# CNG programme in India: The future challenges

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Content

With a large number of Indian cities embarking on natural gas vehicle programme it is essential that the elements of these programmes are well defined for maximum environmental and public health gains. It is important that the lessons are drawn from the well established programmes in the region to chart the future course. The existing programs in Indian cities are of varying scale and scope and reflect the regional imperatives. Environmental imperatives are much stronger in India today, which in conjunction with the energy security concerns are propelling these programs.

The front runner cities that have already established their first generation CNG programmes like Delhi and Mumbai along with the new ones are at the throes of planning the second generation expansion. This will require well thought out policy and criteria to maximize the environmental and public health benefits of these programmes and also make them economically effective. Therefore, it is important to consider the criteria on the basis of which the future expansion of CNG infrastructure and transport sector programmes will be planned in India.

Currently, it is estimated that the transportation sector uses up less than 2 per cent of the natural gas in the country. As the natural gas grid further expands and more cities begin to get access to natural gas, the prospect of its application in the transportation sector also increases. The compressed natural gas vehicle (CNG) programme is expected to expand considerably in future.

According to the estimates of the Petroleum and Natural Gas Regulatory Board, currently, there are 7 lakh natural gas vehicles in the country. This is expected to increase to 58 lakh over the next 10 years. Delhi alone has more than 2 lakh vehicles. Around 30 cities have access to CNG and some of them have implemented the programme of varying scope. It is also expected that the pipeline network will increase to 15,000 Km and implementation of city gas distribution network will cover around 150 to 200 cities by 2014. This potential can be further exploited if the natural gas distribution network is expanded and strengthened. What is driving the Indian CNG programme?

**Table 1: Gas Authority of India (GAIL) Future Plan: The Road Ahead**

| | | |
|---|---|---|
| | • Feasibility studies for additional 20 cities in progress<br>• Commitment for Highways to Greenways<br>• CNG corridors along major highways on anvil | |
| | **National Roadmap for expanding CNG programme** | **Estimates** |
| 2009-14 | Number of Potential Cities* | 298 |
| | Investment Required | Rs. 37,170 Crore |
| | Likely Gas Requirement | 74.34 MMSCMD |
| | Potential Households | 14,871,385 |
| | Potential Vehicles | 3,708,965 |
| 2015-20 | Number of cities in the periphery of 200 km. from existing / upcoming pipeline | 117 |
| | Estimated Demand | 16.3 MMSCMD |
| | Capital expenditure | Rs. 8,150 crore |
| 2021-25 | Number of cities where there is no existing / proposed pipeline connectivity | 69 |
| | Estimated Demand | 10.32 MMSCMD |
| | Cap expenditure | Rs. 5,160 crore |

Source Gas Authority of India Ltd: Future Plan: Road Ahead.

## 1. Imperatives of the NGV programme in India

**Imperatives of energy security:** India is becoming increasingly dependent on oil imports. Given the fact that India imports as much as 75 percent of its crude oil requirement and the petroleum prices have not been fully deregulated, the price shocks have often threatened to destabilize the economy. In the recent past the government and the public sector oil companies have had to absorb as much as 86 per cent of the increased cost of fuel prices due to bullish trends in international crude oil prices. Energy demand in the transport sector is already high and is expected to be particularly high, as vehicle ownership increases. International Energy Agency has estimated that by 2030 India will import more than 85per cent of its crude oil – nearly all of it. This will certainly make India even more vulnerable.

Diversified fuel basket is expected to strengthen our resilience and reduce our vulnerability to international vagaries in crude oil prices. Reducing India's dependence on diesel and petrol can make the country less vulnerable to oil price spikes.

It is estimated that overall local reserves of natural gas in India amount to 27 years of supply at current demand whereas local reserves of crude oil amount to less than 5.5 years. The rate of discovery of natural gas reserves in India also seems to be higher than oil reserve discoveries. Unless India diversifies its energy supply, away from high risk sources such as oil, the country will find itself crippled if it can't afford fuel. Nearly three-fourths of India's crude oil imports come from the Middle East. The Indian government expects this geographical dependence to rise in light of limited prospects for domestic production.

Although India's natural gas production has consistently increased, demand has already exceeded supply and the country has been a net importer of natural gas since 2004. Natural gas presently constitutes about 10 percent of the country's energy basket. India's hydrocarbon vision statement envisages the share of natural gas to be about 25 percent by 2025.

Even though the domestic production of natural gas is also not sufficient to meet the entire industry, power and transport sector demand, still the future prospects of tapping more domestic reserves provides a viable economic alternative to petroleum fuels and to de-risk the energy sector of India. Currently, natural gas shares are roughly 9 percent in our primary commercial energy mix.

Currently, the share of the transport in natural gas usage is miniscule. Natural gas is mostly used in the industry, especially fertilizer sector and power sector. But the environment and public health in cities demand its greater application in the transportation sector where the conventional fuels are the source of extremely toxic emissions and high human exposure. For future expansion, the Government of India will have to lay down clear policy guidelines to enable CNG programmes in new cities. For that it is also important to understand how the CNG prgrammes have benefited so far and their potential benefits in the future.

**Box: Natural gas in India: key highlights**

**Natural gas reserves and production**

- India has 1,074 BCM of natural gas reserves. This includes 287 BCM of natural gas from on-shore and 787 BCM off-shore. In terms of gross production, the figures stand at 32,849 MCM. Of this, 8,763 MCM of natural gas is produced on-shore and 24,086 MCM off-shore. However, the net production of natural gas during 2008-09 was 31,770 MCM.[i]

- The main producers of natural gas are Oil & Natural Gas Corporation Ltd. (ONGC), Oil India Limited (OIL), JVs of Tapti, Panna-Mukta and Ravva and Reliance Industries Limited (RIL) which has discovered gas in the Krishna Godavari basin at its KG D6 block in the east cost of Andhra Pradesh.
- Out of the total domestic production of 132.83 MMSCMD of gas about 43 percent is produced by Reliance Industries Ltd. (as of December 2009) and approximately 57 percent of the gas is produced by others.
- The public sector (OIL and ONGC) produces 92 per cent of the gas from off-shore and 69 per cent from onshore gas reserves. The JVC/private sector produces only 8 per cent in the off-shore and 31 per cent from on-shore.

**Natural gas production**

- The current supply of natural gas is approximately 161.65 million Standard cubic meters per day (MMSCMD). The private sector entered natural gas production in 1998-99. During 2007-08, ONGC and OIL jointly accounted for about 76% of the total gas produced, while the remaining came from private players and JVs. The remaining gas supply has been through re-gasified liquefied natural gas (RLNG). LNG supply which during 2007-08 was about 8.25 Million Tonnes.
- Another new hydrocarbon resource, coal bed methane (CBM), commenced production July 2007. India's CBM reserves are estimated to be 4.6 trillion cubic meters (TCM). Great Eastern Energy Corporation Limited commenced commercial production of CBM in India at a rate of 100,000 SCMD, from its Raniganj (South) block in West Bengal.
- According to the Eleventh Plan document, 'The current level of natural gas production in the country is inadequate to meet the industrial demand, particularly of the power and fertiliser industries. LNG imports since 2004-05 have been able to bridge the gap partially. The situation is likely to improve once production starts from Krishna-Godavari basin reserves in a couple of years.'
- Working Group on Petroleum and Natural Gas, the demand for natural gas in the terminal year of the Eleventh Plan is expected to increase up to 279.43 MMSCMD out of which 126.57 MMSCMD has been assumed for power sector and 76.26 MMSCMD for fertilizer sector.
- Domestic production of natural gas in the terminal year of the Eleventh Plan is likely to be 63.23 bcm, which will be around 100% higher than the current level of production. This increase in gas production will be mainly from K–G basin production of 40 million standard cubic metres per day (MMSCMD). The level of production may go further up if the Gujarat State Petroleum Corporation Limited is able to develop its resources in K–G basin in the Eleventh Plan period itself.

**Pipleline**

- The present gas trunk pipeline grid is about 10,000 km in length. It supplies to 8 lakh households and 4 lakh CNG-vehicles in 25 cities located mainly in the northern and western parts of India.
- GAIL India, a public sector undertaking, owns more than 67% (6800 km) of the network followed by Reliance Industries Limited 14% (1400 km), Gujarat State Petronet Limited (GSPL) which owns GAIL (India) Limited which owns1152 km i.e. 11% of the network. The rest is owned by Assam Gas Company, OIL and Gujarat Gas.
- The largest existing cross-country transmission system is the Hazira-Vijaipur-Jagdishpur trunk pipeline system, which traverses for a distance of 3,187 km. Reliance Gas Transmission Infrastructure Limited plans to develop more pipelines with a total length of 2,875 km across India.

**Natural gas consumption**

- Power generation and fertilizer industry are the major consumers for nearly two-thirds of consumption of natural gas in India.
- Transport sector uses a miniscule 2 per cent

- Sources: 1. Basic Statistics of Indian Petroleum and Natural Gas 2008-09, Ministry of Petroleum and Natural Gas
- 2. Study on Common Pool Price Mechanism for natural gas in the country.
- 3. Eleventh Five Year Plan, Planning Commission
- 4. Report of the Working Group on Petroleum and Natural gas sector for eleventh Plan, 2007-12

**Environmental imperatives of CNG programmes in India:** The use of natural gas in the transportation sector is primarily driven by the environmental and public health imperatives. Indian cities of Delhi and Mumbai had started implementing natural gas vehicle programmes during the nineties when even Euro I emissions standards were not in place and the sulfur content of diesel in India was as high as 5000 – 10,000 ppm. With fuel substitution, these cities were able to leapfrog to much cleaner emission levels.

The India's NGV programmes have primarily targeted the most polluting segments on the Indian roads that include diesel buses, three-wheelers, taxis and small commercial vehicles. This is somewhat different from the much older but very large programmes of Argentina and Pakistan where petrol driven light-duty cars were targeted largely for energy security reasons. Natural gas is abundantly available in Argentina, Bangladesh and Pakistan and it is easier for them to run their spark ignition petrol engines on natural gas as an energy security measure. Pakistan and Bangladesh however, have started to target diesel bus sector now for environmental reasons.

The CNG programme targeted diesel vehicles in India mainly because diesel-related pollutants are either already very high or rapidly increasing in Indian cities. While more than half of Indian cities are reeling under critical level of particulate matter, the NOx levels have also begun to rise. There are serious public concerns over health implications of diesel related fine PM, and other air toxics. These fears are supported by the sprinkling of studies in India on health impacts as well as the epidemiological studies from other parts of the world that have shown statistically significant associations of ambient PM levels with a variety of health effects in sensitive populations, including premature mortality, hospital admissions, respiratory illness and changes in pulmonary function.

Thus, Indian cities cannot continue to add the high emitters of PM and NOx, like conventional diesel vehicles. The level of roadside exposure to pollution from traffic has a significant effect on health and the severity of the public health impact. Rate of dieselization of the light duty vehicle sector is already quite high. In 2000 the share of diesel cars in the new car fleet was just about 4 per cent. This has already increased to 30 percent and is expected to be half by 2012.

In India, rigorous emissions inventories have not been carried out to understand the impact of dieselisation on ambient air. A collage of small evidences, however, bears out the impact on air quality. A World Bank supported study on source apportionment of PM2.5 (particulate matter less than 2.5 micron in size) in selected Indian cities released in 2004 shows that, depending on the season, the contribution of diesel fuel to the total PM2.5 ambient concentration can be as high as 61 per cent in Kolkata, 23 per cent in Delhi and 25 per cent in Mumbaiii.

A 2004 study carried out by Mario Camarsa, then with the UK-based Enstrat International Limited, has assessed the impact of low-sulphur diesel fuel on diesel emissions in three Asian cities — Bangkok, Bangalore and Manila.iii This bears out the varying but growing trends in diesel emissions in these cities. In the Indian city of Bangalore, the Camarsa study found diesel engines to be a significant contributor of the total NOx emissions from vehicles — as much as 40 per cent — and comparatively less significant contributor of PM10.iv

The concern over air pollution and particularly toxicity of diesel pollution had propelled the public campaigns in Delhi.

**Emissions gains from CNG vehicles**: Why CNG programme is perceived to have given health benefits in India cities? The evidence is in the actual emissions levels achieved by the CNG fleet in comparison to the conventional diesel bus fleet and petrol driven two-stroke three-wheelers that it had replaced.

In India all vehicles irrespective of the fuels they use have to meet the same emissions standards. This means the new OEM CNG vehicles are required to meet the same emissions standards as those meant for the conventional fuels and technologies of diesel and petrol. During the transitional phase the programme implementation during 2000 – 05 the OEM vehicles had to meet Euro II standards like other vehicles. Vehicles that had undergone after market conversion had to meet Euro I standards -- one step behind the OEMs. Now the emissions standards for after market conversion have been brought at par with the OEM standards.

The first generation CNG bus technology that rolled out in Delhi and Mumbai meeting Euro II standards is dominated by the conventional stoichiometric CNG engines using mechanical air-to-fuel proportioning and mixing systems with electronic "trim" of the air-to-fuel ratio, based on the feedback from an exhaust oxygen sensor. They are also equipped with three-way catalytic converters (TWC).

The actual tests carried out on the Euro II compliant Indian buses by the Automotive Research Association of India as part of the TERI study found that even the first generation CNG bus technology meeting Euro II emissions standards had significant PM reduction and moderate NOx emissions advantage compared to the diesel counterparts. The PM levels from the Euro II CNG bus were found to be nearly 46 times lower than its diesel counterpart. This CNG technology choice seemed appropriate in terms of meeting the objective of particulate emissions reduction, as it could easily and readily make particulate emissions negligible. (*see Table 2 Comparative emissions of diesel and CNG buses in India*). The same ARAI tests found that only when diesel engines are fitted with advanced emissions control components and run on very low sulphur fuels, are their emissions comparable with the Euro II CNG bus emissions. The emissions test data from ARAI also shows that the NOx emissions from the TWC equipped CNG bus are also lower than the oxidation catalyst equipped diesel buses and CRT equipped diesel bus. However, the gap is smaller in the case of NOx than PM. The natural gas bus program provided an opportunity to leapfrog to much cleaner emissions in Indian cities when diesel technology was stagnating.

**Table 2. Comparative emissions of diesel and CNG buses in India**

| Type of bus | CO g/km | HC g/km | NOx g/km | PM g/km | CO2 g/km | Km/litre |
|---|---|---|---|---|---|---|
| Euro II diesel bus on 500 ppm sulphur fuel + DOC | 1.45 | 0.29 | 6.24 | 0.35 | 798.7 | 3.33 |
| Euro II diesel bus on 350 ppm sulphur fuel + DOC | 0.65 | 0.15 | 5.85 | 0.11 | 766.1 | 3.44 |
| Euro II diesel bus on 50 ppm sulphur fuel + CRT | 1.42 | 0.04 | 13.58 | 0.009 | 781.38 | 3.36 |
| **Euro II CNG bus +three way catalytic converter** | **3.18** | **1.455** | **5.35** | **0.0065** | **729.74** | **NA** |

Source: The Energy and Resources Institute, 2004, *Fuel Choices for Transport and the Environment*, New Delhi, page 9

**Air quality gains of the CNG programme:** Air quality gains of the CNG programme have not been investigated adequately in Delhi. However, collage of small and fragmented studies bring out the gains of this programme. The Central Pollution Control Board the apex air quality monitoring agency in Delhi based on the air quality trends has stated that after the implementation of the CNG programme the particulate levels dropped by about 24 per cent from the 1996 levels.

A study by the Washington DC-based Resources For the Future (RFF), has assessed the impact of various pollution control measures on air quality trends in Delhi over a period of 15 years

(1990-2005) and found that the CNG programme has made the most significant impact on air quality in Delhi.

This quantitative analysis has matched the actual air quality data with the changing trends in key pollution sources in the city to explain the improvements in Delhi's air quality. The study links trends in various air quality indicators---respiratory suspended particulate matter, nitrogen dioxide, sulphur dioxide, and carbon monoxide---to trends in key variables that determine the concentration of these pollutants in the air. It has covered a wide array of variables that include the number of vehicles on the road, the type of vehicles and the fuels they run on, quantity of power generated by Delhi's three coal-based power plants, and quantity of furnace oil and light diesel oil used by industrial units in Delhi. The study has also included the impact of major policy initiatives such as the reduction in the sulphur-content of diesel and petrol, and meteorological factors such as maximum and minimum temperature, average wind speed and average rainfall. The study found that:

- Of all the different interventions made to combat pollution in the city, the conversion of buses to CNG has seemingly had the maximum impact.
- Results suggest that conversion of buses to CNG has helped reduce RSPM, CO, SO2 and have not contributed to the increase in NO2 levels;
- Out of the other interventions, the reduction of sulfur in diesel and petrol has also had a significant impact.
- Cleaner diesel fuel has helped to reduce SO2, and diesel cars have reduced CO. But diesel cars have been found to be contributing significantly to the increasing NO2.
- The reason why conversion of buses to CNG is showing significant impacts is because buses travel more kilometers in the city and contribute more to the pollution load. The conversion has therefore resulted in greater gains.
- The study also suggests that the gains of these interventions could be negated by the increase in kilometer traveled by all types of vehicles.

**Health benefits of the CNG programme in India**: Specific studies have not been carried out to assess the health benefits of the CNG programmes in Indian cities. A World Bank study of 2004 had assessed the health benefits of the first generation air pollution action in five Indian cities that included Mumbai and Delhi which have the largest and the oldest CNG programmes in the country. The CNG programme is also the most important part of the first generation reforms in these cities. The World Bank study shows that the first generation measures in Delhi and Mumbai that also include one of the largest CNG programmes have helped to reduce the number of premature deaths annually – at least 3629 in Delhi and at least 5308 in Mumbai.

**Climate benefits:** The climate benefits of the CNG programmes in India are yet to be evaluated. It is however premised based on the global studies and experiences that in comparison to the conventional diesel, the CNG programme offers greater benefit of lowering CO2 emissions given the lower carbon content of the fuel. Globally studies have established lower CO2 potential of natural gas.

**Black carbon vs methane**: However, a lot will also depend on the relative fuel efficiency of the CNG vehicles. There are sporadic emissions data in India. Automotive Research Association of India, the vehicle certification agency, has developed emissions factors for Indian vehicles in 2007 for different vintage models and fuels. However, CNG models are not well represented in the sample of vehicles tested. First of all they have not considered CNG buses for emissions factor development. Therefore, the only Indian data is available from the aforementioned TERI-ARAI study. Also in the case of car and three-wheeler segments the study has considered only retrofitted vehicles and not the OEM vehicles. Only one OEM four stroke CNG three-wheeler has been tested. The retrofitted vehicles are expected to be less fuel efficient and have higher CO2 emissions.

The limited data from ARAI tests on Euro II CNG and diesel buses show that CO2 emissions from the Euro II CNG buses are comparatively lower than the diesel counterpart (table 2 *Comparative* *emissions of diesel and CNG buses in India***).** The emissions from the subsequent models of both CNG and diesel meeting Euro III norms are not available. However, the bus transit agencies in Delhi, Banglaore, Kolkata (the later two do not have CNG) have complained of increased on-road fuel consumption of the new bus fleet – both CNG and diesel. Higher power, weight and torque of the new buses and congestion are attributed to this increase. But this will have to be evaluated.

**Table 3. Buses: Comparative emissions of diesel and CNG buses in India**

| **Type of bus** | **CO2 g/km** | **Km/litre** |
|---|---|---|
| Euro II diesel bus on 500 ppm sulphur fuel + DOC | 798.7 | 3.33 |
| Euro II diesel bus on 350 ppm sulphur fuel + DOC | 766.1 | 3.44 |
| Euro II diesel bus on 50 ppm sulphur fuel + CRT | 781.38 | 3.36 |
| **Euro II CNG bus +three way catalytic converter** | **729.74** | **NA** |

Source: The Energy and Resources Institute, 2004, *Fuel Choices for Transport and the Environment*, New Delhi, page 9

Fuel consumption in three-wheelers is significantly low compared to cars. However, within the three-wheeler segment the CO2 emissions of the retrofitted three-wheeler models are comparatively higher than the diesel and petrol counterparts. The CO2 emissions of one OEM model are also comparatively higher than the diesel and petrol counterparts. A similar trend is noticed in the car segment (See Table 4 *Emission factors of three-wheelers* and Table 5: *Emission factors of cars*). The emerging data clearly brings out that CNG technology development will have to consider fuel efficiency improvement of the CNG vehicles. However, the ARAI data also shows that the toxic emissions from the CNG vehicles are substantially lower than the petrol and diesel models (Graph 1: *Total toxics emissions: Euro III diesel car emits nearly 7 times more air toxics***)**. Fuel efficiency improvement of CNG technology can maximize the overall environmental gains of this technology.

**Table 4: Emission factors of three-wheelers(gm/km)**

| **Type of engine** | **Engine displacement (CC)** | **Vintage** | **CO2 (gm/km)** |
|---|---|---|---|
| Two stroke | < 200 CC | 1996-2000 | 54.500 |
| Two stroke | < 200 CC | POST 2000 | 62.410 |
| Two stroke | < 200 CC | POST 2005 | 71.500 |
| Four stroke | < 200 CC | POST 2005 | 73.800 |
| Diesel | < 500 CC | POST 2000 | 173.850 |
| Diesel | < 500 CC | POST 2005 | 131.610 |
| CNG OEM Four stroke | < 200 CC | POST 2000 | 77.700 |
| CNG retrofitment To stroke | < 200 CC | POST 2000 | 57.710 |

Source: ARAI 2007, *Draft report on* "Emission Factor development for Indian Vehicles " as a part of Ambient Air Quality Monitoring and Emission Source Apportionment Studies, Pune

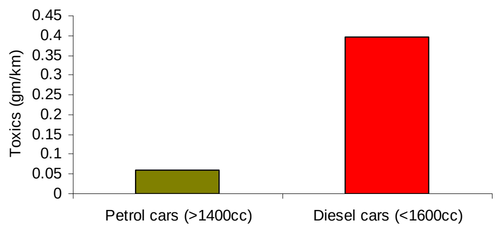
**Table 5: Emission factors of cars (gm/km)**

| **Type of engine** | **Engine displacement (CC)** | **Vintage** | **CO2 (gm/km)** |
|---|---|---|---|
| CNG | 1000 - 1400 CC | POST 2000 (MIDC) | 131.19 |
| CNG | < 1000 CC | 1996-2000 | 149.36 |
| CNG | < 1000 CC | POST 2000 (MIDC) | 143.54 |
| Diesel | < 1600 CC | 1996-2000 | 129.090 |
| Diesel | < 1600 CC | POST 2000 (MIDC) | 155.66 |
| Diesel | < 1600 CC | POST 2005 (MIDC) | 148.76 |
| Diesel | 1600 - 2400 CC | 1996-2000 | 166.14 |
| Petrol | < 1000 CC | 1991-1996 | 95.650 |
| Petrol | < 1000 CC | POST 2000 (MIDC) | 126.370 |
| Petrol | 1000-1400 CC | POST 2000 (MIDC) | 126.500 |

| | | | |
|---|---|---|---|
| Petrol | > 1400 CC | POST 2000 (MIDC) | 142.860 |
| Petrol | > 1400 CC | POST 2005 (MIDC) | 172.950 |

Source: ARAI 2007, *Draft report on* "Emission Factor development for Indian Vehicles " as a part of Ambient Air Quality Monitoring and Emission Source Apportionment Studies, Pune

**Graph 1: Total toxics emissions: Euro III diesel car emits nearly 7 times more air toxics**




Source: ARAI 2007, *Draft report on* "Emission Factor development for Indian Vehicles " as a part of Ambient Air Quality Monitoring and Emission Source Apportionment Studies, Pune

However, there is an interesting study in Delhi that has evaluated the warming implications of the CNG programme. This study carried out by the scientists of British Columbia on the Delhi CNG programme shows that in comparison with the warming potential of black carbon emissions from the older diesel bus fleet that the CNG fleet has replaced, the CNG bus fleet has been less warming despite the methane emissions from the CNG vehicles. When black carbon from diesel is not considered, the estimated CO2 (e) from the CNG bus fleet increase due to methane emissions. But when black carbon emissions from diesel vehicles is taken into account the CNG switch becomes carbon neutral as it leads to upto 30 percent reduction in CO2 (e).

**CNG: panacea for fuel adulteration:** Fuel adulteration is a serious risk in liquid fuels and the vehicle technology especially to the advanced emissions control systems needed to reduce emissions from petrol and diesel. Gaseous fuel is seen as a means to liberate from the evil clutches of adulteration. In fact, the Supreme Court of India has made observations in its rulings in April 2002 that CNG is environmentally acceptable fuel and it is non-adulterable.

## 2. Policy drivers of CNG programme in India

Regulatory and Judicial mandates have created opportunities for the CNG programmes in Indian cities. The CNG programmes of Delhi and Mumbai are the oldest and well established programmes in India. Mumbai programme was initially driven by public policy and also strong commercial interest of the large taxi fleet in substantially cheaper CNG fuel compared to petrol (not diesel) that was their key fuel in the city. Much later, Bombay High Court had intervened to direct CNG conversion of the freight vehicles in the city to CNG as a pollution control measure.

The situation in Delhi was different. A very small scale CNG programme had started in Delhi during the early nineties when Delhi was connected with the main trunk pipeline and gas supply for industrial use had started in its vicinity. A couple of CNG stations were set up and a voluntary conversion had started. A public interest litigation on air pollution was filed by MC Mehta, a noted lawyer in Delhi, in the Supreme Court of India way back in 1987. But this did not immediately kick start any major change. Only voluntary CNG conversion plans were proposed especially targeting the car fleet owned by the government. In addition in 1995 the Supreme Court also mandated use of catalytic converter in cars and introduction of unleaded petrol.

The major impetus came from the public campaign for clean air and health that gathered momentum towards the later part of the nineties. The Supreme Court responded to the public concern and issued series of directives in quick succession in the same on-going public interest litigation on air pollution. Following a court directive an empowered multi-stakeholder body –

Environment Pollution (Prevention and Control) Authority, was created in January 1998, under the Environment Protection Act to advise the court on pollution control measures and also monitor implementation of the court orders. Since then a spate of ruling on CNG as well as other measures for vehicular pollution control followed in Delhi.

The order of July 28 1998 laid down the foundation of the CNG programme in Delhi. This order came in response to the recommendations that the Environment Pollution (Prevention and Control) Authority had formulated based on its deliberations with the Delhi government. It is important to note that the Delhi government had itself recommended the CNG programme for Delhi. The Supreme Court had only endorsed the proposal and turned it into a specific directive with clear deadlines and timeline for implementation. The key highlights of this direction are:

- *Replacement of all pre-1990 autos and taxis with new vehicles on clean fuels by March 31, 2000*
- *Financial incentive for replacement of all post 1990 autos and taxis with new vehicles on clean fuels*
- *No eight year old buses to ply except on CNG or other clean fuels by April 1, 2000*
- *Entire city bus fleet to be steadily converted to single fuel mode on CNG by March 31, 2001*
- *GAIL to expedite and expand from 9 to 80 CNG outlets by March 31, 2000*

The significant element of this order is that except buses for which the Supreme Court had very specifically directed single mode on CNG, for other vehicles – autos and taxis -- it had given the option of CNG or other clean fuels. In fact the acceptable clean fuels were subsequently defined by the court based on the expert opinion assessed and recommended by the Environment Pollution (Prevention and Control) Authority. The Authority's report of July 2001 that was taken on board by the Court defined the acceptable clean fuels as follows:

> *"The hydrocarbon fuels are inherently polluting and hence such fuels cannot be regarded as 'clean fuels' and totally non-injurious to health. The effort is to constantly improve the fuel and engine technology of automobiles to reduce the effect.*
> *(i)However, among these fuels, CNG, LPG and Propane can be regarded as environmentally acceptable fuels.*
> *(ii) To get better emission control in petrol-driven vehicles, it is necessary to improve fuel quality, use catalytic convertors and ensure that fuel is not adulterated.*
> *(iii) In view of the special measures needed for pollution control in the NCT of Delhi, low sulphur diesel with 0.05 % (500 ppm ) sulphur cannot be regarded as an environmentally acceptable fuel.*
> *(iv) In the context of NCT of Delhi, there is need to bring public passenger transport (city buses, autos, taxis) as early as possible on CNG. For vehicles which cannot be converted to CNG for practical reasons, 0.05 percent sulphur diesel may be permitted as a Transitional Fuel for a limited period of time to be kept as short as possible for public health reasons.*
> *(v) Ultra-low sulphur diesel (with 0.001% sulphur) and low PAH content in combination with Continuously Regenerating Traps (CRT) and catalytic convertors can be regarded as environmentally acceptable fuel in the NCT."*

This clearly shows that the option of clean diesel with 10 ppm sulphur was acceptable in Delhi even then but clean diesel was not available in India. It is still not available in India. Therefore CNG became the single mode fuel for public transport modes.

While the July 28, 1998 court order became the basis of the CNG programme in Delhi the subsequent Supreme Court orders created opportunities for expansion of this programme to other cities of India as well.

After the successful implementation of the CNG programme in Delhi in 2002 nearly 14 polluted cities were identified in two court orders — that of April 5, 2002, and August 14, 2003. While there is an overlap in the two lists, together they include Agra, Lucknow, Jharia, Kanpur, Varanasi, Faridabad, Patna, Jodhpur and Pune (as in the first order), and Hyderabad, Chennai, Bangalore, Ahmedabad and Solapur (as in the second order). In its ruling of April 5, 2002, the Supreme Court had warned that "*If no immediate action is taken then it may become necessary for some orders being passed to bring relief to the people of the city*." It also stated very categorically, "*The Union of India will give priority to the transport sector including private vehicles all over India with regard to the allocation of CNG*." In these order the Supreme Court had emphasized the importance of CNG as "*unadulterable gaseous fuel*". With these orders the Supreme Court has established an unprecedented principle that gas allocation would have to accord priority to the transport sector to address the air pollution and public health crisis in cities.

Subsequently, in January 2003, the Central Pollution Control Board had released air pollution data of 22 polluted cities in the country. The Centre for Science and Environment drew the attention of the Chief Justice Bench in the Supreme Court to the list. In the hearing of August 14, 2003, the bench took serious note of this data. The bench observed that though the air quality had improved considerably in Delhi since 1996, particulate pollution in other cities was turning into a crisis.

The bench widened the ambit of the same air pollution case in Delhi to include seven more polluted cities – Bangalore, Hyderabad, Chennai, Ahmedabad, Kanpur, Lucknow and Solapur. The cities of Mumbai and Kolkata were not included as their respective High Courts were already hearing public interest litigation in those cities. The seven cities have submitted their action plan to cut particulate pollution. CNG programme is one of the key strategies listed. The cities that do not have access to CNG like Bnagalore and Chennai have listed LPG programme. The Supreme Court is still monitoring progress in these cities and in Delhi.

It is mainly the weak executive action on air pollution that has led civil society groups to seek remedies from the courts through PILs. The judiciary has consistently invoked Constitutional principles of Right To Life, and precautionary principles for public health protection. The air pollution case in Delhi is continuing even now. The Court is still monitoring air pollution and transportation related control measures and seven other cities. However, the respective state governments are also taking executive measures to further augment and strengthen this programme.

The state of Gujarat however has made proactive move to introduce and popularize CNG programme in its cities. Gas business has propelled the CNG market in this state. A large number of Gujarat cities including Ahmedabad, Surat, Vadodara etc have adopted CNG programme. Proximity of this state to the exploration base and pipeline has enabled this transition. Private players have come up in this state to provide gas and set up infrastructure.

India is at the cross roads today as far as the natural gas vehicle programme is concerned. The older CNG programmes of Delhi and Mumbai are now fully established in terms of scale of the market and refueling infrastructure. While there is much scope in expanding these programmes further, there is also now considerable scope of expanding the programme to much larger number of cities. Nearly 30 cities already have some scale of CNG programmes that are largely concentrated in Maharashtra and Gujarat and a few other states. Gas Authority of India Ltd (GAIL) has plans to expand the national gas grid. The big find and the operations in the KG basin is going to increase the gas market manifold in the future. This means many more cities are expected to have access to gas.

Ahmedabad, Vadodara, Ankleshwar, Surat, Kanpur, Lucknow, Agra, Bareilly, Vijaywada, Hyderabad, Rajamundry, Agartala, Indore, Ujjain etc are among the cities that have already implemented the CNG programmes. More cities are expected to implement CNG programme as a pollution control measure. According to the forecast of GAIL nearly 200 cities have the potential to introduce CNG programme (see map).

**The Auto Fuel Policy** was framed by the Government of India around 2002-03 when Delhi was mandated by the court to implement a compulsory CNG bus programme. Responding to that the Auto Fuel Policy had stated, “The government should decide only the vehicular emissions standards and the corresponding fuel specifications without specifying vehicle technology and the fuel type.” But on the public health grounds the Court did not accept conventional Euro II diesel as an option to CNG in Delhi.

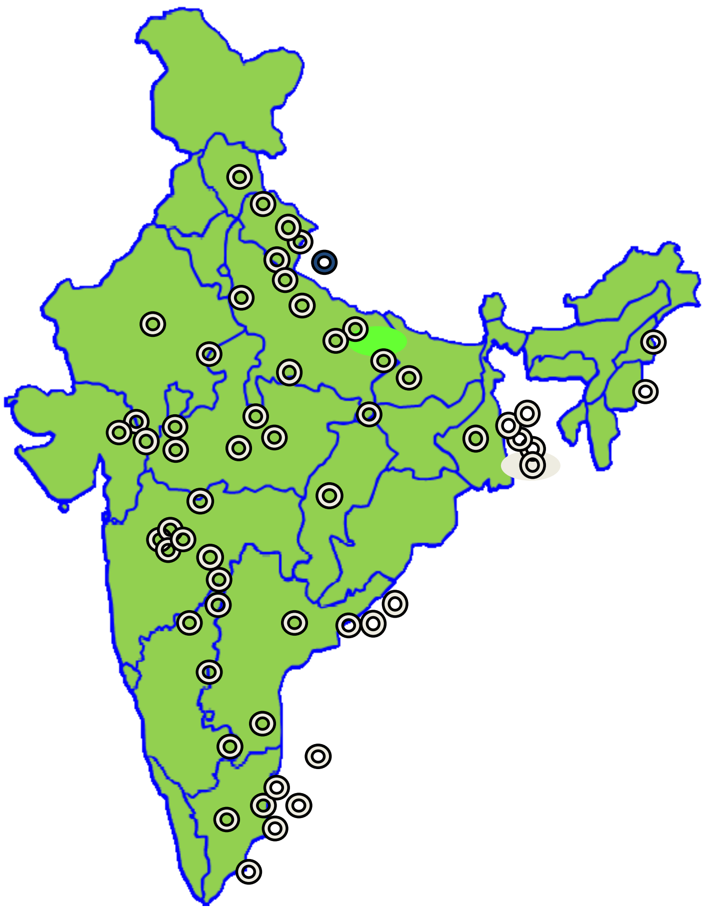
**Emerging public policy:** Gas Authority of India Ltd (GAIL) has launched ‘Project Blue Sky” to implement natural gas programmes in cities through joint venture operations. The model that it followed was to form joint venture with the public sector oil marketing companies to set up the infrastructure in cities for supply of gas. Indraprastha Gas Ltd in Delhi and Mahanagar Gas ltd in Mumbai, Central UP Gas Ltd in Lucknow and Kanpur are such ventures. Similar joint ventures have been formed in more than eight cities already to cater to the retail customers in industry, commercial and automobile sectors.

The Union ministry of petroleum and natural gas has already issued a notification on policy for development of natural gas pipeline and city or local natural gas distribution network in 2006 to promote both public and private investments. Under this regulatory framework the Petroleum and Natural Gas Regulatory Board will have the powers to sanction pipelines, city gas distribution network. The state governments will be responsible for facilitating timely completion of projects. The state governments will also prepare plans for the city distribution network. They will prioritise the cities and local areas based on environmental concerns, and industrial fuel requirement etc.

The next big challenge is to set up adequate refueling infrastructure in new cities. This will require proper network planning and implementation. This therefore brings up the question of how CNG network for transport can be made cost effective with the appropriate business model in the new cities.

The Petroleum and Natural Gas Regulatory Board, estimates that a total of about Rs.76,000 - 84,000 crore investment will be needed to expand the future petroleum & natural gas infrastructure in next five years. Of these only the Natural Gas Pipelines will cost about Rs. 60,000 crore; City gas distribution networks will cost about Rs.10,000 - 15,000 crore; and petroleum product pipelines will cost Rs.6,000 - 9,000 crore.

**Map: The City Gas Distribution is poised for expansion in the near future**
**(***City gas distribution coverage expected to increase to over 200 cities by 2025***)**



Source Indraprastha Gas Ltd

## 3. Technology roadmap for the CNG vehicles

It is important to note that indigenous capacity to produce natural gas vehicles has enabled large scale make over to gaseous fuel in India. As the fuel substitution strategy expanded the industry had to respond to cater to the growing market. The industry – especially the bus industry had to adapt and indigenize the technology quickly. Industry response however varies across vehicle segments. The industry responded more positively to the product segments that had regulatory dictates for conversion like buses, three-wheelers, taxis and light commercial vehicles. In car sector they remained sluggish.

Nearly the entire CNG bus market has been catered to by the two India majors – Ashok Leyland and the Tata Motors. In the last few years we have seen some more players including the Eicher Motor, Swaraj Mazda, Volvo etc entering the market. CNG bus market in India is unique and growing as CNG cities are planning expansion of the bus transport as a mobility measure to reduce pollution and congestion. Industry would need to innovate and diversify its bus product portfolio. Already Tata Motors and Ashok Leyand have begun to produce low floor specially designed urban CNG buses. But supply is not being able to keep pace with the demand for buses in cities that are mandated under the Urban Renewable Missions of the government of India to augment bus fleet as a mobility measure.

In the three-wheeler market Bajaj Auto Ltd has been the monopoly producer of the CNG four-stroke three wheelers for a long time. Only the Scooters' India Ltd produced CNG two-stroke three-wheelers in small scale. But as two-stroke engines, even if they are on CNG, are banned in the major markets like Delhi, this did not expand. Now a couple of new players have joined in. In the light commercial vehicle category Tatas, Swaraj mazda and Hindustan Motors have launched CNG models.

However, the car industry has been slow to respond. This market is largely driven by after market conversion. OEMs have shown little interest as there is no regulatory diktat for cars and this market has been slow to develop. Only a couple models that are popular in the taxi segment were initially made into CNG models by the Tatas and Maruti Udyog Ltd. However, very recently, the car industry has begun to show interest in product diversification and the car majors including Tatas, Maruti Udyog Ltd, General Motors etc have announced more CNG car models. This has been triggered largely by the growing consumer interest in CNG cars and spurt in after market conversion that followed the recent hike in petrol and diesel prices.

So far, CNG programme has not been extended to the large highway trucks. Only in Mumbai there is a court order that bans old trucks in the city unless they are on CNG. Though some after market conversion of trucks has happened in Mumbai it is not extensive. It is not clear yet if there will be any regulatory interest in developing CNG trucks once the various proposals on green highways come into existence in some states like Gujarat and Uttar Pradesh.

During the transitional period problems have surfaced with regard to the OEM products– in both buses and three-wheelers due to the inherent technical glitches. Buses have caught fire and three-wheelers of the earlier batches have been found to be emitting white smoke due to faults in piston rings and leaching of lubricants. It is now important to influence the future investments with robust technology roadmap and quality control to maximize the environmental gains.

However, the advantage of having the home grown producers was that many of the technical glitches were fixed incrementally. The bus industry has carried out voluntary remedial measures to address the initial technical glitches that will be discussed later.

**Technology roadmap for CNG buses:** The technology roadmap for CNG buses require some attention as this is a unique feature of the Indian CNG programme that is directly linked with the clean bus transportation programme. The CNG bus numbers are expected to be sizeable in some of the major cities with CNG. The genesis of this model is the July 1998 Supreme Court order in Delhi that while directing the CNG programme had categorically stated augmentation of the CNG bus fleet to at least 10,000. Most CNG cities of India – Ahmedabad, Kanpur, Lucknow, Hyderabad etc are adopting this model to replace the conventional diesel buses that are also gross polluters. As this approach gains credence and popularity and is further combined with the latest policy of the Government of India under the Urban Renewal Mission to support expansion of the bus transport in cities we are likely to see massive increase in CNG bus numbers in the future. Therefore, assessment of the heavy duty application of CNG technology becomes necessary to maximize environmental benefits.

This discussion is very relevant at this juncture as 11 cities of India are now in the process of introducing Euro IV CNG bus technologies. In considering future technology choices, India should assess the advanced nature of all gas technology evolving elsewhere in the world to meet the more stringent emissions standards.

The original CNG programmes in Indian cities were driven by the singular concern over high particulate levels in Indian cities and the current technology levels have delivered on that. PM emissions from CNG buses are negligible compared to the conventional diesel buses. However, the future technology roadmap will have to address the emerging challenge of multiple pollutants of PM, NOx and ozone and also improved fuel efficiency. While more than half of our cities are reeling under particulate pollution, NOx levels are rising steadily in many cities. Any new technology – either diesel or CNG – will have to address these pollutants simultaneously. Given the fact that many cities of India are now augmenting their bus fleet to build public transport system there is an enormous opportunity to rethink the future technology approaches to exploit the potential of CNG technology in reducing multiple pollutants.

The NGV program has the potential to reduce both PM and NOx significantly compared to their diesel counterpart, depending on the technology approaches. It is important to deepen policy understanding of this.

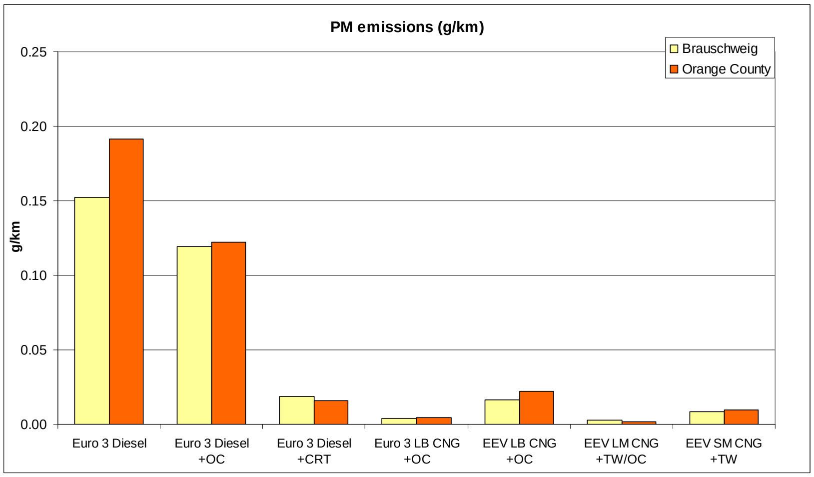
Over time two broad technology approaches have evolved for heavy duty internal combustion natural gas engines that have bearing on emissions, fuel economy and power of the vehicles. These are stoichiometric engines and lean burn engines. In the interest of the long term investments and pollution abatement strategy, it is important to choose a technology approach that will score high on account of both PM and NOx reduction potential. While PM emissions benefits of CNG technology are already proven for both the technology options, -- stoichiometric and lean burn, NOx emissions reduction potential of the two technology approaches can be widely different.

In India the bus industry had started with the conventional stoichiometric engines with three-way catalytic converters but while moving to Euro III they moved to lean burn CNG engines that the US used during the nineties. Delhi Transport Corporation for instance has opted for lean-burn CNG bus engines for its new fleet. But there is very little clarity with regard to the appropriate natural gas technology choices for the next generation bus fleet that can ensure significant emissions reduction in both PM and NOx.

It is now important to assess the future approaches. For instance, the emerging information indicates that at the current level of technology development globally the move is towards advanced stoichiometric engines with advanced three-way cat converters that are more effective in lowering NOx emissions. There are limitations in lowering the NOx emissions from the lean burn CNG engines below the levels achievable by diesel engines fitted with advanced CRTs. A real world bus emissions study was conducted in Europe in the cities of Brussels and Lausanne. It is clear that there is no advantage in NOX of the lean burn CNG bus over the diesel bus. But stoichiometric TWC CNG bus has substantial advantage over advanced diesel buses. The stoichiometric CNG bus has much lower NOx emission and also higher fuel efficiency.

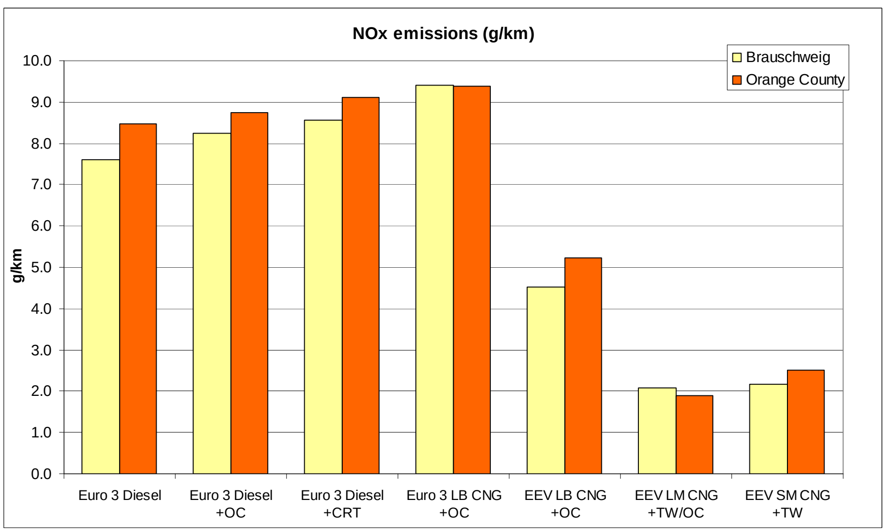
A recent study of comparative transit bus emissions conducted by VTT in Finland using different bus cycles provides important results (Graph 2: *Comparative particulate emissions: CNG and diesel buses* and Graph 3: *NOx emissions levels from different fuel and aftertreatment combinations*). These show very low PM emissions from the lean and stoichiometric CNG buses. But there is little difference in NOx emissions from a Euro III lean burn CNG bus with oxycatalyst, and a Euro III CRT equipped diesel bus. Even the best EEV lean burn CNG bus shows significantly higher NOx emissions than the stoichiometric CNG buses.

**Graph 2: Comparative particulate emissions: CNG and diesel buses**




*Source: Nils-Olof Nylund & Kimmo Erkkilä 2004, Transit Bus Emission Study: Comparison Of Emissions From Diesel And Natural Gas Buses, Paper presented at the NGV 2004, Buenos Aires*

**Graph 3: NOx emissions levels from different fuel and aftertreatment combinations**

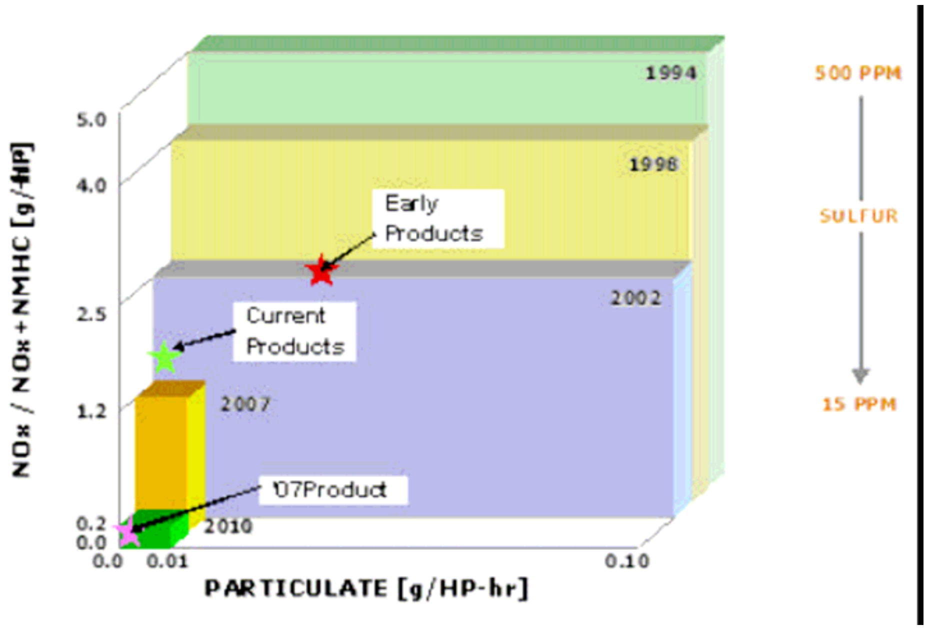



Source: Nils-Olof Nylund & Kimmo Erkkilä 2004, *Transit Bus Emission Study: Comparison Of Emissions From Diesel And Natural Gas Buses*, Paper presented at the NGV 2004, Buenos Aires

Both lean burn and stoichiometric technologies are represented among current European heavy-duty natural gas engines. The US manufacturers have originally favored lean burn engines. But these regions are now moving towards advanced stoichiometric engines that show the maximum NOx reduction potential, with improved fuel efficiency and torque. The new development has been to move to stoichiometric operation with an electronic fuel control valve and three way catalysts, but also using cooled EGR, the combination of which improved fuel efficiency and torque. This was a significant step bringing the technology to meet the EPA 2010 and Euro 6 emission standards. The evolving natural gas engine technology in North America is best summarized in graph 3. John Deere, Mack and Cummins have all moved in this direction with development programs. This shows 92 per cent reduction in emissions levels between the early products of 1998 and those of 2007 model year vehicles in the US (Graph 4: *Successive improvement in emissions from heavy-duty CNG bus in the US*).

The conclusion is clear. Cities implementing NGV program need to leapfrog to a CNG technology which will sustain their pollution control needs for many future years, rather than frequent switching of technologies involving retraining. Thus, the bus procurement policies in cities embarking on natural gas bus program will have to be linked with the best technology options and enabling emissions standards. Even in the US the advanced electronic controlled stoichiometric TWC CNG engine has already met the needs of 2010 and beyond in terms of significant reduction in both PM and NOx emissions. In fact heavy-duty CNG technology has demonstrated one of the cleanest emissions levels ever in the US and Europe. The trend in California is to adopt the new stoichiometric engine technology. In Europe similar trend has been noticed

**Graph 4: Successive improvement in emissions from heavy-duty CNG bus in the US**
*Heavy duty CNG buses have achieved one of the lowest emissions levels in the US*




Note: USEPA automotive emissions
Source: Cummins Westport, Presented at ENGVA conference, Strasbourg, June 2007.

**Concerns over after market conversion**

Since the launch of the CNG programme there have been concerns over the possible implications of allowing large scale conversion of old technologies especially diesel bus technologies. Global experiences have shown that poor quality conversion and diesel to CNG conversion can be particularly problematic and if not done well gaseous emissions can escalate.

Different technical approaches are available in Indian cities to move to CNG – dedicated CNG vehicles built by OEMs, repowering or replacing old diesel engine with new spark ignition one, and, conversion of old diesel engine to run to spark ignition engines. Naturally the conversion of the old engines has been the cheapest option, OEMs being the most expensive (Rs 4 lakh for conversion vs Rs 16 lakh for OEM standard bus in 2002). .

Amongst these three choices operators have opted for either OEM vehicles or conversion of old engines. Repowering has not happened. Conversion has however been very popular in smaller petrol vehicles like cars, and three-wheelers that also have spark ignition engines. This is very common globally and with good quality control this strategy can work well. The key concern is over diesel engine conversion.

Therefore, there are concerns over diesel bus conversion. However, the scale of the old bus conversion has been quite limited in the well established programmes of Delhi and Mumbai. This is mainly because the state transit agency in Delhi that has invested the most in bus transport has decided against after market conversion of buses. One of the big investors in buses was the state owned transit agency Delhi Transport Corporation. It had taken a decision to buy only new buses and not do after market conversion. This agency currently owns nearly 4500 CNG buses and is in the process of acquiring 5000 more CNG buses.

Initially, old diesel bus conversion happened mainly in the informal private sector. About 2,800 old buses were converted eventually. However, even without fiscal incentive the small bus operators in the private sector had also invested in new OEM dedicated buses. Once the policy mandate became clear and there was no further scope of dilution business responded and invested in new fleet. Subsequently, Delhi took a decision of not allowing after market conversion of diesel buses.

Many of the problems pertaining to the in-use CNG vehicles could be traced to the conversion agencies that were mostly fly by night operators. Evaluation show that the retrofitters had claimed to provide one year warranty on components, original conversion kits, and customer support but studies found frequent breakdowns and poor workmanship, and lack of customer support.

Technical evaluation has recommended national regulations for authorization and accreditation of the conversion workshop, periodic audits, withdrawal of the accreditation in case of default. But these have not been implemented with adequate stringency.

**Transitional technical glitches:** A large number of factors that influence the quality of NGV program came into play in Delhi as this was the pioneering large scale CNG bus programme in the country. Inadequate emissions and safety regulations, ineffective enforcement and compliance system, poorly designed refueling infrastructure, and serious safety risks plagued this program in the beginning. Around 12 CNG bus fire incidents were reported during 2001-2002. OEM buses were also involved. These required immediate corrective action through constant monitoring. This is an example of quality problems arising from implementation of a large scale NGV bus fleet, from which others can profitably learn. The Delhi program is an excellent example of quality issues being addressed under public scrutiny.

During 2001-02, two studies were commissioned by the Centre for Science and Environment to investigate the safety of CNG buses operating in Delhi, following the occurrence of a number of bus fires[1]. Many quality issues were found throughout the chain of supply from the chassis builder to the bus operators. They occurred in both OEM new buses, and in the conversion of existing older diesel engines to natural gas operation. Summary of technical flaws noted in OEM CNG buses during 2001-02:

- Damage to high pressure gas piping
- Pulling out of high pressure gas pipes from fittings
- Failure of PRDs. There was an unusually high number of burst disc failures.
- Short circuit in electric wiring creating sparks.
- Insufficient flexibility in the high-pressure gas piping.

Generally, the conversions were found to have much poorer quality than the OEM vehicles. Irrespective of the type approval certification, variance with the approved specifications was noticed.

[1] Frank Dursbeck, Lennart Erlandson, Christopher Weaver 2001, Status of implementation of CNG as a fuel for urban buses in Delhi, CSE, New Delhi
Lennart Erlandson, Christopher Weaver, et al 2002, Safety of CNG buses in Delhi: Findings and recommendations, CSE, New Delhi

- Stress loops at the gas piping from the from the cylinder were missing
- Clamping of gas pipes was not sufficient in several locations
- The distance between the gas cylinder and the exhaust muffler was less than 75 mm and the heat shield was missing
- Dust protection caps were missing at gas filter inlets

To address these issues a separate safety council was set up by the Delhi government to deal with CNG related safety issues and carry out "root-cause" evaluations of CNG-related safety problems, identify solutions, and ensure implementation. Independent third party inspection was introduced in which buses identified with flaws are sent back for remedial action. A special check list for this specialized inspection has been prepared. The objective of this program is to establish inspection of the engine and high-pressure fuel storage system and also improve the interface between the type approval agency and the inspection centre in the city for feed back and constant monitoring. This inspection is now carried out annually. At the beginning of the program the number of buses failing the third party checks was high but it declined thereafter. But the failure rate began to rise once again from 2004 onwards. Clearly, these systems are not being enforced effectively.

Since 2005 few more fire incidents in CNG buses have been reported in Delhi until the very recent episodes during the summer months of 2007. These involve OEM buses. As a result of this the Supreme Court appointed committee, Environmental Pollution (Prevention and Control) Authority (EPCA), directed more technical evaluation and made recommendations on corrective action to eliminate the deficiencies.[2] The evaluation exposed that many of the earlier problems have persisted. The range of problems identified includes bulk/continuous release of gas from the fuel system of the bus and fire triggered by a short circuit in the electrical system or hot spots in the system that created the conditions for fire. Other deficiencies include faulty routing of electric wiring harness, overheating of the engine and excessive lube oil consumption, flaws in exhaust manifold design, problem with engine cylinder heads among others. Manufacturing deficiencies, coupled with poor maintenance and use of substandard components aggravated the problem.

A set of remedial measures have been recommended, and are being put in place, which involve all parties from the chassis builder, converter, the Transit Corporation, and inspection agencies in taking corrective action. A mobile inspection and maintenance facility is planned to carry out unscheduled and random checks. OEMs were asked to replace the cracked exhaust manifold, remove the 12-volt terminal tapping from the 20-volt battery bank and reroute the wiring harness to separate the gas and electric lines. These took time to implement.

In fact many of the deficiencies could have been easily rectified. Damage to high pressure piping from rough roads, for example, could be prevented by use of stone shields, or relocation of tanks and fittings (roof mounted). Pulling out of high pressure gas pipes from fittings can be prevented by use of stress relieving loops in the gas line. In some cases PRDs were fitted with stronger burst discs to allow cylinders to be filled to higher pressures to improve the range of the vehicle. The latter, is really tampering carried out by the bus operators, and should be strongly discouraged and stopped. Electrical short circuits are easily preventable in the first place.

To improve the inspection system maintenance facilities have been instituted in DTC workshops where all buses including private buses are scheduled to go for quarterly inspection. Delhi transport has been asked to carry out unscheduled and random checks. All buses are now required to keep logbooks onboard with details regarding inspection and repairs carried out. All buses have been asked to register with the authorized service stations for periodic check ups. It was further noted that some key components including the low pressure and high pressure regulators, solenoid valves,

[2] EPCA Report No. 30, March 2007, CNG safety: Progress and action taken report, *Mimeo*
EPCA Report No. 26, July 2006, Investigations relating to fire hazards and safety in CNG Buses, *Mimeo*
H B Mathur, Report on the fire incidents in a converted CNG Bus, 2006, Mimeo

catalytic converters etc will have the registration number of the vehicle embossed on them to prevent use of floating components that are used only at the time of inspection. Testing Centers are being set up for periodic inspection. A common periodic testing checklist is followed at each of these centers. Audit of Periodic Testing Centers is being carried out.

**Lessons on regulatory approaches for a quality programme**: The experience with the CNG programme has demonstrated that India needs to develop a more robust regulatory framework for vehicle certification, quality control and in-use emissions and safety check for more advanced bus technologies – be it CNG or diesel – that will come equipped with advanced emissions control devices in the future.

Improvements in type approval process, durability requirement, and on-road enforcements will be crucial. For instance, we cannot rely on a type approval process alone to guarantee a quality system. For example, use of stress loops in high pressure CNG lines is documented in the Indian type approval requirements under AIS 028 D1, and should have been picked up in the type approval inspection, but obviously was missed. Perhaps the inspectors are not familiar enough with the requirements of AIS 028 D1, but it is clear the converter was not complying with the requirements.

Therefore, an additional quality action should be considered which is fundamental to quality systems, to prevent the design failure in the first place before release of the vehicle. Getting it right the first time involves a much lower cost than dealing with warranty costs subsequently, to correct failures in the field. Much of what has been observed above could have been prevented through use of a simple Design Failure Mode and Effects Analysis (DFMEA) process. This quality system is in place in many countries. Going through the whole system provides the opportunity to determine what could possibly go wrong before the vehicle design is released. It is common, however, for company personnel to believe they do not have the time to go through this, but in fact it saves the company time and money in the long run by not having to fix field failures. The DFMEA process should catch missed items. The DFMEA will also catch issues not covered under the type approval process. One example of this is the fuel/air ratio control system. There is a safety check and specifications for a gas/air mixer, but nothing on performance. So, the DFMEA in this case would look at the Fuel/Air ratio control system to determine possible losses of control, which could result in lean operation causing misfire to occur with subsequent catalyst damage. The DFMEA also flags the need for maintenance of the A/F ratio control system which may be vulnerable to drift. The DFMEA process should be conducted prior to the vehicle being submitted for type approval, and provided as evidence that a quality system is in place, and could be part of the type approval. By taking these steps in the first place, robust designs will minimize field failures, and warranty costs.

Similarly, catalytic converters in the current CNG bus fleet in Delhi are particularly vulnerable as these bus technologies use older distributer ignition systems, and mixer systems for CNG fuel control. Studies show these can have extensive catalyst durability problems when misfire occurs during loss of fuel and spark control. Greater than 2 per cent misfire will kill a catalyst. Under the current emissions regulations in India, the durability requirement for the emissions control equipment has been fixed at a very low level – only 80,000 km. This may amount to replacing cat converters almost ten times during the useful life of the vehicles – given the annual mileage of the buses and the fixed age of 15 years for buses.

Experts point out that catalyst technology has advanced considerably in recent years. Advanced thermally stable oxygen storage materials have considerably improved long term thermal stability. Achieving durable emissions performance is a combination of calibration technique and catalyst technology. India needs to look at the regulatory developments worldwide on extended durability requirements for heavy duty vehicles to comply with useful life emissions standards and recall and corrective action as in North America. It is important to ensure that even as the emissions deteriorate on the new emission control system with mileage accumulation, the emissions must remain below the useful life emissions standards. In North America, heavy duty durability requirements are now 435,000 miles or 700,000 kilometers.

In-use NOx emissions measurements have been recommended in Delhi that requires a loaded mode test procedure, to determine in-use emissions performance for NOX. In the US EPA sets in use emissions requirements. EPA sets in use emissions requirements to be higher than the useful life standards, so that the manufacturer is not faced with recall if he exceeds the standards in use by a small amount. For example, EPA sets in use emissions limits at 1.75 times the standard at 290,000 km, and 2 times the standard at 700,000 km. So, there is a big difference between a 2.0 g NOx engine and a 0.2 g NOx engine in terms of its loading on the atmosphere with deterioration. Also this means the manufacturer is not faced with recall if he exceeds the standards in use by a small amount.

**Paradigm shift in CNG technology**:

**Industry develops CNG hybrid buses:** A large scale CNG programme in Indian cities has stimulated innovation. Bus industry has already developed prototype for CNG hybrid technology. Ashoke Leyland has developed a CNG plug-in-hybrid bus HYBUS. The company claims 20-30 per cent fuel savings compared to a conventional IC engine. However, fuel efficiency and emissions data for these vehicles are still not available to assess their performance. There is also no clear deployment strategy for these more expensive models. Some of these buses will be show cased during the upcoming Commonwealth Games scheduled to be held in Delhi during the October 2010.

**CNG gate-way to Hydrogen future – hythane:** The pilot project on hythane programme (blending of hydrogen with natural gas) in Delhi demonstrates the future possibilities of making a transition and bridge the gap with new generation fuels and technology that are needed to combat pollution and climate change. This will enable future solutions.

In a major initiative the Indian Oil Corporation Limited commissioned a H-CNG dispensing station at Dwarka in January 2010. This dispensing station will make H-CNG available or three-wheelers and cars. The project is funded jointly by the Ministry of New and Renewable Energy and the Ministry of Petroleum and Natural Gas with an investment of Rs. 5 crore. The first experimental H-CNG dispensing station was commissioned at the IOC-R&D center campus, Faridabad in October 2005 for conducting studies on emission and performance characteristics on three and four-wheelers using various blends of hydrogen in CNG. Since then field trials have been underway on three-wheelers and passenger cars.

The CNG blended hydrogen fuel produced at the dispensing station will be used to fuel vehicles. The ratio of natural gas to hydrogen in hydrogen-CNG (H-CNG) is 80 per cent natural gas and 20 per cent hydrogen by volume. This has been determined to be the best ratio when all factors such as emissions reduction, cost, and storage capacity are considered.

At the Dwarka station, hydrogen for H-CNG fuel is being produced through electrolysis. In addition to the electrolyser, the station has a compressor along with a buffer storage facility. The station which will enable the IOC to continue its R&D for use of hydrogen as a transport fuel has capacity to fuel nearly fifteen three-wheelers. Initially, CNG vehicles will be targeted which will run on a mixture of hydrogen fuel with little modification.

H-CNG can use the existing natural gas infrastructure. Addition of hydrogen to CNG improves efficiency, while retaining the low emission characteristics of CNG. Its use in vehicles leads to 50 per cent reduction in NOx emissions. Reduction of CO emissions has also been reported. In addition to emission reduction, engine power is maintained along with fuel mileage efficiency. It is important to note that an engine must be calibrated to achieve emissions reductions when running on hythane. The electronics in the engine will have to be re-tuned. Industry says this is only a software modification, and does not require any change in hardware to an existing natural gas engine.

Ashok Leyland has developed a 6-cylinder, 6-litre 92 kW BS-4 engine for operation with H-CNG, in association with Eden Energy, Australia. A 4-cylinder 4-litre 63 KW engine is also being developed for H-CNG blend in a joint R&D programme with MNRE and IOC. Standards for H-CNG are being developed by the Oil Industry Safety Directorate. Safety standards are being worked upon.

One of the key challenges is high cost of hydrogen production. In electrolysis, the electricity cost is about three to five times more as compared to the cost of fossil fuel feed stock. There is a need to look at other options which would reduce the cost of hydrogen production. Mass production of the fuel will further lower the cost. India has an ambitious plan to have one million hydrogen fuelled vehicles by 2020 mostly two and three-wheelers. A total investment requirement of Rs. 25,000 crores has been projected in the Road Map for creating the required hydrogen supply infrastructure to realize the goals of one million vehicles and 1,000 MW power generation capacity by 2020. It will take some time when hydrogen fuelled vehicles will ply in India, hydrogen-compressed natural gas (H-CNG/hythane) is being promoted as the fuel of the future. There have been a number of projects in the US involving hythane.

## 4. Fiscal policy to promote natural gas

Currently, the national policies are largely focused on dedicated gas supply and pricing for the power and fertilizer industry. However, official support for the CNG programme has begun to evolve in response to the expanding city programmes. Fiscal support to the CNG programme will have to be understood separately at the central and at the city level.

**National fiscal policy**: National government does not have any direct fiscal policy to promote CNG programme in cities. In fact, the central excise duty has been rationalized to be uniform for all vehicles irrespective of the fuel they use. The only policy that has worked in favour of some of the city based CNG programmes is the natural gas pricing policy that has a component of administered pricing mechanism. This is the subsidy element.

In India there are broadly two pricing regimes for gas - gas priced under administered price mechanism (APM) and free market gas. The price of APM gas is set by the Government. The free market gas can also be broadly divided into two categories, -- domestically produced gas from joint venture (JV) fields and imported LNG. The pricing of JV gas is governed in terms of the production sharing contract provisions. While the price of LNG imported under term contracts is governed by the special agreement between the LNG seller and the buyer, the spot cargoes are purchased on mutually agreeable commercial terms.

APM which is the subsidy component of the gas market refers to gas produced by entities awarded gas fields prior to the production sharing contract regime. The prices of gas from these fields are administered by the Government of India. All the APM gas is supplied to only these categories:

- Power sector consumers
- Fertilizers sector consumers
- Consumers covered under court orders
- Consumers having allocations of less than 0.05 MMSCMD and transport CNG

The older CNG programmes of Delhi and Mumbai and a small component of the Agra and a couple of other cities are based on the APM gas. Therefore, only these city programmes enjoy some degree of fiscal benefit on account of the gas pricing regime. However, it is important to note that APM gas is being phased out progressively and all the new programmes are based on market driven gas pricing.

Since 2005 the APM prices are being steadily increased. With effect from May 6, 2005, the APM gas price to small consumers and CNG sector was increased by 20 percent, to bring it to Rs.3840 / MSCM. The price of natural gas for customers only in the North-Eastern region has been kept at 60 percent of the price in the rest of the country. The Tariff Commission then had recommended Producer price of Rs.3710/MSCM and Rs.4150/MSCM for ONGC and OIL respectively. The government then took the decision that the price of gas supplied to small consumers and transport sector (CNG) would be increased over the next 3 to 5 years to the level of the market price.

Finally, in May 2010 the Union Cabinet approved a sharp revision of the APM price of natural gas to Rs.6818/mscm narrowing the gap with the market prices. This has substantially increased the retail CNG prices in the city from June 8, 2010 onwards. In Delhi the retail prices of CNG increased from Rs 21.9 per kg to Rs 27.5 per kg – an increase of more than 25 percent. . However, the price differential with diesel and petrol prices further widened when liquid fuel prices were raised in the last week of June, 2010. Petrol prices are 46.52 percent higher than CNG and diesel is 31.42 percent higher than CNG in Delhi. Petrol costs Rs 51.43/litre and diesel costs Rs 40.1/litre in Delhi currently.

This pushed up per km running cost of various public transport modes marginally. But after the petrol and diesel prices too were raised in end of June the cost-benefit once again bounced back in CNG's favour. These prices vary across the states given the differences in the state taxes. In fact state taxes in other cities are actually higher than Delhi.

**CNG pricing in the era of price deregulation:** Fuel price rationalization and liberalization is inevitable for all fuels in India. Already petrol has been fully liberated. Diesel and CNG are closing gaps and are expected to be free as well. Already different models of pricing mechanism for natural gas are being discussed in India – such as gas pool prices etc.

In anticipation of the increase in CNG prices due to price deregulation the Supreme Court had directed the Union government in 2002 to devise a favourable taxation policy for natural gas in the interest of the public health to maintain an effective differential between the CNG and diesel prices. However, a composite policy has not been put in place yet.

As CNG is displacing diesel for maximum environmental benefit, the success of the programme is directly linked to the behaviour of diesel vs CNG prices in the market. It is estimated that when prices of diesel and petrol are 50 per cent higher than natural gas, then the pay-back period for the CNG vehicles is just about two-three years: this acts as an incentive. With a 30 per cent difference, the pay-back period will be three-five years or more.

However, the new CNG programmes that are now being established are based on free market prices and LNG import. In Gujarat, a sizeable portion of the CNG sales is based on market-driven prices. Gas distributors in Ahmedabad, Surat, Bharuch and Ankleshwar buy natural gas from companies at market rates and also source imported LNG. For instance, Gujarat Gas Company Ltd is the largest private gas distribution company which buys gas from the Cairns Energy-led consortium, the Gujarat State Petroleum Corporation Ltd (GSPCL), NIKO, GAIL, etc; it supplies gas to Surat, Bharuch and Ankleshwar. Its gas basket, therefore, includes a small component of APM gas, gas from old contracts, imported LNG and so on. As a result, the average prices are influenced by the multi-player dynamics. In Ahmedabad,Gujarat Adani Energy Ltd buys gas from GSPCL which in turn purchases from GAIL. In Gujarat, therefore, some of the possible impacts of deregulation on CNG prices are already visible.

Even with market-driven prices Gujarat cities have been able to maintain a differential with diesel so far. In Ahmedabad, the differential between diesel and CNG prices is 35 per cent. But this margin can reduce if conscious policy efforts are not made to maintain an effective differential with taxes. The new programmes that are based on market-driven prices have an advantage over the programmes that are based on APM prices, as these do not face the risk which arises from the dismantling of APM. But only a carefully designed taxation policy will make these programmes more sustainable in the long run.

**Favourable taxation:** The Ministry of Petroleum and Natural Gas (MoPNG) in its written submission to the Supreme Court in 2002 had stated: “MoPNG reviews the prices of various transportation fuels on a regular basis. Depending upon the international prices of fuel oils, we would recommend to the ministry of finance to have such a fiscal regime as may be necessary to keep the prices of all environment-friendly fuels competitive.” Subsequently, the Supreme Court in its order of August 14, 2003 had asked the Central government to clarify the stand taken on the CNG pricing issue *vis-à-vis* other petroleum fuels in the petroleum regulatory bill. The Union of India informed the court in its affidavit of October 8, 2003, “...In future when the natural gas pricing policy is formulated, various fiscal instruments including the one suggested by the EPCA in its report would be borne in mind by the government, so as to keep the price of CNG fuel competitive in the deregulated scenario.” These steps will now have to be taken urgently.

As markets have begun to open up without a cohesive policy for the post-deregulation scenario, there are serious risks of market distortions arising from monopoly practices leading to inflated prices that can harm the programme.

The impact of the imported LNG and its regassification on the gas prices is expected to be quite significant. In view of this, an inter-ministerial group (IMG) was constituted under the leadership of finance minister P Chidambaram in July 2004. The IMG directed that the regasified cost of LNG, the transportation tariffs for the DVPL and the HVJ pipelines, and the marketing margin on the sale of regasified LNG be examined by an independent expert agency — the tariff commission. The MoPNG then in February 2005 advised the commission to consider all relevant issues pertaining to tariff calculations made in the interim report.[v] Though the details are not yet available, the linking of CNG pricing to regassified LNG will require special attention.

Instead of subsidy a favourable tax policy will be important for the CNG programmes. This will also be more sustainable as the market will then be able to adjust and absorb the cost of transformation and not collapse like some of the older global programmes. For instance, New Zealand was heavily involved in the NGV programme and provided generous financial incentives both for conversion and establishing refuelling stations, so that the number of CNG vehicles doubled every year.[vi] When the new Labour government began deregulating the economy, withdrawing financial incentives for the CNG industry, the NGV market almost died in New Zealand. NGVs today number about 10,000 in the country, a decline of 100,000 from the peak of 110,000.[vii] Therefore, for the long-term sustainability of any clean fuel programme, it is important to design differential fuel taxes instead of direct subsidies. For example, the Argentina government instead of direct subsidies offered the incentive for fuel switching in the form of high taxes on gasoline.[viii]

**Fiscal incentives in states:** Respective state governments have also begun to devise their own tax policies to provide support to the CNG programme.

**Delhi**: One of the big regulatory challenges in Delhi has been to meet the cost of transformation to CNG. Anticipating the high cost of the programme the Supreme Court of India order of July 28, 1998 had made the provision for the fiscal incentives only for three-wheelers and taxi owners.

- **Subsidised loan for three-wheelers and taxis**: In response to the court order the Delhi government had designed a loan package with four percent interest subsidy to be given by the Delhi Finance Corporation. But this incentive was not utilized effectively in the three-wheeler segment mainly because the three-wheeler owners could not often meet the criteria for obtaining loan. This informal sector has other distortions in terms of middlemen, etc. However, three-wheeler operators were encouraged by the enormous price difference between petrol and CNG that lowered their operational costs and allowed quick recovery of the conversion costs.

- **Only partial support for the CNG bus operators**: There was however, no fiscal incentive for the bus operators except for a very delayed decision to offer incentives to only the operators of lower socio economic status. The cost of this incentive was expected to come from the fiscal penalty that were imposed on the diesel buses after April 2002 that were still running in violation of the court order. However, only 80 bus operators had availed of this scheme.

- **VAT subsidy to phase out diesel light commercial vehicles:** The Delhi government has taken the decision to phase out 15 year old diesel light commercial vehicles (LCVs). This is complemented by a fiscal incentive scheme that has been prepared to encourage voluntary phase out the vehicles that are less than 13 years old. To enable the transition the Delhi government has announced a subsidy scheme. The subsidy will be equivalent to VAT (12.5 per cent) that will be provided on purchase of new LCVs. Owners of LCVs below 13 years of age can avail benefit of the VAT subsidy. This is a voluntary programme. This programme has started in 2008. These vehicles will be replaced by new CNG vehicles.

- **CNG fuel for automotive use fully exempted from sales tax**: This has helped to maintain an effective differential with diesel fuel that CNG has replaced in public transport buses and petrol used earlier in three-wheelers. The differential between CNG prices and diesel and petrol prices is a very powerful incentive. This has certainly helped in the expansion of the programme.

- **Delhi subsidy is beginning to get revenue neutral**: In 2008 Delhi government has introduced a scheme of Air Ambience fee of 25 paise per litre on sale of diesel fuel in the city. Revenue from this fee goes to a dedicated fund called Air Ambience Fund. This fund is now available for many of the clean transportation subsidy.

**Other cities:** have also begun to provide incentives for CNG and LPG programmes. Some examples are:

> **Fiscal incentive for LPG conversion:** Bangalore has launched one of the largest LPG three-wheeler programmes as it does not have access to CNG yet. The city government has offered a subsidy of around Rs 2000 to three-wheeler owners to help bear the cost of conversion. Nearly 70,000 autorickshaws have already converted to LPG.
>
> **Exemption of motor vehicles tax on CNG, battery and solar powered vehicles:** The Andhra Pradesh Motor Vehicles Taxation Act, 1963 provides for exemption of motor vehicles tax for a period of 5 years from the date of registration of motor vehicles using CNG, battery and solar power.

**Harmonisation of prices*:*** As more cities begin to introduce CNG programmes across different states, CNG prices will have to be rationalised across the borders to prevent cross-border disparities. For instance, neighbouring towns of Noida, Guragaon, Faridabad around Delhi are implementing CNG programmes. The tax differences create price disparities across borders. As Delhi has already waived off sales tax, hiking prices in Noida can lead to a cross-border shift of demand to Delhi. The revenue in Noida will be undermined, making cost recovery difficult. This calls for more harmonised regulatory and pricing policies across the national capital region of Delhi and other states and better coordination among state governments.

## 5. Market development

Natural gas vehicle sector that has originally begun with regulatory and judicial mandates is already moving from being a highly centralized government controlled business to one that relies increasingly on reduced regulation and more market responsive pricing climate with more private players in it. The gas exploration sector has already been opened up to the private corporate players – British Gas, Cairn Energy, Reliance etc. National Gas transmission and pipeline is still largely controlled by the public sector Gas Authority of India with a few more players in Gujarat. However, gas transmissions companies bring the gas till the city gate. Cities then need to develop infrastructure for the city gas distribution for transportation, industrial and domestic use. CNG supply for transportation is dependent on the city gas distribution system.

Currently, there are two approaches to developing city gas distribution infrastructure. The predominant one is to form joint ventures between GAIL and the public sector oil companies. This has been the most widely followed model in the programmes that use gas priced under the administered pricing mechanism. GAIL has thus formed joint venture companies to form the Indraprashtha Gas Ltd in Delhi and Mahanagar Gas Ltd in Mumbai. Similar models have been followed for Kanpur, Agra and Lucknow.

In the second approach private players have begun to enter the city gas distribution. These players source gas at market driven prices. Some of these players are Guajarat Gas Company, Gujarat Adani Ltd etc. Private investments have begun to grow in this sector.

Experience in Delhi and other cities has demonstrated that cleaner technology and fuels face strong competition from the entrenched conventional fuels and technology — thus necessitating a regulatory mandate to shift around demand.

The plans for future expansion of the city gas distribution have raised many questions. In most cities the base demand for CNG is small as they are mostly limited to three-wheelers and small commercial vehicles and limited number of cars and buses. It takes time for the demand to build up in cities. A typical city gas distribution network costs Rs 250-300 crores to provide about 1.5 MMSCMD of CNG. There are various ways demand can be generated for commercial viability as well as environmental gains.

Price behaviour of liquid fuel will also influence the CNG market. For instance, during the recent oil price hike Delhi witnessed massive conversion of personal cars to CNG as well. While a compulsory mandate is possible in the case of commercial vehicles, the personal car segment will have to be encouraged with fiscal incentives. But low tax CNG must also not create perverse interest in increasing personal car fleet.

**Challenge of small CNG markets:** It is also being said that the economics of setting up of CNG refueling network as a stand alone venture in cities may not be effective if cities do not have the critical mass of vehicles to ensure a viable scale of market. That CNG business in the transport sector is possible only if it is backed by a business model that targets to create a market for other sectors like industry and power in the city as well. Most cities of India have so far followed the model of CNG business combined with supportive business in other relevant sectors -- the industry, power plant or piped gas network for domestic uses -- to make it commercially viable. As a ball park the industry guess estimates that a minimum gas sale of at least 8000 cum per day should be ensured. This figure will have to be assessed further based on actual market surveys. The industry argues that CNG programme will not be viable as a stand alone programme in cities that do not have adequate number of other users.

These issues will now have to be urgently dealt with as more cities have the chance to introduce this clean fuel to clean up their air and protect public health.

In cities that cannot justify natural gas infrastructure for the industrial sector, there can be resistance to establishing pipelines just for CNG stations. The alternative could be to establish mother/booster daughter stations for transportable storage. This has worked well in other countries. The number of options for these arrangements is increasing and costs are coming down. These arrangements end up being not too dissimilar to diesel supply arrangements - Fuel produced at one source is transported and stored for distribution at another.

Smaller cities like Kanpur, Noida, Gurgaon and Faridabad also face a special challenge of attaining a critical mass of vehicles. As of now, various estimates available about the number of vehicles that can switch over to CNG in the next five years in some of these cities, seem very small. For instance, nearly 80 per cent of the vehicle fleet in Kanpur, for instance, comprises two-wheelers that cannot move to CNG. Yet again they need to build up their public transport programmes as well. Kanpur is in the process of expanding its bus transport programme and is adding 350 buses under the JNNURM programme. Both Kanpur and Lucknow, which have virtually no city bus services, have planned to build public transport systems based on CNG. This is expected to create captive demand for CNG.

Kanpur and few other cities in Gujarat are also looking at the way to develop green highways based CNG connectivity. This is expected to expand the demand.

**Link the CNG programme with public transport augmentation programme**: Nearly all class I cities that fall under the Jawaharlal Nehru National Urban renewal Mission (JNNURM) programme are expected to implement the National Urban Transport Policy for sustainable transportation. In fact, many cities are now augmenting their bus fleet to enhance public transport services. Linking the CNG programme with the public transport augmentation plan that includes both buses and intermediate public transport of autos and taxis etc, a sizeable CNG market can be created. Clearly, therefore, the cities will have to develop a public transport bus programme linked to the clean fuel programme. In Ahmedabad, the bus transport was nearly decimated following drastic decline in the number of diesel buses during the late nineties. The bus transport is now being rebuilt in the city as part of the CNG programme. About 800 new buses have been inducted into the city fleet and the number is expected to grow.
Similar approach has helped the Delhi programme to attain an impressive scale, as also make a perceptible impact on air quality.

In cities of Gujarat not only the city bus service is being strengthened, even intercity CNG bus services are possible due to green highways that are being constructed. This improves the scale of captive demand. Fiscal support for these programmes will be critical to expand the fleet further.

**Coupling of other business models with stand alone transport CNG programmes:** Industry and regulators are increasingly looking at the possibilities of coupling other viable gas based projects that can make stand alone CNG programme viable.

- One option that is being explored is the possibility of decentralized gas based power generation in power starved cities where huge amount of captive power generation is already happening with diesel generator sets. This is not only further increasing demand and usage of diesel within close proximity of residences and commercial complexes but these are also adding hugely to pollution. For instance, studies carried out in Kanpur have shown that diesel generator sets are also contributing hugely to air pollution. If done on a need based basis gas based small power generation can also be a lot cleaner compared to coal based power plants.

- Biomethane from garbage, sewage treatment, and other agricultural sources, can be a good supplement to the CNG programmes in Indian cities and can be a local stand alone operation, employing local people, etc. India has a valuable opportunity to solve two problems at once by turning trash into treasure. Garbage could become a commodity by collecting it and processing it to fuel buses and trucks. Sweden has a very aggressive biomethane program that is leading them towards becoming independent of oil imports by 2020. They have a minimalist gas network but a growing network of biomethane stations that produce the gas on or nearby to where they are using it. Trash is only one possible source but bio-methane is one of the highest yielding renewable fuels - just what India needs. Delhi has very recently started a waste to gas project..

## 6. Prospects of clean diesel

**It is possible to clean up diesel:** In Indian cities CNG has been the opportunity to skip ahead of the slow-to-improve conventional diesel to cut harmful emissions. In the meantime, globally, diesel technology itself has improved dramatically in response to the stringent emissions standards set by the industrialized nations. The US has already adopted fuel neutral and very stringent emissions standards that do not differentiate between petrol and diesel vehicles any more. All light duty vehicles irrespective of the fuels they use have to meet same and equally stringent emissions standards. Equally stringent standards have been set for the heavy duty diesel vehicles. This helps to create level playing field for all types of technologies and fuels to compete fairly on emissions ground. This coupled with narrow price differential between diesel and petrol fuels diesel penetration in the US car market has been less than 1-2 per cent.

Similarly, Europe and Japan have tightened their emissions standards to phase in the clean diesel fuels and technologies. The particulate norms for diesel cars in Europe have closed gaps with the US and Japan in 2009 when Euro V was enforced. However, European NOx norms catch up with Japan only in 2014 when Euro VI norms are expected to be enforced. But even then it will trail behind the current US norms by at least 43 per cent.

The US Tier 2 bin 5 norms and the Euro V norms in Europe that are currently in place, have cut mass PM levels to as low as 5 to 6 miligramme -- this is 90 per cent lower than the Euro IV levels of 25 miligramme (Euro III levels are 50 miligramme) that India has just implemented. Besides, Euro IV does not require application of advanced particulate traps. Estimates from the International Council on Clean transportation shows that the current US Tier-2 NOx and PM limit values for light-duty vehicles are approximately 80 per cent tighter than the current Euro IV car limits. Similarly, new US limits for heavy-duty vehicles are approximately 90 per cent tighter for NOx and 60 per cent tighter for PM than the future European heavy-duty Euro V limits.[ix]

Cleaning up of diesel has been possible due to significant improvement in emissions control technologies that when used with nearly zero sulphur fuels can effectively control both mass and number of ultrafine particles. The European regulators are additionally setting count based particle standards that will force industry to use the most effective particulate filters to reduce the ultra fine particles effectively, to negligible levels. Clean diesel is a combination of improved engine systems along with advanced emissions control systems that run on diesel fuel with sulphur content as low as 10 to 15 ppm. The emissions control technologies that make diesel clean can work effectively only with ultra low sulphur fuel. High sulphur fuel can damage them.

**Indian diesel norms need to leapfrog**: The Government of India however has not come up with any roadmap so far for introduction of clean diesel technology and fuels for the entire country. Even the Euro IV standards have been enforced only in 11 cities that benefit less than the quarter of the urban population in India. But pollution levels are growing more rapidly in non-metro cities today. Having two quality of fuel in the market also increases the chance of misfuelling and this constraints city based diesel cars and buses from adopting more advanced emissions control solutions.

Also uniform stringent norms are particularly important to improve emissions levels of heavy-duty trucks and buses that have been the slowest to develop in India. Due to the two step approach towards emissions standards, the trucks and buses are mostly registered outside the major cities and thus escape the tighter standards. Many cities do not have their own dedicated city bus fleet and depend on the inter-city bus service. As a result both trucks and buses that are on highways meet poorer standards and cause enormous pollution while transiting through cities. These segments will improve only if India introduces uniform tighter norms across India. The highway heavy duty fleet is not easily substitutable with CNG. Even the car sector across India will not be covered by low taxed gaseous fuel mandate.

There is no official timeline for introduction of 10 ppm sulphur diesel uniformly across India. The Supreme Court of India has already taken on board the internationally accepted definition of clean diesel that has sulphur content of 10 ppm and is used along with the advanced emissions control technologies for PM and NOx. This combination makes diesel environmentally acceptable. But Indian refineries are not producing this diesel.

This essentially implies that the polluted cities in India facing the brunt of increased use of diesel in high mileage vehicles like buses and para transit will increasingly look at the CNG programme to cut emissions.

**Locating CNG in the future roadmap**

**Fuel neutral approach is possible when diesel cleans up nationally:** Fuel neutral approach is possible when equally clean alternatives are available across India. As of now there is no official roadmap that indicates the date of introducing clean diesel on a nation-wide scale. CNG therefore will continue to be preferred in cities that have access to natural gas. As there are no constraints of fuel quality in CNG these cities can adopt Euro IV technology that will also give them considerable emissions advantage.

Currently, CNG is a preferred solution in high mileage city buses and para-transit that are also part of the mobility strategy in the cities. Cities are in any case discouraging small para transit like three-wheelers on diesel. Cars will not be part of any regulatory mandate and will be driven by the customer preferences, and fuel pricing. There are concerns over public health impacts of dieselization of the car sector across India. (See Annex 1: Cars: dieselized). The price differential between petrol and diesel is a loophole that is leading to dieselisation. Also the government has to absorb colossal revenue losses on account of the ‘luxury’ consumption of diesel in personal cars. While the Union government earns nearly Rs 15.18/litre from every litre of petrol used by a petrol car as excise, it earns Rs 5.20/litre from a litre of diesel used by a diesel car. There is a growing demand for deregularisation of fuel prices and additional taxes on diesel cars to reduce the incentive for diesel cars in India. At the same time introduce clean diesel.

**Future roadmap for CNG and diesel to address PM, NOx and fuel efficiency challenge**: In this context the unique challenge will be in the heavy-duty sector. The future roadmap of either CNG or diesel buses will have to take on the combined challenge of both PM and NOx emissions reduction. It is still not known how this comparative challenge will play out in Indian cities given the enforcement challenges of the future technologies of both CNG and diesel buses.

In response to increasingly stringent emissions standards in Europe, and US more complex engine technology and emissions control systems are being adopted. Advanced particulate traps are being fitted to nearly eliminate particulates, and a combination of advanced engine control, and selective catalytic reduction (SCR) with a urea solution injected into the exhaust are being adopted to cut NOx emissions. This is also increasing the cost and complexity of the emissions control systems for both PM and NOx in diesel. The SCR system will additionally need urea tank, urea injection system, and an SCR catalyst and ammonia slip catalyst to prevent ammonia tailpipe emissions. A NOx sensor to provide feedback to closed loop control, and feed-forward control to the SCR model for urea and ammonia control etc. It may also need urea quality sensor. All these will add to the sophistication and complexity of the vehicle operations, costs and regulations.

The cost of urea refill will be an extra issue. More important drivers will have to ensure compliance which is a challenge in India. The vehicle operators must also not use cheaper agriculture grade urea as formaldehyde impurities can poison the catalyst, and particles may plug the urea injection system and lead to high emissions. This can be an added risk in India. This will be a serious enforcement challenge. Even though the vehicles are expected to be equipped with driver deterrents if the urea is insufficient (vehicle will lose power and be disabled etc) the implementation can be a challenge. If the SCR does not work then it can lead to sky high emissions in the real world. The technology will also have to be made suitable for city driving cycle.

Indian cities will have to assess the enforcement challenges and economics of PM and NOx control in both CNG and diesel buses and other vehicles in the second generation programmes. New CNG technologies are also evolving as discussed earlier that promise significant reduction in PM, and NOx emissions as well as improve fuel efficiency.

In future the CNG cities will have to weigh in the cost benefits and enforcement issues with regard to the technology improvement and emissions control strategies for diesel and CNG vehicles, fuel costs, life cycle costs of the vehicles, and the feasibility of the enforcement strategies and regulatory capacity.

The imperative of energy security of diverse energy basket will continue to remain strong in India. In a longer time frame India will also have to assess the possibility of riding on the CNG programme to make a paradigm shift to frontier solutions. The hythane project in Delhi indicates that the mature CNG markets can also offer more innovative solutions and make paradigm shift to high end technology solutions and phase in hydrogen technologies. Indian has the opportunity to plan its CNG roadmap more innovatively.

Ultimately, India needs a robust post 2010 roadmap to ensure that all types of vehicle technology and the requisite fuels are improved in an integrated way within a tight time frame to achieve clean air and reduce the energy and climate impacts of motorisation.

**Annex 1**

**Dieselisation of car segment**

Even before diesel could be cleaned up diesel car numbers have begun to gallop in India. From just 4 per cent of new car sales in 2004 it has exploded to 30 per cent now and is expected to be 50 per cent of the new sales by 2012.

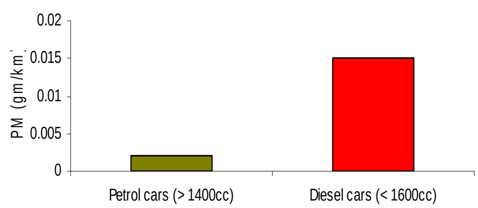
Under the current level of European emission standards that India has adapted, diesel cars are ‘legally’ allowed to emit nearly three times more NOx than the comparable petrol cars and also several times more particulates. Petrol vehicles have negligible emissions of particulates, while every diesel car is allowed to emit 0.05 gm/km in the Euro III norms. Petrol vehicles on the other hand are given higher limit for CO, as compared to diesel. But diesel related pollution is of serious concern in Indian cities. Standards are not fuel neutral.

Actual emissions data available from the Pune-based Automotive Research Association of India, show enormous differences in the actual emission levels of Euro III (Bharat Stage III) diesel and petrol cars that are currently sold in India.

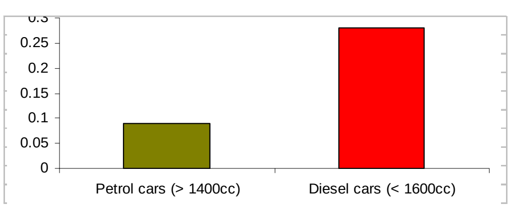
Euro III diesel cars emit 7.5 times more toxic particulate matter (PM) than comparable petrol cars. This means, one diesel car is equal to adding 7.5 petrol cars to the car fleet in terms of PM emissions and 3 petrol cars in terms of NOx emissions. This clearly reflects the flawed emission standards that allow diesel cars to emit more NOx and PM compared to petrol cars. Total air toxics from a diesel car that are very harmful and carcinogenic are 7 times higher than petrol cars.

**Emissions data for Euro III diesel and petrol cars from ARAI**

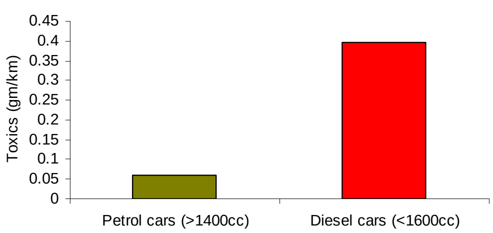
**i. PM emissions: Euro III diesel car emits 7.5 times more PM than petrol cars**




**ii. NOx emissions: Euro III diesel car emits 3 times more NOx than petrol cars**

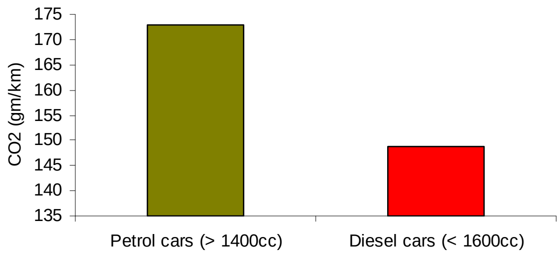



**iii. Total toxics emissions: Euro III diesel car emits nearly 7 times more air toxics**



**Trade-off between efficiency and pollution**: Diesel cars are 15 to 20 per cent more fuel efficient than a comparable petrol car and therefore emits lower greenhouse gas emissions.
ARAI data shows Euro III Indian diesel cars emit 1.2 times less carbon dioxide emissions compared to their petrol counterparts. Better fuel efficiency in combination with cheaper diesel prices and weaker emissions regulations is causing a major shift towards diesel cars. But the pollution and health cost of this shift are expected to be high.

**iv. CO2 emissions: Euro III diesel car emits nearly 1.2 times less carbon dioxides**




To stem this tide India needs to deregulate, rationalize and reduce price gaps between petrol and diesel to reduce the incentive for conventional diesel cars. Impose additional environmental tax on diesel cars to neutralise the revenue losses on account of subsidized fuel and also recover its environmental costs. Clean up diesel technology and fuel to the level of international benchmark of 10 ppm sulphur fuel with advanced emissions control systems. . Or else use of personal cars on subsidized conventional diesel should be discouraged.

**Annex 2**

**Status of CNG transport program in India (2008-2009)**

**(A) Cities where CNG fuel in transportation**

| Sr. No. | Name of the city | Status of CNG program | Name of implementing agency | Sale of CNG | Price of CNG (Rs/kg) | Number of vehicles running |
|---|---|---|---|---|---|---|
| 1. | **Delhi** | No. of CNG stations: 171<br><br>(Mother: 73, Online: 51, Daughter booster: 43, Daughter: 4) | Indraprastha Gas Ltd. (JV GAIL, BPCL, GNCTD) | 1.39 MMSCMD<br><br>1252.71 TPD | 18.90 | No. of vehicles: 289,866<br><br>Cars/taxis: 177,328<br>Autos: 93,440<br>LCV/RTV:5780<br>Buses:12,918<br>Others/phatphat:400 |
| 2. | **Mumbai/ Thane/Mira Bhayander/ Navi Mumbai** | No. of CNG station: 136<br><br>(Mother: 9, Online: 113, Daughter booster: 14, Daughter: 0) | Mahanagar Gas Ltd. (JV between GAIL, British Gas, UK and Govt of Maharashtra) | 1.10 MMSCMD<br><br>770.25 TPD | 21.70 to 22.23 | No. of vehicles: 190,926<br><br>Cars/taxis: 56,061<br>Autos: 130,447<br>LCV/RTV:1,829<br>Buses:1,547<br>Others/phatphat:1,042 |
| 3. | **Pune** | No. of CNG station: 7<br><br>(Mother: 1, Online: 0, Daughter booster: 6, Daughter: 0) | Maharashtra Natural Gas Limited | 0.002 MMSCMD<br><br>1.73 TPD | 28 | No. of vehicles: 612<br><br>Cars/taxis: 46<br>Autos: 481<br>LCV/RTV: 0<br>Buses:85<br>Others/phatphat: 0 |
| 4. | **Vadodara** | No. of CNG station: 3<br><br>(Mother: 2, Online: 0, Daughter booster: 1, Daughter: 0) | GAIL India Limited | 0.03 MMSCMD<br><br>28.34 TPD | 23.79 - 24.78 | No. of vehicles: 3,913<br><br>Cars/taxis: 623<br>Autos: 3,131<br>LCV/RTV: 0<br>Buses: 159<br>Others: 0 |
| 5. | **Surat** | No. of CNG station: 25<br><br>(Mother: 2, Online: 21, Daughter booster: 2, Daughter: 0) | Gujarat Gas Company Limited | 0.15 MMSCMD<br><br>153.52 TPD | 27.50 | No. of vehicles: 79,768<br><br>Cars/taxis: 36,826<br>Autos: 40,417<br>LCV/RTV: 0<br>Buses: 515<br>Others/phatphat: 2010 |
| 6. | **Ankaleshwar** | No. of CNG station: 4<br><br>(Mother: 1, Online: 2, Daughter booster: 1, | Gujarat Gas Company Limiteds | 0.03 MMSCMD<br><br>26.22 TPD | 27.50 | No. of vehicles: 10,687<br><br>Cars/taxis: |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | Daughter: 0) | | | | 4,213<br>Autos: 6,268<br>LCV/RTV: 0<br>Buses: 60<br>Others/phatphat: 146 |
| 7. | **Lucknow** | No. of CNG stations: 4<br>(Mother: 1, Online: 0, Daughter booster: 3, Daughter: 0) | Green Gas Limited (JV GAIL & IOCL) | 0.04 MMSCMD<br>36.18 TPD | 29 | No. of vehicles: 7,242<br>Cars/taxis: 384<br>Autos: 6,502<br>LCV/RTV: 0<br>Buses: 279<br>Others/phatphat: 77 |
| 8. | **Agra** | No. of CNG stations: 3<br>(Mother: 1, Online: 0, Daughter booster: 2, Daughter: 0) | Green Gas Limited (JV GAIL & IOCL) | 0.02 MMSCMD<br>24.44 TPD | 28.00 | No. of vehicles: 6,195<br>Cars/taxis: 165<br>Autos: 5,736<br>LCV/RTV: 0<br>Buses: 294<br>Others/phatphat: 0 |
| 9. | **Kanpur** | No. of CNG stations: 7<br>(Mother: 1, Online: 6, Daughter booster: 0, Daughter: 0) | Central UP Gas Limited (JV GAIL & BPCL) | 0.04 MMSCMD<br>40.05 TPD | 27.00 | No. of vehicles: 9,581<br>Cars/taxis: 297<br>Autos: 8,799<br>LCV/RTV: 0<br>Buses: 396<br>Others/phatphat: 89 |
| 10. | **Bareilly** | No. of CNG stations: 1<br>(Mother: 1, Online: 0, Daughter booster: 0, Daughter: 0) | Central UP Gas Limited (JV GAIL & BPCL) | Included in Kanpur | 29 | Included in Kanpur |
| 11. | **Vijyawada** | No. of CNG stations: 6<br>(Mother: 1, Online: 0, Daughter booster: 5, Daughter: 0) | Bhagyanagar Gas Limited (JV GAIL & HPCL) | 0.01 MMSCMD<br>10.42 TPD | 25 | No. of vehicles: 4,863<br>Cars/taxis: 720<br>Autos: 3997<br>LCV/RTV: 0<br>Buses: 119<br>Others/phatphat: 27 |
| 12. | **Hyderabad** | No. of CNG stations: 3<br>(Mother: 0, Online: 0, Daughter booster: 3, Daughter: 0) | Bhagyanagar Gas Limited (JV GAIL & HPCL) | 0.01 MMSCMD<br>6.22 TPD | 35 | No. of vehicles: Included in Vijaywada |
| 13. | **Rajamundery** | No. of CNG stations: 1<br>(Mother: 0, Online: 0, Daughter booster: 1, Daughter: 0) | Bhagyanagar Gas Limited JV GAIL & HPCL) | 0.00 MMSCMD<br>0.01 TPD | 27 | No. of vehicles: Included in Vijaywada |
| 14. | **Agartala** | No. of CNG stations: 1 | Tripura Natural Gas Company Limited s | 0.00 MMSCMD | 22.15 | No. of vehicles: 853 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | (Mother: 0, Online: 1, Daughter booster: 0, Daughter: 0) | | 2.22 TPD | | Cars/taxis: 65<br>Autos: 788<br>LCV/RTV: 0<br>Buses: 0<br>Others/phatphat: 0 |
| 15. | **Indore** | No. of CNG stations: 4<br><br>(Mother: 1, Online: 0, Daughter booster: 0, Daughter: 3) | Aavantika Gas Limited | 0.00 MMSCMD<br><br>0.78 TPD | 32 | No. of vehicles: 650<br><br>Cars/taxis: 300<br>Autos: 350<br>LCV/RTV: 0<br>Buses: 0<br>Others/phatphat: 0 |
| 16. | **Ujjain** | No. of CNG stations: 1<br><br>(Mother: 0, Online: 0, Daughter booster: 0, Daughter: 1) | Aavantika Gas Limited | 0.00 MMSCMD<br><br>0.78 TPD | 33 | No. of vehicles: Included in Indore |

Source: Anon 2009, *Basic Statistics on Indian Petroleum and Natural Gas 2008-09*, Ministry of Petroleum and Natural Gas, Delhi.

**(B) CNG projects under implementation**

| Sr. No. | **Name of the city** | Status of CNG program | Name of implementing agency |
|---|---|---|---|
| 1. | **Pune** | 1st station expected to commission soon with completion of spur pipeline from Dahej-Uran pipeline | Maharashtra Natural Gas Ltd. (JV GAIL and BPCL) |
| 2. | **Faridabad** | IGL got allocation of 0.7 mmscmd for Faridabad, Noida, & Gurgaon for CGD.<br><br>Two CNG stations opened in Greater Noida in Feb 2009. CNG cost Rs 22.10 per kg in Greater Noida.<br><br>IGL presently supplying gas cascades to Haryana City Gas C Ltd. in compliance to per SC Order | Indraprastha Gas Ltd. (JV GAIL, BPCL, GNCTD) |
| | **Noida** | | |
| | **Gurgaon** | | |
| 3. | **Ahmedabad** | CNG supplied by HPCL | MOU signed for JV between GAIL, HPCL |
| 4. | **Varanasi** | Project implementation linked with completion of Jagdishpur-Haldia pipeline expected by 2010-11 | Central UP Gas Ltd. (JV GAIL & BPCL) |
| 5. | **Patna** | Project implementation linked with completion of Jagdishpur-Haldia pipeline expected by 2010-11 | Yet to formed |
| 6. | **Sholapur** | Project yet to be taken up | Maharashtra Natural Gas Ltd. (JV GAIL and |

| | | | |
|---|---|---|---|
| | | | BPCL) |
| 7. | **Bangalore** | Project implementation linked with completion of Dabhol-Bangalore pipeline | MOU signed between GAIL and BPCL for formation of JV company |
| 8. | **Kolkata** | Project implementation linked with completion of Jagdishpur-Haldia pipeline expected by 2010-11 | JVA between GAIL and IOCL for formation of JV company |
| 9. | **Chennai** | Pipeline and gas source not in the vicinity however Reliance Gas Transportation Infrastructure Ltd. is laying Vijayawada-Nellore-Chennai pipeline and a decision on CGD will be taken at the appropriate time | Yet to be formed |

Sources:
– Anon (undated), Petroleum and Natural Gas Statistics (*Table: CNG activities in India as on 01.04.2008*), Ministry of Petroleum and Natural Gas, Delhi, p23
– Anon 2008, *Supply, Distribution And Marketing Of Natural Gas Including Cng And Lng, [Action Taken Report]*, Standing Committee On Petroleum & Natural Gas (2008-09), Ministry Of Petroleum & Natural Gas, 24th Report, Lok Sabha Secretariat, New Delhi, December, p40-41

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**Refernces**ii

1. Basic Statistics of Indian Petroleum and Natural Gas 2008-09, Ministry of Petroleum and Natural Gas

2. Marcados Energy Markets India Private, 2010, Llimited Study on Common Pool Price Mechanism for Natural Gas in the Country for GAIL.

3. Eleventh Five Year Plan, Planning Commission, Government of India

4. Report of the Working Group on Petroleum and Natural gas sector for eleventh Plan, 2007-12

5. World Bank 2004, Towards cleaner urban air in south Asia: tackling transport pollution, understanding sources, Energy Sector Management Assistance Programme of World Bank and United Nations Development Programme,Washington DC, USA,

6. ARAI 2007, *Draft report on* "Emission Factor development for Indian Vehicles " as a part of Ambient Air Quality Monitoring and Emission Source Apportionment Studies, Pune

7. The Energy and Resources Institute, 2004, *Fuel Choices for Transport and the Environment*, New Delhi

8. Enstrat International Limited 2004, The emission reduction potential of low-sulfur diesel fuel in Asian countries, , UK

9. Frank Dursbeck, Lennart Erlandson, Christopher Weaver 2001, Status of implementation of CNG as a fuel for urban buses in Delhi, CSE, New Delhi

10. Lennart Erlandson, Christopher Weaver, et al 2002, Safety of CNG buses in Delhi: Findings and recommendations, CSE, New Delhi

11. EPCA Report No. 30, March 2007, CNG safety: Progress and action taken report, *Mimeo*

12. EPCA Report No. 26, July 2006, Investigations relating to fire hazards and safety in CNG Buses, *Mimeo*

13. H B Mathur, Report on the fire incidents in a converted CNG Bus, 2006, Mimeo

14. 2008, *Supply, Distribution And Marketing Of Natural Gas Including Cng And Lng, [Action Taken Report]*, Standing Committee On Petroleum & Natural Gas (2008-09), Ministry Of Petroleum & Natural Gas, 24th Report, Lok Sabha Secretariat, New Delhi, December, p40-41

15. Nils-Olof Nylund & Kimmo Erkkilä 2004, *Transit Bus Emission Study: Comparison Of Emissions From Diesel And Natural Gas Buses*, Paper presented at the NGV 2004, Buenos Aires

19. Gas Authority of India Limited, 2005, 'Transmission fee — GAIL for uniform methodology for all players', press release, New Delhi, March 10

20. Anon 2001, International experience with CNG vehicles, south Asia Urban Air Quality Management briefing note No 2, World Bank, Washington DC, USA,

21. World Bank, 2004, Breath of Fresh Air, Washington

22. Michael Walsh et al 2003, Progress towards clean cars, trucks, and buses, International Council on Clean Transportation, San Francisco, The Hewlett Foundation and The Energy Foundation, San Francisco, USA,

23 A Roychowdhury, V Chattopadyayay et al, 2006, The Leapfrog Factor, Centre for Science and Environment, New Delhi