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Air Pollution & Co-Benefits Analysis for Hyderabad, India

Dr. Sarath Guttikunda
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Hyderabad, a 400 years old city, is the state capital of Andhra Pradesh, India, and the fifth largest city in India with a population nearing 7 million. The twin cities of Hyderabad and Secunderabad of Municipal Corporation of Hyderabad (MCH) and the neighboring ten municipalities together form Hyderabad Urban Development Area (HUDA), a major high-tech center, with increasing economic activity.

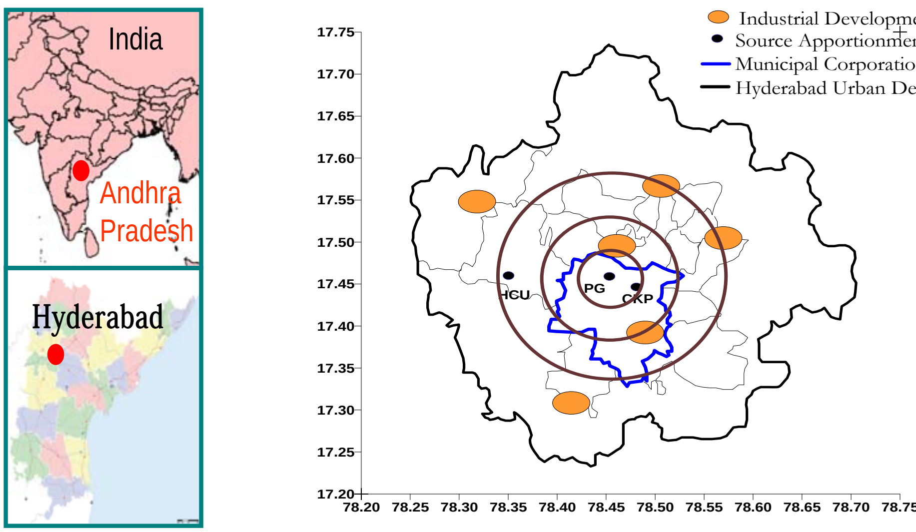

Figure 1: Geographical location of Hyderabad Urban Development Area (HUDA) and major industrial development areas (IDAs)

This multi-agency study[1] was designed to prepare a co-benefit action plan for air pollution control in Hyderabad, India, with base year 2006. The program included (a) a year long source apportionment study using mini-vol sampler, chemical analysis, and receptor modeling using CMB model (b) bottom-up air pollution analysis by developing emissions inventory for local and global air pollutants, dispersion modeling, and co-benefits analysis of the city action plan. The study results are published[2] and disseminated at a workshop in December, 2007[3].

[1] Andhra Pradesh Pollution Control Board, in collaboration with the Desert Research Institute (Reno, USA) and co-financing from the USEPA Integrated Environmental Strategies program (Washington DC, USA), and the World Bank (Washington DC, USA)

[2] Hyderabad Co-benefits study report – www.urbanemissions.info/hyderabad

[3] IES India program phase II workshop, December'07 - http://www.epa.gov/ies/india/apportionment_documents.htm

Air Quality and Sources

In HUDA, 20 monitoring stations are installed in polluted hot spots and background sites, measuring respiratory PM, sulfur dioxide (SO_2), and nitrogen oxides (NO_x). **Figure 2** presents annual average concentrations on PM_{10} (averaged over all stations in the city) for the last 10 years. In 2007, the city averaged ~120 µg/m3 for PM10 concentrations, which is above the threshold for health impacts (WHO, 2006). Although the concentrations in the recent years show a value lower than those measured in 1999, the hot spots in the city measure ~2 times the city averages presented here. The number of monitors operating across the HUDA boundaries increased since 1999, which also led to lowering of the averages; while in 1999 most of the measurements were made at the hot spots.

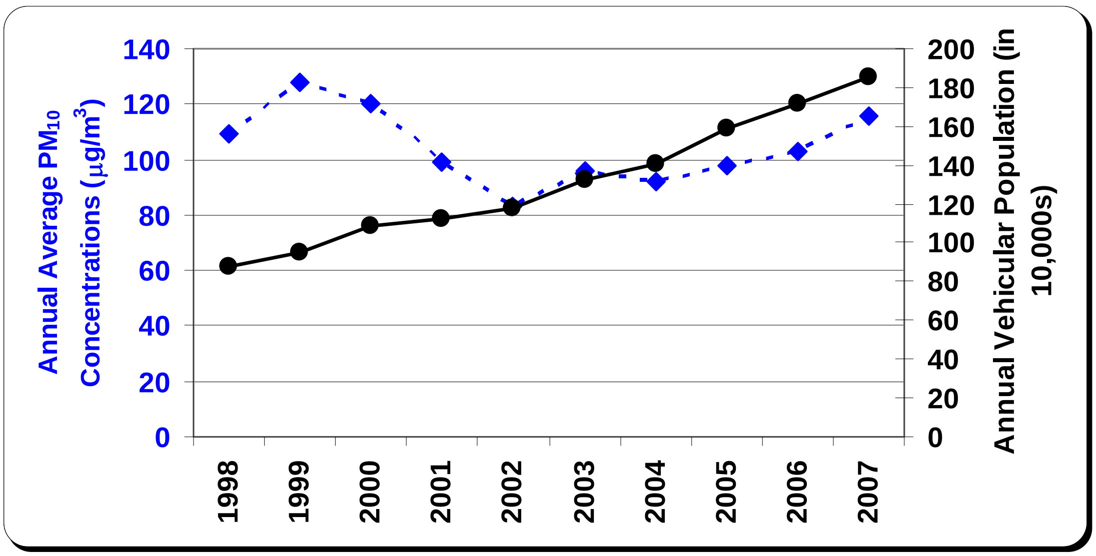

Figure 2: Annual average air quality and vehicular population trends in Hyderabad

Two main reasons for reduction in PM pollution in the early 2000s, is an ordinance to replace petrol based 3-wheelers with liquefied petroleum fuel (LPG), and relocation, shutting down, and merging of some industries falling within the now residential zones. Over a four year period, concentrations reduced from 128 µg/m^3 in 1999 to 83 µg/m^3 in 2002. However, recently, increase in passenger cars and 3 wheelers (petrol, diesel, and LPG; 2 stroke and 4 stroke) nullified the impact of this conversion. Currently, 40 percent of the ~80,000 3-wheeler fleet is LPG based.

The in-use vehicular population presented in **Figure 2** grew from 1.45 million vehicles in 2001 to 2.0 million vehicles in 2007. Of the total, 2 wheelers (2-stroke and 4-stroke) dominate with a 79 percent share and passenger cars (petrol and diesel) at ~230,000. The passenger cars are estimated to grow at ~10 percent a year. The public transport system operates ~15,000 point to point buses with good frequency. All of the goods vehicles run on diesel and the average age of the diesel fleet (for both public transport buses and goods vehicles) is high (~10 years). Also, lack of effective inspection and maintenance programs is the leading cause of higher emission levels from these vehicles. Some 3-seater and 7-seater auto rickshaws cover a share of the public transport system.

In parts of the city, including smaller clusters of settlements, commercial motorcycles offer a ready alternative transport mode for commuters. The motorcycles serve as a viable option for overcoming the traditional traffic hold-ups and for accessing unmotorable roads. However, the size, number, and aggressive driving style of these operators exacerbate congestion and hinder the speed and reliability of other modes, particularly buses. On the main roads, because of increasing number of personal vehicles, operating speeds have reduced for the public transport buses and result in higher pollution levels due to idling. In spite of a number of flyovers connecting and by-passing major choke points in the city, due to increased on-street parking; encroachments by hawkers; and stopping of vehicles in the middle of the road (especially autos and buses) to service their passengers, has increased congestion problems.

In the city, the non-transport sector is also prevalent, in the form of steel, textiles, paper, pharmaceuticals, and paints, in five of the largest industrial development estates (represented by elliptical circles in **Figure 1**), are located within 10 km radius of the city. In 2005, the number of industries was listed at ~390 following the new industrial and residential zoning in HUDA. The relocation of the industries in the early 2000's along with improvements in the energy efficiency of new constructions was also responsible for the slower rise in the annual average concentrations presented in **Figure 2**.

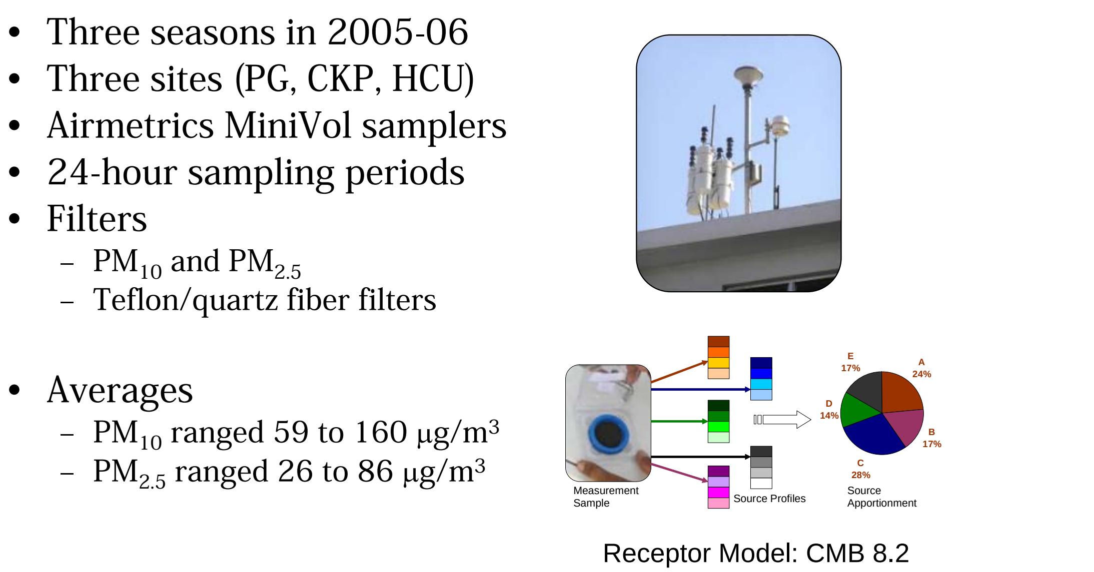

Figure 3: Source apportionment methodology and monitoring results

This study included a year long study of source apportionment covering three seasons and three sampling sites between November 2005 and December 2006. A detailed description of the study methodology, analysis, and results is presented in IES, 2007[4]. The equipment details are presented in **Figure 3**.

[4] IES, 2007. The Hyderabad source apportionment report is available @ www.urbanemissions.info/hyderabad

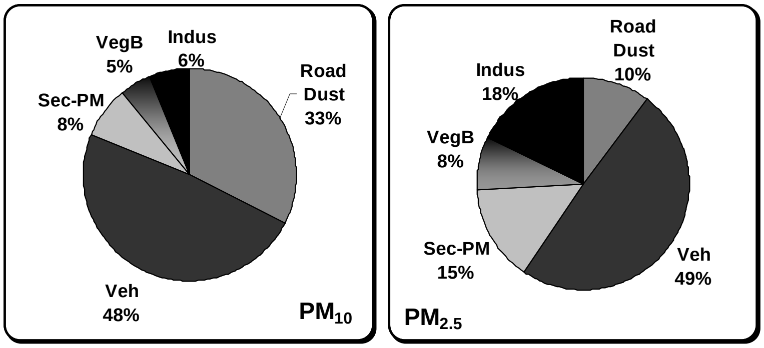

Figure 4: Estimated average sectoral contributions based on source apportionment

The sampling was carried out using AirMetrics MiniVol[5] samplers at three locations presented in **Figure 1**. Punjagutta (PG) is an urban site dominated by transport, Chikkadpally (CKP) is also an urban site dominated by industrial and residential sources, and Hyderabad Central University (HCU) is a background site on campus. Following the sampling and composition of PM was determined by analyzing the parameters: ions (anions and cations), crustal elements, organic and elemental carbon fractions, and heavy metals; and conducting receptor modeling using CMB version 8.2. A summary of receptor modeling results presented in **Figure 4** concluded that more than half of all observed PM in Hyderabad can be attributed to vehicular activity (direct vehicular exhaust and indirect fugitive dust due to resuspension on roads). The fugitive dust is predominant in the coarser PM_{10} fraction due to its larger particle size and the industrial sources dominate the finer $PM_{2.5}$ fraction. The secondary PM due to chemical transformation of SO_2 and NO_x emissions from coal and diesel combustion was included in the fine fraction.

Emissions & Pollution Analysis

Abatement of air pollution is one of the biggest challenges and presents a clear need for better understanding of sources of air pollution and their strengths. Following the source apportionment study in 2005-06, an emissions inventory was established for base year 2006 for pollutants PM_{10}, SO_2, NO_x, and CO_2. A consolidated exercise of bottom-up and top-down approaches established a baseline for validating the estimated emissions and projections through 2020. The emission inventory was established using existing fuel consumption and activities data by inserting applicable emission factors for transport and industrial sectors in Hyderabad for base year 2006. The methodology details, inventory, and parameters utilized are presented in the final report and a summary of the results is presented in **Table 1**.

Overall, PM emissions are dominated by vehicular, industrial, and fugitive sources. The garbage burning, a very uncertain source of emissions due to lack of necessary information on the amount burnt and proper emission factors, is a significant unconventional source. Only one landfill to the southeast of MCH border is estimated to burn on average 5 percent

[5] AirMetrics Samplers - http://www.airmetrics.com/products/minivol/index.html

of the trash collected and combined with the domestic fuel consumption accounts for ~10 percent of the annual PM_{10} emissions. Emissions of PM_{10}, SO_2, NO_x, and CO_2 are estimated at 29.6 ktons, 11.6 ktons, 44.5 ktons, and 7.1 million tons respectively. For CO_2, a major GHG gas, the transport sector accounts for 90 percent of the emissions.

Table 1: Estimated emissions inventory for Hyderabad in 2006 (tons/yr)

Category	PM_{10}	SO_2	NO_x	CO_2
Vehicular Activity	8,410	6,304	39,262	6,400,337
Paved Road Dust	3,272			
Unpaved Road Dust	4,279			
Industries	8,985	4,606	5,070	654,717
Domestic	1,845	667	545	83,485
Waste Burning	810			
Total	**27,599**	**11,577**	**44,877**	**7,138,538**

The study also included dispersion modeling to underpin the discussions on the share of the various sources to ambient air quality (**Figure 5**). The share of transport sector is high, averaging above 40 percent in the central Hyderabad.

For dispersion of emissions, the Atmospheric Transport Modeling System (ATMoS) was utilized with meteorological data from NCEP Reanalysis fields for the grid containing Hyderabad. The main city center was divided into a 20 x 20 grid based on geographical information from the city council. Note that the distribution of emissions to the grids was subjective where real location information was not available, especially for non-industrial sources and was based on geographical maps of population and road networks.

The estimated annual average concentrations presented in **Figure 5**, include both primary PM and secondary PM due to chemical conversion SO_2 and NO_x emissions to sulfates and nitrates. In the HUDA region, on an average, secondary PM contributes 20-40 percent of total PM_{10}. The estimated annual average concentrations were calibrated against the measurements for year 2006 with urban hotspots averaging ~200 $\mu g/m^3$, on a daily basis. The highest concentrations in the first panel of **Figure 5** represent the areas with highest industrial density; largest density of the population is within the 10 km radius and MCH boundary lines. The ambient concentrations for HUDA urban area are frequently above the national ambient guidelines. Within the MCH boundary, in 2006, the contributions of individual sectors ranged between 20-50 percent for vehicular sources, 40-70 percent when combined with road dust, 10-30 percent for industrial sources, and 3-10 percent for domestic and garbage burning sources.

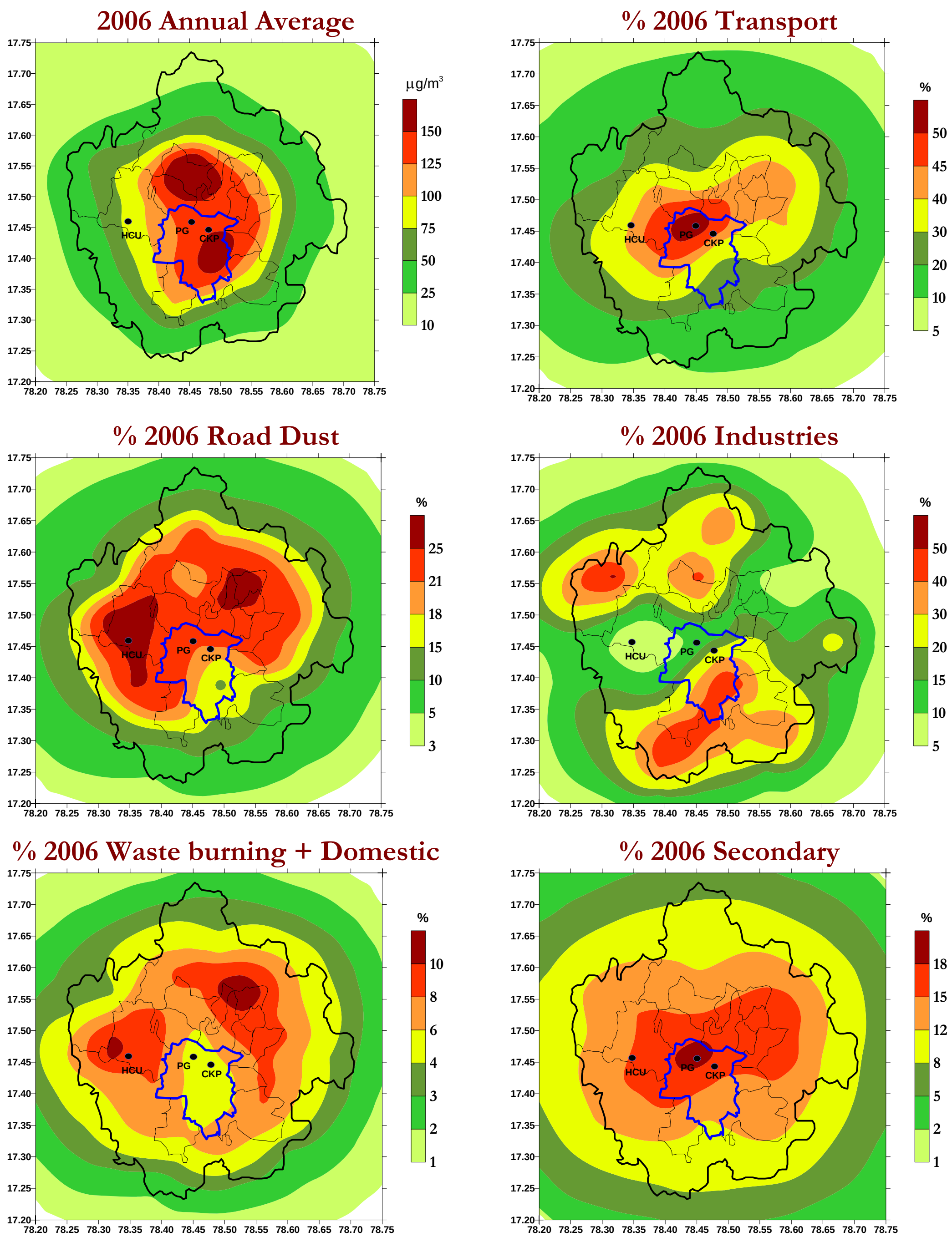

Figure 5: Modeled annual average concentrations and percent contribution of sectors to annual PM_{10} in 2006

Consolidation of Top-Down & Bottom-Up

Table 2 presents a comparison of range of modeled concentrations to estimated source apportionment results for the three sampling stations. The modeled (M) results indicate the color range over the monitoring site in **Figure 5** and source apportionment (SA) results indicate the range of results from CMB modeling for each monitoring site.

Table 2: Comparison of top down and bottom up analysis results (%)

Location	Vehicles		Veh + Road Dust		Industries		OWB+Dom	
	SA	**M**	**SA**	**M**	**SA**	**M**	**SA**	**M**
Punjagutta	54 ± 10	50 - 55	81 ± 10	70 – 75	13 ± 10	10 – 15	5 ± 10	4-6
Chikkadpally	45 ± 10	45 - 50	80 ± 10	60 – 70	15 ± 10	20 – 30	4 ± 10	4-6
HCU	43 ± 10	30 - 40	80 ± 10	60 – 70	16 ± 10	5 – 10	5 ± 10	8-10

Note: Top-Down is source apportionment (SA) and Bottom-Up is modeled (M)

The analysis presented above is for qualitative and quantitative comparison, with the given level of uncertainties in receptor and source modeling[6]. This should not be considered the final or the only comparison possible for the following reasons.

During the source apportionment CMB modeling,

- No distinction is made between diesel and fuel oil utilized by vehicles and industries. The entire diesel portion is assigned to the vehicular contribution thus over predicting the vehicular and under predicting the industrial contribution.
- Similarly, coal combustion between industries and domestic sector are not distinguished.
- All types of dust – road and soil – are clubbed together. Thus, over predicting the road dust contribution.
- Two of the sampling points are urban with most vehicular activity. An average of these points will be biased towards vehicular contributions, as seen in Table 5.1.
- Source profiles used for CMB modeling were based on similar studies conducted elsewhere, which puts an unknown uncertainty on the results. Having said that, the source profiles for similar technologies and similar fuel characteristics present comparable results.
- Air pollution modeling results are annual average values, where as the CMB modeling results are averaged over the three sampling months and three sampling sites.

Given the uncertainties and deficiencies in emissions estimation, air pollution modeling, and source apportionment, qualitatively and quantitatively, the results present a close comparison between the two methodologies; further emphasizing need for such consolidated and integrated studies for urban centers to identify the potential for reducing local pollutants.

[6] The source apportionment methodology has some uncertainties as it is based on the chemical signatures of various pollution sources. For details on the source apportionment study in Hyderabad and general techniques, refer to www.urbanemissions.info/pmsa

Proposed Action Plan & Co-Benefits

As part of APPCB's report to the Burelal committee of Government of India, a number of control options were outlined for air pollution reduction in Hyderabad. EPCA[7] has identified four key areas that have the potential to engineer a fundamental transition. Suggested actions include:

- Gaseous fuel programs, both compressed natural gas (CNG) and LPG to leapfrog from current polluting diesel to cleaner fuel, particularly in grossly polluting segments like public transport and 3 wheelers.
- Public transport and transport demand management to reduce the demand for growth of private motorization and reduce emissions.
- Vehicle inspection program for the on-road vehicles to combat pollution from large fleets of existing vehicles.
- Management of transit traffic and phasing out of old vehicles to reduce the burden of pollutants in the city.

The action plan includes the following decisions[8]:

- To expedite the supply of CNG/LPG for subsequent conversion and consumption of vehicles. Out of 68,840 3 wheelers in Hyderabad, a total of 29,346 have been converted to LPG based vehicles. Rest of the conversion is expected to finish in 2009-10.
- Currently, 2,836 buses are operated by Andhra Pradesh State Road Transport Corporation in the city. It is estimated that there are ~7 million commuters daily of which 42% travel by public transport and the remaining by personal transport. In order to increase the number of commuters traveling by public transport from 42 per cent to 50 per cent, there is a need to increase the number of buses by another 850 by 2009.
- APPCB will examine and plan for networking of "Pollution Under Control (PUC)" centers for the transmission of the emissions test data to a central server to be located at the transport department. This is expected to help improve surveillance and track emissions inspection status more effectively and check corruption. This system will be integrated with the vehicle registration data to enable tracking. Hyderabad has already initiated a pilot project in 2006. APPCB will take the lead role to model a plan for implementation.
- The Department of Transport has submitted an action plan to control emissions from in-use vehicles like:
  - Euro-III norms for all new passenger cars and vehicles below 3.5 tons laden weight.
  - Bharat-II norms for all new buses / good vehicles.
  - Bharat-II norms for all new 3 wheelers.
  - All in-use petrol driven 3 wheelers to be converted to LPG.

[7] Environmental Pollution (Prevention & Control) Authority (EPCA), is part of the Burelal committee for air pollution control in India, was constituted by the Central Government on January 29, 1998, with Central Pollution Control Board of India providing all the technical and secretarial support in carrying out its functions.

[8] http://www.hyderabadgreens.org/automobile.html

  - o Phasing out of heavy goods carrier of +15 years.
  - o Phasing out of heavy goods carrier of +20 years.
  - o All petrol taxies to be converted to LPG.
  - o No fuel at gas stations with PUC certification.
  - o Govt. vehicles older than 15 years to be replaced by Euro-III complaint vehicles or converted to LPG
  - o Permits to be cancelled for 10+ year diesel taxis.
  - o No permits for taxis above 10 years.
- APPCB has identified and inventoried 333 air polluting industries in HUDA area, with details including their addresses, fuel used, control equipment provided, pollution load and whether meeting the air emission standards are also outlined for inspection and control strategies. Based on study conducted with NEERI, Nagpur, of the 333 industries, 301 are meeting the emission norms, 7 are not meeting and 25 are closed. So far, 192 industries are fitted with air pollution control devices such as wet scrubbers, cyclones, multi-cyclones, bag filters, dust collectors, etc.
- Air pollution due to waste/vegetative burning in the city one of the uncertain sources. Discussions are in consideration for better solid waste management and to include provisions for Clean Development Mechanism (CDM) facilities under approved landfill methodologies.
- Conduct routine wet street sweeping on roads with the highest traffic volume and eliminate dusty shoulders

By improving traffic flow, public transport, emission standards, industrial efficiency, domestic LPG use, and reducing waste burning, a reduction of ~44% and ~32% in PM_{10} and CO_2 emissions respectively and ~US$472 million in health and carbon benefits is expected by year 2020[9].

Table3: Summary of emission reductions from Hyderabad action plan

	PM_{10}	SO_2	NO_x	CO_2
2006 Emissions BAU (tons)	27,599	11,577	44,877	7,138,538
2010 Emissions BAU (tons)	34,620	14,520	58,638	9,352,590
2010 Emissions – with controls (tons)	27,755	12,377	48,312	7,559,229
Estimated emission reductions (tons)	6,864	2,143	10,327	1,793,361
% Reduction from 2010 BAU	19.8%	14.8%	17.6%	19.2%
2020 Emissions BAU (tons)	43,550	18,670	63,694	10,310,520
2020 Emissions – with controls (tons)	24,110	13,365	40,059	6,968,693
Estimated emission reductions (tons)	19,440	5,035	23,635	3,341,847
% Reduction from 2020 BAU	44.6%	27.0%	37.1%	32.4%

Largest benefits for GHG emissions are achieved via a combination of interventions for gross polluters - goods vehicles and buses such as BRT planning and improving fuel standards; introduction of inspection and maintenance to improve deterioration rates; and introducing LPG for domestic cooking to LPG.

[9] For details on the health impact analysis and co-benefits, refer to the final report @ www.urbanemissions.info/hyderabad

The combined benefits of integrated air quality and climate change policies by 2020 (or earlier depending on the feasibility and accelerated actions) are expected make substantial improvements in the city and given time, technical, and financial support for implementing measures will lead to a better urban environment. The health benefits of air pollution reduction outweigh the carbon savings, but the carbon finances where available (and the estimated savings similar to health impacts) can be used to co-finance (and justify) projects which otherwise would not get implemented.