utilisation in road transport, the work in India so far has been limited due to non-availability of countrywide filling stations facility and for lack of optimisation of specific brands of engine.

Liquified Petroleum Gas

Liquified Petroleum Gas (LPG) availability in the country from domestic sources is about one third the total demand which was about 3.6 MT in 1995-96, requiring large imports to meet its requirement largely as domestic fuel. Further, its use is till recently restricted for any other use. However, with de canalising of the imports, its use is being considered for transport sector for autorickshaws, taxis and cars in the metropolitan cities. The Government of India has recently approved LPG as an automotive fuel and Norms and Safety Code of Practice for use as automotive fuel is being drawn.

Like natural gas, LPG comprising of largely propane, is a clean burning, low polluting engine fuel. It can be used as a substitute or sole fuel in place of diesel or gasoline. LPG vehicle (LPGV) uses LPG as a sole fuel in spark ignition (SI) engines fully replacing gasoline or as a supplementary fuel in compression ignition (CI) engines in dual-fuel mode partly replacing diesel. In either case, option of switch back to gasoline or diesel operation is possible.

LPG fuel-system technology is well developed, and mostly are mechanical based and are designed as 'Second Fuel System', to be added onto gasoline fuel systems, for dual-fuel operation in either/or mode. Retrofits for automotive diesel engines are also available for dual-fuel mode operation, replacing about 30-40% diesel by LPG with a substantial reduction in smoke and particulates.

A quicker cold start with lower emissions is expected of LPG operation because it is introduced into the engine as gas (rather than as liquid that has to be vaporised first). LPG has a higher octane number than gasoline and has potential to produce less CO and smog-causing reactive hydrocarbons than gasoline. Exhaust emissions of unburned hydrocarbons for LPG vehicles are about the same as or higher than those of gasoline vehicles, depending upon the interaction with the emission controls of the original gasoline fuel system. Carbon monoxide is normally lower, while oxides of nitrogen show no change. In diesel engines, nitrous oxides emission is lower at part-loads and higher at full load and is expected to be lower than diesel operation over the duty cycle of the engine.

In India, detailed engine performance studies were carried out at IIP Dehradun on bus and tractor engines using commercially available dual-fuel engine kits. The kits were required to be modified for operating these engines. Studies on automotive diesel engines were also conducted at IIT Chennai, Anna University Chennai. Studies with LPG on car engines have not been reported so far from any official agency but results of conversion of two stroke moped engine and scooter engine is published. LPG has been proven technically feasible for use on both CI and SI engines. Abroad, however, use of LPG for cars is quite popular and it is available for conversion of car and heavy-duty engines.

With good properties as an engine fuel, LPG is a compound fuel with propane and butane as the main components. Its emissions levels compete with those of CNG; it has the advantage that it can be stored in the liquid state at pressures in the range of 15 to 30 bars. However, it presents a higher safety risk than natural gas in transport, handling and storage, mainly because it is heavier than air and any leaked vapour tends to pool and make an explosive mixture. It has an octane rating that allows its use engines with a compression ratio of about 10 or 11. It is cost competitive with CNG. Transport, storage and handling are less safe than is the case with natural gas.

LPG is an important feedstock for petrochemical products and is also widely used as a cooking fuel, particularly in developing countries. It is seen as having limited availability, depending as it does on oil production and refining. In view of these competing uses it is seen - perhaps optimistically - as a possible replacement for a maximum of 10 - 15% of gasoline on a global scale.

LPG Vehicles

As LPG is Petroleum based, its cost and availability tracks that of oil, and so LPG is not the most attractive fuel from an energy independence perspective. Nevertheless, current estimates suggest enough LPG to cost-effectively fuel several million vehicles in California. World-wide, there are perhaps 10 times as many vehicles powered by propane than any other alternative fuel although most of the vehicles fall in the light duty class. Of the more than 8.3 million alternate fuel vehicles in the world, 3.6 million use propane as fuel of choice.

Propane is widely available, particularly in the US and Canada. In Canada 5000 propane refuelling centres dispensed 1.3 billion litres of the fuel in 1992. More than 750 centres perform vehicle conversions. As a comparison Canada has 184 natural gas outlets and 78 locations offer NGV conversions. In Canada, because of regulatory, information, supply and cost of capital barriers impeding the widespread use of propane, governments at both the federal and provincial levels launched a co-ordinated programme of support to propane, designed to remove the barriers and inspire public confidence in the fuel. The programme was quite successful, with well over 150,000 vehicles now running on propane in Canada.

About 350,000 LPGVs and 70,000 NGVs are in use in the US. In Australia, the market for LPG has been growing steadily to a stage where there are now approximately 40,000 LPGVs (1-2% of Gasoline use) and over 40,000 LPG vehicles.

In New Zealand, a decade of LPG use in a fleet of trucks and light vehicles, demonstrated LPG's technical feasibility with marginal economic benefits particularly in applications which apply a high value to pay-load, range and engine output.
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Large quantities of LPG are being sold in certain European countries offering tax incentives, primarily the Netherlands, Belgium and Italy. The Netherlands is one of the most advanced nations in the use of clean fuels, with propane vehicles accounting for about 15% of all vehicle mile traveled. Automotive LPG market development in the world has been given in the Table overleaf.

Status of LPG Vehicles

Country	Estimated no. of cars running on LPG	No. of LPG Service Stns
Austria	12,400	187
Belgium/Luxembourg	95,700	750
Mexico	200,000	-
Australia	190,000	-
South Korea	160,000	-
Canada	150,000	5000
New Zealand	60,000	-
Denmark	40,000	800
France	53,000	1,300
Greece	8,000	100
Ireland	14,000	250
Italy	900,000	1,500
The Netherlands	540,000	2,400
Norway	5,000	30
Spain	33,000	200
Sweden	5,000	60
United Kingdom	50,000	500
Germany	25,000	700
USA	350,000	-
Japan	320,000	-
Erstwhile USSR	230,000	-

Source: IIP, Dehradun

Electric Vehicles

Oil crisis since 1973 and concern about environmental protection stimulated the need for R&D on electric vehicles (EVs) worldover. As a result, significant progresses in research development and popularisation of EVs in many countries have been made. The main limitations of battery technologies have been, and continue to be, range, size, weight, and cost, with power output and recharging times sometimes also an important criteria. Fuel cells tend to be limited by many of the same factors, with on-board hydrogen storage and/or generation becoming an additional factor. Three key specifications tend to determine whether batteries and fuel cells are appropriate for transportation uses:

i) energy density (specific energy),
ii) power density (specific power), and
iii) life.

Specific energy determines the amount of energy which can be stored in a given size system, and hence the range of the vehicle and the size and weight of the power plant. Specific power determines the maximum rate at which a given amount of energy can be supplied, and hence the number of cells required to meet peak power requirements. This typically limits vehicle acceleration, and can be just as important as range in determining power plant requirements. In the case of batteries, lifetime represents the number of recharges that can be made before the battery requires replacement, for instance, 20% of its ability to store energy (cycle life); in the case of fuel cells, lifetime is generally limited by contamination of catalysts, which depends on fuel purity.

Technology Status

Compressed Natural Gas

Engine Technology

Most of the early development of internal combustion (IC) engine was based on gaseous fuels. In fact, as far back as 1899, Rudolf Diesel took out a patent on gas engine. But gradually the liquid fuel replaced the gaseous fuel because of higher energy density and ease of handling.

Revival of the gas-fuelled vehicle on a commercial basis is again being actively pursued, primarily because of the concern for growing air pollution and also the cost of uncertainty associated with the supply of liquid fuel.

The technical feasibility of using natural gas as a fuel in transport sector is very well established. A large number of vehicles are operating on CNG in different parts of the world, Italy being the leader.

The trend has been to use natural gas in spark-ignition (SI) engines. Natural gas can, however be used in both SI as well as compression ignition (CI) engines with different degree of conversion requirements.
For using CNG in transport vehicles, two separate sub-systems are required. The first of course is the refuelling station, and the second is the CNG conversion kit for each vehicle, which commonly consists of

1) high pressure cylinders for on-board gas storage,
2) filling valve,
3) pressure regulator,
4) load dependent CNG regulator in case of diesel engines,
5) gas-air mixer,
6) CNG mode switch,
7) shut-off and control valves and
8) high and low pressure tubing, etc.

Most kits are mechanical in operation and are designed typically for use as a 'second fuel-system'. Kits with electronic control, based on engine performance map system has also been developed. Kit and engine development are also underway which take care of variations in gas

composition and maintain engine performance close to gasoline or diesel operation through electronic control. The choice between mechanical or electronic kit would depend upon the cost of the kit, ease of conversion, ease of maintenance, and type of application.

The conversion option can be either a Dual-Fuel operation where CNG and diesel/gasoline both can be used or a dedicated 100% CNG operation where gasoline engines would require a partial redesign but diesel engines would require a complete redesign to operate as an S.I. (Otto cycle) engine. The dual-fuel CNG retrofit systems for both gasoline and diesel engines have following principle of operation. Initially when the engine is started and is idling, it runs on 100% gasoline, or 100% diesel as the case may be. As the engine is loaded and its speed increases, CNG mode switch is operated to change from 100% diesel operation to 30-80 % CNG-diesel dual-fuel operation in case of diesel engines, and to 100% CNG operation in case of gasoline engines. Different technology options for use of natural gas in IC engines is summarised below.

a)**Gasoline Engines** - Use of natural gas in gasoline engines is confined to

i) **Either/Or (Dual-Fuel) Mode** where generally the existing in use gasoline vehicle is converted for NG use and option exists to run the vehicle on either of the two fuels, starting usually on gasoline.

ii) **Dedicated Mode** where the engine is designed to operate solely on natural gas. Such NGVs are generally designed and manufactured afresh. In both the cases NG can replace almost 100% gasoline. In some parts of the world these technologies have in use for quite some time now. Passenger car conversions in India so far are non-captive either/or mode type.

B) Diesel Engines - Diesel engines can be made to run on natural gas in three broad classes.

i) **Low/Medium Level Replacement (Dual-Fuel Engine)** - generally up to 50% on the average duty cycle. Here a retrofit kit is used to convert in-use vehicles and largely dual-fuel operation takes place. Ignition is through diesel injection and replacement is limited by knock free operation and by remaining close to the design torque characteristics. The interesting feature is that the conversion is non-captive.

ii) **High Level Replacement (Dual-Fuel Engine)** - generally around 90% the conversion is captive. Modified smaller throughput injectors are used and considerable optimisation of design features and combustion geometry may take place. Such engines can only be manufactured afresh.

iii) **Total Replacement (Dedicated Engine)** - in this case, the engine is converted run as a Otto cycle SI engine. This technology has largely been in use in North America, some countries of Europe, and elsewhere. In India the low/medium replacement approach has so far been practised to reduce diesel smoke and particulate emission, and to conserve diesel fuel.

C) **Two Stroke Engines** - In India some interest has been shown on possible use of natural gas in two wheelers and three wheelers equipped with two stroke SI engines. It is generally agreed that physical limitation precludes this possibility. However, there are possibilities on conversions of three wheelers for gas use. IIP has already developed a CNG three wheeler under a GAIL sponsored project.

There are several vendors who can convert vehicles to dual-fuel CNG-gasoline operation. Basically, all the conversion systems are similar except for different regulator packages and the only differences are in the pressure levels at various reduction stages.

In India, Transenergy, Chennai is the leader in commercial conversion of cars, bus and trucks for CNG operation. Lately GAIL has also set up points in Delhi, Mumbai where cars can be converted to CNG-gasoline operation. IIP, Dehradun is also capable of such conversions.

Future Engine Concepts

The development of engine technology has proved that there are no barriers in running vehicles efficiently on natural gas. Efforts are under way to further reduce the emission levels and bring the thermal efficiency values close to diesel engines. It is now well established that for stretching the performance of NG powered vehicles, dedicated systems are a must. The different approaches that are being tried are:

a) The lean burn spark ignited gas engines, with closed loop mapped control and oxidation catalysts and

b) Combination of exhaust gas recirculation (EGR), advance control and a three-way catalyst, which is expected to provide lowest achievable gas engine emission.

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Scientists are trying to modify the existing diesel engines to run on natural gas without major engine changes, using the pre chamber ignition concept. The aim is conversion be retrofitable without dismantling the engine, which precludes piston changes to reduce compression ratio or to modify combustion chamber shape.

Storage, Handling and Dispensing of CNG

The storage and handling requirements of natural gas (NG) are a major hurdle in its being a vehicular fuel. This stems from NG's low energy density. NG has only 1/900 as much energy as an equal volume of gasoline. To overcome this energy density enhancement becomes mandatory. Natural gas can be stored on board a vehicle either as a compressed gas (CNG) in high-pressure cylinders or as a cryogenic liquid (LNG). A third option is to store it in low or medium pressure tanks as absorbed gas (ANG), technologies for which are still under development.

In liquid state the gas shrinks to about 1/635th of its volume at STP. CNG at 200 bar has about 1/4th energy (volumetric) as that of gasoline or 1/5th as that of diesel, while that of LNG is a little over 1/2 that of diesel. The present technology of on board storage utilises high-pressure cylinders storing gas at 2400 -3000 psi (165-207 bar) pressures and located usually in the trunk of the vehicle.

Storage - CNG is stored in a cascade of high-pressure cylinders from where it can be dispensed to vehicles. It can be trolley or truck mounted. The capacity of which can be decided depending upon the gas filling and the capacity of the compressor.

Studies are underway to develop techniques by which NG can be stored at medium and low pressures. These techniques are,

i. Adsorption on high surface area carbon,
ii. Adsorption on high porosity zealots,
iii. Storage in clathration compounds, and
iv. Storage by dissolution in liquid solvents.

Various studies carried out so far indicate a high potential for adsorbent technique for low-pressure NG storage system. By adsorption on the commercially available carbon, it is possible to store NG at 500 psi (35 bar) approximately 705 of the volume of methane that can be stored at 2000 psi (138 bar) and 45% of that stored at 3000 psi (207 bar). With the development of new types of charcoal materials which have particularly high microscopic volume suited to retaining the small methane molecule, it is expected that the storage of the gas at moderate pressure will eventually make home refuelling possible. Problems of vibrational settling of the absorbent, preferential adsorption of higher hydrocarbons and the heat generation in natural gas adsorption system call for further development of this technique. In the commonly employed quick fill mode, the poor heat flow characteristics of the packed bed combined with rapid heat evolution during adsorption can increase the temperature by 70-80°C, thus decreasing the specific adsorption. Also in summer, when temperature goes above 40°C, storage capacity reduces by 10%.

Refuelling - A CNG refuelling outlet essentially consists of the low-pressure gas inlet, the compressors, gas storage facility and dispensers. Connecting the refuelling probe to the fill connection and turning on the gas supply refuels the vehicles. Gas flow stops when the tank reaches pre-set pressure. The gas supply is then shut-off, which automatically bleeds the remaining gas in the line and the hose is disconnected from the vehicle. An interlock prevents engine starting while refuelling.

CNG can either be dispensed directly from the compressor to the vehicle (slow fill) or stored under pressure in cascades until needed for filling vehicles (quick fill).

(a) **Slow Fill** - In slow fill mode filling is done directly from the compressor. This takes much longer time e.g. overnight but allows many vehicles to be refuelled at the same time. The pressure requirement of this type of system is limited and cost is also low. Slow filling is suitable for large operators who can refuel their fleet centrally overnight. Slow fill is economical too.

(b) **Fast Fill** - For fast filling static storage cylinders or cascade system is used. In Canada and US refuelling through the fast-fill system takes about 3.5 minutes as compared to 2 minutes for gasoline. If the CNG tanks provided only half the range of the gasoline tanks, as is often the case in dual fuel applications, then an additional 3-4 minutes should be added for comparison. This system has added cost for a required bank of high-pressure cylinders (typically 250 bar) and the added compressor required to maintain the cylinder bank pressure.

A third approach of refuelling is the slow filling of vehicle tanks from small home rechargeable compressors. This concept, however, applies to the countries where domestic supply of NG exists. A 0.6m x 0.15m x 1.2m, 600 kg home compressor unit manufactured by RIX, operating off 0.02 bar (above atmospheric) residential gas line pressure, can fill a CNG container to 200 bar overnight.

Compressors - The compressors used in refuelling stations are either Reciprocating compressors driven by electric motor/gas engine, or Hydrostatic drive compressors.

Compressors of varying capacity 1-300 cfm (3.5-635 m^3/h) are available in the world market for compressing natural gas. These are divided in three basic ranges Small compressors are up to 10 cfm (3.5 m^3/h) capacity, medium compressors are in 20-40 cfm (42-85 m^3/h) range and large compressors are beyond 75 cfm (159 m^3/h) capacity. The thumb rule is that one vehicle can be refilled per each cfm compressor capacity. The larger ones have capacity to refuel many vehicles as well as provide gas to storage cascades.

The reciprocating compressors generally are multistage compressors with number of stages depending on the inlet gas pressure.

The CNG compressor for MRL CNG trials at Nagapattinam, supplied by Sulzer India Ltd., Pune, type C5U 214.6, is a 5 stage, 87.2 m^3/h capacity unit with suction pressure of 1.5 bar and discharge pressure of 250 bar, and driven by a 37 kW motor at 585 rpm.

The GAIL CNG compressor station at Ghaziabad has a 2 stage compressor supplied by Bharat Pumps and Compressors Ltd. Naini, type oz/2, capacity 625 m^3/h, suction pressure 35 ata and delivery pressure 250 ata, and driven by 75 kW motor.

A well-established service station in New Zealand, Canada or Italy, which refills as many as 300 cars per day is equipped with compressor capacity of approximate 200-300 m3/h.

The hydrostatic drive compressors, which were first patented and built in Italy, replaced the traditional crank/flywheel arrangement with a double acting hydraulic cylinder driven by fluid from a pump. These compressors are capable of frequent starting and stopping as opposed to traditional compressors where frequent start/stop is difficult and mostly require rheostat starting in order to bring the heavy flywheels up to speed.

Dispensing - The CNG fuelling stations can be of two different types.

a) **On-line stations** consisting of one or more compressors at retail bullet connected directly to the existing pipeline.

b) **Mother-daughter stations** - consisting of major compressor stations (the mother station) and the daughter stations, which receive the compressed gas in trailer tube or cascade storage by road.

Dispenser in roadside service stations can be single or dual mode for 1,2,3 or 4 line system. It generally incorporates a fully electronic gas meter equipped with easy to read display of amount of gas and price. Although volumetric metering is more popular, many installations charge on mass or heat value basis.

Cylinder Material - Three types of CNG cylinders are presently being marketed:

i) The thick walled Cr-Mo steel cylinder,

ii) The reinforced aluminium cylinder wrapped in fibreglass, kevlar or carbon, and

iii) The thin walled lightweight C-Bo steel reinforced fibreglass cylinder. The composite high-pressure tanks made of glass/epoxy resin are also under development. These are substantially lighter and can easily be made of in different sizes to suit the space available in a vehicle. At burst pressure, these cylinders do not fail explosively but gradually de laminate.

The conventional steel cylinders have so far been widely used. The lightweight steel and aluminium cylinders, which are now commercially available, seem to be having a distinct preference for use in vehicles.

Cylinder Safety and Testing - As high pressure gas is involved, sufficient safety factor is incorporated in design of CNG cylinders and the cylinders are built as per rigorous quality standards. The qualification tests require every cylinder to be hydrostatically tested at about 1.7 times the service pressure and subjected to thermal cycling, fatigue test and immersion in fire to test the operation of the pressure relief valve. The minimum burst pressure of at least 2.5 times the rated service pressure indicates that a very conservative approach is taken in the design of cylinders. Apart from the initial testing, pressure testing of each cylinder is also carried out at an interval of 5 years for steel and at an interval of three years for aluminium.

The US Department of Transport cylinders also insists that the cylinder should be equipped with rupture (burst) discs. In event of fire, the soldered backing of the rupture disc will melt causing the disc to rupture at the designed pressure. The four exit ports on the disk housing will then release the contents of the cylinder in a controlled manner rather than giving rise to a violent split from end to end. Italian authorities are however opposed to the use of burst discs in motor vehicle cylinders. In their opinion, the gas released from the burst disc can feed the flames of an existing fire and can create an additional hazard.

Introduction of reinforced aluminium cylinders, led to a concern whether these cylinders will be able to withstand crash impacts. A free fall drop test, simulating rear end collisions at 30-40 mph (48-64 kmph) and severe abuse testing with gunfire and dynamite, revealed that these cylinders offer a fuel container with safety equal to or greater than the conventional gasoline tanks.

Safety With CNG

Vehicles that run on clean burning natural gas are as safe as vehicles operating on traditional fuels like Gasoline. CNG, unlike gasoline, dissipates into the atmosphere in the event of an accident. Gasoline on the other hand accumulates on the ground and creates a fire hazard.
The relative safety of NG production and transport by pipeline is well established and their are no serious hazards associated with CNG refuelling. Practical experiences indicate that the safety record of CNG is quite exemplary.

In US a survey was carried out on more than 8000 vehicles that cumulatively traveled approximately 278 million miles from 1987-1990. The survey found that the injury rate for CNG vehicles per vehicular miles traveled (VMT) was 37% lower than the rate for Gasoline powered fleet vehicles and 34% lower than the entire population of registered Gasoline vehicles. In addition to lower injury rate, no deaths were recorded for the CNG vehicles in the survey.

In a somewhat similar study carried out in 1979, it was found that out of the 1360 collisions involving natural gas vehicles, there were no failures or fires involving the fuel system. 180 of these, were rear end collisions, which further strengthens the case, as NG tanks are generally stored in the car trunk. One manufacturer has found that dragging a cylinder from the back of a car, dropping it repeatedly on to a steel plate from 3-5m, partially cutting its fibre wrap, or leaving it pressurised out doors for up to 11 years does not lower the burst pressure.

In Italy, keeping in view, the safe record of CNG operation, their regulatory organisations like SNAM, ANCC, etc. wanted relaxation of some CNG regulations.

According to the American Gas Association, natural gas has a high, 1200°F (648°C) ignition temperature and a narrow range of flammability: in concentrations in air below 5% and above 15%, natural gas will not burn. The high ignition temperature and limited flammability range make accidental ignition or combustion unlikely. An NGV has a 'closed' fuel system. If a leak does occur, natural gas does not pool or puddle, but dissipates harmlessly into the atmosphere because it is lighter than air.

Methane has relatively high diffusivity - three times that of gasoline vapour which means that in case of leaks, it will disperse quickly to a density below its lower flammability limit. Compact methane molecules are hard to ignite. Methane flames are colder and therefore, radiate less heat. Moreover quenching of methane air flame by cold surfaces and atmosphere is much easier than in the case involving other fuels such as gasoline. Unlike liquid Petroleum fuels storage in thin sheet metal containers which are extremely vulnerable to impact damages, CNG is stored in much sturdier cylinders which are less prone to collision damages. All these factors make natural gas somewhat less hazardous than gasoline.

Natural gas is neither toxic, nor carcinogenic or caustic, although it can be an asphyxiant. The gas is generally odourised to detect leaks. Combustible gas indicators are also available which can detect quantities of gas in air.

Contact with LNG may result in severe frostbite, and when highly compressed NG expands to normal atmospheric pressure, the sudden cooling can also cause frostbite.

Natural Gas Vehicle Standards

Codes and standards prepared by different countries are to be followed by CNG users. In the US, National Fire Protection Association (NFPA) has developed NFPA 52 Standard for CNG Vehicular Fuel System relating to CNG vehicle equipment installation, fuel dispensing, bulk facilities and fuelling connections based on a report of American Gas Association. This is the foundation document of the US NGV industry. The 1992 edition of this document has been approved by American National Standards (ANSI) and encompasses many fuel system areas. The Canadian General Standard Board (CGSB) has also prepared a standard for NGV in liaison with NFPA . A manufacturer of NGV conversion system currently certifies individual NGV components by complying with AGA Requirement 7-93 in the US, or the CGA (Canadian Gas Association) 12.3 standard, which are nearly identical.

The Australian standard for CNG fuel systems for vehicle engines is known as the SAA Automotive CNG code and was first published in 1984.

In India, in absence of any national standard for NGVs, presently New Zealand Standard NZS 5422: Part 2: 1987, which describes code of practice for the use of LPG and CNG fuels in IC engines, Part 2 CNG fuel, is used. However a draft Indian national standard for compressor and storage stations for CNG (code of practice and safety) is in circulation for comments.

Liquified Petroleum Gas

Engine Technology

For using LPG in transport vehicles, two separate sub-system are required. The first of course is the refuelling station, and the second is the LPG conversion kit for each vehicle, which commonly consists of:

i) motor fuel tank - a moderate pressure cylinder for on-board liquefied gas storage,
ii) filler valve,
iii) relief valve,
iv) 80% fixed liquid level gauge,
v) bulk head fitting with hydrostatic relief valve,
vi) vaporiser-pressure regulator,
vii) load dependent LPG regulator in case of diesel engines,
viii) gas-air mixer,
ix) LPG mode switch,
x) shut-off and control valves and
xi) high pressure hose for liquid propane and low pressure hose for gaseous propane, etc.

Most kits are mechanical in operation and are designed typically for use as a 'second fuel-system'. Kits with electronic control, based on engine performance map system has also been developed for lower emissions and better performance. The choice between mechanical or electronic kit would depend upon the cost of the kit, ease of conversion, ease of maintenance, and type of application.

The conversion option can be either a Dual-Fuel operation where LPG and diesel/gasoline both can be used or a dedicated 100% LPG operation where gasoline engines would require a partial redesign but diesel engines would require a complete redesign to operate as an S.I. (Otto cycle) engine. The dual-fuel LPG retrofit systems for both gasoline and diesel engines generally have following principle of operation. Initially when the engine is started and is idling, it runs on 100% gasoline or 100% diesel as the case may be. As the engine is loaded and its speed increases, LPG

mode switch is operated to change from 100% gasoline/diesel operation to 100% LPG operation in case

of gasoline engines and to 30-40% LPG-diesel dual-fuel operation in case of diesel engines. Different technology options for use of LPG in IC engines is summarised below.

a) **Gasoline Engines** - Use of natural gas in gasoline engines is confined to

(i) **Either/Or (Dual-Fuel) Mode** where generally the existing in use gasoline vehicle is converted for LPG use and option exists to run the vehicle on either of the two fuels.

(ii) **Dedicated Mode** where the engine is designed to operate solely on natural gas. Such LPGVs are generally designed and manufactured afresh. In both the cases LPG can replace almost 100% gasoline. In some parts of the world these technologies have in use for quite some time now.

b) **Diesel Engines** - Diesel engines can be made to run on LPG in two broad cases.

i)**Low/ Medium Level Replacement (Dual-Fuel Engine)** - generally up to 30% on the average duty cycle. Here a retrofit kit is used to convert in-use vehicles and largely dual-fuel operation takes place. Ignition is through diesel injection and replacement is limited by knock free operation and by remaining close to the design torque characteristics. The interesting feature is that the conversion is non-captive.

ii)**Total Replacement (Dedicated Engine)** - in this case, the engine is converted run as a Otto cycle SI engine. This technology has largely been in use in North America, some countries of Europe, and elsewhere. In India the low/medium replacement approach has been experimentally demonstrated to reduce diesel smoke and particulates emission, and to conserve diesel fuel.

C) Two Stroke Engines - In India some interest has been shown on possible use of LPG in two wheelers and three wheelers equipped with two stroke SI engines. It is generally agreed that physical limitation precludes this possibility. However, there are possibilities on conversions of three wheelers for gas use.

There are several vendors that can convert vehicles to dual-fuel LPG-gasoline operation. Basically, all the conversion systems are similar except for different regulator and gas-air mixer packages. The vehicle manufacturers' importers for the country often convert vehicles as intended by the manufacturers before delivery to customers. In India, Transenergy, Chennai used to provide commercial conversion of cars and buses for LPG operation. IIP, Dehradun is also capable of such conversions.

Air intake temperature - Propane fuel is converted from a liquid to vapour in the vaporiser and delivered to mixer and engine cylinders in gaseous form. Engines fuelled with propane will operate more efficiently with lower intake temperatures. Propane conversion equipment should include an enclosed air cleaner with an intake tube extending behind the vehicle grill to provide a cooler supply of intake air.

An open-style air cleaner takes in extremely hot air under the hood. For every 5.5°C rise in air intake temperature above atmospheric temperature, a 1% power loss will be experienced. High intake air temperature contributes to detonation in the combustion chambers. Cooler air intake temperature allows additional spark advance and improves economy and performance.

Air-fuel ratio - Correct air-fuel ratios are critical in a propane-fuelled engine. Propane vapour has very little cooling effect on engine parts. A rich air-fuel mixture can cause engine overheating, and lean propane air-fuel ratios result in slower combustion in the cylinders, excessive burning continues to take place when the exhaust valve opens. As a result, exhaust valve temperature is increased and valve life is shortened.

Ignition - A propane fuelled engine must have correct distributor advance curves and initial timing settings. Excessive distributor advance results in detonation and engine damage whereas insufficient spark advance may lead to engine overheating, power loss, and reduced engine life. . Propane fuel requires additional spark advance at low rpm. In general, considerably more spark advance is required for propane, although again the amount of spark advance would be reduced if the propane fuelled engines were optimised for emissions. Less spark advance than shown would be required at part loads if the mixture is richer than optimum.

In contrast to gasoline, propane vapour between the spark plug electrodes increases the normal required secondary voltage under all operating conditions. Secondary voltage requirements are particularly high on sudden acceleration at low speeds. The general condition of the ignition system is of greater concern when propane fuel is used. All spark plugs with wide gap specifications should be set to 0.035 (0.889 mm) on a propane fuelled engine. Propane-fuelled engines operating under light duty conditions should have the same spark plug as a gasoline-fuelled engine. When a heavy-duty application is converted from gasoline to propane, spark plugs one range colder than originally specified should be installed because propane vapour entering the combustion chamber has no cooling effect. Furthermore, the ignition temperature of propane is also higher than gasoline.

Engine design - Engine compression ratios could be increased to gain optimum power and economy from propane fuel. Engines designed for propane fuel could have the CR increased to 10.5:1 without detonation problems. Propane is a cleaner burning fuel than gasoline, and in most cases exhaust emission requirements can still be met with the higher CRs. A propane fuelled engine does not require a choke for cold mixture enrichment because the propane enters the intake manifold in a gaseous state. Sudden acceleration no longer requires a richer mixture, and the acceleration pump is eliminated in the propane mixer. Normal propane air-fuel mixtures are leaner than gasoline mixtures. A propane fuelled engine will operate more efficiently than a gasoline-fuelled engine. The gain in efficiency is most noticeable at low rpm.

Lubrication - The average high detergent, multiple viscosity engine oil contains barium and calcium additives. Gum and sulphur deposits from gasoline are suspended in the oil by these additives. Propane fuel, on the other hand, does not contain gum or sulphur deposits, so that the oil additives have nothing to combine with in a propane-fuelled engine. Many oil companies produce a specially formulated low additive oil for propane fuelled engines. Some propane equipment manufacturers do not recommend the use of ash-less oil (synthetic oil) with propane fuel. Ash-less oil can contribute to valve seat recession because the reduced carbon content of propane fuel provides less cushioning action between valve face and seat. Higher oil consumption on eight out of twenty four LPG-gasoline bi-fuel vehicles have been reported in the alternative fuel vehicle programme in Nebraska.

One of the greatest challenges faced in the design of a propane engine is the elimination of valve and seat wear problems. Use of propane in an engine designed for unleaded gasoline will result in dramatic increases in exhaust seat wear by a factor of 10 to 20 over the same engine operating on unleaded gasoline are common, though it is expected that valve seat recession should not be a problem when propane fuel is used in engines designed for unleaded gasoline since these engines have harder valve seats.

Exhaust Valve Recession Rates

Stellite faced exhaust valves were used with the standard diesel camshaft in the conversion of Caterpillar 3306T heavy truck engines to LPG operation in New Zealand and after trials using various oils. Shell oil was selected as meeting the combined requirements of high mechanical loading, gas-fuelling and high temperature stability for lubrication and cooling of turbochargers. In Canada, Chrysler's 5.2 L V-8 and 2.2 L 4-cylinder propane engines, valve seat inserts made of a sintered powdered metal tool steel alloy with a high temperature solid lubricant (PMF16) were used on the exhaust in place of the standard induction-hardened cast iron seats used in the gasoline engine. These inserts provide a 70-75% reduction in valve seat wear versus cast nickel-based inserts and stellite, without the need for a hard-faced valve. The Fig. above shows the comparative wear rate of the above inserts.

Performance of Gasoline to LPG Converted Engines

Performance of Indian Cars on LPG is not available though several persons have converted their vehicles for LPG operation using some crude easy-to-install conversion equipment with domestic gas cylinders as fuel tank.

The general trend of engine and vehicle performance expected of LPG operation is discussed in the following sections.

Torque and Power - Factors affecting the power output of a given engine when converted to operate on propane include:

i) The energy density of the fuel-air mixture used,

ii) The volumetric efficiency of inducing that mixture,

iii) The air-fuel ratio and

iv) The ignition timing.

Since the energy density of propane-air mixtures is 2.3-3.1% lower than that of gasoline-air mixtures, a corresponding reduction in power would be expected, all other factors being equal. The use of LPG, as with any gaseous fuel, would lead to a power loss of about 5 percent.

In the case of dedicated propane conversions, it is possible to improve the volumetric efficiency to help compensate for the lower energy density. Manufacturers of propane carburettor systems recommend that the intake manifold heating system used to vaporise gasoline be blocked and that a 71°C coolant thermostat be used in place of the usual 88°C. With lower intake manifold temperatures, the volumetric efficiency of the propane fuelled engine is increased. This increase helps to offset the lower energy density of the propane-air charge and thereby raise the power output to gasoline equivalent levels.

Maximum power values essentially equivalent to those obtained with gasoline can be obtained from propane by using an excess air ratio of about 0.9.

Fuel Economy - Fuel consumption, expressed in terms of brake specific fuel consumption (bsfc), is strongly influenced by air-fuel ratio and by ignition timing. It has been observed that minimum bsfc is obtained with a lean mixture, excess air ratio about 1.3 at part load and about 1.05 at full load, in contrast to the rich mixture which produces maximum power. The dependence of bsfc on excess air ratio is quite strong. Bsfc is also more strongly influenced by timing than maximum power output. The slower burning leaner mixtures require greater ignition advance.

The bi-fuel LPG-gasoline operation of 25 vehicles fleet consisting of nine 7.5 L 1991 Ford buses, eight 5.8 L 1991 Ford vans and seven 4.9 L Ford vans in Nebraska, US showed that the average fuel efficiency (km/l) of gasoline is

greater than the average fuel efficiency of LPG for LPG bi-fuel 7.5 L buses and 5.8 L vans. For the 4.9 L van fuel efficiency on LPG and gasoline were comparable.

Engine Starting, Driveability and Acceptance - A quicker cold start with lower emissions is expected of LPG operation because it is introduced into the engine as gas (rather than as liquid that has to be vaporised first). Market research of existing LPG users in Australia, indicate the main advantages of LPG as its low cost and availability, whilst its disadvantages generally involve technical/performance issues such as reduced power, lack of refuelling stations, loss of boot space, conversion cost, fuel safety and cold starting. The majority of these problems, like CNG conversions, result from poor quality control at the time of conversion rather than as a result of any limitation of the fuel itself.

Storage, Handling and Dispensing of LPG

LPG is stored and transported in the liquid form to improve the energy storage density. Thus an LPG fuel tank must be a pressure vessel, able to withstand pressures up to 2.4 MPa, the maximum vapour pressure that would be expected even in very high temperature industrial environments.

The present technology of on board storage utilises moderate pressure cylinders storing gas at 160 psi (10 bar) pressures and located usually in the trunk of the vehicle. Inspection of motor fuel tanks is usually the responsibility of the authority in-charge of high-pressure vessels. In most countries, approval is necessary for importing or manufacturing propane fuel tanks. Each tank must also be inspected and stamped by the local authority in-charge of high-pressure vessels.

Propane fuel tanks are constructed from heavy gauge steel. The external tank fittings are:

i) Relief valve,
ii Filler valve,
iii) Fixed liquid level gauge,
iv) Shut-off gauge and
v) Liquid contents valve.

The filler valve contains a double flow check valve that allows fuel to flow into the fuel tank and prevents propane from flowing out of the valve. An excess flow valve is located in the tank shut-off valve. If the liquid fuel line was broken and the shut-off valve turned on, the excess flow valve would snap closed when fuel discharge exceeded the normal flow. The relief valve will open if tank pressure becomes excessive. On the internally mounted fuel tanks the relief valve must have a vent hose connected from the valve to the outside of the vehicle. Relief valve discharge pressure is the same as the tank pressure rating, 250 psi (17.5 bar) on externally mounted tanks, and 312 psi (2.2 bar) on internally mounted tanks. The motor fuel tank should only be filled to the 80% level. The space at the top of the tank allows for fuel expansion in hot weather.

Fuel lines carrying liquid propane from the tank to the vaporiser must be stainless steel braided hose rated at 350 psi (2.45 bar). A hydrostatic relief valve of 375-500 psi (2.6-3.5 bar) discharge pressure rating must be installed in the liquid fuel line. Regulations in most areas require the hydrostatic relief valve to be located at the bulkhead fitting where the fuel line comes through the vehicle floor.

Refuelling of LPG is carried similar to liquid fuels but features of the fill probe and filler valve are different than that used for gasoline or diesel fuel because liquid under pressure is involved. Refuelling station technology for servicing large numbers of vehicles has not been widely developed in the US, but several European cities have large transit programs powered by propane.

Safety with LPG

Safety is an issue with LPG use; however, LPG is widely used in heating applications, and standards for storage and distribution already exist. The hazard associated with on-board storage should be similar to that of gasoline, especially if reinforced cylinders similar to CNG tanks are used.

Propane fuel systems have many built-in safety features. Propane automotive fuel systems generally maintain their integrity in severe collisions and do not permit massive leaks; however, minor damage of valves on the fuel container can cause leaks, which are difficult to stop. Accident statistics, although limited, indicate that propane is as safe as gasoline.

LPG is about twice as heavier than air, and unlike NG does not disperse easily in air. Its flammability limits (2.1-9.5vol.%) and auto ignition temperature (450°C) are also lower than NG. These make propane a dangerous fuel when handled carelessly.

LPG Vehicle Standards

In Canada, federal regulations governing the fuel system integrity of vehicles originally equipped to use gaseous fuels came into effect in 1983. These regulations govern the design and manufacture of vehicles fuelled by either propane or natural gas, and which are intended for use on road. The regulations require that propane-fuelled vehicles be subjected to barrier collision test requirements without leakage of fuel, or alternatively they comply with Canadian Gas Association (CGA) codes governing the fuel system components and their installation. Later versions of CGA codes are expected to adopt more stringent hose requirements for propane fuel system.

In New Zealand, NZS 5422: Part2: 1987, which describes code of practice for the use of LPG and CNG fuels in IC engines, Part 1 LPG fuel, is used for LPGVs.

In India, presently, the Government is preparing regulations for installation of LPG conversion equipment.

Electric Vehicles

Batteries And Fuel Cells

Two important factors distinguish batteries and fuel cells from IC engines:

1) electrochemical reactions take place at relatively low temperatures compared to hydrocarbon-air combustion processes, and
2) power plant efficiencies do not decrease drastically at part-loads as they do in homogeneous charge vehicles. The lower reaction temperature means that nitrogen and oxygen do not mix at high temperatures, and hence NOx emissions from fuel cells are non-existent.

The second point is mentioned because some of the gaseous and/or fumigated alternative fuel heavy-duty engines use throttling for power control. Electric vehicles are often classified as zero emission vehicle because no pollutants are emitted directly from the vehicle. This does not imply they are zero emissions overall, for only that the emissions are displaced from congested urban areas to (hopefully) remote locations. In case of rechargeable batteries, this applies to power plant emissions; in case of fuel cells commercial hydrogen production results in substantial copious CO_2 emissions.

The main limitations of battery technologies have been, and continue to be, range, size, weight, and cost, with power output and recharging times sometimes also an important criteria. Fuel cells tend to be limited by many of the same factors, with on-board hydrogen storage and/or generation becoming an additional factor. Three key specifications tend to determine whether batteries and fuel cells are appropriate for transportation uses:

i) energy density (specific energy),
ii power density (specific power), and
iii) life.

Specific energy determines the amount of energy which can be stored in a given size system, and hence the range of the vehicle and the size and weight of the power plant. Specific power determines the maximum rate at which a given amount of energy can be supplied, and hence the number of cells required to meet peak power requirements. This typically limits vehicle acceleration, and can be just as important as range in determining power plant requirements. In the case of batteries, lifetime represents the number of recharges that can be made before the battery requires replacement, for instance, 20% of its ability to store energy (cycle life); in the case of fuel cells, lifetime is generally limited by contamination of catalysts, which depends on fuel purity. The different types of batteries and their developing agencies are given in Table.

Basic Types Of Batteries & Their Developing Agencies

BATTERY	DEVELOPER
Lead Acid	Chloride GB, Varta Germany, Delco Remy USA, Johnson Controls USA, Yuasa Japan, Electroscope USA, RWE Germany
Nickel Cadmium	SAFT France, Hoppecke Germany, Japan Storage, Yuasa Japan
Nickel Iron	Eagle Picker USA, Farukawa Japan, SAFT France
Nickel Zinc	Yuasa Japan, Istocknick Russia
Zinc Bromine	Meidensha Japan, SAE Austria, Johnson Controls USA
Sodium Sulphur	Yuasa Japan, RWE (chloride) GB, ABB Germany
Sodium Nickel Chloride	AEG Germany, Beta R&D GB

Lithium (all types)	Valency USA, Hydro-Cubec Canada, Harwell Lab GB, US Dept. of Energy, Innocel Energy Denmark, Yuasa Japan, Varta Germany, SAFT France, Eagle Picher USA, ENEL Italy
Nickel Metal Hydride	Ovionic USA, Yuasa Japan, Matsushita Japan, SAFT France, Varta Germany, Eagle Picher USA
Zinc Air	Dreisbach Electromotive USA
Aluminium Air	Alupower

When one considers the entire weight of the power plant plus fuel storage plus drive train, one sees that battery technologies generally suffer from low specific energies (and hence, reduced vehicle range) and to a lesser extent, low specific powers (and hence slow acceleration), as compared to IC engines. Fuel cells show the reverse trends, i.e. low specific powers and to a lesser extent, low specific energies. Note also that a rather large percentage of these technologies operate at above ambient temperatures, and therefore require warm-up periods before they can be driven. The length of warm-up periods range from two to nearly thirty minutes, depending on the technology, even when ambient conditions are near 21°C.

The values for specific energy and specific power for batteries are typically measured at a given steady-state power output with the battery fully charged. For many systems, as the percent discharge increases, the specific power output also decreases. Conversely, as the discharge rate increases, the available specific energy decreases. This results in a decreased vehicle range as speed increases. The effect is even worse for transient driving cycles, since vehicle acceleration cause peaking in the required power outputs. The use of regenerative braking, which recovers some of the vehicle kinetic energy and uses it to recharge the batteries, typically extends the range on the order of 10%. Cold weather presents yet another problem: as the temperature drops, so does the specific energy, which the battery can store, and hence vehicle range. Factor of two reductions are not uncommon.

Finally, batteries must be recharged. For fleet vehicles with set schedules and well-defined ranges, this can generally be done overnight, with the advantage of off-peak electrical rates. A problem arises for any case where extended operation is desired; one must either 1) exchange batteries, 2) exchange electrodes/electrolytes, or 3) supply electrical energy via power cables to the vehicle or via inductive coupling from coils buried in the roadway. First option poses problems because batteries deteriorate with age, and deep discharges can severely decrease battery life for some types, e.g. lead-acid. This, along with space requirements for storage and recharging of batteries at service stations, pretty much rules out the first option for personal vehicles, although not necessarily for fleets. The second option, replacing electrodes or electrolytes, is somewhat less problematic, although significant replacement inventories would be required and one would have to have a program in place for recycling. The last option has been proposed for Los Angeles area - this obviously requires both specialised vehicles and specialised roads, both of which would be expensive. Moreover, the electricity to power the vehicles would now be required during peak utility load times.

Fuel cells have several advantages over batteries. First of all, the energy density can be increased by increasing the size of the fuel tank, since the specific weight (kg/W) of the fuel plus fuel tank are typically much less than the fuel cell itself. Secondly, fuel cells can be quickly 'recharged' by refilling the fuel tank. Because of the difficulty of on-board hydrogen storage, a good deal of work has gone into developing reformers to convert methanol or other liquid hydrocarbon fuels into mostly H_2 and CO_2. While this alleviates the hydrogen storage problems, it adds a complicated, heavy, relatively large reformer which is about 75% efficient, and often does not follow transients well, and generally requires 10-30 minutes to warm up, and which now produces some CO and HC emissions. In addition, maintenance of the reformer can be a significant task.

Phosphoric acid fuel cells (PAFC) are fairly well developed and are being demonstrated as part of a hybrid PAFC-battery electric power plant for a small bus. This is the only fuel cell technology, which has demonstrated the ability to run on hydrogen from reformed hydrocarbon fuels for long periods without degradation. Disadvantages include the use of noble metal catalysts, slow start-up (200°C operating temperature), large volume, and weight. Proton exchange membrane (PEM) fuel cells (also known under the trademark of solid polymer electrolyte, or SPE, fuel cells) require purer grades of hydrogen (typically in excess of 95% H_2), and only ppm concentrations of CO, which can poison the noble metal catalyst. Noble metal loading are currently about ten times higher than those required for PAFCs, which adds a significant cost to the cell. However, PEM fuel cells offer fast start up, rapid response, good power density (relative to other fuel cells), long life, and good low-temperature performance. Ballard Power Systems of Canada is participating in a 9.8 m (32 ft) bus demonstration project in which 120 kW will be supplied by a group of 5 kW PEM stacks. The current cost of such a system is not commercially viable ($10,00/kW), but costs should fall dramatically if a significant market develops and mass production becomes possible. Therefore this technology is still some years away from large-scale use.

Other promising fuel cell technologies have also been proposed for electric vehicles, but have not yet been proven. Alkaline fuel cells (AFC) have power densities (60-250 W/kg), can be made without noble metal catalysts, and have rapid response and start up capabilities, but are sensitive to poisoning by CO_2. Thus, operation on reformed fuels is not possible. Several vehicle demonstrations were carried out in the 1960s, and the technology has found fairly extensive application in spacecraft power generation. Finally, high temperature (800-1000°C) solid oxide fuel cells (SOFC) similar to those being developed for stationary utility applications, are also being considered for vehicle use. This technology is still many years away: safety hazards, warm up time, and start/stop operation difficulties associated with vehicle applications have not yet been addressed.

Ethanol

Ethanol has attracted considerable attention as a motor fuel due to the success of the Brazilian Pro-alcohol program initiated in 1975 as a response to the global oil crisis of the 1970s. Despite the technical success of this program-around one-third of Brazil's 12 million cars are powered by ethanol fuel- the high cost of producing ethanol (compared with hydrocarbon fuels) has required large direct and indirect subsidies amounting to over U. S $ 1.0 billion per annum.

As the next higher of the alcohols in molecular weight, ethanol resembles methanol in most combustion and physical properties, except that it is considerably cleaner, less toxic and less corrosive. In addition ethanol has a higher volumetric energy content. Ethanol or grain alcohol can be produced by processing agricultural crops such as sugar cane or corn but it is more expensive to produce than methanol and requires large harvest of these crops and large amounts of energy for its production. This can lead to environmental problems, particularly soil degradation (OECD 1995).

Ethanol is most conveniently manufactured in one of the two forms: a 95 percent mixture with water, known as hydrous or hydrated ethanol, and 99.5 percent mixture with benzene, known as anhydrous or absolute ethanol. Fuel grade ethanol, as produced in Brazil, is manufactured by distillation, and contain several parts water (by volume).

When ethanol is blended with ordinary gasoline in proportions up to 22 percent, the resulting mixture known as gasohol, may be burned in ordinary spark-ignition automobile engines. Pure ethanol is used extensively as a blend stock for gasoline in Brazil, South Africa, and the United States. While ethanol is completely miscible in gasoline, the presence of even a small amount of water can result in phase separation. Hence, only anhydrous ethanol is used in the gasohol mixture. Gasohol blends from azeotropes which cause a disproportionate increase in vapor pressure together with a reduction in front-end distillation temperature.

This effect varies with ethanol concentration but in particularly significant at low-ethanol concentration upto around 10 percent. Such an increase in vapor pressure can cause hot driveability problems in vehicles. As a consequence, the base gasoline must be tailored to accept ethanol. Compared to the base gasoline, gasohol has a higher RON while the MON is about the same. Under low speed and acceleration conditions, road performance of gasohol is generally similar to or better than gasoline with the same octane quality. The high-speed, high load performance of gasohol however, tends to be inferior to that of an equivalent octane quality gasoline (Hutcheson 1995; Weiss 1990)

Engine technology and performance. Anhydrous ethanol has about 65 percent of the heat energy content of an equal volume of gasoline. However, the physio-chemical and combustion characteristics of alcohol permit it to achieve a higher thermal efficiency in an internal combustion engine. Up to proportion of about 20 percent anhydrous ethanol this increase in efficiency compensates almost fully for the slightly lower energy content of gasohol blend, so that there are no noticeable mileage penalties in substituting gasohol for gasoline. The fuel economy of vehicles using gasohol is dependent mostly on the engine type and driving conditions Dynamometer test results and road trials on non-catalyst cars show no change in fuel economy for ethanol content up to 5 percent volume. For closed loop catalyst-equipped cars there is a noticeable reduction in fuel economy associated with gasohol (Hutcheson 1995).

A special engine is required to burn mixtures richer than 22 percent ethanol " All alcohol" cars bearing such engines normally burn hydrates ethanol and require special adaptations mainly to prevent corrosion. These adaptation costing about US$500 per vehicle, include coating the insides of the fuel tank with tin, the fuel lines with copper and nickel, and the carburetor with zinc. The pistons also have to be strengthened to permit the use of higher compression ratios possible with the use of alcohol.

Such engines cannot compensate for the lower energy content of a given volume of ethanol compared to gasohol, even though their higher compression ratios achieve even higher thermal efficiency than those with gasohol in an ordinary engine. About 1.25 litres of pure hydrated alcohol give the same mileage as one litre of gasoline- a significant fuel economy penalty. Ethanol-powered cars tend to be poor starters in cold weather (Homewood 1993; Weiss 1990). To ease this problem, flexible-fuel vehicles have been developed in the United State s to operate on any blend of gasoline and ethanol up to 85 percent ethanol by volume. Emissions, By blending 22 percent anhydrous ethanol with gasoline to produce gasohol, Brazil has been able to eliminate completely the requirement for lead as an octane enhancer. Emissions from a sample of non catalysts Brazilian vehicles using ethanol and gasohol fuels are compared.

Emissions from ethanol-powered vehicles are not as well characterized as for other alternative fuels, but are believed to be high in unburnt ethanol, acetaldehyde (more than 12 times compared to gasoline vehicles), and formaldehyde. These emissions, however, can be effectively controlled with a catalytic converter. Ethanol-run vehicles generate 20 to 30 percent less CO and roughly 15 percent less NOx compared to gasoline-fueled vehicles. As the vapor pressure of pure ethanol is much lower than gasoline, evaporative emissions from ethanol powered vehicles are significantly lower. The low vapor pressure of ethanol, however, could cause cold-starting problems in colder climates and result in higher cold start exhaust emissions. Emissions of benzene 1.3 butadiene and particulate matter are also substantially lower for ethanol-powered vehicles (Homewood 1993; Pitstick 1993).; Limited ozone modeling of speculated emissions from ethanol-fueled vehicle suggests that the ozone-forming potential of neat ethanol is less than that of gasoline and diesel, about the same as that of reformulated gasoline, and higher than that of LPG, methanol, and CNG.

Some of the limitations of pure ethanol such as cold start problems and the need for dedicated OEM vehicles can be addresses by blending ethanol with gasoline to form E85 fuel (85 percent ethanol and 15 percent gasoline) for use in dedicated variable fuel vehicles (VFVs)/ Flexible Fuel Vehicles (FFVs). The gasoline component vaporizers more readily than ethanol, and makes cold starting possible. But ethanol blended with gasoline diminishes some of the inherent such as low volatility; no benzene in fuel, and lower CO emissions. FFV/VFVs running on ethanol-gasoline blends are likely to have higher evaporative emissions (with greater ozone-forming potential) than gasoline vehicles as well as increased emissions of CO and benzene (Pitstick 1993; OECD 1995).

A limited investigation by AQIRP to compare the exhaust emissions of catalyst-equipped FFV/VFVs operated on E85 fuel and gasoline showed that NOx emissions were significantly reduced with E85, by as much as 50 percent. Total toxic emissions were two or three times greater with E85 compared to gasoline due to a large increase in acetaldehydes. Formaldehyde emissions with E85 also increased to twice the level of gasoline while benzene and 1.3 butadiene were greatly reduced. CO emissions also increased with E85. Energy specific fuel economy changed less than one percent while volumetric fuel economy was 25 percent lower with E85 (AQIRP 1995d).

Safety, In much the same manner as other fuels, ethanol present a fire hazard if handled improperly. The explosion hazard of ethanol is rated as moderate when exposed to flame. Although ethanol is less volatile than gasoline, it is considered to be more explosive. Vapors that form above a pool of ethanol are potentially explosive. Repeated overexposure to ethanol will cause redness and irritation of the skin. The fuel is not considered to be particularly hazardous and inhalation of small amounts of ethanol vapor are not considered toxic. Excessive ingestion of ethanol vapor is dangerous and will require medical care. As an intoxicating beverages, ethanol premedical care.

As an intoxicating beverage, ethanol presents a special supervisory challenge. Supplies of ethanol must be carefully monitored (Maggio and other 1991).

Fuel prices and supply: Ethanol is produced primarily by fermentation of starch from grains or sugar from sugar cane. As a result the production of ethanol for fuel competes directly with food production in most countries. The resulting high price of ethanol (ranging from US$0.26-0.41) per liter equivalent to US &0.40 - 0.65 per liter of gasoline on an energy basis) has effectively rules out its use as a motor fuel except where (as in Brazil and the United States) it is heavily subsidized.

The Brazilian pro-alcohol program has attracted worldwide attention as the most successful example of implementing an alternative fuel program. Despite the availability of a large and inexpensive biomass resource, this program has required massive government subsidies for its viability. To address a severe shortage of ethanol in 1990, a blend of methanol, ethanol, and gasoline was developed for use in dedicated alcohol vehicles. Because of earlier disruptions in supply of fuel alcohol and reductions in direct, the share of ethanol-powered cars in new car sales in Brazil dropped to less than one percent in 1996.

Biodiesel

Vegetable oils considered as possible substitutes for diesel fuel can be produced from a variety of sources including rape (also known as canola or colxza), sunflower, sesame, cotton, peanut, soya, coconut, and oil palm. Vegetable oils have been promoted as possible replacement for diesel fuel because of their good ignition quality. However, their high viscosity (about 20 times that of diesel), which results in poor fuel atomization, fuel injector blockage, ring sticking, and contamination of lubricating oil, makes them best used as blends with diesel fuels in mixtures of up to 50 percent.

When used in blends, vegetable oils produce higher emissions of CO, HC, and PM as compared to pure diesel fuels (OED 1995; IEA 1993). Biodiesel is produced by reacting vegetable or animals fats with methanol or ethanol (trans-esterification to produce a lower viscosity fuel (oil ester) than is similar in physical characteristics to diesel, and can be used neat or blended with Petroleum diesel. Care must be exercised to completely remove the glycerin residues produced as a by-product. Engines running on neat Biodiesel or blended with Petroleum diesel tend to have lower black smoke and CO emissions but higher NOx and possible higher emissions of particulate matter. Other advantages of biodiesel include high cetane number, low viscosity, very low sulfur content, and the fact that is a renewable resources. Disadvantages include high cost (U.S $ 0.39 – 0.91 per liter before tax) and reduced energy density (resulting in lower engine power output). The effects of biodiesel on engine performance and emissions over a long period in actual service are not well documented.

Although the use of vegetable oils in diesel engines dates to 1900, the modern use of biodiesel fuel started in the early 1980's which vegetable oils – soybean oil, sunflower oil, corn oil, cottonseed oil, and rapeseed oil – were first used as experimental substitutes for diesel fuel in farm tractors. Interest in biodiesel plunged along with the price of oil in 1983. Recently, interest in cleaner air and renewable energies has led to renewed private and public focus on biodiesel fuel. A small-scale program to convert palm oil to methyl ester for use in taxis has been successful in Malaysia (Ani, Lal, and Williams 1990).

Properties. The properties of biodiesel are compared with those of diesel fuel in table 5.18. The important properties include viscosity, which indicates the flow characteristics of the fuel; pour point, which describes the cold-flow characteristics of the fuel; alkaline content or acid number (soap content), which measures the amounts of deposit-forming sodium and potassium in the fuel, sulfur and nitrogen contents, which affect the amount of PM and NOx emissions formed; and iodine number, which indicates the fuel stability (level of saturation of the fuel). Biodiesel has many physical properties (such as the cetane number) quite similar to conventional diesel. It differs from ordinary diesel fuel in terms of its lower energy content (due to its higher oxygen content), which reduces engine power output; it has a higher density and a lower volatility compared with diesel, and a stronger affinity for water; and it contains no aromatics and only trace amounts of sulfur. Both the low sulfur content and the significant oxygen content should help to reduce soot formation and emissions from biodiesel. Low volatility and poor cold flow properties could constrain the use of biodiesel in colder climates. Being hydrophilic, biodiesel requires special car in storage. It is fully biodegradable – 98 percent of the spilled material is broken down within three weeks and the remainder within five weeks (Hutcheson 1995).

Owing to the high price of conventional diesel fuel in Europe (U.S $ 3 to U.S $ 4 a gallon including taxes), a sizeable number of diesel vehicles in Austria, Belgium, France, and Italy run on biodiesel fuel made primarily from rape-seed oil (U.S DOE 1994). In the United States biodiesel fuel has been used mostly in demonstration projects in which it is blended with conventional diesel fuel to reduce sulfur and particulate emissions from diesel vehicles Some limited demonstration projects using neat biodiesel in diesel vehicles have also been initiated (U.S DOC 1994; Reed 1994).

Property	Methyl ester (biodiesel)	Common diesel fuel
Viscosity @ 40^{0}C	4.1-4.5	2.3-2.8
Pour Point, ^{0}C	-4	-29
Cloud point, ^{0}C	-6.7	-20
API gravity @ 15.6 ^{0}C	27.8	35.5
Net heat of combustion, MJ/Kg	37.1-37.	42.8
Cetane number	46-52	47-51
Oxidation stability, mg/1000ml	0.06	0.11
Carbon, % weight	77-78	86
Hydrogen, % weight	11-12	13
Oxygen, % weight	10-12	0
Sulfur, % weight	0.002-0.0	0.15-0.2
Water, mg/kg	500	50
Nitrogen, ppm	29	0
Total acid no., mg KOH/g	0.14-0.45	n.a
Flash point, ^{0}C	152-171	61-92
Iodine value 133		n.a.
Density at 15^{0}C, (Kg/m^3)	882-885	850-860
Distillation		
T10, ^{0}C	334	227
T50, ^{0}C	336	283
T95, ^{0}C`	345	348

Engine emissions, performance, and durability. Results from laboratory studies (Alfuso and others 1993; Pagowski and others 1994; Scholl and Sorenson 1993; Tritthart and Zelenk 1990; Ziejewski, Gettler, and Pratt 1986 generally agree that blended or neat biodiesel has the potential to reduce diesel CO emissions (although these are already low), smoke opacity, and HC emissions particularly polycyclic aromatic hydrocarbons. But these studies show an increase in NOx emissions for biodiesel fuel compared with diesel fuel at normal engine conditions. The higher NOx emissions from biodiesel fueled engines are partly due to the higher cetane number of biodiesel, which causes a shorter ignition delay and higher peak cylinder pressure. Some of this increase may be due to the nitrogen content of the fuel. The reduction in smoke emissions is believed to be the result of better combustion of the short-chain hydrocarbons found in biodiesel, as well as the effects of the oxygen content. Other data have shown that mixing oxygenates with diesel fuel helps reduce smoke.

Several European studies have also investigated the emissions performance of rape-seek methyl ester (RSME) as a neat fuel or as a blend with conventional diesel fuel up to 20 percent. As reported by Hutcheson (1995), RSME compared to conventional diesel fuel has the following emission characteristics;

Lower HC and CO emissions. Consistently higher NOx emissions.

Generally lower particulate emissions particularly under high-speed and moderately high-load conditions but a dramatic increase under low-speed and light-load conditions (Cold ECE 15).

The increased NOx emissions may be attributed to increased combustion temperatures due to better availability of oxygen within the combustion zone. This phenomena may also influence the formation of soot.

As for the HC emissions, research by School and Sorenson (1993) shows a reduction in HC emission when biodiesel is used. There is some concern, however, that the organic acids and oxygenated compounds in biodiesel may affect the response of the flame ionization detector, thus understanding the actual HC emissions. Scholl and Sorenson also mention that the behavior of these compounds with respect to adsorption and desorption on the surfaces of the vas sampling system is unknown. Thus more studies are needed to understand the organic constituents in the exhaust from biodiesel fueled engines before firm conclusions can be drawn regarding the effects on HC emissions.

There is controversy concerning effect of biodiesel on particulate matter emissions. Alfuso and others (1993) report that some studies claim a reduction of particulate emissions when biodiesel is used, while some studies show an increase. Alfuso and others found that the particulate matter produced by diesel fuel in light-duty transient driving (ECE 15 testing cycle). This effect may depend on the selection of the injection timing. According to an analysis of particulate composition reported by Hutcheson (1995), soot emissions (insoluble) were significantly reduced with RSME but the proportion of the emissions composed of fuel-derived hydrocarbons (fuel soluble) condensed on the soot was much higher (a five to six fold increase compared to diesel). This suggests that RSME may not burn to completion as readily as diesel fuel. Although the total PM emissions for diesel (0.275 g/mile) were significantly higher than RSME (0.224 g/mile), the soluble organic fraction (16 percent) in diesel emissions was substantially lower compared to RSME (51 percent). In addition, a general trend toward lower emissions of PAH and aldehydes has been found with RSME, although in cold FTP and ECE tests, an increase in these emissions was observed.

In general, no engine, ignition system, or fuel injector modification is necessary for diesel engines to operate on biodiesel. However, the solvent characteristics of the fuel require the replacement of the hoses and fuel lines that contact the fuel. Furthermore, the work of Scholl and Sorenson (1993) has shown that a 5 degree retardation of injection timing is required to lower NOx emissions using biodiesel. Scholl's research also showed that the peak cylinder pressure and the peak rate of pressure rise were higher for biodiesel-fueled engines than for diesel-fueled engines. This suggests that biodiesel engine carrying higher stress than components engines using diesel, and this may affect their durability and reliability. These findings imply that some eking adjustments or modifications may be needed with the use of bio-diesel to optimize engine performance, emissions, and durability.

Research has shown that the combustion characteristics of biodiesel are comparable to diesel fuel (Scholl and Sornson 1993; Alfuso and others 1993), but the sodium and potassium atoms in biodiesel fuel can form deposits in the combustion chamber. AS these deposits build up, they can affect combustion characteristics, and influence engine performance and operability ad well as increase exhaust emissions. Substantial deposit build-up in the combustion chamber can also degrade engine durability.

Another common finding on the use of biodiesel as a vehicle fuel is that biodiesel tends to dilute engine oil. More frequent oil changes may be required with biodiesel fuel. Prolonged engine operation with diluted engine oil may cause the oil to break down and the engine oil may cause the oil break down and the engine to seize. Other concerns regarding the use of biodiesel fuel are that the vehicle is likely to have problems operating in cold weather, due to the fuel" relatively high cloud and pour point (Perkins, Peterson, and Auld 1991). Although pour point depressant and cold-flow improvers may help alleviate this problem, such additives might affect the biodegradability of the fuel, which is an important advantage of biodiesel (U.S DOE 1994).

Fuel cycle emissions and fuel cost. OECD/IEA (1994) includes a detailed evaluation of the economics of biofuels. The production of vegetable oil based biodiesel fuel involves plowing the ground (tillage), planting the crops (rape, soybean, sunflower, corn), and fertilizing and harvesting the crops. These processes require the use of motorized farm equipment, which produce exhaust emissions and use fossil energy. In addition, methanol or ethanol are needed in the transesterification process, and the emissions emitted to produce these compounds should be taken into account. In a life cycle study on rape seed oil and its esters, the German Federal Environmental Agency has noted that other factors such as odor generated by fuel combustion and large emissions of nitrous oxide (N_2O) in the production cycle render the use of this fuel less attractive (OECD 1995). Therefore the overall energy consumption and full fuel cycle emissions for biodiesel fuel might be as high as those from conventional diesel fuel. Thus biodiesel fuel might not be as attractive as other alternative fuels, such as natural gas, as a substitute for conventional diesel fuel.

The cost of biodiesel fuel is one of the principal barriers making it less attractive as a substitute for diesel. The cost of vegetable oils is U.S.$2-3 a gallon. If the credit for glycerol, which is a by-product of the biodiesel transesterification process and a chemical feedstock for many industrial processes, is taken into account, the cost of converting vegetable oils to biodiesel is approximately U.S $0.50 a gallon (Reed 1994). Thus the total cost for biodiesel fuel is U.S $ 2.50 – 3.50 a gallon. This is substantially higher than the cost of conventional diesel, about U.S $ 0.75 – 0.85 a gallon before tax. If waste vegetable oil is used, the cost of biodiesel could be reduced to about U.S $ 1.50 a gallon (Reed 1994). Since the heating value for biodiesel is less than that for diesel, more fuel must be burned to provide the same work output as diesel. This adds further to the cost disadvantage of biodiesel. Considering these limitations and the availability of less greenhouse gas intensive alternatives at similar cost, the use of rape-seed oil or its derivative cannot be justified from the standpoint of environmental protection.

Hydrogen

Although hydrogen has the potential to be the cleanest-burning motor fuel, it has many properties that make it extremely difficult to use in motor vehicle. Hydrogen's potential for reducing exhaust emissions stems from the absence of carbon atoms in its molecular structure. Because of the absence of carbon, the only pollutant produced in the course of hydrogen combustion is NOx (of course of the absence of carbon, the only pollutant produced in the course, the lubricating oil may still contribute small amounts of HC, CO and PM). Hydrogen combustion also a produces no direct emissions of CO_2. Indirect CO_2 emissions depend on the nature of the energy source used to produce the hydrogen. In the longterm event of drastic measures to reduce CO_2 emissions (to help reduce the effects of global warming), the use of hydrogen fuel produced from renewable energy sources would be a possible solution. Mackenzie (1994) provides an excellent review of the prospects and potential of hydrogen vehicles.

Fuel supply: Hydrogen suffers from two major problems; production and storage. Hydrogen is not a fossil fuel, and is not found in significant quantities in nature. It therefore must be manufactured. Hydrogen can be produced by a number of methods, of which the most common are electrolysis of water, reforming natural gas, or partial oxidation and steam reforming of other fossil fuels. (It should be noted that hydrogen produced by reforming fossil fuels does not reduce greenhouse emissions because the CO_2 emitted in the reforming process in comparable to that what which would have been emitted if the fossil fuels were used directly in a vehicle). The most economical source of hydrogen is from reforming natural gas. Hydrogen is currently manufactured in limited quantities as an industrial chemical, as rocket fuel. And in larger quantities for use in Petroleum refineries and chemical plants. Electrolysis is sometimes used to produce high-purity hydrogen for special purposes but cannot compete economically with natural gas reforming for large-scale production.

Advocates of a future "sustainable" hydrogen economy have proposed many ideas for renewable sources of hydrogen. These potential future sources include electrolysis of water using large-scale, cheap photoelectric or solar-electric systems, or cheap abundant, and environmentally benign hydroelectric or nuclear-electric plants. In the nearer term, renewable hydrogen could be produced from biomass using any of several processes. It is unclear, however, why hydrogen would be produced from biomass instead of easier-to-handle fuels such as methanol, ethanol, or methane. Hydrogen also could be produced on a large scale through in-site gasification of coal, but this would result in large emissions of CO_2, as well as localized environmental damage due to subsidence, possible groundwater contamination, and so on.

In order for hydrogen to become available as a motor fuel, significant investments would be needed in the infrastructure for the delivery, storage, and dispensing of the fuel. These investments are unlikely to occur as long as the costs of hydrogen production and use exceed those of other available motor fuels.

Fuel storage: Hydrogen can be stored on-board a vehicle as a compressed gas a liquid, or in chemical storage in the form of metal hydrides. Hydrogen also can be manufactured on-board the vehicle by reforming natural gas, methanol, or other fuels, or by the reaction of water with sponge iron. In the latter case the sponge iron is oxidized and must be regenerated periodically. Compressed hydrogen occupies roughly fourteen times the space of an equivalent amount of gasoline. Thus compressed gas storage would add significant bulk and weight to a vehicle – about three times the bulk and weight of a equivalent volume of compressed natural gas. Vehicle range and refueling frequency would be significant constraints.

Hydrogen can also be stored on-board a vehicle as a liquid, but this requires that it be cooled below its boiling point of –423^{0}F (at 36^{0}F above absolute zero, the lowest boiling point of any substance except helium). Even as a liquid, however, hydrogen would still occupy roughly four times the volume of an equivalent amount of gasoline. Furthermore, the energy required for refrigeration to liquefy the hydrogen could easily exceed the energy value of the fuel itself, resulting in an extremely inefficient system.

The third option for hydrogen storage is in the form of metal hydrides. Current metal hydride storage systems are heavy and bulky, but less so than the storage cylinders required for compressed hydrogen (Billings 1993). This is considered the leading technology for storing hydrogen for vehicular use. Research is under way in several countries to improve these characteristics, and some vehicle manufacturers in Germany and Japan are developing prototype vehicles.

Engine and vehicle technology: Aside from its low emission characteristics, hydrogen is a poor fuel for internal combustion engines. This is due to it spoor knock resistance compared with other gaseous fuel (such as natural gas or propane). Hydrogen-fueled spark-ignition engines are susceptible to detonation or knock, which limits the compression ratios that can be used and thus the efficiency attainable. Rotary engines have met with limited success in past engine research. Some research also has studied the possibility of using hydrogen in an ignition-assisted diesel engine, which would avoid the problem of knock.

The most promising approach to the use of hydrogen for vehicular propulsion is to react it with oxygen in a fuel cell to supply electric energy to a hybrid-electric vehicle. Fuel cell care extremely efficient compared with internal combustion engines and hydrogen-air fuel cells produce no pollutant emissions. Thus this system would be similar to a battery-electric propulsion system, except that the fuel cell and fuel supply would require significantly less weight and bulk than a battery system for the same energy storage. The fuel could be supplied and stored as hydrogen or could be produced on-board by the reformation of methanol, natural gas, or by the reaction of water with sponge iron. Producing hydrogen for the fuel cell by reforming hydrocarbon fuels may be especially attractive – both because of the increased case of handling compared with pure hydrogen and because this approach could continue to use the fuel supply infrastructure already in place.

Research and development work on hydrogen-powered vehicles is progressing in several countries including Canada, Germany, Japan and the United States. One of the most promising developments is a prototype 60 passenger hydrogen bus produced by Canada's Ballard Power Systems, a leader in fuel cell technology. The proton-exchange-membrane (PEM) fuel-cell bus has been put in service in Vancouver, Canada. It travels at normal operating speeds and can go more than 400 km on a single hydrogen charges. The Ballard prototype, however, costs three times as much to operate as a comparable diesel bus. Economies of scale and improved fuel cells might make it competitive with conventional diesel buses beyond 2000 (AASHTO 1996; MacKenzie 1994).

Emissions. Hydrogen has the potential to be the cleanest – burning motor fuel. With the virtual elimination of CO and HC exhaust emissions, only nitrogen oxide emissions would be present in any significant quantify in the vehicle exhausts; NOx emissions from existing prototype hydrogen vehicles are similar to those from gasoline vehicles (Kukmkonen and Shelef 1994).

Economics. Due to the high cost of production, lack of storage reserves, and the large quantities required for hydrogen to be used as a motor fuel, it is unlikely that hydrogen will be as cost-effective fuel in the near future. New production and storage techniques will be required before hydrogen fuel becomes economically – much less technology – feasible.

ANNEXURE II

CASE STUDIES

Ethanol in Brazil

Ethanol as a neat or as a additive, has been use extensively in Brazil, and also in the United States, Sweden, Kenya, South-Africa and Zimbabwe. The Brazilian experience has been extensively researched and shows the critical importance of consistent government support for the promotion of alternative fuel technologies.

Brazil has used small amounts of ethanol for decades as an enhancer in gasoline and to provide a by-product market for the sugar industry. In the late 1970s, rising oil prices coupled with high interest rates and a crash in the world sugar market created a foreign debt-service crisis. This compelled the Brazilian government to look at options to reduce Petroleum imports.

During 1975-79, the government sponsored pro-alcohol program increased the ethanol percentage in gasohol to 20percent (and after 1984 to 22 percent). From 1979 to 1986, Pro-alcohol promoted dedicated ethanol vehicles and in 1985, ethanol vehicles comprised 95 percent of new car sales. From 1986 onwards, however, alcohol production could not keep pace with the demand. This reflected mainly a lag between sugarcane and fuel alcohol prices. Brazil produced 11.7 million cubic meters and consumed 12.5 million cubic meter of fuel alcohol in 1988. In the first phase of Pro-alcohol program, the government provided up to 75 percent subsidies for ethanol producer investments and assured a 6 percent return on investment. At this stage, however, car manufacturers were unwilling to produce ethanol-only vehicles. During the second phase consumer incentives were introduced for vehicle purchases, and the pump price of ethanol was guaranteed to be no more than 65% that of gasoline. The car industry was encouraged by the government's commitment and started producing ethanol vehicles. Despite the poor redesign and inadequate performance of alcohol-powered vehicles initially, the consumer take-up was massive.

The world sugar market began improving in the late 1980s , and the government increased the ethanol price from 54 percent of gasoline price toward the 65% limit. After 1989, this ratio was further raised to 75%. In addition, credit subsidies for distilleries were suspended.

The combination of vigorous demand and a production level which repeatedly fell short of the projections and commitments made by distilleries led to the depletion of strategic inventories in 1988 and to disruptions in fuel alcohol supply in the following years. In 1990 a new fuel blend, referred to as MEG (METHANOL-ETANOL-GASOLINE) WAS INTRODUCED IN Sao Paulo and some cities in the State of Minas Gerais, made up of volumetric blend of about 60% hydrates alcohol, 33% methanol, and 7% gasoline, to substitute for neat ethanol in alcohol-powered vehicles (box 5.5). The disruption in alcohol fuel supply produced a rapid fall in purchases of ethanol vehicles. The government later regained public confidence by restoring incentives but pro-alcohol's credibility was irreparably damaged. By 1996 the share of ethanol cars had dropped to less than one percent of new car sales.

The opportunity cost of ethanol production in Brazil was claimed to be about $30-35/toe. This would require sugar prices below US$100 per ton. Sugar prices often have exceeded US$200 per ton and independent analyses have put the Brazilian ethanol cost at nearer U S $70/toe. At U S$0.43 per liter this exceeds the net-of-tax price of gasoline in most countries by a large margin. The economic subsidy attributed to the alcohol fuel program in 1995 was about US$1.9 billion (alcohol fuel consumption of 12.3 billion liters and an estimated subsidy of US$ 0.15 per liter).

Although an outstanding technical success, the Pro-alcohol program became an economic liability when the world energy prices plunged in mid-1980s. Oil prices would have to return to US$25-30 a barrel for the program to cover even the operating costs making it a costly insurance policy against an unlikely contingency. Pro-alcohol offered extremely generous investment incentives and price guarantees to expand sugarcane production and distillery capacity. These arrangements, however, placed a heavy implict tax on the Brazilian motorist (compared to the price of imported gasoline), and encouraged the production of alcohol-fueled cars well past any possible economic justification. With ethanol production costs US$ 30-40 per barrel (159 liters) and no immediate risk of a hike in world oil prices, it is quite likely that production of ethanol cars may cease by year 2000 with ethanol becoming simply a gasoline additive. Until then, there remains of fleet of about 4.5 million ethanol fueled cars in Brazil that will continue to require a steady and reliable supply of fuel alcohol.

Compressed Natural gas in New Zealand

The New Zealand government launched a CNG program in 1979, aiming to convert 150,000 vehicles to CNG by the end of 1985. By 1986, 110,000 vehicles (11 percent of all cars and light trucks) had been converted, and New Zealand had 400 falling stations dispensing CNG. In 1979, CNG sold for NZ$0.29 per liter compared to NZ40.42 per liter for premium gasoline. The price advantage for CNG peaked in 1984 when CNG cost about 40% the price of gasoline. Following deregulation of fuel prices in 1986, gasoline prices fell more rapidly in real terms than CNG prices, significantly narrowing the price difference between the two fuels. Incentives were provided in the form of vehicle conversion grants. The cost of conversion at the time was about NZ$1,500 (US$750 in 1984 prices), of which the government provided NZ$150 initial take-up was poor, but it was improved in late 1980 by an increase in the grant to NZ$200 and increased subsidies to fuelling stations, along with tax benefits to consumers. The average payback period for car conversion was about two years. Motorists, however, were reluctant to convert to the new technology and were concerned about fuel availability. Some poor conversions contributed to consumer doubts. A large increase in governments support in 1983 included a low-interest loan for conversions,

The increase in conversions was halted in 1985 when a new administration reduced support for the program. The conversion rate fell from 2,400 a month in 1984 to 150 a month in 1987. By 1988, sales of conversion kits had slumped to levels below the earlier years of the program.

CNG Argentina: An Alternative Fuel for the Buenos Aires Metropolitan Region

In 1985 a program of tax exemptions was introduced in Argentina to promote the replacement of Petroleum fuel by compressed natural gas (CNG). The program was quickly adopted by mid-sized trucks and taxis. By the end of 1994, 210,000 vehicles in the Buenos Aires Metropolitan Region had been converted to the CNG usage. Of the nearly 40,000 officially-registered taxis, about 65% use CNG, with the remainder running on diesel; of the 150,000 registered buses, only 300 run on CNG. The CNG program has substituted for about 12% of diesel fuel use in the Buenos Aires Metropolitan Region. This translates into a 6 percent reduction in particulate emissions.

CNG fueled are preferred by taxi owners because the nominal cost of CNG (US$)>26% per cu.m) is lower than diesel (US$0.27 per liter) and is substantially below the price of gasoline (US$0.81 PER LITER). CNG is supplied to gas stations at a price of US$ 0.13 per. Cu.m., compared with US$0.21 per liter for diesel. In addition, a new CNG taxi is 30 to 35% less expensive than a new diesel fueled taxi.

Despite the fuel price advantage, the potential for switching buses to CNG seems limited, mostly due to the inconvenience associated with refueling a bus with CNG during the day takes about 15 minutes with a fast fueling pump and 20 minutes or more with a normal pump. During the evening hours. When pressure is higher, tanks are filled within 8 minutes.

A CNG station, including compressors, requires an investment of about US$ 1.5 MILLION. In addition, CNG buses tend to be more expensive than diesel-fueled buses: the price of a new diesel bus is about US$85,000 compared with US$90,000 for a new CNG bus. CNG vehixles are some what less fuel efficient than diesel and gasoline fueled vehicles, due to the extra weight of the gas cylinders.

CNG-fueled vehicles emit no lead and produce fewer NOx, CO and HC emissions than gasoline-fueled vehicles. There is concern about possibly higher NOx emissions from burning CNG compared with conventional fuels under real-life operating conditions. On balance, however, there appears to be a grater health risk attributable to lead and particulate than NOx, CO, or HC in Buenos Aires. Thus until further evidence becomes available, it is appropriate to regard CNG as an environmentally cleaner fuel and to signal this virtue through appropriate pollution-based fuel tax differential on both gasoline and diesel.

Electric Vehicle Program for Kathmandu, Nepal

Kathmandu suffers from severe air pollution due to vehicle emissions and provides ideal circumstances for the introduction of zero emission electric vehicles With a population of approximately 1.5 million people, the city occupies an area roughly 12 kilometers wide. Thus distances traveled are quite short. Speeds seldom exceed 40 kilometers hour and are generally below 30 kilometers per hour. Inexpensive, non-polluting hydroelectric power is available. And the total number of motor vehicles including motorcycles is under 100,000. Because they are on the streets all day, the 3,500 three wheelers providing public transportation account for 25 percent of the road traffic and, because they are poorly maintained, more than their share of the air pollution. Thus, at a relatively small cost and in a short time, a dramatic change can be made in Kathmandu's air quality.

Global Resources Institute initiated the first phase of the electric vehicle program for Kathmandu in September 1993 with the conversion of a diesel three wheeler to electric power. The Vikram three wheeler was chosen because of its reputation as the worst polluter in Kathmandu. Following extensive tests on the initial vehicle to optimize the drive system, seven new three wheelers were built and the first converted vehicle was retrofitted with the new drive system. In August 1995, these eight vehicles were placed into service as a six-month demonstration project with a company providing public transportation. On going work is focused on developing a sustainable electric vehicle industry in Nepal.

The Electric Vehicle Program for Kathmandu has gone well. Since its inception in September 1993, the Safa Tempo ("safa" mean clean and "tempo" is the local generic name for a three wheeler) program has become widely recognized and supported by the public. It has been featured in the press and on local and worldwide television and radio. In July 1995, the government reduced import duties on components for local assembly of electric three wheelers from 6 percent to 5 percent and on fully assembled electric vehicles of all types from as much as 150 percent to 10 percent.

During the first six months of service the demonstration fleet of Safa Tempos carried over 200,000 people and traveled 175,000kilometers. Within four months of operation on a new route, the fleet reached 95 percent of its target revenue figures to make it more profitable than diesel three wheelers. Public response has been overwhelmingly favorable – the only criticism being the presence of too few Safa Tempos. Two companies have formed to assemble, manufacture, import and service electric vehicles in Nepal. In addition several transport companies plan to operate fleets f 30 to 50 electric three wheelers. Additional companies have expressed interest in manufacturing components and supporting services for the electric vehicles. Banks in Nepal and Bangladesh have indicated interest in providing loans to the electric vehicle industry.

Other cities in South and East Asia have become aware of the developments in Kathmandu and have asked for guidance to promote electric vehicle programs to reduce air pollution.

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