Asian and Pacific Centre for Transfer of Technology

Assessment Report

Technological Interventions and Gaps in Air Pollution Control in Gurugram, India

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FOREWORD

It is with great pleasure that I introduce this document: *Technological Interventions and Gaps in Air Pollution Control in Gurugram, India*.

The Asian and Pacific Centre for Transfer of Technology (APCTT) of the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP), has long been dedicated to fostering innovation and facilitating the transfer of technology across our diverse member countries. APCTT's key mandate is to strengthen the technology transfer capabilities in the Asia- Pacific region and to facilitate exchange of new, emerging and environmentally sound technologies between the member countries.

This document was produced under the project "Enhanced capabilities to adopt innovative technologies for city air pollution control in select countries of the Asia Pacific" supported by the Korea ESCAP Cooperation Fund. The project objective was to support three ESCAP member States (Bangladesh, India and Thailand) to strengthen policies and city level action plans to facilitate adoption of innovative technologies for controlling air pollution. The project aimed to improve the availability of technical knowledge regarding innovative technologies, and good practices and enabling policies for air pollution control in three cities (Bangkok, Dhaka and Gurugram).

This assessment report examines the current state of air pollution technologies employed in Gurugram. It identifies the key technological needs and gaps that require urgent attention for controlling urban air pollution. As we attempt to enhance our understanding of the complexities of air pollution in key cities in Asia Pacific, the findings of this report will serve as a valuable resource for policymakers, city planners and practitioners. I hope that this report will play an important role in shaping the trajectory of air pollution control initiatives in Gurugram and other cities in Asia Pacific.

Preeti Soni
Head
Asian and Pacific Centre for Transfer of Technology
Economic and Social Commission for Asia and the Pacific

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This document: *Technological Interventions and Gaps in Air Pollution Control in Gurugram, India* is part of a set of reports developed under the project "Enhanced Capabilities to Adopt Innovative Technologies for City Air Pollution Control in Select Countries of the Asia-Pacific" funded by the Korea ESCAP Cooperation Fund. It has been prepared under the overall guidance and direction of Dr. Preeti Soni, Head, Asian and Pacific Centre for Transfer of Technology (APCTT) of the Economic and Social Commission for Asia and the Pacific (ESCAP).

This publication was prepared by Dr. Ajay A. Deshpande under a consultancy assignment with ESCAP-APCTT. Mr. Subhash Yadav of Gurugram Metropolitan Development Authority provided valuable information and insights for the study. The report benefited from comments and suggestions from Mr. Satyabrata Sahu and Mr. Pankaj Kumar Shrivastav from the ESCAP-APCTT.

We gratefully acknowledge all of the above.

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ACRONYMS

ASG	Anti-Smog Gun
CAP/CAAP	City Action Plan/ City Air Action plan
CAAQMS	Continuous Automatic Ambient Air Quality Monitoring Station
CAQM	Commission of Air Quality Management for NCR
CEMS	Continuous Emission Monitoring system
CNG	Compressed Natural Gas
CPCB	Central Pollution Control Board
DEP	District Environmental Plan
EPCA	Environment Protection and Control Authority
GMC	Gurugram Municipal Corporation
GMDA	Gurugram Municipal Development Authority
GRAP	Graded Response Action Plan
HSPCB	Haryana State Pollution Control Board
LCS	Low-Cost Sensors
MoEFCC	Ministry of Environment and Forest and Climate Change, Govt. of India
NCAP	National Clean Air Programme
NCR	National Capital Region Territory of Delhi
PM2.5	Particulate matter less than 2.5 micron size
PM10	Particulate matter less than 10 micron size
SPCB	State Pollution Control Board

1. INTRODUCTION

Rapid urbanisation and industrialisation, coupled with increasing population at an unprecedented rate in cities of the developing world, have drastically deteriorated the air quality and subsequently the atmospheric conditions. Many of the cities with their significant anthropogenic activities, increased energy and fuel use, waste burning and associated emissions in the urban and the peri-urban areas have become hotspots of air pollution. It is well documented that a significant portion of urban air pollution in India also has transboundary implications viz. dispersion of pollutants from the area of origin to another area. The air pollution challenge in India is therefore inherently multi-sectoral and multi-jurisdictional. The common geographic area where pollutants mix and create similar air quality for everyone is called an airshed. Cities need to look beyond their immediate jurisdiction for effective air pollution control strategies and apply a new set of tools for airshed-based management.

Northern India has long been experiencing significant air pollution, mainly in the winter season when the air quality index goes very high signifying hazardous levels of pollution. Even though several regulatory measures, including the use of cleaner fuel, stringent air quality emission norms, improved measurements and increased enforcement have been taken in the past by several authorities, the menace of air pollution continues. With the advent of National Clean Air Programme (NCAP) in India in 2020, 132 cities, presently under non-attainment category, have developed their respective Clean-Air Action Plans (CAPs) to improve urban air quality. These CAPs are available on CPCB website[1]. These action plans are limited to administrative boundaries of the city and do not integrate transboundary considerations to climate change. Similarly, a specific portal 'PRANA' or Portal for Regulation of Air-pollution in Non-Attainment cities[2] has been developed for monitoring the implementation of National Clean Air Programme (NCAP). The portal aims to support the tracking of physical as well as financial status of city air action plan implementation and disseminate information on air quality management efforts under NCAP to the public.

The present assignment is a part of the broader APCTT project titled ` Enhanced capabilities to adopt innovative technologies for city air pollution control in select countries of the Asia-Pacific'[3]. This project will support ESCAP Member States to strengthen policies and city level action plans to facilitate adoption of innovative technologies for controlling air pollution in Asia-Pacific. The project will improve availability of technical knowledge regarding innovative technologies and good practices and create better understanding of technology needs and gaps for air pollution control in the three selected cities in South Asia and Southeast Asia. The experience and outcomes of the project would be shared with stakeholders from other Member States of the Asia-Pacific region for wider dissemination and adoption. The project targets policy-makers, pollution control authorities/departments, city municipal authorities and the private sector.

The project implementation strategy is based on two main pillars to achieve the outcome: (1) improving availability of technical knowledge regarding technologies, innovations and good practices and better understanding of technology needs and gaps for air pollution control in the selected cities; and (2) increased awareness and capacity of city officials and stakeholders to strengthen action plans for adoption of innovative technologies to control air pollution. First, a compendium of the existing cases of technologies for air pollution control, which have been successfully implemented at the city level, will be developed. While developing the compendium, special focus will be given to the application of innovative technologies from the cities of Asia-Pacific region. The current technologies being used in these cities for air pollution control and related aspects will be studied. This assessment will also identify the current gaps and needs for technological interventions in the selected cities. In parallel, the action plans of the selected cities will be examined to understand the strengths and challenges of the current strategies for adopting innovative technologies for air pollution control.

1 https://cpcb.nic.in/approved-city-action-plans/

2 http://www.prana.cpcb.gov.in/#/home

3 Source: UN-ESCAP document on project proposal

1.1 Scope Of Work

The broad scope of the present study is as under:

1. In consultation with APCTT and other national consultants, provide inputs to prepare and finalise the inception report on the approach, methodology, outline and structure of the two assessment reports in Gurugram on (a) technological interventions and assess technology gaps/needs for air pollution control; and (b) city-level action plans and their alignment with national plan and the strengths and challenges of current strategies for adopting air pollution control technologies.
2. Study the technological interventions and assess technology gaps/needs for air pollution control in Gurugram, India.
3. Review and examine city-level action plan for Gurugram (and its alignment with the national plan of India) and assess the strengths and challenges of current strategies for adopting air pollution control technologies.
4. Conduct the assessments in close coordination with the relevant city stakeholders and national policymakers from the country. While the responsibility of engaging with the city stakeholders and national policymakers shall be of the consultant, APCTT would assist in connecting the consultant with key stakeholders.
5. Prepare and submit draft versions of the two assessment reports under 2 and 3, incorporating all the relevant elements and features in the approved format and style, in consultation with and based on the feedback received from APCTT.
6. Organise a multi-stakeholder consultation at the city level to discuss the outcomes of assessment reports under 2 and 3, and develop draft recommendations for strengthening the city action plan for adoption of enabling mechanisms for innovative technologies.

1.2. Need Of Technological Intervention

Air pollution is one of the most pressing environmental issues of our time. It not only affects the environment but also has a significant impact on human health. In recent years, there has been a growing awareness of the role of technology in reducing air pollution. The use of several technologies that can be adopted for mitigating or even solving air pollution problems is easier than ever due to developments in science and technology.

Renewable energy sources like solar, wind, and hydro power – shifting away from fossil fuels– can significantly help to reduce the amount of pollution generated by traditional power plants.

- Electric vehicles cause significantly less air pollution than traditional cars running on gasoline or diesel. As the electricity grid becomes cleaner over time, the emissions from EVs will also decrease.
- Air quality sensors are devices that measure the levels of pollutants in the air. Air quality sensors can help identify areas with high levels of pollution, allowing authorities to take action to reduce pollution levels. This technology can also help individuals protect their health by alerting them to areas with high levels of pollution to avoid exposure.

1.2.1 There are several high-end, cutting- edge technologies that are being adopted for early assessment and improved predictive capacity, which can help the local agencies control pollution by taking mitigatory measures. Some of them are listed[4] below:

4 https://www.indiascienceandtechnology.gov.in/featured-science/government-geared-tackle-air-pollution-challenge-st-intervention

- A high- tech Air Quality Early Warning System for forecasting extreme air pollution, developed by scientists of Indian Institute of Tropical Meteorology (IITM), Pune, India Meteorological Department, and National Centre for Medium Range Weather Forecasting (NCMRWF), under the Ministry of Earth Sciences was unveiled recently.
- Advanced technology for real-time pollution monitoring and effective alerts; action on the ground on the basis of such alerts and emission inventories, which identify sources of pollution, can check the alarming ways in which this problem is becoming a national crisis, especially during winters.

1.2.2 Technological interventions are therefore necessary to: i. correctly identify the problem of air pollution through advanced monitoring and measurement techniques and know the source and composition of pollution; ii. use prediction modelling to get an early warning and information about the scale of the problem for effective response; iii. identify hotspots and also quantify source- wise pollution data to design suitable control systems; iv. enable effective public disclosure and awareness through tools like AQI and digital mapping of pollution details; iv. evolve policies and actions based on available technologies.

1.2.3 NCAP and CAQM action plan therefore emphasise the technological interventions at various stages of air pollution management, including control at the source and mitigation close to the receptor. The point sources such as industry, DG sets, automobiles, construction sites, etc. are covered in the first category (source control), whereas road dust control, intelligent and efficient traffic management, and development of infrastructure are covered in the second category (mitigation). Some of the prevailing technologies have been discussed in subsequent sections.

2. REVIEW OF PRESENT TECHNOLOGIES ADOPTED IN GURUGRAM

2.1 As there is no city specific action plan for the city of Gurugram, a reference is taken from the clean air plan prepared for Delhi, which is available on CPCB website[5]. Based on discussions with GMDA and other local agencies, some of the technological interventions proposed in the action plan on sectoral basis are as under:

2.2 Transportation Sector

- Improved emissions standards and technologies
- Cleaner fuels
- Improved fuel efficiency
- Improved inspection and maintenance
- Improved transport planning and traffic demand management
- Shift to public transport, promotion of non-motorised/active transport (i.e., cycling, walking, etc.)

2.3 Industrial Emissions

- Land use planning and zoning
  - Location of new industries should be assigned keeping planning regulations in mind. Along with this, suitable industrial areas/zones should also be established as part of city planning.
  - All new industries, especially specific major industries, should compulsorily undergo environmental impact assessment for ascertaining their potential to contribute to air pollution. This should be followed by recommendations to improve location, processes, fuels, industry technology and emission limits and relocation of existing industries away from residential and other sensitive land uses.

5 https://cpcb.nic.in/approved-city-action-plans/

- Promotion of cleaner production
  - Increase the efficiency of industrial processes
  - Promote energy and materials saving by adopting good manufacturing practices
  - Use of improved quality fuels (e.g.,those with lower sulphur content) or switch to cleaner fuels such as natural gas
  - Adoption of new technologies
- Reduction of emissions in industry
  - Setting priorities by focusing on emissions from the major emission sources
  - Emphasising the requirement for use of cleaner fuels
  - Highlighting the requirement for the use of – and providing an action plan for the implementation of – best available technology for specific industrial processes
  - Compulsory notification of accidents
  - Strict licensing of specified polluting processes
  - Follow the norms of compulsory emission standards as well as an enforcement strategy ; and
  - Imposing strict fines for exceeding emission standards

2.4 Measures to Reduce Emissions from Area Sources

- Enforcement of bans on burning of materials or waste
- Water fogging and spray at construction and demolition sites and roads
- Promotion of alternative solutions to burning of waste
- Better waste management and monitoring
- Proper strategies for paving roads, revegetation programs in dust control areas
- Use of street sweeping equipment for road cleaning

It is noted that all the efforts for technology interventions in Gurugram are initiated as part of CAQM directions and also HSPCB consent management. The examples are Pollution Under Control (PUC) certificates, cleaner fuel for industries, brick manufacturing with new standards, road sweeping machines, use of anti-smog guns (water sprinkling) and solid waste dumping site remediation through biomining. However, there are no efforts for evaluation of performance and adequacy of such interventions so as to achieve the desired air quality.

3. POTENTIAL TECHNOLOGICAL INTERVENTIONS

This section attempts to identify the technological interventions required and, more particularly, the technologies which can be adopted for the control of air pollution as part of the city-specific action plans. The city-based action plans in India are generally designed for control of PM10; although, the PM2.5 will also be reduced in the process. It is well documented that the contribution of `secondary' particulates is significant in India's context, and, accordingly, stringent standards have also been prescribed for SO2 and NOx from various sources, including the thermal power plants. There are several references available for the air pollution control technologies, including the UNIDO compendium[6]; however, this report is specific to exploring the air pollution control technologies for Gurugram city, and the discussions below are focused on technology interventions that can be applicable for improvement of air quality in the city of Gurugram.

6 Compendium of Air Pollution Technologies UNIDO 2007

3.1 Air Pollution Measurement and Monitoring

3.1.1 The present national air quality monitoring network is limited in scope and comprises manual and automatic stations. Although India has been expanding the automatic air quality monitoring network, there is still a significant gap in the provision of adequate numbers of CAAQMS. The air quality measurements are therefore generally indicative, and there is an immense time lag in reporting the data. However, of late, CPCB has placed all the CAAQMS data on a portal, but the data quality and reliability is one serious issue as the involvement of various monitoring agencies, personnel and equipment in sampling, chemical analyses and data reporting brings uncertainty and biases. But even with the existing system, the non-compliance with standards is enormous in the cities. The city of Gurugram has four air quality stations, which are grossly inadequate in terms of the population and spread of the city, given its commercial importance. It is necessary to expand this network, essentially to identify the `hotspots' of air quality so that immediate interventions can be taken at the local level. Internationally, sensor-based technologies are used for such screening methods, but, in India, sensor based technologies have not been used or promoted by regulators for their concerns related to the quality of data. However, internationally, such technologies have been used widely for non-regulatory purposes, and found to be very useful for `hotspot' analysis. They have various advantages including low capital and operation costs, movability, real-time data transmission and a variety of pollutants that can be measured. Even though there is a wide range of sensors floating in the market, suitable technology and precision requirements can be adopted to select appropriate sensors. However, this technical assessment and appraisal needs to come either through regulatory agencies like CPCB or HSPCB, or it can be done through Research and Development departments like DST.

3.1.2 Carbon Fraction Measurements: The present CAP under NCAP does not specifically deal with the Carbon Fraction of the particulates. The 'carbon fraction' may refer to black carbon and primary organic and/or secondary organic carbon. Black carbon (BC) is the light-absorbing carbonaceous material in atmospheric particles; most BC is primary. Terms that are sometimes used interchangeably include elemental carbon (EC), soot and graphitic carbon. BC is chemically complex: it can include light-absorbing solids or liquids, and its composition varies with the source. Conventional analytical methods for BC do not measure its composition, but rather measure parameters that serve as indicators of BC concentrations. For historical reasons, specific measurement methods often use a particular term (e.g., BC, EC, soot, etc.) to identify the measured quantity; for example, BC and EC are often used to indicate optical and thermal measurement methods, respectively. In this assessment, we use BC generically and apply the other terms only when required by context. Organic carbon (OC) includes both primary emissions and secondary organic PM. Secondary organics are produced in the atmosphere by chemical transformations of volatile organic compounds (VOCs) or by the uptake of organic gases by particles. Organic compounds play an important role in the PM problem. Appropriate assessment of carbon fraction of the particulates would give an opportunity for selection of appropriate particulate control strategies.

3.1.3 Airshed approach: It is well documented that a significant portion of urban pollution in India is coming from outside the city limits, either short distance or long distance. It should be appreciated that the city air quality managers would not have any control on the sources outside the city limits. This aspect is very important to assess the performance of the city government and local agencies in improving air quality. It is therefore necessary to adopt the airshed approach, which can enable better understanding and control of air pollution sources in a holistic manner. This is more relevant for cities like Gurugram, which is surrounded by industrial areas, and for cities like Delhi and Faridabad, which are affected by sources like stubble burning, the airport, etc. The environmental regulators like CPB and HSPCB would need to take a proactive step to adopt an airshed approach for effective control of air pollution in the region. Recently, CPCB has started deliberation on this important topic, and the World Bank has initiated a study for Indo-Gangetic plains as a large airshed.

3.2 Technologies for Pollution Control

It would be interesting to understand the theoretical framework of air pollution control technologies before source-specific interventions are discussed. As the main focus of the NCAP and CAP is on the particulate control and reduction, the focus of the discussions in the present report is on particulates. The devices that remove particles from gas streams rely on one or more of the following physical mechanisms[78]:

- Sedimentation. The particle-containing gas stream is introduced into a device or a chamber where the particles settle under gravity to the floor of the chamber. Devices of this type are called settling chambers.
- Migration of charged particles in an electric field. The particle-containing gas stream is introduced into a device in which the particles are charged and then subjected to an electric field. The resulting electrostatic force on the particles causes them to migrate to one of the surfaces of the device, where they are held and collected. Devices of this type are called electrostatic precipitators.
- Inertial deposition. When a gas stream changes direction as it flows around an object in its path, suspended particles tend to keep moving in their original direction due to their inertia. Particulate collection devices based on this principle include cyclones, scrubbers and filters.
- Brownian diffusion. Particles suspended in a gas are always in Brownian motion. When the gas stream flows around obstacles, the natural random motion of the particles will bring them into contact with the obstacles, where they adhere and are collected. Because we know that Brownian motion is more pronounced in the smaller particles, we expect that the devices that are based on diffusion as the separation mechanism will be most effective for small particles.

3.3 Approach and Application of Technologies in Emission Control[9]

A variety of particulate removal technologies, with different physical and economic characteristics, are available. This includes: a. Inertial or impingement separators; b. Electrostatic precipitators; c. Filters and dust collectors (baghouses); and d. Wet scrubbers.

3.4 Construction Industry

Dust is the pollutant of concern caused by construction and demolition; it refers to all airborne particulate matter (PM), including solid particles that are suspended in air, or have settled onto a surface after having been suspended in air. Particulate matter (PM) is a complex assemblage of non-gaseous material of varied chemical composition. It is categorised by the size of the particle (for example, PM10 is a particle with a diameter of less than 10 microns (mm)). Construction sites with high volumes of dust and emissions from machinery are also major sources of local PM pollution.

3.4.1 The Ministry of Environment and Forest has made it mandatory to obtain environmental clearances for construction projects having covered built-up area greater than 20,000 sqm. MoEFCC has also issued directions to prioritise the green certification buildings in the environmental clearance process to promote green building construction. The Indian Government has also set forth guidelines and made it mandatory for construction site owners to implement dust-preventive measures in order to minimise the harm done to the environment. The air pollution can be controlled best at source, and there are several technological developments that the construction industry has already adopted as under:

7 https://authors.library.caltech.edu/25069/1/AirPollution88.pdf

8 FUNDAMENTALS OF AIR POLLUTION ENGINEERING: Richard C. Flagan, John H. Seinfeld California Institute of Technology, PRENTICE HALL, Englewood Cliffs, New Jersey 07632

9 https://www.ifc.org/wps/wcm/connect/53afc833-56ff-4b08-b4b6-4e6c694ee30b/HandbookAirborneParticulateMatterPollutionPreventionAndControl.pdf?MOD=AJPERES&CVID=jkD0BOe

- Use of fly ash bricks replacing the traditional red mud bricks
- Use of ready mix concrete instead of the concreting at site
- Use of fly ash mixed cement
- Increased use of pre-fabricated walls and construction

3.4.2 Some of the good construction practices that are mandatory for air pollution control at construction sites are:

- Construction material at the site and on the vehicles that carry them should be properly covered.
- Covering of the demotion area and also the material handling area
- Water fogging and jets to be deployed in case of air pollution
- The vehicle tires shall be washed and cleaned before leaving the construction premises.
- Regular air monitoring to be done at the construction site when the work is in progress, and suitable action to be taken on the air quality data
- Keeping the ground at construction sites wet to let the dust settle and inhibit it from spreading.
- Setting barriers around the construction site and covering mounds of sand with dust barrier sheets.
- The construction companies are being asked to submit reports on the current status of construction, and steps are being taken by them to comply with the Ministry of Environment and Forests Guidelines, 2010, with respect to the prevention of dust and garbage accumulation on their construction sites.
- Littering or obstruction to public drains, water bodies, traffic and direct dumping of Construction and Demolition (C&D) waste in landfill sites should not be done.
- According to the C&D Waste Management Rules, 2016, the system should support proper collection of segregated C&D waste from the generator, proper transportation of waste, storage of waste followed by proper processing of waste into recycled or reusable products that have market value and minimal rejects that get disposed in designated landfills.
- Follow the practices and guidelines for green building construction.

3.4.3 Control Equipment

As dust is the major pollutant, several equipment have been in use in the field based on all the four technologies referred above (although several trade names have been given to them). However, these equipment provide only some relief as their area of influence is comparatively small, thereby necessitating locating the equipment as near to source as possible. Some of the technologies available are listed below:

1. Air Filters with a small low-powered fan can remove the PM10 coarse dust at the source of construction activities inside a building. Nearly 12 air changes per hour can be achieved in a 4000 cubic air room by a 800 CFM filtration.

An Equipment Proposed by IIT-Kanpur

2. More effective backpack street sweepers can be much lower in costs, generate employment and be a lot more manoeuvrable in small lanes of India.

Shoulder mounted Dust Collection System Proposed by IIT-Kanpur

3. Wayu is a filtration-based air cleaning technology developed by NEERI and IIT-B and is useful for local areas. This can be used for both streets and construction sites.

4. Water fogging and water jet mist spray machines: CPCB has issued directions to use such equipment for large projects in the NCR region; increasingly, the SPCBs are also recommending these equipment for large construction projects. Anti-smog Gun (ASG) is a device spewing fine nebulised water droplets (atomised water droplets) through high pressure propellers in air making a curtain of very fine water droplets and making particles in the air increase in mass and settle by inertia. ASG uses high-pressure water fogging with turbo air flow, which creates ultrafine fog consisting of very fine droplets that are 10–50 microns in size. These tiny droplets absorb the smallest dust particles in the air, and yet fall to ground without causing wetness. Anti-smoke guns are also called spray guns. Mist guns or water cannons are suitable for suppressing or settling down localised dust in the work zone. The important factors governing deployment of these equipment include nozzle and propeller configurations, water supply to ASG, zone of influence, type of smoke guns, frequency of operation, fuel and power supply.

   Construction and demolition sites with an area more than 20,000 m² shall have at least two ASGs. They should be capable of producing water droplets in the range of 10–50 microns. One ASG shall have a water-throwing capacity of 70–100 m, and one ASG with a water-throwing distance capacity of 30–50 m shall also be installed. These equipment should be operated on rotation based on operational needs.

3.5 INDUSTRY

3.5.1 Industries produce air emissions through the consumption of fuel for energy, as well as through process-related emissions, such as those generated during activities like painting, chemical handling, and similar processes. Gurugram is an industrial district and primarily houses engineering industries, including automobile and its ancillary industries.

3.5.2 The industries are most regulated for air and water emissions. They need to obtain consent from Haryana State Pollution Control Board for establishment of the industrial plant and also regularly renew it for the operation of the plant. This consent is granted by HSPCB only upon verification of the fact that the required pollution control systems, including air pollution control systems, are installed, and they are operated continuously and regularly to meet the prescribed standards. In case of any non-compliance, the Board has the statutory powers to take legal action, including imposing compensation costs, refusal of consent and also closure of industry, depending upon the seriousness of non-compliance and the track record of industry.

3.5.3 HSPCB has already issued directions to all major industries to set up the Continuous Emission Monitoring System (CEMS) and communicate that data online to the HSPCB and CPCB, who initiate the alerts in case of an exceedance of emission standards. Moreover, some large scale industries are also directed to install the continuous automatic ambient air monitoring stations and the data is transmitted to HSPCB on a real-time basis.

3.5.4 Emission standards have been notified for most of the industries and, more specifically, for brick kilns and DG sets that are relevant to Gurugram. CAQM has further issued directions for the use of clean fuel in place of coal and pet coke. Emission standards have also been issued for NOx and SOx for the thermal power plants.

3.6 SOLID WASTE MANAGEMENT

Solid waste management is a major concern for cities in India. India has had Solid Waste Management Rules since 2000, which have been amended from time to time, and presently 4 different waste management rules namely, solid waste, e-waste, plastic waste, and construction and demolition waste rules, have been notified in 2016. All these rules are essentially based on international development in resource conservation, best available technology and public participation.

3.6.1 The urban solid waste management in India is seriously plagued with issues related to non-segregation, non-collection of huge volumes of waste, mixing of plastic and inert waste, and, most importantly, the lack of availability of funds for efficient waste management practices. The cities are therefore using landfills for the dumping of waste without any adequate treatment. This is in non-compliance with the provisions of the regulations and has been under intense scrutiny of the higher judiciary for a long time. Still, such unscientific disposal in landfills can lead to fires, which can deteriorate the air quality significantly. The landfills as such are known to emit significant methane, which is a greenhouse gas. The uncontrolled fires in landfills are known to emit a combination of hazardous air pollutants, and, with the presence of chlorinated plastics, the possibility of generation of dioxin and furan is significant.

3.6.2 In the last decade, there has been an increased focus on the scientific management of solid waste, including segregation, composting, recovery and disposal of inert waste. There has been an increase in fund allocation and technology support through missions like JNNRUM and Swaccha Bharat. The plastic is segregated for disposal in cement plants, considering its calorific value. Recently, many corporations, including Gurugram, have been practising bi-mining for landfill waste, which significantly reduces the size of dump sites, and the bio-mined organic component can now be sent to cement or thermal power plants for incineration.

3.6.3 The technologies to scientifically manage the MSW and further reduce air emissions include landfilling with biogas recovery, composting of selected waste fractions, anaerobic digestion and thermal processes including incineration, gasification and pyrolysis. The applications of these technologies depend on local, regional and national drivers for both waste management and GHG reduction. Direct landfill and composting, due to disadvantages like low and inconsistent performance and complaints of odour nuisance, are gradually being replaced by other technologies. In spite of the advantages derived from incineration of MSW, such as heat recovery, there are numerous disadvantages, including the production of large volumes of flue gas , waste streams associated with the fly ash and a poor public image and acceptance. A more recent trend for the treatment of solid waste is the combination of incineration and energy recovery in the so-called 'waste-to-energy (WtE)' plants. This combination helps to solve two problems: one is the recovery of the energy entrapped in waste; and the other is environmental protection. Biomethanation or anaerobic digestion may be perceived as a potential alternative to treat MSW as it not only provides a renewable source of energy but also utilises recycling potential of degradable organic portions of solid waste generated by numerous activities. MSW pyrolysis and gasification technology is an attractive way to treat MSW with lesser pollution emissions than other methods of treatment. It especially offers the potential of higher efficiency in energy production.

3.6.4 Although there are several technologies available, the real field-level challenges are non-segregation of wastes, increasing presence of plastics in waste, inconsistent quality of solid waste, involvement of a large number of informal workers in the entire waste management chain, and lack of financial model for such plants, besides stringent regulatory requirements. The city governments are therefore expected to strictly follow the Solid Waste Rules of 2016, which mandates segregation at source, recovery of material and scientific approach for solid waste management. Several initiatives under Swachha Bharat mission have been taken to provide funds to urban local bodies for improving their solid waste management. Many cities are adopting decentralised waste management by providing biogas/ biomethanation for bulk generators like vegetable markets, clusters of restaurants, etc. The residential and commercial projects requiring environmental clearance are also required to set up their own solid waste management in place.

3.6.5 Twenty-first century faces one of the most pertinent development challenges of managing ever-growing urban areas. However, cities can also take advantage of urbanisation, flourish and be liveable. People have become more aware comparatively and need to change and renew existing technological production and social behavioural patterns. These changes bring about innovative responses that transform society to move towards more sustainable pathways. Innovations are of various kinds and some suit certain locations while some are of global suitability and acceptance. Several analytical tools have been developed in environmental management viz. eco-efficiency, industrial ecology, design for environment, eco-effectiveness, natural capital, biomimicry and eco-innovation. Eco-innovation is a new concept of immense importance to trade and policymakers, which covers many innovations providing environmental advantage. In common terms, eco-innovation refers to new technologies that improve economic and environmental performance, with a few definitions including organisational and social changes for improving competitiveness and sustainability as well as its social, economic and environmental pillars.

3.6.6 There are several startups working in the field of waste management including plastics, recovery of materials, etc. These startups find opportunity in a real-time problem and apply innovative solutions that are commercially viable. These startups receive sufficient financial support through impact and social investments giants. For example, a fund called Circulate Capital supports various startups that are dealing with waste management. Some of the startups in waste management are Phool, Thaily, Swachha Pune, Saahas Zero Waste, Bengluru, etc. There is enough space and government policy support through schemes like Atal Innovation Mission to foster the growth of these startups. It is necessary that the Gurugram Municipal Council encourages startup innovations to deal with the issue of solid waste in the city.

3.7 TRANSPORTATION

Vehicular emission is a major contributor to air pollution. In mitigation strategies, vehicle technology gets more importance than improving urban mobility. This is probably because the link between the latter and emission reduction is difficult to establish. On an average, action points for the mobility sector form around a quarter of all NCAP actions in a city.

3.7.1 An ideal emission mitigation strategy for mobility should encompass the following:

- Fuel economy and vehicle technology improvement to reduce tailpipe emissions
- Higher share of trips by sustainable modes of transport in the total mix
- Use of intelligent traffic management systems including signalling systems, traffic diversions, segregation of heavy and light traffic, etc. to reduce congestions
- Public transport network, its carrying capacity, optimising services and affordability
- E-vehicles and e-public transport
- Improving street network to prioritise pedestrian and non-motorised transport activities
- Parking management to rationalise the use of limited urban space; parking pricing to justify equitability in usage; vehicle restraint strategies to discourage dependency on private vehicles

3.7.2 India has already adopted stringent vehicle emission norms, Bharat Stage-VI, and fuel quality norms that are internationally competent. In addition to this, India is pushing for e-vehicles and there are several schemes for supporting e-vehicles by provision of suitable infrastructure for charging even within city limits. There are schemes for e-mobility through public transport systems on battery-operated vehicles. However, growing cities and increasing number of vehicles on the road are still causing congestion, which is one of the main causes of air emissions within city limits.

Typical traffic at a toll post between Delhi and Gurugram (Courtesy: Times of India)

3.7.3 Although the new vehicles generally have stringent emission standards and use clean fuel, the challenge is to regulate the older vehicles. Presently, the regulations restrict the use of public vehicles for more than 15 years, and the new scrapping policy is an initiative to clean up the old fleet for new vehicles with stringent emission norms. Diesel engines are important power systems for on-road and off-road vehicles. These reliable, fuel-efficient, high torque engines power many of the world's heavy-

duty trucks, buses and nonroad vehicles. While diesel engines have many advantages, they have the disadvantage of emitting significant amounts of particulate matter (PM) and the oxides of nitrogen (NOx) into the atmosphere. The strategies for old vehicles can be summarised below:

Retrofitting

Retrofit technologies may be added to further reduce emissions from certified engine configurations.The most common retrofit technologies are retrofit devices for engine exhaust after-treatment. These devices are installed in the exhaust system to reduce emissions and should not impact engine or vehicle operation. Examples of retrofit devices include diesel particulate filters (DPFs) and diesel oxidation catalysts (DOCs). They are designed and evaluated to reduce emissions from certified engine configurations and should be added only to properly maintained engines.

Rebuild

Diesel engines can often be rebuilt and continue to operate in the same capacity. An engine in need of rebuilding may have low power, increased emissions and increased fuel consumption. In some cases, an engine can be rebuilt to comply with cleaner emission standards.

Repower

Replacing an older engine with a new one, which has been certified with cleaner emission standards, is another option for some equipment and vehicles. Repowering with a new engine may extend the life of the machine, reduce fuel consumption and significantly reduce emissions.

Refuel

A variety of alternative fuels can be used in diesel engines. Some require little or no modification to the engine while others require engine conversion or replacement. Some of the alternative fuels include emulsified diesel, biodiesel, natural gas, propane and ethanol. In addition to these fuels, use of diesel fuel with lower sulphur content can help to reduce emissions.

There is a critical debate on the effectiveness of emissions[10] of different mitigation scenarios, such as retrofit and scrappage policies, to estimate the emission reduction potentials of these scenarios for the future fleet of India. Retrofit policies, such as the advancement in emission norms (shift to Bharat Stage (BS)-VI from BS-IV), the increased share of compressed natural gas (CNG) vehicles and fuel efficiency (FE) improvements have reduced vehicle emissions significantly. It is expected that the scrappage of old vehicles from the fleet will further reduce the emissions for such identified vehicles.

3.7.4 Approaches to Remote Sensing Instruments for On-road Vehicles

EPCA in its 99th report[11] has dealt with the application of remote sensing instruments for on-road vehicles. The report refers to submissions made by International Centre for Automotive Technology (ICAT) before the Supreme Court of India. It suggests that remote sensing technology has been found to be helpful in reducing the pollution level and, as per the finding of the ICAT, it is an effective method to check pollution. Adding a remote sensing test has become necessary as PUC is a very simple and basic test that lacks quality control and is not appropriate for screening vehicles with more advanced emissions control systems, such as those under BS IV and BS,VI regime. Not only do the results of these tests not correlate well with dynamometer tests (that are used at the time of vehicle certification), they are also increasingly unreliable for 'BS IV and Beyond' vehicles. They also fail to capture NOx emissions, which contribute to ozone formation and secondary particulate matter formation. It may be noted that at present, the PUC programme relies upon idle speed testing mode for petrol/LPG/CNG

10 https://doi.org/10.1177/03611981211028867

11 https://epca.org.in/EPCA-Reports1999-1917/EPCA-Report-Remote-sensingNo99.pdf

vehicles and free acceleration mode (FAS) or smoke opacity test for diesel vehicles. These tests measure carbon monoxide (CO), and hydrocarbon (HC) concentration in exhaust from petrol/LPG/CNG vehicles and peak smoke opacity for diesel vehicles, which is meant to be a proxy for particulate emissions. If vehicles tested cross the prescribed limit values, they have to go for repair.

However, the challenge is to work out how this would coexist with the ongoing pollution under the control certificate programme (PUC) for the physical checking of emissions. Both the programmes have different objectives and scope, but they are complementary, and this needs to be clarified. While under the PUC programme, periodic physical checks of exhaust emissions from vehicles will continue to assess compliance with limits imposed on idling emissions, remote sensing programmes will screen vehicles on the road to identify gross or very high emitters. Catching and removing the worst polluters on the road can give substantial emissions benefits. It is possible that some vehicles may escape or even pass PUC tests and yet experience technical anomalies that may make them high emitters between two scheduled PUC tests. Moreover, PUC is not a very effective way of assessing the real magnitude of emissions from vehicles.

The big advantage of remote sensing is that it can be carried out in a non-intrusive fashion and without vehicles having to report physically to centralised test centres or PUC stations. The same remote sensing set-up can be used to measure emissions from different vehicle types and evaluate hundreds to thousands of vehicles each day. The objective is to identify and penalise gross polluters – vehicles with high pollution levels. Many countries in the world are using this technology to combat pollution from vehicles. The equipment for testing is mobile – it can be moved from place to place as the need arises. It would be best if the testing is done on elevated areas, like flyovers,as this is where the pollution is the highest. EPCA suggested that the first testing sites should be close to the major entry points (toll gates) into Delhi so as to identify gross polluters from heavy vehicles.

The system is capable of measuring NO, NO2, HC, CO, CO2 and opacity at a minimum. Measurement of N2O, NH3, SO2 and CH4 can be desired based on city- specific requirements. A city can work on more details, based on its requirements including the number of such equipment, location, penalties and vehicle emission correction programmes.

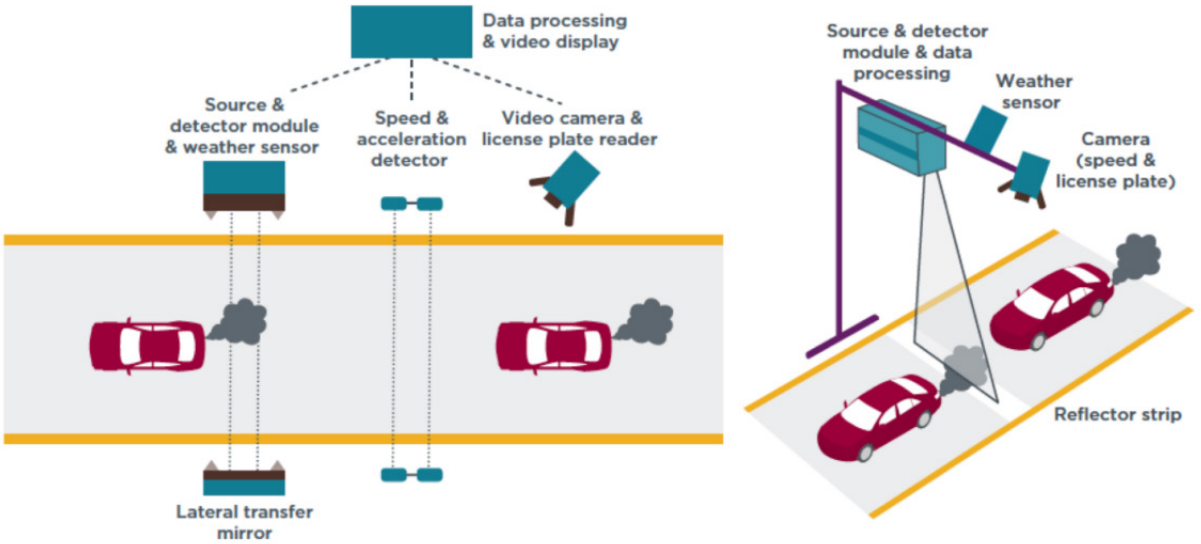


Figure: Typical Remote Sensing Set-up for On-road Vehicles

Source: https://theicct.org/publications/worldwide-use-remote-sensing-measure-motor-vehicle-emissions

Subsequently, in September 2020, the Ministry of Surface Transport notified draft standards,[12] Draft AIS-170/DF September /2020 `Remote Sensing Devices for on-road Emissions Monitoring – Product Specifications and Programme Guidelines'. This standard is technology-neutral; it does not restrict any arrangement for implementation based on the recommendations for remote sensing of emissions of in-use vehicles for on-road monitoring, as per the directions of the Hon'ble Supreme Court and the EPCA Report No. 99, dated 26th July, 2019. Another detailed reference and discussion on this technology in the Indian context can be found in CSE publication[13].

3.8 PLANTATION

Urban trees are crucial for checking road dust and gaseous contaminants. Hence, tree plantation is one of the key actions listed in the National Clean Air Programme (NCAP) to reduce pollution in the non-attainment cities. Vegetation provides one of the natural ways of cleaning the atmosphere by scavenging or trapping the suspended particulate matter through the process of absorbing, metabolising, detoxifying or accumulating the gaseous pollutants. This behaviour of plants led to the emergence of a concept called 'green belt' development, and it is now being considered a standard practice for air quality improvement. There are several advantages of green belt, some of which are summarised below.

Green belts can be raised for the improvement of air quality in a wide variety of situations. In urban and industrial contexts, they are more commonly used for the following purposes:

- To combat fugitive emissions of air pollutants and to lessen the impact of accidental releases of air pollutants.
- To protect ecologically sensitive areas, archaeological monuments and residential areas.
- To improve the urban environment by developing roadside plantations of avenue trees/shrubs/sedges/grasses along traffic corridors.

It is therefore necessary that multi-level functions of green belts are recognised, which includes: their role as pollutant absorber; collection of dust particles; absorption of gaseous pollutants; reduction of noise pollution; absorption of wastes to reduce pollution load on water bodies; soil and water conservation (prevent erosion); habitat improvement for biotic life; role as carbon sink; its aesthetic, recreational and socio-economic value in the area, etc.

NEERI has conducted studies and, in a presentation, has referred to the following dust- collecting tree species:

Preferred Tree Species for Dust Collection	
Azadirachta indica	Ficus religiosa
Bauhinia purpurea	Mangifera indica
Butea monosperma	Pithecellobium dulce
Cassia fistula	Shorea robusta
Ficus benghalensis	Tamarindus indica
Ficus infectoria	Tectona grandis
	Terminalia arjuna

12 https://morth.nic.in/sites/default/files/ASI/Draft%20AIS-170%20-%20RSD_DF_Sep_20200930_C.pdf

13 https://shaktifoundation.in/wp-content/uploads/2022/08/Remote-Sensing.pdf

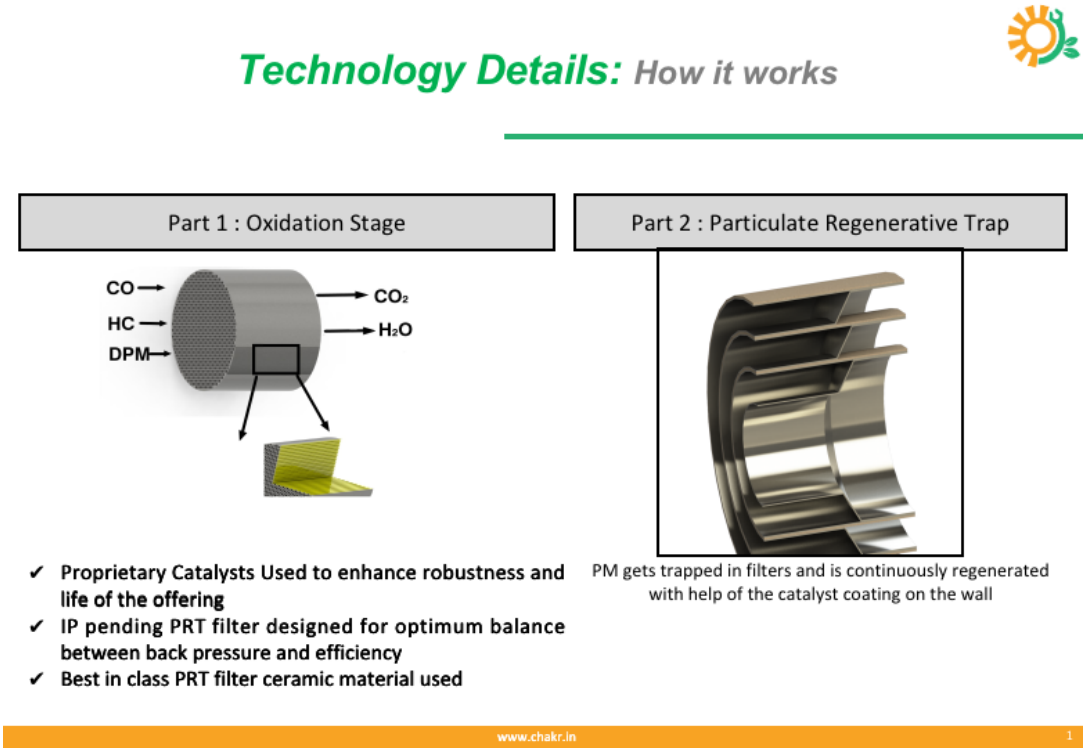
3.8.1 A technology called UBreathe uses 'Breathing Roots Technology'; it soaks up polluted air through bio-filtration and reaches the roots and, thereafter, with the help of phytoremediation, the polluted air reaches the Ubreathe Pot after touching its roots, from where the purified air is produced. Ubreathe enhances the performance of plants that improve air quality. The Ubreathe Mini Pot could be kept indoors, and it is generally advised to keep it at a distance of 100 feet. One such device costs Rs 4,999.

3.9 OTHER SOURCES:

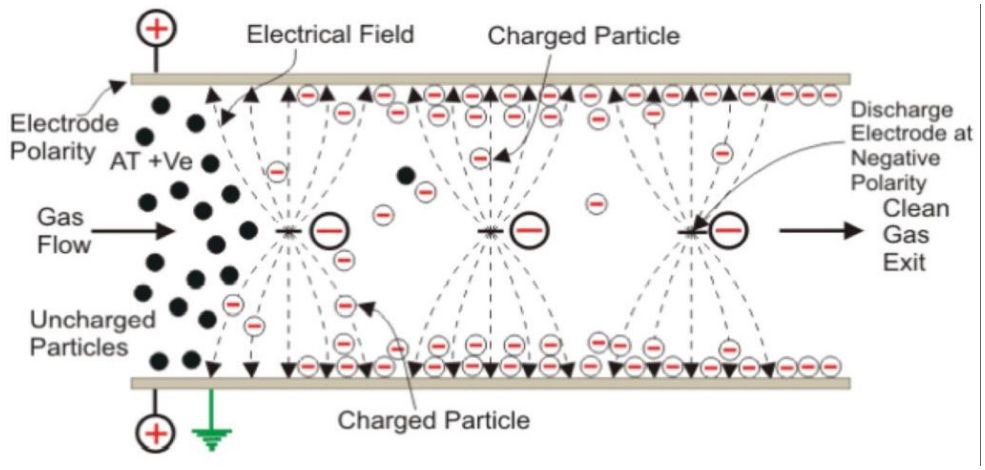
Cities generally have multiple point sources, such as DG sets, small bakeries, *dhabas* and hotels and food joints, which consume fuel and emit a certain quantity of pollution. Besides this, there would be several point sources such as *dhabas*, brick kilns, small/tiny industries, which also contribute to air emissions, affecting the city air quality. The NCR air quality management action plan already has a regulatory regime to control the emissions from these sources through adoption of clean fuel, like PNG, for their operations. Burning of coal and pet coke has been prohibited. The important step is to identify such sources for their regulatory compliance. The brick kilns in the NCR area have also been directed to comply with these standards, and, therefore, their emissions are already regulated. There has been a long debate on DG sets that are installed in industries and private places like malls, shopping centres, etc. Cities experience unreliable power supply, and, therefore, the use of DG and Gen sets was very common. However, it is reported that the power supply is now very stable and, therefore, the use of DG and Gen sets is limited. NAQM has also issued directions for the use and emissions from DG sets, providing exemptions to DG sets used for emergency purposes like hospitals, lifts, etc.

3.9.1 DG sets emission reduction

There are emerging technologies for further reduction in emissions from the DG sets, which can be achieved by retrofitting the equipment. There are mainly two technology providers for such retrofit, and the performance of such equipment has been verified by regulators. The first one is an electrostatic precipitation-based carbon cutter, which is a modular self-cleaning electrostatic precipitator and is used to capture suspended particulate matter (SPM) from flue gases. It is claimed that such use of ESP makes the equipment a filterless, retrofit, fully automatic and compact device that integrates seamlessly with stationary sources of combustion, with features like: no back pressure; no maintenance; no additional utilities required; and ultra-efficiency. The second one is catalytic oxidation, which also has similar advantages. This is in addition to the new standards prescribed by CPCB.



Catalytic Oxidation: Courtesy: Chakra Innovation Pvt Ltd

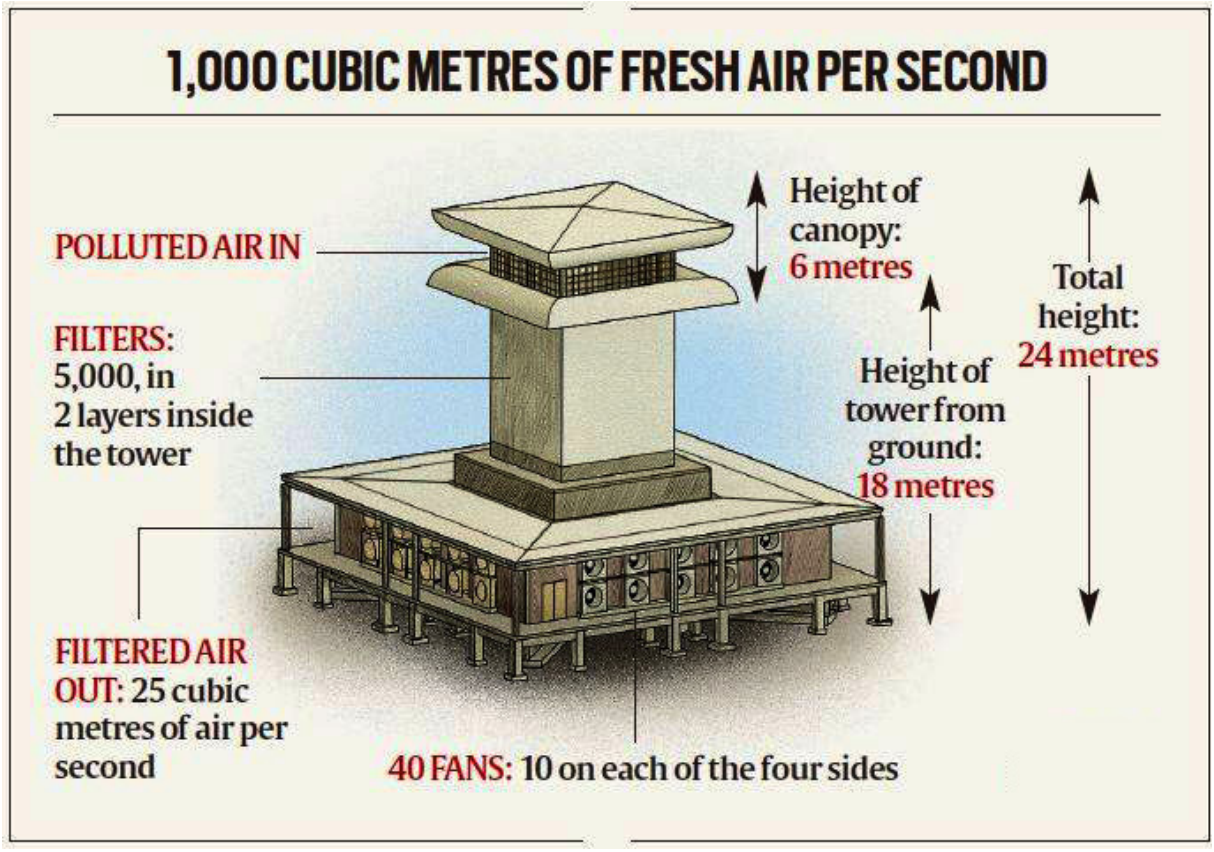


Electrostatic Precipitation based Carbon Cutter: Courtesy M/s. Pi-Green Innovations Pvt Ltd

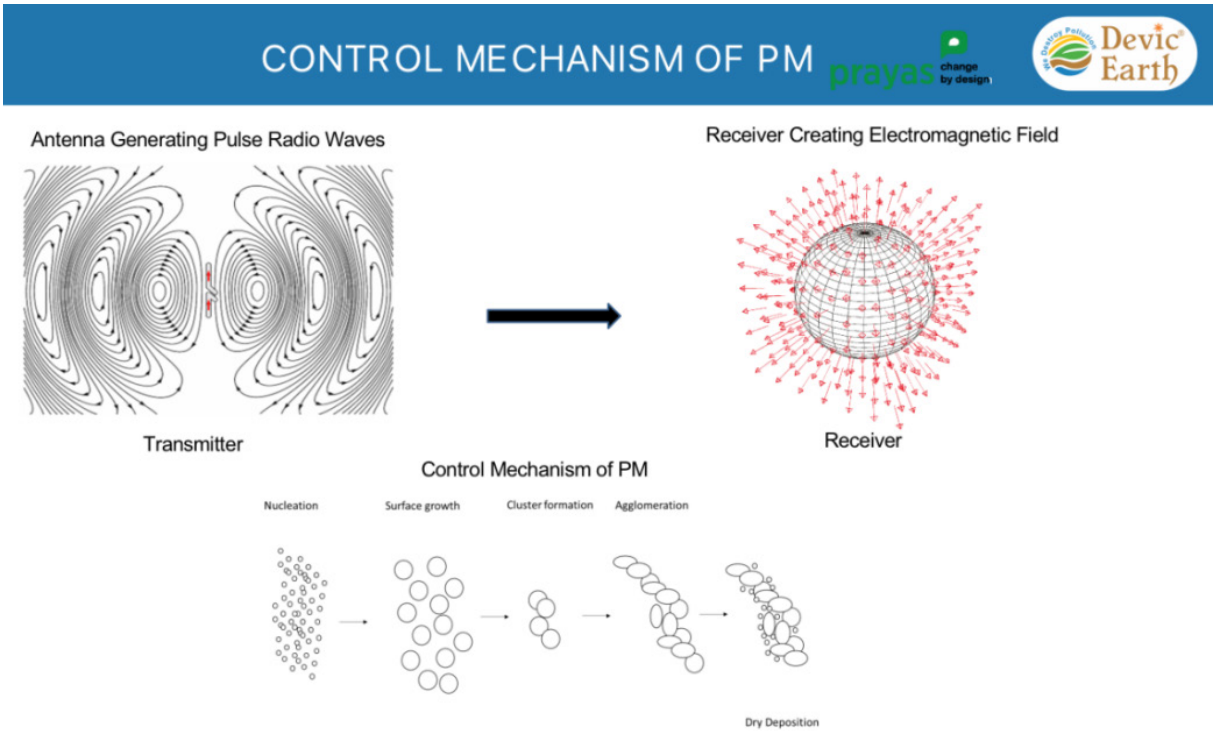
3.10 SUMMARY:

It can be seen that there are several policy, strategy and technological options available for the control of air pollution. Based on the theoretical framework presented earlier, there are several market-based products that are designed to suit the specific requirements of the city, though the main considerations are: volume of air to be passed; dust removed in g/hr; energy required; cost (capex and opex); ease of operation and maintenance; suitability to field requirement. Broadly, the control equipment can be categorised as source-specific and for ambient air cleaning. The source-specific control measures are generally the responsibility of the polluter, while ambient air cleaning systems are generally provided by ULB, often backed by financial support from the government and corporations. The following table summarises the various technologies available in the market and compares them for their suitability, operation and performance. The generic photographs of these technologies have also been provided subsequently.

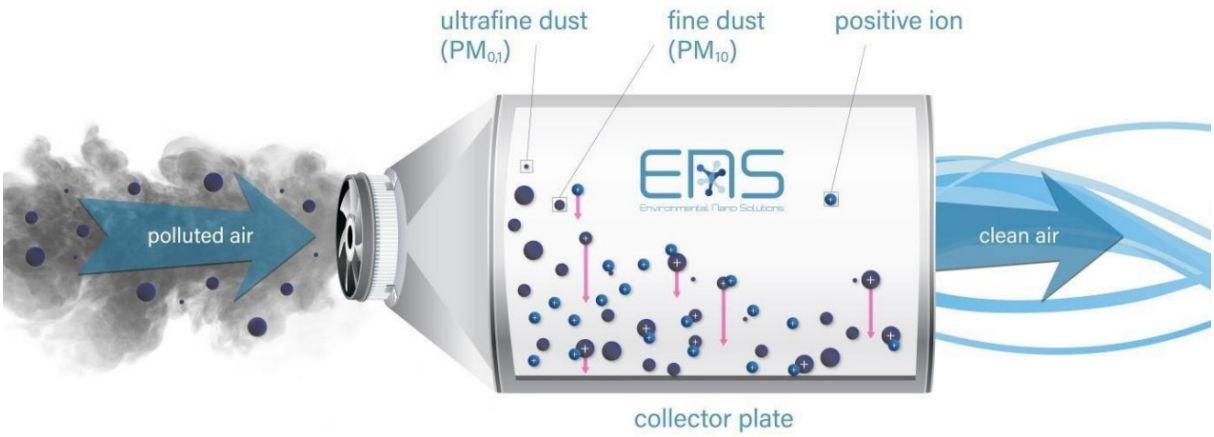
	Air pollution control technology, its principle	Application, features and operations	cost, effectiveness
1	**Pulse radio wave:** pulse wifi in 2.4-2.5 GHz range, omnidirectional transmitter. Pulse causes coagulation of particulates, leading to its early settling	Ambient air application in open spaces; claims 30-40% dust removal; however, no scientific evaluation available; installed in Lucknow and Udaipur	Capex: Rs. 30 Million Opex: Rs. 1.4 millions However, there are concerns over health impacts of pulsification, which leads to coagulation
2	**Smog Towers:** Air filtration for large volume of ambient air; air volumes @1000 cum/sec	Claim to reduce particulate concentration in 1 m radius; no technical evaluation data is available for Indian conditions; installed in Delhi	Capex: @Rs. 280 millions Opex: Not available, but likely to be high because of high quantity of HEPA filter and energy
3	**Smog-free Towers:** Positive ionisation based particulate removal; air volumes @ 30000cum/hr	Several international installations and evaluation data available, but no Indian installation or study. 7m high with 1000w/hr energy requirement	Capex Rs. 70 million Opex 0.3 million
4	**Vehicle-mounted mist spray (Anti- smog guns (ASG)) -- road washing and plantation washing** Water mist and spray for scrubbing particulates and gases	Used for ambient air cleaning, road washing, construction project dust Many units already in use; widely used and tested Water consumption is a concern	Cost varies from RS. 6 -9 millions, based on the capacity of water tank and spray throw distance.
5	**Stationary filter based air filtration** Can be located near sources; example, indoor location like parking; Can be mounted on vehicles Can be suitably designed to be carried by a person for road cleaning	Air filtration widely in use Various sizes, shapes and capacity air flow available in market Challenge is the quality and maintenance of filters	Cost varies from Rs. 0.1 million to 1 million Opex @ 20%
6	**Road-sweeping machines** Suction of roadside dust and then filtration Widely used and also promoted under NCAP Vehicle-mounted and used for road sweeping	Though field level evaluation studies are not available, the collection of dust from roadside, which otherwise would have re-suspended, is well demonstrated. Lower handheld or small trolley-mounted versions are also available.	Cost varies with vehicle-mounting machines and features of dust separation and storage. Cost of a typical truck-mounted machine is Rs. 7-9 millions, and opex is @ 20%.



Smog Tower, a schematic : Source: Internet



Pulse Wifi technology for Particulate control in ambient air: Courtesy: Devic Earth presentation



Positive Ionisation-based Smog Tower for Ambient Air particulate removal: Courtesy: Next Engineering

Vehicle-Mounted Mist Water Spray (Anti-smog gun (ASG))

Typical Road Sweeping Machine in use

4. CAPACITY GAP ASSESSMENT OF STAKEHOLDERS

The scale, complexity and urgency of the problem necessitates a strong, coherent and coordinated response from all concerned stakeholders in order to address the air pollution issues. To strengthen institutional capacities on implementation and research for air quality management, multidisciplinary collaborative governance involving existing regulatory institutions, especially in public health and livelihoods, must be encouraged. This can be initiated by simply ensuring representation at the decision-making table.

4.1 The air quality management for a city is a complex exercise involving multiple stakeholders including the urban local body, district administration, environmental regulators at state and central level, environment ministries at state and central level, air quality professionals, meteorological professionals, industry, NGO/CSO, health professionals, air pollution control technology experts and professionals and public in general. With such a wide range of stakeholders, it becomes a challenging task for an environment regulator to bring all the stakeholders to a common understanding of air quality action plan formulation, enforcement and monitoring. Though different stakeholders have different roles and responsibilities in the overall air quality action plan, a basic understanding about the air quality issues is essential for their execution. Air quality itself is a highly complex technical issue, which involves understanding pollution in terms of particulates and gases, meteorology, pollution removal processes, chemistry and physics of pollution, control techniques and, most importantly, the health impacts of such pollutants. It is, therefore, imperative that capacity building of all the stakeholders is prioritised by the policymakers so that all stakeholders play their role effectively in the action plan.

4.2 A mere look at the city action plan demonstrates that there are multiple stakeholders with varied, but sometimes, overlapping responsibilities; therefore, capacity building is a critical factor. Continuous efforts have been made by the environmental regulators to develop the capacity of the regulating institutions like CPCB and SPCB; recently, with the introduction of NCAP, there have been consistent efforts to involve the urban local bodies in the overall capacity building initiatives. MoEFCC has also now evolved a scheme to designate an institute of repute (IoR) for every non-attainment city, which is a local technical institute providing technical support and understanding to the urban local bodies to facilitate local capacity building. MOEFCC has also evolved National Knowledge Network[14] (NKN) to facilitate standardisation of research and technology development in the process of air quality management.

4.3 Gurugram, being the city not included in the NCAP so far, does not have the benefits of IOR and NKN. However, it is necessary that all stakeholders are invited to a common table for discussions and interactions that may facilitate many of the actions proposed. The table below demonstrates the roles and responsibilities of different organisations and groups in air quality management at the city level. There are several actions designed and implemented at the state and national level, and those agencies are not included in the city-specific context. It will be necessary for the city administration to form a formal group for air quality management and have regular interactions; HSPCB can provide suitable technical guidance and support to this group. In fact, it is necessary that the Gurugram Municipal Corporation form an air-quality cell within the Corporation with necessary technical expertise and infrastructure, including air quality measurement systems and effective integration with municipal authorities.

14 https://nkn.urbansciences.in/

Sr. No	Stakeholder	Role and Responsibility
1	HSPCB	Overall responsible for air quality management, identification of sources, control and regulation of source emissions, standards for emissions, measurement and monitoring, enforcement and compliance, legal actions, air quality data disclosures
2	Gurugram Metropolitan Development Authority (GMDA)	Overall ownership of the action plan, including implementation and coordination of the implementation Traffic systems and planning, solid waste management, construction and demolition waste management, construction activities enforcement, road cleaning, plantation, etc. Promotion of e-vehicles, sufficient charging stations, clean fuel Hotspot identification, grievance redressal
3	District Administration	Fuel supply, overall coordination of government authorities, solid waste management compliance
4	Road Transport Office	Vehicle registration, pollution under control certification, phasing out old and scrapped vehicles, traffic management
5	Health Authorities	Records for air pollution-related disease cases, awareness
6	Academic Institutes	Air quality research, monitoring, performance evaluation of control measures, development of control techniques for site specific conditions
7	NGO/ CSO	Awareness, information dissemination, public concerns
8.	Construction Industry	Construction and demolition waste, green and sustainable construction practices, material handling, good construction practices
9	Industry	Air pollution control to meet standards, material handling emission control
10	Air quality professionals including environmental labs, control equipment suppliers, maintenance facilities, etc.	Interact with GMDA and HSPCB for effective implementation of the action plan.

4.4 It is reported that several initiatives, like continuous air quality monitoring, source apportionment studies, source inventory, etc., have been initiated in the city. Similarly, several actions for road cleaning, construction/demolition waste engagement, solid waste management, etc., have also been initiated. Efforts like source apportionment and source inventory would help build an understanding of pollution contributions from various sectors, identifying that successful implementation of sustainable solutions is crucial for developing proper strategies. For any policy to be successful, it is critical that the awareness

of the problem and its solution must reach the masses. Outreach activities in the sectors responsible for pollution will create awareness on the subject. Proactive involvement of entities from various walks of the society (schools, citizen groups, NGOs, institutions, govt bodies, media houses etc.) can help in disseminating information on sources of air pollution and its solutions. Information shared in accessible language can help the citizens understand air pollution and its health impacts comprehensively.

5. FINANCIAL ASPECTS

Ambient air pollution poses grave, multi-faceted risks to India's prospects for achieving its development goals. It leads to a rapid increase in public health expenditure, diminished labour productivity and reduced agricultural yields.

5.1 Air pollution is known to inflict a massive toll on a country's economy. Its scale, complexity and urgency necessitate a strong, coherent and coordinated fiscal response, more particularly because there are adverse health effects. Earlier, in India, the city air action plans were not directly funded through any central or state programme. However, with NCAP, there is a formal funding line available to different cities covered under the programme, based on their performance and implementation of the action plan. Still, many of the proposed actions, like road development, road infrastructure like bypass and flyovers, supply of clean fuel, greening the transportation fleet, public transport system and mass public transport system, etc., requires significant financial resources that are generally not available with the urban local bodies, necessitating support from the Government of India or the state governments. Fortunately, there are a significant number of projects in these areas of action, including Smart city, Swachha Bharat, E-vehicles policy, etc., which provide the necessary finances to the local bodies based on their proposals and performance. Some of the international programmes, where funding has been made available for air pollution control, are listed below:

- Beijing-Tianjin-Hebei Air Quality Improvement-Hebei Policy Reforms Program, funded by ADB and World Bank[15]
- Egypt Environmental Pollution Abatement Project, funded by EU, EIB and JICA in multiple phases[16]
- Metro Manila Air Quality Improvement (Investment Loan)[17]
- ADB's Asia Clean Blue Skies Program[18]

5.2 It is the responsibility of the public urban local body to design an action plan and prepare financial requirements for various actions to raise funds through state or central support. In fact, with the new climate finance lines available in private and public domain and air pollution control's direct linkage to GHG reduction, initiatives like e-vehicles, mass rapid transit systems etc. can also find new financing avenues. It is imperative that urban local bodies prepare a holistic action plan and also create a financial architecture that can mobilise private finance for cleaner solutions in the city. The green sectors such as clean energy, e-mobility and public transport are likely to be the driving force for developing and implementing tangential solutions to improve air quality. Internationally, funds are available to catalyse the growth of green industries and simultaneously address problems of air pollution and climate change.

5.3 New opportunities in the form of startups can also be explored to deal with complex environmental issues, including air pollution. Startups can raise their finances through high-impact ventures and other social ventures. There are several other channels through which the private sector can contribute to clean air and demonstrate that economic development and air pollution abatement are not mutually exclusive.

15 https://www.adb.org/projects/49232-001/main

16 https://moic.gov.eg/project/307

17 https://www.adb.org/projects/30480-033/main

18 https://www.adb.org/news/adb-launches-program-scale-investments-air-quality-improvement

However, this would require developing a roadmap for catalysing actions in the private sector to promote clean air. One good example is the problem of crop stubble burning where many innovative ideas have been optimised into solutions like biogas, ethanol and other alternative products in the private sector. Another major area is sensor-based air monitoring for real-time measurements of various pollutants to allow the local authority to identify hotspots and make meaningful and timely interventions based on reliable real-time pollution data and prevailing air quality levels.

5.4 Gurugram is one of the most developed towns in terms of housing offices for various multinationals and corporates, which provides an opportunity to raise funds and investments through corporate social responsibility (CSR). However, this would again require a holistic action plan, containing implementation, monitoring and operations for at least 3 to 5 years. Technological interventions would require financial support.

5.5 In summary, it can be seen that there are plenty of opportunities for financing the clean air action plan, which is emerging as an important environmental initiative with co-benefits in terms of GHG reduction and climate change mitigation. The financial support can be categorised into three broad segments:

- Large-scale investments like bypasses, road infrastructure, public transport, e-mobility: They can be funded through the State and Central programmes, where assistance of DFIs like World bank and ADB can be taken.
- City-level initiatives like solid waste management, construction and demolition waste management: This can be developed with state and central government funding and also participation of private commercial agencies in PP mode.
- Innovative solutions and control measures: This can be supported by corporates under CSR and also through specific funds available in environmental compensation received through HSPCB.
- Public awareness and information disclosure: This can be effectively done through stakeholder engagement and CSR.

6. RECOMMENDATIONS

The air quality improvement plans for Delhi NCR areas that cover Gurugram city have been under implementation since nearly the last decade. However, considering the complexity of air pollution management and also the fact that the present action plan has not resulted in the desired air quality improvements, it is necessary to review these action plans based on scientific and technological aspects. The present study has identified several technical interventions that can be effectively adopted in the city air quality action plans. The study has also discussed the various aspects of such technology adoption, including its applicability, availability, affordability, scalability, effectiveness, among other criteria, and has appended this report in matrix form. It is observed that there is no single solution but an array of various technologies that need to be implemented simultaneously for getting the desired results on a regular basis. The study also identifies the critical role science and technology play in air quality improvement plan designs: effective measurements and monitoring capacity are required for designing appropriate solutions. Finally, moving forward, the air quality management plan for the city has to be dynamic and must account for the changing profile of the city over the years. The recommendations of the study are summarised below:

1. There is a need for source inventory and source apportionment studies to identify the major sources and source-wise contribution in ambient air quality for effective interventions for city-wide actions.
2. Improved monitoring for identification of hot spots within city limits would enable the local authorities to take immediate and effective actions. Use of Low Cost Sensors (LCS) and remote sensing could be potential options, though operation of LCS could be comparatively easy.

3. Promote innovations and startups in the field of air pollution control and mitigation through policy interventions, mainly for areas of green construction, air pollution hotspot identification and circular economy in urban environments.
4. Technological interventions provide an opportunity to mitigate air pollution, mainly at the receptor level; although, significant efforts are required for control of air pollution at the source.
5. Transport, industry, construction, road dust and solid waste management have been reported to be the main contributors to city air pollution. They should be given priority in the implementation of city action plans. Point sources like gensets, bakeries and tandoors are also important.
6. Though there are several technologies for abatement, mitigation and control of air pollution, their performance to achieve ambient air quality has not been tested sufficiently; hence, there is a need to include performance evaluation of such technology intervention in city action plans.
7. The area of influence of air pollution control technologies warrants research and evaluation. Considering the capacity of urban local bodies, the environmental regulators including SPCB and CPCB need to play a critical role for technology appraisal and validation for uniform and consistent adoption in city action plans.
8. There is an urgent need to develop infrastructure and capacity at the level of urban local bodies and SPCB to deal with technical and scientific aspects of air pollution, including technology adoption, evaluation and operation for effective implementation of city action plans.
9. Airshed approach needs to be adopted for holistic air quality management as significant contribution has been reported from sources located outside city limits.
10. More studies are required to assess the adverse impacts of air pollution on human health, particularly focusing on poor and marginalised communities: women, children and aged persons.
11. More studies are required to assess the adverse impacts of air pollution on flora and fauna (including urban and rural areas and agriculture).
12. Effective cost-benefit analysis of air pollution mitigation action plan and preparation of detailed comprehensive action plan would attract investments in this sector, as already evident in various countries, including China and Philippines.
13. New principles and governance tools such as circular economy, carbon and green credits and innovations need to be integrated in city action plans.
14. Economic instruments like green credits need to be explored for adoption of new technology and practices, such as conversion of transport fleet to electrical/CNG, bakeries, tandoors, small boilers, etc. There are opportunities to get institutional funding if such projects are planned.
15. The city action plan needs to be supplemented with various city-specific policies, like parking policy, old vehicle scrapping policy, mobility action plan, development plan, among others.
16. There is a need to develop a city-specific action plan for Gurugram based on source inventory and source apportionment studies, which is dynamic but aimed to achieve the desired air quality in a time-bound manner, using the technologies discussed in this report.
17. There is a need to increase meaningful public participation in city action plan through continuous engagements throughout the life cycle of city action plan, and also use the city-specific portal to give all relevant information,including grievance redressal mechanism, on city air quality action plan.

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ANNEXURE-1

Summary of the Action Points mentioned in the NCAP Clean Air Plans where use of technologies are relevant

Sector	Action Points
Transport	1. Plying of electric vehicles for public transport and establishment of charging stations for all vehicles 2. Construction of expressways/ bypasses/ peripheral roads 3. Arrangement of multi-level parking facilities 4. Development of cycle zone 5. Retrofitting of particulate filters in diesel vehicles 6. Use of bio-ethanol 7. Widening of Roads 8. Remote sensor based PUC system
Industry	1. Adoption of zig zag technology in brick kilns 2. Monitoring of industrial emissions through Online Continuous Emission Monitoring System (OCEMS) 3. Shifting of air pollution industries to conforming zones 4. Installation of web cameras and OCEMS in gross polluting industries
Waste burning	1. Extensive drive against open burning 2. Proper collection of horticultural waste burning 3. Door-to-door collection of segregated waste 4. Establishment of compost pits
Construction	1. Control measure for fugitive emissions 2. All construction areas must be covered to avoid dispersion of particulate matter 3. Ensure carriage of construction material in closed/covered vessels
Dust	1. Maintaining 33% forest cover 2. Creation of green buffers 3. Maintain potholes free roads 4. Introduce water fountains 5. Wall-to-wall pavement 6. Blacktopping of metallic roads