India-California Air Pollution Mitigation Program (ICAMP)

Initiative for Mitigating Air Pollution from the Transportation Sector

Co-Chairs: R.K. Pachauri, M. Nichols, and V. Ramanathan

A joint initiative by The Energy and Resources Institute (TERI) India, University of California at San Diego (UCSD), and the California Air Resources Board (CARB)

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Knowledge to Action Plan
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Released for Comments

The Knowledge to Action Plan (KAP) document will be presented at the ICAMP conclave organized by TERI , UCSD and CARB as part of the Delhi Sustainable Summit during Feb 4 and 5, 2014. KAP was written by the ICAMP project group based on a workshop held in Oakland, California during October 21 to 23. This work shop was inaugurated by the Governor of California and Dr. R. K. Pachauri. The Delhi conclave will be inaugurated by Minister of Road Transport and Highways, India. The participants at the Oakland workshop and the Delhi conclave are listed below. The primary purpose of the Delhi conclave is to seek comments and suggestions from the participants. It should be noted that the authors listed in the next section, and not the participants of the workshops, are solely responsible for the contents of the report.

Participants

- Honorable Minister of Road Transport and Highways, (GOI) Oscar Fernandes, (TBC)
- R.K. Pachauri, The Energy and Resources Institute
- R.K. Singh, Ministry of Petroleum and Natural Gas, GOI
- Leena Srivastava, TERI University
- S. Sundar, The Energy and Resources Institute
- H.K. Dash, Government of Gujarat
- A.S. Bhal, Ministry of Urban Development
- R. Hasan, Ministry of Environment and Forests
- Phanindra Reddy, Government of Tamil Nadu
- U. Panwar, Government of Uttarakhand
- S. Bandopadhyaya, Ministry of Road Transport & Highways, GOI
- Prashant Gargava, Central Pollution Control Board
- A. Aggarwal, Cummins India Ltd.
- A.A. Gupta, Indian Oil Corporation Limited
- I.V. Rao, Society of Indian Automobile Manufacturers
- Honorable Governor Jerry Brown of California
- K. Alex, Office of Governor of California
- M. Nichols, CARB, California
- P. Khosla, University of California at San Diego
- V. Ramanathan, University of California at San Diego
- Durwood Zaelke, Institute for Government and Sustainable Development
- B. Croes, CARB, California
- A. Lloyd, International Council on Clean Transportation

- A. Bakre, PCRA
- A. Bandivadekar, ICCT
- A. Chandra, Indian Institute of Technology
- A. Dutta, The Energy and Resources Institute
- A. Haritash, Delhi Technological University
- A.D. Lee, World Bank
- A. Shrestha, World Bank
- B. Deol, Natural Resources Defense Council
- B. Bhanot, TEDC (BIS) & (ILFS), Former ARAI
- D. Ganguly, Indian Institute of Technology
- D. Mohan, Indian Institute of Technology
- E. Jain, The Energy and Resources Institute
- G. Beig, IITM, Pune
- G. Habib, Indian Institute of Technology
- I.H. Rehman, The Energy and Resources Institute
- J. Apte, Energy and Resources Group, UC
- J. Burney, UCSD
- J. Seddon, OKAPI Research
- Jie Li, World Bank
- Ke Fang, World Bank
- K Ravinder , Central Road Research Institute
- K. Sharma, Shakti Foundation
- M. Sharma, Central Pollution Control Board
- N. Ramanathan, Nex Leaf
- N S Murthy, Reliance Industries Limited
- Nitin Gokarn, National Automotive Testing and R&D Infrastructure Project
- R. Desai, Reliance Industries Limited
- R. Harnish, Center for Environment and National Security
- S. Gudhe, Indian Institute of Tropical Meteorology
- S. Guttikunda , Urban Emissions
- S. Mohanti , Shakti Foundation
- S.N. Tripathi, Indian Institute of Technology
- S. Sharma, The Energy and Resources Institute
- S. Yeh, University of California, Davis
- T.K. Joshi, Maulana Azad Medical College
- W. Al-Delaimy, University of California, San Diego

Authors of this Draft

Chairs: V. Ramanathan and S. Sundar

Lead Authors: B. Croes; A. Dutta, R. Harnish; A. Lloyd, V. Ramanathan, S. Sundar, S. Sharma; J. Seddon; S. Tripathi

Contributing Authors: A. Agarwal, A. Bandvadekar, K.K. Gandhi, S. Guttakunda, N. Iyer, J. Kubsh, U. Panwar , I.H. Rehman, N. Iyer, T. Kirchstetter, N. Ramanathan, P. Sharma, R.P. Singh, U. Panwar, S. Yeh, M. Waugh, T.K. Joshi, Al Delaimy, A. Dutta ,M. Panwar, R. Bahadur, J.Burney, G.Beig.

We would like to thank Mr. Phanindra Reddy as well as Ms. Manisha Panwar and Dr. Umakant Panwar for their insights..

Table of Contents

OVERVIEW

ICAMP GOALS

Protect the Air

Protect Public Health

Protect Food Supply

Protect Water Supply

The transportation sector has witnessed rapid growth rates during the last few decades. This trend is expected to continue through this century. Worldwide sales of new road transportation vehicles are expected to grow from about 110 million vehicles a year in 2010 to almost 200 million vehicles a year by 2030, with most of this growth in developing nations. The global vehicle fleet is expected to triple by 2050. In India, the focus of this report, vehicles have grown from 20 million in 1991 to 140 million (mostly two and three wheelers) in 2011. While this growth in global vehicle fleet has contributed significantly to the mobility of the population and the impressive economic growth of many developing nations, the development has come at a huge cost to human well-being and sustainability. First, the transport sector is responsible for about 25% of all energy related greenhouse gas (GHG) emissions. It is also one of the major sources of air pollution in urban locations. The two dominant air pollutants from the transportation sector are: Particulate matter (PM) and ozone in the lower atmosphere. PM comes in variety of sizes ranging from nanometers to tens of micrometers. WE are primarily concerned with PM smaller than 2.5 micrometer. The negative impacts of these pollutants embrace all aspects of human wellbeing: Health, Food, Water.

Health: Ambient particulate matter (PM) from all sources, including the transport sector, lead to about 3.2 million premature deaths every year. Asia is a high-risk region with 2.1 million premature deaths and disability-adjusted life-years of 52 million years lost. In India, ambient air pollution caused an estimated 627,000 deaths in 2010. The corresponding estimate for the US is 103,000 deaths

Food: The ground level ozone produced by pollutant gases (such as nitrogen oxides, NOx) released during combustion of fuels leads to over 100 millions of tons of crop damages globally every year.

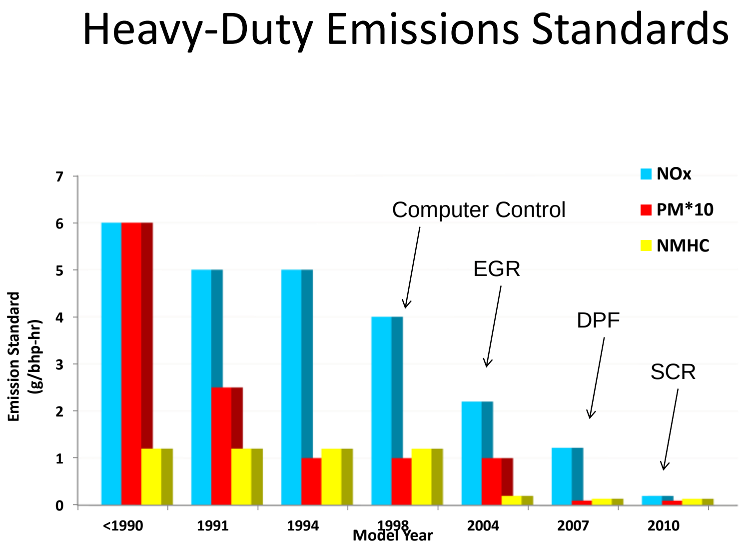
Water: Although not widely recognized, air pollution has significant effects on water directly and indirectly through climate change. PM (sulfates, nitrates, organics and dust) reduces sunlight (called as dimming) reaching the ground which reduces evaporation and hence precipitation. Some of the PM also nucleates copious amounts of cloud drops which reduces the precipitation efficiency of low level clouds. In addition, some of the PM cause surface cooling and alter land-ocean differential heating which also leads to reduced rainfall. Lastly, ozone and black carbon (part of PM from diesel and other sources) cause surface warming (see Scientific Basis chapter for more details) as well as warming of elevated regions of the Himalayas.

The largest sources of air pollution at a national level are residential burning of solid fuels (biomass and coal), power generation and industry, open burning of crops and the transport sector. The relative fraction of these sources vary from region to region and from nation to nation within each region. However, in major urban areas with high population density, the transportation sector contributes up to 40% to 50% to PM sources and even larger percentages to pollutant gases (e.g NOx) that produce Ozone.

ICAMP focuses on the transport sector and explores practical and proven pathways for mitigating air pollution from the transport sector. It relies heavily on decades of California's experience in developing the scientific basis for air pollution impacts, the engine and fuel technologies that were proven to drastically reduce pollution levels and the governance for effective implementation of mitigation polices. The Californian experience has demonstrated that technologies are available to drastically cut PM and other pollutants. The cost of clean up, although not small, is far less than the cost of remedying the negative impacts on sustainability and human well being. The economic value of lives saved alone far outweighs the clean-up costs. Lives lost in India from ambient PM is 627,000 deaths per year and another one million (10 lakhs) deaths per year due to exposure to indoor PM from cooking with solid biofuel, lighting with Kerosene and heating with open biomass burning. The fundamental issue that ICAMP confronted was the following:

How do we deploy such technologies to reduce vehicular emissions without inhibiting growth and development?

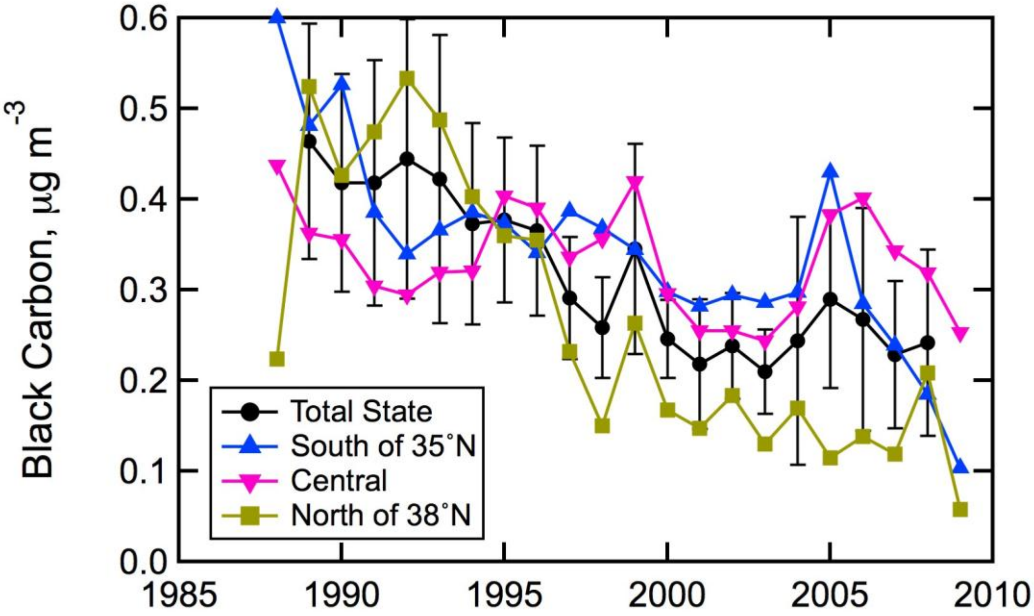
It is in this respect, the California experience in cleaning up the air without slowing development is of great relevance for India's trajectory. In the 1960s, California had the worst air pollution in the world with 8-hour ozone in excess of 350 ppb. Between 1968 to 2008, California reduced emissions of ozone precursor gases (CO, NOx and SO_2) by 75% to 90% and cut its black carbon (major part of diesel PM) emissions by 90% while its population increased by 100%, number of vehicles increased by 175% and its diesel consumption as well as miles traveled increased by 225%. The cost of control was about 0.5% of GDP and brought in \$10 to\$30 of health benefits for each \$1 spent in control and added 30000 jobs in the air pollution control industry and 123000 jobs in the clean energy industry.



[3]

HISTORY OF ENGINE AND FUEL IMPROVEMENTS IN CALIFORNIA AND IMPACTS ON EMISSIONS OF NOx, PM and volatile organics (NMHC). SOURCE: CROES (CARB, 2013).

Comprehensive statewide measurements of ambient black carbon and other particles revealed the success of the improvements in improving air quality (Figure below):



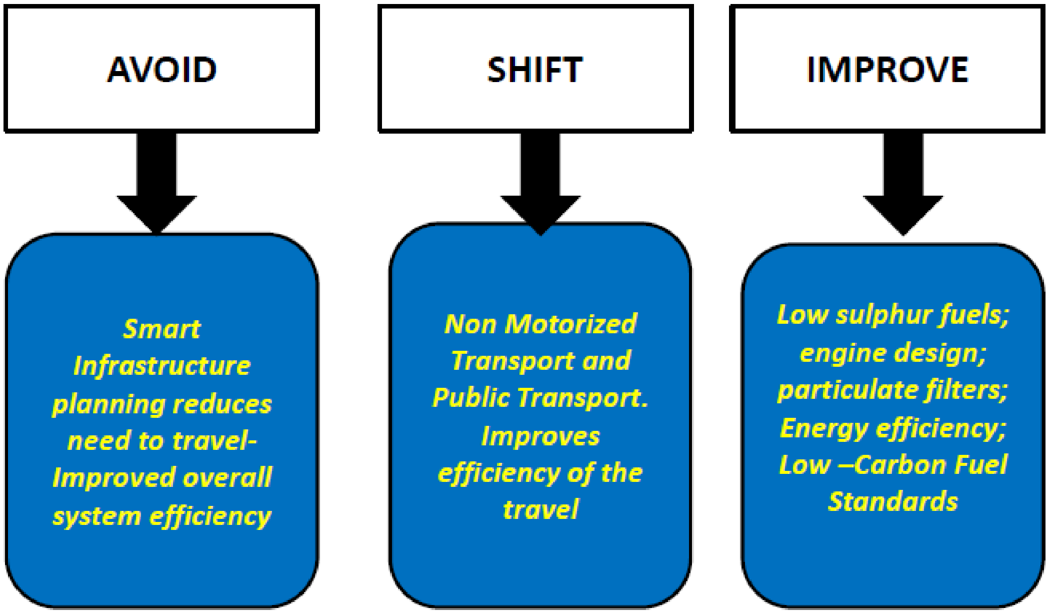
Trends in Black Carbon over south, central and northern California in response to emission reductions from diesel engines (on-road and off-road). Source: Ramanathan et al (2013; Report to CARB).

Black Carbon is not only a PM but also the second largest contributor to global warming. The reduction in diesel BC emissions from 1989 to 2008, is equivalent to California reducing its CO_2 emissions by 21 to 50 million metric tonnes annually, i.e, it is equivalent to taking 4 million cars off the road. The primary message from the California experience is that:

Targeting air pollution emissions from the transportation sector has huge benefits for human health and food security. It also has a major co-benefit of mitigating climate change immediately since the warming pollutants in the transport emissions (black carbon and ozone) have very short life times (weeks to months)

India has a great opportunity to benefit from the *Improvement* in the transportation sector demonstrated by California and leapfrog to a sustainable transportation by adopting the holistic path of: AVOID, SHIFT AND IMPROVE. (http://www.unep.org/transport/About.asp) One that provides mobility for individuals and supports freight movement for business with minimum emissions. “Avoid” and “Shift” require first, strategic urban planning to reduce amount of travel required; and second, investment in creating attractive, competitive lower emissions options for passenger travel and freight movement. With 130 billion USD investment in transport infrastructure anticipated during the period 2012-2017 (Planning Commission (Government of India) 2013), India has an opportunity to develop a sustainable transport system. This

The Avoid-Shift-Improve approach to Sustainable Transport Systems



Knowledge to Action plan document lays the groundwork for the AVOID, SHIFT AND IMPROVE (ASI) transport system.

KAP relies heavily on 'Science informing Policy' and the first of three sections describes the scientific basis of the proposed action plan. It calls for a balance between field studies and monitoring stations to determine compliance and health exposure studies, and modeling studies at air-basin scales to determine priorities in technology measures. Field studies are required to reduce the huge uncertainties in emission inventories and in addition determine emission reductions from the technologies and improved fuels. We recognize air pollution has a large impact not only urban situations but also on regional climate. Health impacts take the central role in our criteria for air pollution mitigation.

The second section delves into technology nuances required to drastically cut emissions of PM and ozone precursors. Basically KAP recommends technologies that have high potential for emission reduction. For Mobile source, it proposes (for >95% reduction in tailpipe emissions): Cleaner engines; After treatment such as filters; Cleaner gasoline and diesel fuel and Alternative fuels. For stationary sources, it prescribes for 80-90% reduction: Low-NO_X burners; Selective catalytic reduction and cleaner fuels. All of these changes follow California's path and falls under the 'IMPROVE" part of ASI transport system.

In the third section, KAP outlines strategies for Governance of the ASI transport system. Governance is commonly defined as the process of integrating public priorities and expert information to effectively allocate public financial and human resources toward development and welfare goals. The last section (to be done based on the feedback at the Delhi Conclave) develops a practical implementation plan and propose pilot projects that can provide us valuable data to dynamically adapt KAP's plans to India's conditions.

Executive Summary

Major Findings and Recommendations

The overarching findings and recommendations for mitigating air pollution from the transport sector are summarized below.

- ***Drastic reduction (more than 90%) of PM and nitrogen oxides (NOx) from the transportation sector, primarily diesel vehicles (on-road and off-road) and buses, would have the largest and most immediate beneficial impact on human health, food and water supply, and regional to global climate change. It is a win-win action for all aspects of sustainability.***

- ***The California experience demonstrates that technologies to improve engine emissions and to distill ultra-low sulphur fuels are available and can be implemented successfully on a large scale. More importantly, California has demonstrated that these pollutants can be mitigated drastically without slowing down economic devlopment***

- ***There is a large potential to reduce diesel particulate matter (PM) emissions by implementing stricter vehicle emission and fuel quality standards. Nation-wide switching to BS-IV standards (50 ppm sulphur) by 2015 and to BS-V standards (10 ppm sulfur) by 2017, would enable the adoption of Bharat Stage (BS) VI emission standards for the entire country.***

- ***The new standards would enable all diesel vehicles in India to be fitted with diesel particulate filters (DPF) which would help reduce per vehicle $PM_{2.5}$ emissions by over 90 percent from today's levels. Considering that the share of diesel in the transportation of passengers and freight is about 70%, a reduction of this magnitude in emissions from diesel vehicles would have a significant benefit.***

  The California example demonstrates that technologies are available to accomplish such massive reductions (>90%) in air pollution.

- ***The use of unadulterated low sulphur fuels and the effective performance of the DPF and other after treatment devices would call for significant investments in Inspection and Maintenance (I&M) facilities across the country, especially in cities with the population of one million or more. A coordinated (between academia and government) observational and modeling effort is required to develop Science Based Policy directives, similar to California's efforts.***

- ***We strongly endorse India's National Urban Transport Policy approach of "Avoid (transport use), Shift (from high to lower-emission forms of transport), and Improve (transport technology to reduce emissions). The lessons for India from California are clearest on the means to "Improve," but Avoid and Shift are also part of India's aspirations since India has an important opportunity to build a transport system in which public and non-motorized transport become the first choice for mobility. India should break away from the motor vehicle based path that the developed countries took in their process of growth.***
- ***The Government of India should without further delay mandate the refineries to upgrade their facilities and supply Euro-IV fuel all over the country by no later than 2015 and Euro –V fuel by 2017.***
- ***State governments in India have enormous potential as the locus for comprehensive, integrated air quality management, while building state leadership will require national funding to both motivate and enable action, State governments should also be encouraged to invest in effective in Avoid-Shift-Improve interventions to place transport systems in their cities on a sustainable path.***

State governments empowered as they are by the Air Act and EPA to seek more stringent vehicular emission standards should any of their cities be highly polluted, should demand more stringent standards. This would, as in California compel the oil industry to advance the supply of better quality fuel and the automobile industry to respond to tighter emission standards.

- ***A coordinated (between academia and government) observational and modeling effort is required to develop Science Based Policy directives and to monitor the effectiveness of mitigation actions in improving ambient air quality and human health.***

Observations should include field measurements to improve emission inventories and tail pipe emission factors; it should also include high quality monitoring capabilities of ambient composition of PM including black carbon, sulphates, organics and nitrates aerosols. Cell-phone based soot monitors can revolutionize data collections at massive scales, of the order of few hundred stations or more per city. Air-basin to regional scale chemistry-transport models are required to explore various policy options. Such high resolution monitoring stations and models are also required to understand the health impacts and agriculture impacts.

The major findings and recommendations under each category (Science, Technology Measures, and Governance) are described next.

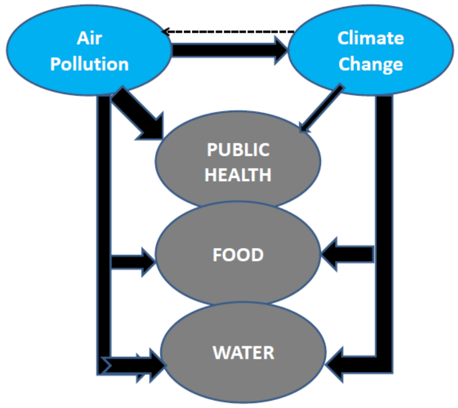
I. Scientific Basis

Major Findings

- ***Air Pollution Impacts on Human Wellbeing and Sustainability***

There are two types of air pollution: Gases (Ozone, SO_2, NOx, CO, and methane and VOCs) and Particles. Methane (leaks from gas pipes; cattle; rice paddies; waste fills; etc) is unique in that it is a major greenhouse gas but its oxidation leads to ozone formation in the lower atmosphere. There are two sources of particles: primary particles emitted directly from the sources such as smoke from fires and diesel exhaust. In addition, pollutant gases such as SO_2 and NOX form particles (sulfates and nitrates) through gas to particle conversion… known as secondary particles. The primary and secondary particles are referred to as PM for particulate matter. In this document, our primary focus is on PM and ozone. Ozone is not emitted by human activities but is formed by photochemical oxidation of the pollutants: CO, NOx, VOCs and Methane).

THE AIRPOLLUTION-HEALTH-CLIMATE CHANGE NEXUS



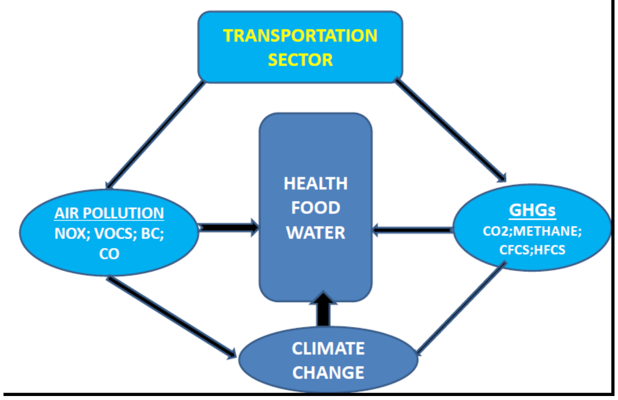
Our concern for these air pollutants is from the following impacts (see inset image):

Public Health: Both PM and Ozone negatively affect human health. However, with respect to mortalities of about 3.2 million from ambient air pollution, PM is the dominant source and is more damaging than ozone by a factor of 10 to 1. This is not to minimize the health effects of Ozone, but simply to emphasize the enormous effect of PM in health effects.

Agriculture: The situation is reverse with respect to agriculture damages of air pollution. Ozone is the most damaging air pollutant, leading to millions of tons of reduction in rice, wheat, Soy, maize and other food crops.

Climate: PM and Ozone have major influences on regional climate. Ozone is a greenhouse gas. The back carbon in PM is the second largest contributor to global warming and likely in regional arming too. The sulphates, nitrates and organic carbon particles in PM have negative impacts on precipitation and also have a cooling effect. For the diesel

THE TRANSPORTATION SECTOR



transportation sector, about 75% of the PM is black carbon. In addition to the warming effect of black carbon, the greenhouse gases emitted by the transportation sector include: CO2; methane (fugitive emissions); CFCs and HFCs used as refrigerants.

- High population densities, mobility demands, and expanding transportation sector have led to accumulation of high quantities of emission loads in cities. This also means that the huge population base is exposed to alarmingly high pollution levels- mainly particulate matter (PM)- presently in Indian cities.
- The main air pollutant of concern is PM2.5 for human health impacts and surface ozone for impacts on food production. 627,000 people die each year from ambient PM. Black Carbon in PM2.5 is emerging as a carcinogen.
- Nearly 40,000 premature deaths each year are caused by vehicle $PM_{2.5}$ emissions in India's cities alone.
- Surface ozone is the major pollutant with respect to crop damages. India produces around 150 million tons of rice (paddy) and 80 million tons of wheat annually, and plays a key role in global food security [FAO, 2013]. Nationally aggregated relative yield loss of wheat and rice due to high ozone exposure totals 5.5 million tons in 2005, which could have fed 94 million people in India. The loss is also about double the amount of wheat exported yearly and about 50% of the rice exported annually. It has been estimated India lost another 4 million tons of wheat due to climate change.
- Nationwide, the residential sector eclipses the contribution of other major sectors towards PM2.5 (particulate matter less than 2 micron) emissions. However, in cities, the transport sector is the major contributor to PM2.5. With respect to ozone, NOx is the major precursor gas and the transportations sector is the major source: 45% nationally and more than of 60% in cities.
- The emissions from transport sector are going to grow about three folds for PM2.5, and five folds for NOx. Black carbon emissions which are the subset of PM2.5 only can also be assumed to grow with similar rates. The dominant sources of PM within the transportation sector are diesel Trucks and Buses (52%) followed by 2-wheelers (25%). Black carbon is the significant part of the emissions form diesel vehicles, which is also the second largest global warming pollutant (next to CO2) and thus reducing diesel PM (black carbon) is a climate-friendly air pollution mitigation action.

- Trucks and buses are also the dominant source of NOx (83%). Reduction of NOx can reduce surface ozone and reduce the effects of the transportation sector on destruction of crops (wheat and Rice mainly). Ozone is also a greenhouse gas. In addition, if NOX reduction leads to reduction in nitrate aerosols (this depends on sulphate and ammonia loading), the negative impact of air pollution on India's precipitation reduction will also decrease.

2. *Major Recommendations*

- Overall, drastic reduction of PM (and hence BC) and NOx from trucks and buses, would have the largest beneficial impact on human health, food availability, and regional climate change. Next in priority is the reduction of PM and NOx emissions from two wheelers.

- The California example demonstrates that technologies are available to accomplish such massive reductions (>90%) in air pollution.

- A coordinated (between academia and government) observational and modeling effort is required to develop Science Based Policy directives. Observations should include field measurements to improve emission inventories and tail pipe emission factors; it should also include high quality monitoring capabilities of ambient composition of PM including black carbon, sulphates, organics and nitrates aerosols. Cell-phone based soot monitors can revolutionize data collections at massive scales, of the order of few hundred stations or more per city. Air-basin to regional scale chemistry-transport models are required to explore various policy options. Such high resolution monitoring stations and models are also required to understand the health impacts and agriculture impacts.

II. Technology Measures

- There is a large potential to reduce diesel particulate matter (PM) emissions by implementing stricter vehicle emission and fuel quality standards. Implementing ultra-low sulfur fuels (ULSF – fuels with under 10 ppm sulfur content) would enable the adoption of Bharat Stage (BS) VI emission standards, which would require all diesel vehicles in India to be fitted with diesel particulate filters (DPF). DPF implementation would reduce per vehicle $PM_{2.5}$ emissions by over 90 percent from today's levels.

- There are technologies to achieve more than 90% reductions in emission as demonstrated by USA and Europe.

- The diesel particulate filter technology in transportation is primarily applicable to new private, light duty and heavy-duty vehicles. Technology to be retrofit is custom built and therefore expensive. In California, small transport companies argue that retrofit of their trucks and buses is not possible if they are to remain in business. In a determined campaign to reduce premature death and agricultural crop damage in India, it may be cheaper for society to remove older vehicles from service rather than attempt to regulate retrofit technology.

- The biggest barrier to progress in India is the continued delay in implementing the supply of ultra-low-sulfur fuels, which would enable the sale of vehicles meeting more stringent emission standards and adoption of diesel particulate filters (DPFs) and other advanced vehicle after treatment systems in India.

- The refinery investments needed to transition to ULSFs in India will be in the range of 2 to 5 percent of the present fuel price. Significant capital costs will be required for refiners to produce low-sulfur diesel fuel but the widespread use of diesel fuel keeps the cost-per-gallon impacts relatively low. The California experience is that the cost-per-gallon to meet the lower diesel fuel sulfur requirements is about 2.5 cents per gallon.

- For controlling emissions, there are several technology options available, requiring work in combustion research, fuel systems, air-handling systems, controls and after-treatment for providing the most appropriate emission control solution. What is important is to develop the right technology for each application and market served. Different operating conditions and economic factors can and do influence the technology path which is most appropriate for each market. A second, but no less important part is to involve original equipment manufacturers as early as possible in the development and integration process. This is not a call for research, but rather for close collaboration.

- Coming to NOx reduction technologies, we have advanced combustion, cooled EGR, variable geometry turbochargers and various after treatment solutions.

- Two and three wheeled vehicles produce roughly 40 percent of PM2.5, 35 percent of PM10, 40 percent of carbon monoxide and 70 percent of volatile organic compounds. A major tightening of emission limits in the year 2000 led the manufacturers to gradually shift from two-stroke to less polluting four-stroke engines and the relative share of 2-stroke engines is now only around 6% of the total powered two-wheeled sales in the country.

- The approach for three-wheeled vehicles using two-stroke petrol engines was the same as for two-wheeled vehicles. However, the shift to four-stroke engines did not reach the same proportions as in case of two-wheeled vehicles. The application of air-assisted fuel injection can help to reduce PM emissions to the levels of four-stroke engines. Air Assisted Direct Injection employed on 2-stroke engines can also reduce fuel consumption significantly, say 25 to 30%.

- The emission control of inuse vehicles is largely based on periodic vehicle inspection namely PUC testing. The periodicity of PUC testing varies form 4 times a year to once a year depending on the State concerned. The PUC system which is based on idle testing and is essentially intended to identify heavy polluters is totally ineffective due to inadequate compliance, poor quality of testing due to non-calibrated equipment, and untrained operators and needs to be strengthened. In addition, in use testing facility should also be structured on the lines of the practices in US where deterioration factors are taken into account. The Type Approval and COP testing should be backed up by a recall policy. A major improvement in the much debated PUC system, particularly in relation to two and three-wheelers, can be achieved by adopting the Automotive Research Association of India Two-Wheeler loaded mode test as a part of the regular procedure for periodic vehicle inspection.

- A major improvement in the much debated PUC system, particularly in relation to two and three-wheelers, can be achieved by adopting the Automotive Research Association of India Two-Wheeler loaded mode test as a part of the regular procedure for periodic vehicle inspection.

- Due to limited availability for vehicular usage, CNG and LPG will remain niche market solutions and cannot be considered for widespread usage.

III. Governance

- Developing transport governance institutions seizes an opportunity to create a sustainable transport system that delivers mobility with the lowest possible environmental cost.

- Investing in public transport ensures that more environmentally friendly options remain competitive with vehicles as more people can afford cars. Public transport can be faster, safer, and more convenient than private vehicles – if it is well-designed and integrated into urban planning.

- Vehicle ownership is just 13 cars/84 two-wheelers per 1000 people. Car ownership is concentrated in the urban areas, but a substantial portion of passenger-kilometers traveled in urban India are still by public or non-motorized transport.

- The Government of India should without further delay mandate the refineries to upgrade their facilities and supply Euro-IV fuel all over the country by no later than 2015 and Euro –V fuel by 2017, towards a one country-one fuel vision.

- While upgrading fuel quality is presently a national government effort given the industry ownership, scale of supply chains, and national movement of fuels and vehicles, there is no reason why this should continue. The State governments can demand better quality fuel and in the process compel the industry to supply fuel required.

- State governments in India have enormous potential as the locus for comprehensive, integrated air quality management, but building state leadership will require national funding to both motivate and enable action.

- Invest in upgrading ambient air quality monitoring and creation of locally specific emissions inventories, particularly, but not limited to, all million + cities, as well as comprehensive source apportionment studies combining top-down and bottom-up assessments.

We also reiterate the following recommendations by the NTDPC report:

- Consolidate the fragmented jurisdiction over urban transport to create entities at the city and metropolitan level.

- Ensure that investment in urban infrastructure is technology neutral, if not actively encouraging improved public transport.

- Take advantage of less capital-intensive ways to improve the customer functionality of existing public transport, including: unified ticketing; provision of feeder services and/or policy incentives to support private provision of feeders such as auto-rickshaws; lighting, toilets, and other “amenities” in and around stations; transparent scheduling and communication about routes via SMS and other widely accessible formats.

- Demand-side management. Consider some measures to ensure that drivers internalize externalities (e.g. air pollution, traffic, noise, and accident hazards), including congestion pricing, limiting parking spaces (rather than mandating construction of additional parking), and quotas on vehicle registration.

I. SCIENTIFIC BASIS

S. Sharma, S. Tripathi, S. Guttikunda, N. Ramanathan, R. Bahadur, T. Kirchstetter, T.K. Joshi, W. Al-Delaimy, A. Dutta, M. Panwar, J.Burney, G. Beig, V. Ramanathan

Technical Summary

Emission Scenarios India has followed a steep economic growth trajectory in the last two decades. The population has grown by a factor of 3.3 since 1950 and the index of production has grown by 50 folds during the same period. With growing industrial production bases, higher income levels, and sprawling cities, mobility demands have also gone up many folds. The number of vehicles which were less than a million in 1950, has increased to more than 140 million in 2011. High population densities, mobility demands, and expanding transportation sector have led to accumulation of high quantities of emission loads in cities. This also means that huge population base is exposed to alarmingly high pollution levels-mainly particulate matter- presently in Indian cities.

Emissions from transport sector mainly depends upon: 1) Estimates of on-road vehicles, 2) Technological distribution of vehicles (Engine capacity, power, sizes), 3) Fuel-wise distribution of vehicles (Gasoline, Diesel, Gas), 4) Vintage of vehicles (compliance with emission norms) and 5) I&M schedules and practices. Fuel-wise distribution of vehicles is important as different pollutants are emitted in varying proportions while running vehicle on different fuels. Gasoline driven vehicles are known to emit unburnt hydrocarbons and carbon monoxide (CO) which is a product of incomplete combustion of gasoline. On the other hand, diesel driven vehicles emit more particulates and oxides of nitrogen due to high temperature combustion.

National level estimates of different pollutant emissions from transport sector have been presented by many research studies. Trends of emissions of different air pollutants at the National scale during 1990 to 2010 and thereafter projections till 2030 are presented in IIASA, 2010. Based on this, it can be concluded that at the National scale domestic sector eclipse the contribution of other major sectors towards PM2.5 (particulate matter less than 2.5 micron) emissions. However, this is to be noted that majority of these emissions happen in rural regions while transport sector contributes much more in cities. A study spanning over six cities showed the shares of various sectors in prevailing PM10 and PM2.5 concentrations in major cities. While road and soil dust have been the dominant contributors to PM10 concentrations, the transport sector is one of the major contributor to PM2.5 fractions. On the other hand, NOx emission (caused due to high temperature combustion) from the transport sector has a dominant share at both national and urban scales. The share of transport is about 44% at the national scale in 2010 and dominant across different cities. TERI, 2013 estimated the Non Methane Volatile Organic Carbon (NMVOC) emissions in India and the contribution of transport sector is 12% in 2010. The projections for the year 2030 suggest further increase to about 28% (9% tail-pipe and 19% evaporative). Various estimates suggest that at the national scale, the transport sector has contributed to 7-34% in overall Black Carbon (BC) emissions across different years. However, the contributions may increase from urban centres, e.g. in Bangalore, the contributions are as high as 56% from the transport sector. It is quite evident that heavy-duty vehicles have major shares of 52% and 83% in PM2.5 and NOx emissions from transport in India, respectively. Transport sector energy projections for the year 2030 shows that the BAU (Business as Usual) scenario (where no further action is assumed till the year 2030), the emissions from transport sector will grow by about three folds for PM2.5, and five folds for NOx. Black carbon emissions which are the subset of PM2.5 only can also be assumed to grow with similar rates. This also means that air quality concentration levels in the present context are going to be worse in future.

Monitoring Delhi National Capital region (NCR) is one of the severely polluted regions of the world. A major air quality mitigation step was taken in the year 2001 when the public transport sector was converted from diesel/petrol to CNG. Despite great efforts, air quality remains poor in this region. Recently Ramanathan (2013) has shown drastic reduction in Black Carbon (BC) concentration across California due to technological interventions and policy measures introduced in transport sector during previous decades. Here we propose a framework for establishing a monitoring network to evaluate the changes in vehicular emission and ambient air quality in a city in response to mitigation measures. We consider the city of Delhi as an example.

We propose to develop a network to monitor PM2.5, Ozone (O_3) and BC to cover the Delhi city as well as other nearby polluted (e.g. Noida, Gurgaon and Faridabad) and relatively clean areas. Entire NCR may be divided into 10 km by 10 km area. A total of 24 sites is proposed to measure BC, O_3, CO and PM2.5. The central part of Delhi should have more concentrated measurements, about12 sites.

Network Five additional sites will be chosen to monitor vehicular emission, as these are the major entry points for the heavy-duty vehicles. Highly time resolved measurements of CO_2, BC, and NOx concentrations would be ideal at these locations to enable quantification of emission factors for the heavy-duty vehicles that pass the sampling locations. Using a carbon balance method, the measured CO_2 is related to the amount of fuel burned to compute fuel-normalized emission factors, g pollutant emitted per kg fuel burned. If an increase in diesel particle filter use is likely during the study, the additional measurement of NO and NO_2 would be of interest because these filters have been shown to increase NO_2 emissions and the NO_2/NO_x emission ratio. Additional information about the passing heavy-duty trucks, such as engine model year and installed emission control equipment (e.g., if the truck was retrofitted with a diesel particle filter), would add value to the study. A mobile sampling platform, such as a van outfitted with the air pollution monitors, has proven useful in past studies of vehicular emissions.

For all 41 sites, a cell phone monitoring network will be set up at each site in order to collect immediate measurements of black carbon from filters [Ramanathan et al, 2011]. Each 24-hour filter sample can be photographed with a cellphone camera, and submitted by email to a server, which will automatically analyze the filter image for black carbon loading, store the result in a centralized database, and make the data available to public?? via a website.

Instrumentation At all the proposed sites, the following instruments will be used: 1. Aethalometer (AE 42) – to measure BC at 5 min interval, 2. Gas-analyzer – to measure O_3 and CO at 1 min interval and 3. EBAM PM sampler – to measure PM2.5 at 15 min interval. The proposed three supersites will have the additional instruments: a. Bulk filter sampler – to collect 8 hourly samples on filter for the 24 hour duration every third day. The samples will be utilized for chemical measurements, b. EC-OC analyzer – to measure OC and c. Seven-wavelength Aethalometer - to measure the absorption spectra

India and Global Food Security The four largest crops in the world – rice, wheat, maize, and soybeans – provide 75% of all calories consumed by humans on the planet. Of these, rice and wheat are the most important for India. India produces around 150 million tonnes of rice (paddy) and 80 million tonnes of wheat annually, and plays a key role in global food security [FAO, 2013]. Climate change has important ramifications for agricultural production and food security.

Long-term Climate Change Most crops exhibit a non-linear relationship between growth and temperature. At low temperatures, growth (yield) increases slightly with increasing temperature, but above a critical temperature, yields drop dramatically with increasing temperature. A rule of thumb is that, absent adaptation, each 1°C increase in temperature would correspond to about a 10% reduction in yields [Lobell et al., 2008]. Over the past several decades, India's main rice- and wheat- producing areas have seen warming trends equal to or beyond the global average. Precipitation patterns have been more varied, with some states exhibiting upward trends and some downward. Global studies have shown that Indian agriculture has already been negatively impacted by temperature and precipitation trends.

Short Lived Climate Pollutants (SLCP) Impacts SLCPs – tropospheric ozone (O_3), methane, BC, and HFCs – have important impacts on agricultural production. HFCs contribute to warming via the greenhouse effect, so their impacts are entirely encompassed in temperature impacts on yields. The other two SLCPs – BC and O_3 – are tremendously important for agricultural production. Ozone is toxic to plants, damaging them through direct stomatal gas exchange, and

BC has important radiative impacts. However, since tropospheric ozone formation depends on the presence of precursor compounds – volatile organic compounds (VOCs, including methane), NOx, and carbon monoxide (CO) – and since BC is often co-emitted or mixed in the atmosphere with other aerosols – like sulfates (mostly formed from sulfur dioxide (SO_2) emissions) and organic carbon (OC) – impact analysis necessitates discussion of broader aerosol impacts (BC + OC + SO_2/sulfates) and joint analysis of and O_3 and its precursors NOx, NMVOCs (non-methane VOCs), and CO.

BC and Other Aerosols The main impact of aerosols on plant growth is through radiation. Black carbon absorbs sunlight in the atmosphere, cutting the total amount of solar radiation reaching the surface. Two studies have examined the historical impact of atmospheric BC on kharif rice yields in India but found no significant impact due to black carbon [Auffhammer et al., 2006; 2011]. This may be because they only considered monsoon crops (where ABC impacts would be lowest due to precipitation), and/or because they considered net surface radiation changes, as opposed to the impacts of BC versus scattering aerosols separately. More research is needed to understand and untangle the impacts of BC on crop yields through its various channels -- temperature, water availability, and radiation.

Ozone and its Precursors Elevated O_3 levels and increasing overall O_3 concentrations are now major concerns to crop producers worldwide. This is true as well for India, where urbanization, industrialization and expanding economy have led to increased emissions of O_3 precursors [Ghude et al., 2008, 2013] and tropospheric O_3 concentration [Ghude et al., 2009, Kulkarni et al., 2011, Lal et al., 2012]. Studies have projected that half of ozone-related crop yield loss in 2030 would be in India, absent adaptation [van Dingenen et al., 2009]. A recent study [Beig et al. 2013] made first estimates of the national risk to crop damage caused by surface O_3 pollution. This assessment indicates significant production losses for four major crops, cotton, soybean, rice and wheat due to ozone exposure.

Climate Mitigation It is amply clear that anthropogenic emissions of both greenhouse gases and aerosol particles are responsible for the climate change, with CO_2 being the largest contributor followed by BC particles (Ramanathan and Carmichael, 2008;Jacobson et al., 2010; Bond et al., 2013). Therefore, in order to slow down/reverse climate change one must reduce the emissions of CO_2, BC and other manmade greenhouses gases such as methane, nitrous oxide, HFCs and ozone precursor gases such as NOx, Volatile Organic Compound (VOC) s and CO. Here we discuss the possible mitigation strategies in the context of India, particularly for the emission from the transport sector.

Climate Change: CO_2 and BC Although both CO_2 and BC warm the atmosphere, they do it in different ways. While CO_2 absorbs outgoing long wave radiation, and adds heat energy to the atmosphere as well as the surface, BC absorbs the incoming solar radiation, which warms the atmosphere but leads to solar dimming at the surface. Because of short life time of BC (weeks or less), its radiative effect is concentrated close to the sources; whereas CO_2 is globally distributed and its effects are more globally uniform. It has also been recently shown that controlling BC may be a faster way of reducing Arctic ice loss and climate warming than other options including CO_2 reduction (Jacobson, 2010).

Considerations for BC Mitigation Based on Climate Forcing Radiative forcing (RF) is defined as the change in vertical irradiance at tropopause. Climate forcing ($W\ m^{-2}$) is the RF after rapid adjustment processes in the climate system caused by changes in clouds and snow cover are incorporated. The climate forcing from on- and off-road diesel is positive (with high confidence) leading to climate warming with largest contribution from heavy-duty trucks. The control of BC from on-road diesel engine thus offers an effective means of mitigating near-term climate change. In addition, sulfur content in on-road diesel source is low in developed countries and lowering elsewhere. Organics also form a lesser constituent of diesel PM compared to other BC sources. Therefore, control on diesel PM will reduce BC without affecting the emission of sulfate and organic carbon (OC) resulting in net cooling. Recently, this fact has been established in California (Ramanathan, 2013).

Mitigation in Indian Transportation Sector It is evident from the analysis that in the BAU scenario (where no further action is assumed till the year 2030), the emissions from transport sector are going to grow about three folds for PM2.5, and five folds for NOx. Black carbon emissions which are the subset of PM2.5 only can also be assumed to grow with similar rates.

India's transport sector contributes significantly to the air pollutant emission loads especially at the urban centres which accommodate dense population densities. With more than 100 kT BC emission per year from transport sector it is the fourth largest sector, next only to domestic, industries and Biofuels. Cities like Bangalore, Pune and Kanpur show significant contribution of transport sector in the emissions of $PM_{2.5}$. Within transportation sector, Heavy Duty Trucks are the largest PM2.5 and BC emitters. Heavy Duty Trucks are largest BC and $PM_{2.5}$ emitters in the transportation sector in the states such as Maharashtra and Gujarat as well as cities such as Delhi and Chennai. Transportation sector appears to be the largest emitter of NO_x and second largest for CO and NMVOC, both are the main O_3 precursors. While heavy duty vehicles have higher shares in the NOx emissions loads the gasoline driven private vehicles contribute to emissions of unburnt hydrocarbons.

Mitigation Strategies On-road diesel vehicles in general and Heavy Duty Trucks in particular should be targeted to reduce PM2.5 emissions in India to reduce health impacts at the local scales. The associated reduction in BC will have co-benefits in slowing down climate warming in short time scales. From the ozone precursor point of view, transportation sector should be targeted as the first priority considering its high shares in NOx, CO and VOCs.

The PM2.5/BC/NOx reductions in the heavy duty vehicle sector can be achieved through introduction of advanced emission norms with the use of high efficiency tail-pipe treatment devices like diesel particulate filters (DPF) and Selective catalytic reduction (SCR). This could be achieved through adoption of a road map which adopts BS-VI (Euro -6 equivalent) standards by the year 2020. However, this needs to be complemented with commission of an effective inspection and maintenance system, sustainable public transport systems, and measures to reduce energy demands from the sector.

Emission Scenarios

1. Background

India has followed a steep economic growth trajectory in the last two decades. The population has grown by a factor of 3.3 since 1950 and the index of production has grown by a factor of 50 during the same period. With growing industrial production bases, higher income levels and sprawling cities, mobility demands have also gone up many folds. The number of vehicles which were less than a million in 1950 have grown upto more than 140 million in 2011. Rapidly increasing high consumers of energy in the cities and electrified rural regions have led to tremendous increase in power demands. The power sector in India is coal dependant which is known to have high ash (30-45%) and somewhat lower sulphur (<1%))content and hence higher PM emissions. However, the widening demand-supply gap of energy has steered the growth of industry towards diesel based generator sets. In spite of this growth story, there exist the sectors which have not progressed with the same pace. More than 80% rural households in India are still dependant on biomass for cooking and on kerosene for lighting. In summary a variety of sources exist in India which contribute to deterioration of air quality in the cities and rural regions. High population densities, mobility demands, industrial activities have led to accumulation of high quantities of emission loads in cities. This also means that huge population base is exposed to severely high pollution levels present in Indian cities. Not surprisingly, 80% of Indian cities violate the standards for air quality (mainly for PM).

The energy use scenario in India is presented in Figure 1. Power plants and domestic sector have the largest proportions in the overall energy use in the country. Transport sector although shows lesser shares in the energy mix, but its presence in highly dense cities and its rapidly growing share points towards the attention it deserves.

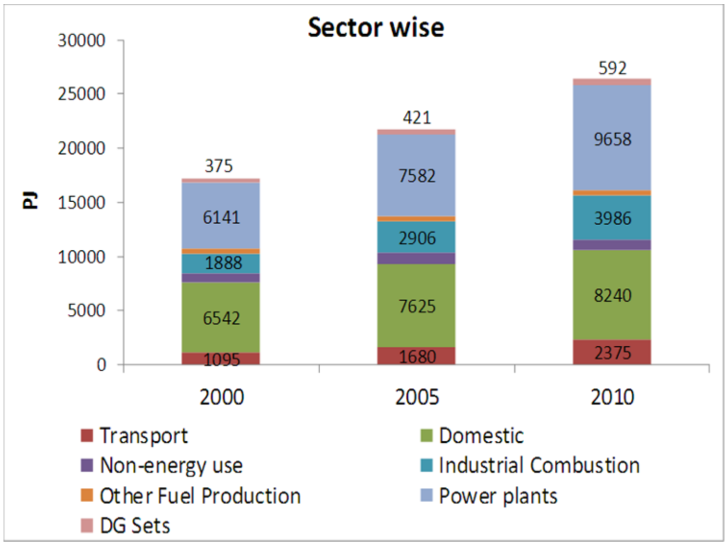


Figure - 1: Sectoral energy use (in Peta Joules (PJ)) scenario in India
Source: TERI, 2013

2. Transport sector in India

Transport sector in India has grown exponentially since independence. Growing per capita income levels, competitive auto-markets, lack of an effective public transport system all contributed to this demand of personal vehicles. Moreover, the growth of vehicles is eccentric towards the cities. Over one third of the total registered vehicles are in 53 cities which have a million plus population. The second tier cities are now showing even greater increase in the vehicle population. About 28000 two wheelers, and 4200 cars are added to India's vehicular fleet daily (2011). By 2011, India has already registered 141 million vehicles (Figure 2).

Despite a steep growth in vehicle sales in the last decade, India in comparison to the developed world still ranks very low in per capita vehicle availability. As per Census 2011, just 21% households have two wheelers whereas a meagre 4.7% have cars/jeeps/vans. India falls very low in per capita car ownerships and hence the growth potential is huge with the economic growth.

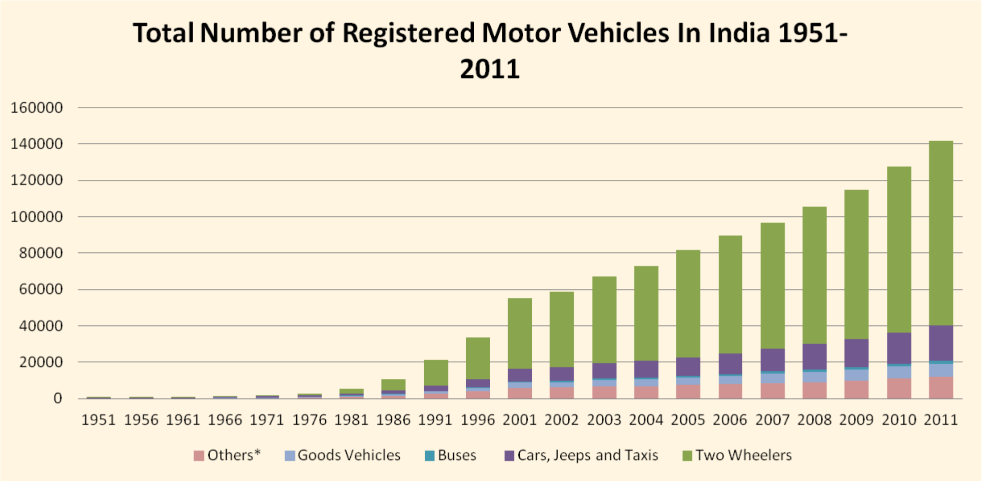


Figure - 2: Growth of vehicles in India (1951-2011)
Data source: MoRTH, 2011

3. Present contribution of transport sector in emissions and air quality

Contribution of transport sector in emissions and air pollutant concentrations has been significantly high at city levels. Although, the per capita vehicle ownership is less in rural regions but shift of older vehicles from cities to these areas, improper maintenance practices, and infrastructural constraints lead to higher emissions.

Emissions from transport sector mainly depends upon:

1. Estimates of on-road vehicles
2. Technological distribution of vehicles (Engine capacity, power, sizes)
3. Fuel-wise distribution of vehicles (Gasoline, Diesel, Gas)
4. Vintage of vehicles (compliance with emission norms)
5. I&M schedules and practices
6. Estimates of daily usage (km run) of vehicles
7. Emission factors

Fuel-wise distribution of vehicles is important as different pollutants are emitted in varying proportions while running vehicle on different fuels. Gasoline driven vehicles are known to emit unburnt hydrocarbons and carbon monoxide (CO) which is a product of incomplete combustion of gasoline. On the other hand, diesel driven vehicles emit more particulates and oxides of nitrogen due to high temperature combustion (Figure 3).

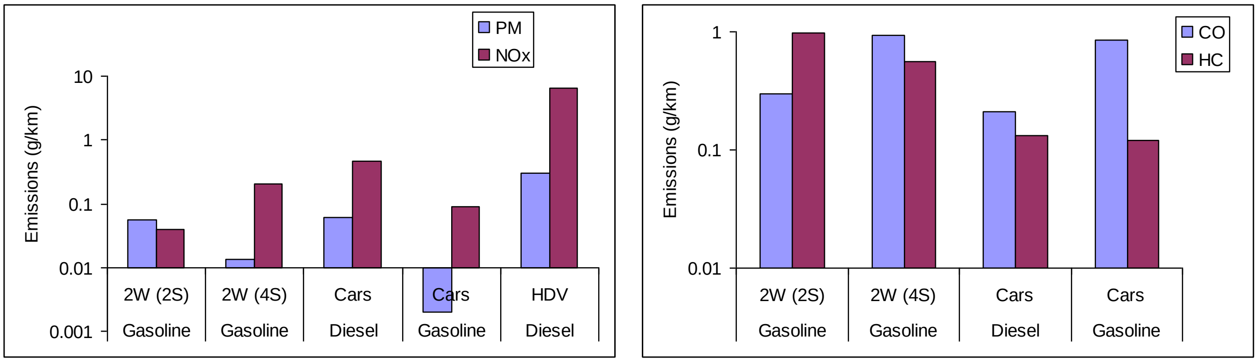


Figure - 3: Emissions (g/km) from different categories of vehicles running on different fuels.
Data Source: based on ARAI, 2010

Based on this, Table 1 summarises the possible pollutant emissions and their impacts on air quality, health and others.

Table - 1: Vehicle-wise major pollutant emissions and their secondary impacts on air quality

Type of vehicles	**Fuel**	**Major primary pollutants**	**Secondary pollutants**	**Possible major impacts**
Two-wheelers (2S)	Gasoline	CO, PM, HC	SOA	Respiratory and cardiovascular health, Agriculture, Climate
Two-wheelers (4S)	Gasoline	NOx, CO	Ozone	Respiratory health, Agriculture

Cars	Gasoline	CO, HC	SOA	Respiratory health
	Diesel	PM(BC), NOx	Nitrates, Ozone	Respiratory and cardiovascular health, Agriculture, Climate
HDV	Diesel	PM (BC), NOx	Nitrates, Ozone	Respiratory and cardiovascular health, Agriculture, Climate
	CNG	NOx, HC	Ozone, Nitrates, SOA	Respiratory health, Agriculture

This is to be noted that while gaseous pollutant impacts the respiratory health, particulates additional impacts the cardiovascular activities also. Moreover, the black carbon (a constituent of PM) emitted from diesel driven vehicles is now known to have second highest radiative forcing after carbon dioxide (CO2). In NOx sensitive conditions (for Ozone formation) as they prevail in India, NOx emitting vehicles play an important role in Ozone formation which is known to have considerable impact over human health.

Vintage of vehicles is an important aspect for estimating emissions. In 2002, the Auto Fuel Policy (MoPNG, 2002) recommended a road map for advancement of vehicular emission norms in India (Table 2). Bharat Stage (BS) norms were introduced in India.

Table – 2: Road map for introduction of vehicular emission norms in India

Coverage	Passenger Cars, light commercial vehicles, and heavy duty diesel vehicles	2/3 wheelers
Entire country	Bharat Stage (BS) II – 1.4.2005	Bharat Stage-II- 1.4.2005
	Euro III equivalent – 1.4.2010	Bharat Stage III -
11 major cities (Delhi/NCR, Mumbai, Kolkata, Chennai,	Bharat Stage II – 1.4.2003 Euro III equivalent – 1.4.2005	Preferably from 1.4.2008 but not later than 1.4.2010

Bangalore, Hyderabad, Ahmedabad, Pune, Surat, Kanpur & Agra)	Euro IV equivalent – 1.4.2010

(Source: Based on MoPNG, 2002)

Figure 4 shows the emissions norms which were made more stringent as per the road map suggested by MoPNG, 2002. This depicts that the newer vehicles are emitting much less than those which were registered pre 2000 in India.

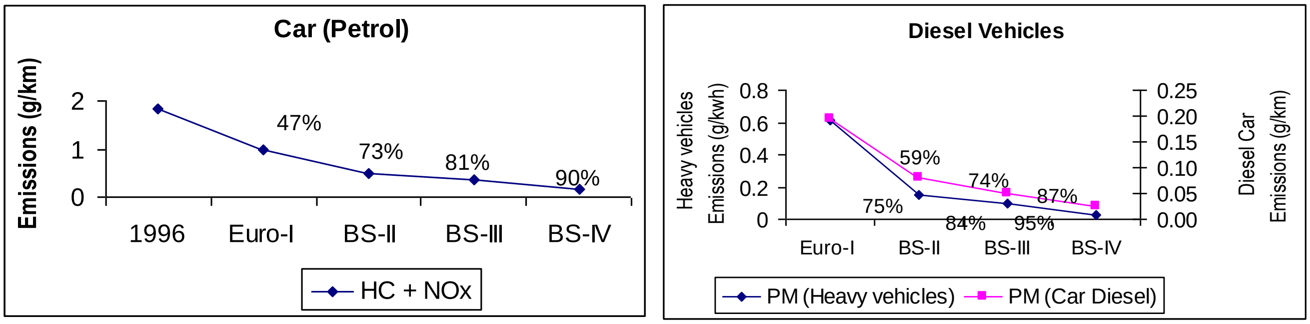


Figure – 4: Emission norms of different vehicles as per the suggested roadmap in India

The road map was more or less successfully implemented with differentiation between some hotspot regions and the rest of the country; currently Bharat Stage (BS) IV for 13 cities and BS III for the rest of the nation. Since 2010, at least seven more cities have been added to Bharat IV fuel standards. Emission estimates from the sector needs to take these developments into account.

3.1 Emission estimates: share of transport sector

National level estimates of different pollutant emissions from transport sector have been presented by many research studies. Trends of emissions of different air pollutants during 1990 to 2010 and thereafter projections till 2030 are presented in IIASA, 2010 (Figure 5). This can be concluded that domestic sector eclipses the contribution of other major sectors towards PM2.5 emissions. However, this is to be noted that majority of these domestic emissions happen in rural regions while transport sector contributes much more in cities.

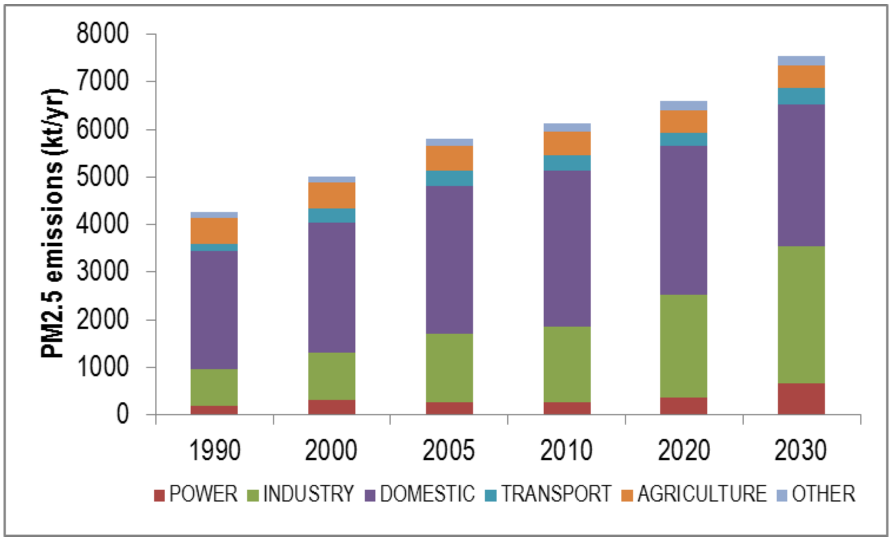


Figure - 5: Estimates of sectoral PM2.5 emissions in India during 1990 to 2030
Data source: IIASA, 2010

This was instated by the conclusions of the source apportionment studies carried out in 6 cities of India.

Figure 6a/b shows the share of sectors in prevailing PM10 and PM2.5 concentrations in three major cities. While, road and soil dust has been the dominant contributor in PM10 concentrations, the transport sector is the major contributor to PM2.5 fractions. PM2.5 emissions from transport can have deeper penetration into the lungs and hence a larger health impact.

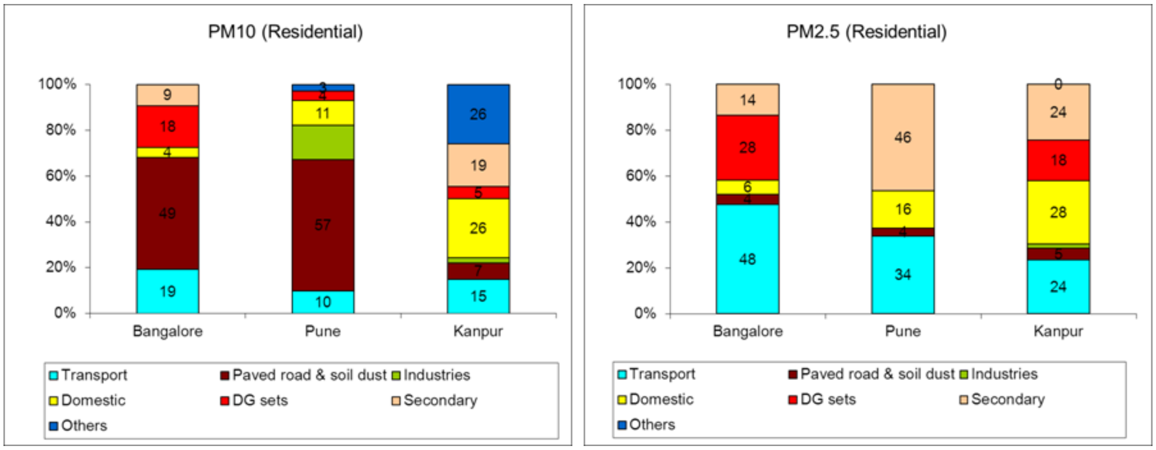
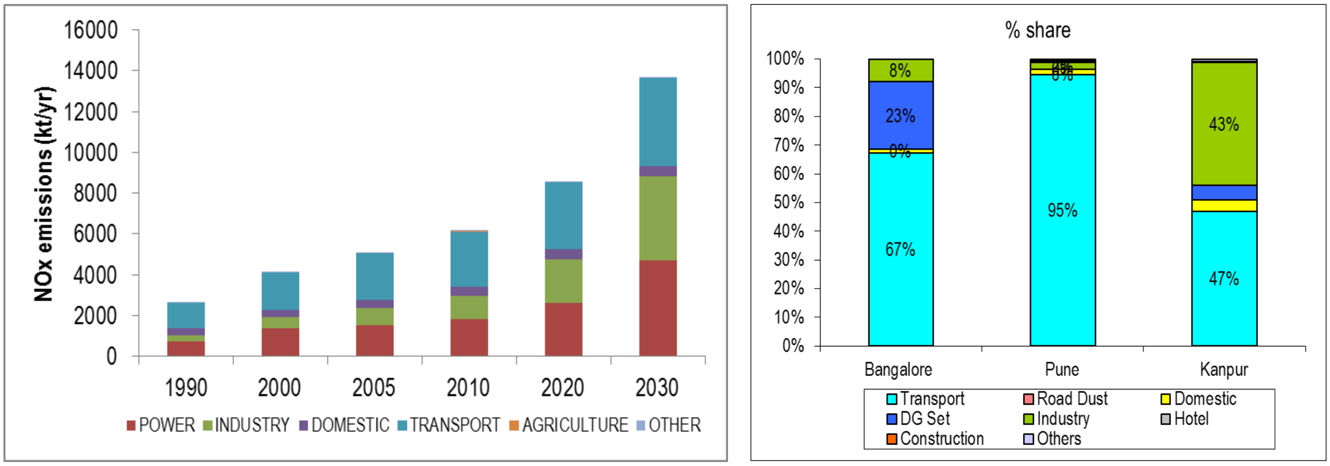


Figure - 6a,b: Results of source apportionment studies for PM_{10} (a) and $PM_{2.5}$ (b) in Indian cities
Data source: CPCB, 2011

On the other hand, in NOx emissions (caused due to high temperature combustion) , transport sector has a dominant share at both National and Urban scales (Figure 7). The share of transport is about 44% at the National scale in 2010 and dominant across different cities except in Delhi where contributions were higher from power plants.



National

Urban

Figure - 7: Sectoral shares in NOx emissions at National and urban scales in India
Source: IIASA, 2010, CPCB, 2011

NOx not only has its own health impacts but also contributes to secondary particulate formation (as nitrates), acid raid (as Nitric acid), and formation of ground level Ozone. TERI (2013) showed very high sensitivities of NOx towards Ozone formation in Indian conditions. Sensitivity of Ozone concentration with reduction of NOx emissions has been tested by TERI, 2013. Figure 8 shows the possible percentage reductions in Ozone concentrations due to 40% reductions in NOx and NMVOC emissions in India. The reductions are to the tune of 15% in the agriculture dependent Indo-Gangetic plains in India. It is to be noted that Ozone concentrations may initially increase in the urban centres due to reduction of primary NO emissions (due to titrating chemistry). However, in the longer run, reductions of NOx along with VOCs will mitigate Ozone at both regional and urban scales.

TERI, 2013 estimated the NMVOC emissions in India and the contribution of transport sector is 12% in 2010 (9% tail-pipe and 3 % evaporative). The projections for the year 2030 suggest further increase of share to 28% (9% tail-pipe and 19% evaporative) (Figure 9). While tail-pipe emissions will be somewhat controlled by introduction of BS-III/IV vehicles in the business as usual scenario, evaporative emissions will continue to grow at the same pace.

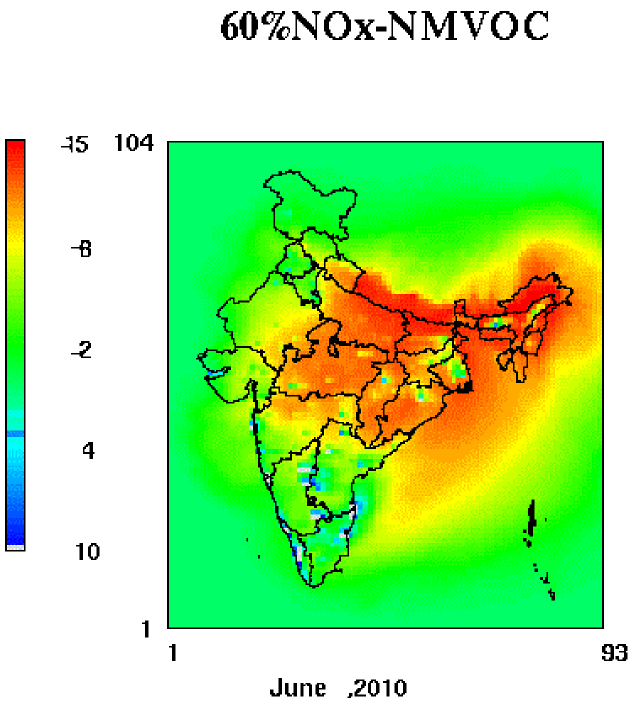


Figure – 8: Percentage change in Ozone concentrations across the Indian subdomain due to 40% reduction in NOx and NMVOC emissions in 2030 ***Source: TERI, 2013***

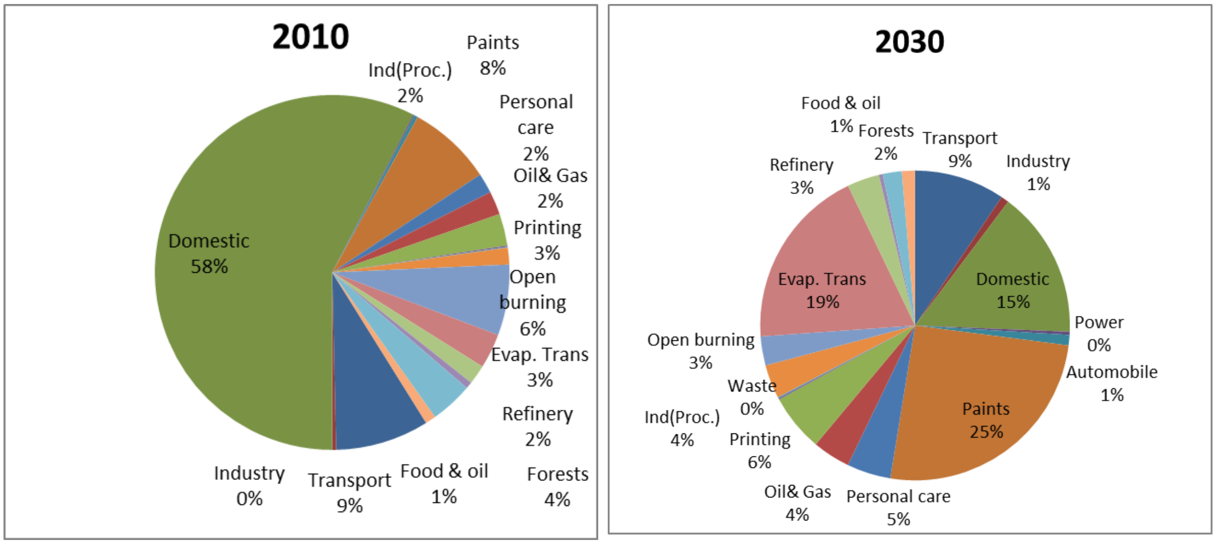


Figure – 9: Sectoral shares of NMVOC emissions in India (2010 and 2030)
Source: TERI, 2013

3.2 Black carbon emissions

In past, emission inventories of black carbon have been developed and presented for India by many research studies (Sahu et al, 2008 , Bond et al, 2004, Reddy and Venkataraman (2002), Streets et al. (2003), Streets et al. 2004, Venkataraman et al. (2005), IIASA, 2010). Table 3 shows the various estimates of BC emissions and the share of transport sector in India.

Table – 3: Emission estimates of BC in India and share of transport sector

Study	**Total BC emissions (All sectors)**	**Transport sector**
Sahu et al, 2008	1.34 Tg and 0.84 Tg for 2001 and 1991	34% and 26% in 2001 and 1991 respectively
Reddy and Venkataraman (2002),	0.35 Tg in 1996-97	16.5% from diesel vehicles
GAINS (Sloss, 2012)	1.10 Tg in 2010	7%
Lu et al, 2011	1.01 Tg in 2010	10%

Although, emission inventory approach showed limited contribution of fossil fuel (transport sector) in the BC emissions, measurement based radio-carbon analysis shows much higher contributions (about 54%) from fossil fuels (Gustaffson et al., 2009). INDOEX experiments over the Indian Ocean also pointed towards higher contributions of fossil fuels in the BC concentrations. The measurements and underestimations of models have depicted the gap in emissions from sectors like transport. Under estimation of emissions from transport sector in the region could be attributed to

a) Indian driving cycles on which emission factors are developed do not account for varying real-world driving conditions (Sharma et al 2013) e.g. congestion, high accelerations which lead to higher on-road emissions despite compliance with emissions norms.
b) Emission factors are developed on limited set of vehicles which may not include high emitters
c) Over-loading of vehicles lead to increased emissions
d) Inaccurate information on on-road vehicles as very old vehicles still ply on the roads without re-registrations after 15 years

It can be summarised that various estimates suggest that at the National scale transport sector has contributed to 7-34% in overall BC emissions across different years. However, the contributions may increase when we move to urban centres, e.g. in Bangalore, the contributions are as high as 56% from the transport sector. As the growth of transport sector is relatively more in the cities, the contributions are found to be higher there. Moreover, the fact that cities are densely populated the overall exposure to these concentrations could be much more than in rural regions. With growing number of cities, and exponential growth of vehicles, the BC emissions are bound to grow in future. Also, other than PM, gaseous pollutants like NOx are dominantly emitted from transport sector both at National and urban scales.”

3.3 Vehicle-wise contribution in emissions from transports sector

The vehicle wise distribution of emissions of different pollutants in India for the year 2010 is presented in Figure 10.

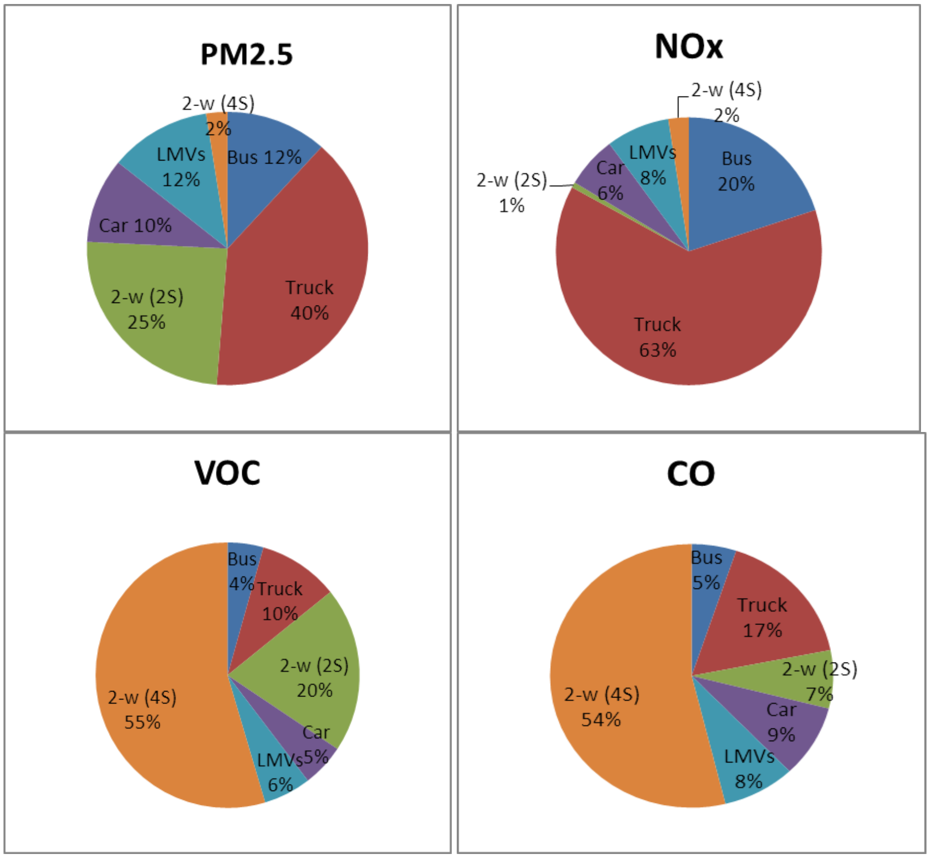


Figure - 10: Vehicle wise distribution of emissions of different pollutants in India for the year 2010

It is quite evident that heavy duty vehicles have major shares of 52% and 83% in PM2.5 and NOx emissions from transport in India. However, combustion of gasoline in vehicles leads to higher emissions of CO and HC.

4. Transport sector emission projection scenarios

Transport sector energy projections for the year 2030 have been made using the TERI-MARKAL model. The emissions for the year 2010 (based on current fleet) and 2030 (based on projections) were estimated using the GAINS Asia framework. The model was then used to assess the emission reduction potential of different strategies listed in Table 4.

Table – 4: Description of scenarios evaluated for possible emission reduction in the transport sector in 2030

Area	**Scenario**	**Description**
	BAU	Based on the current plans and policies of the government without any further intervention. BS-III all across the country and BS-IV in 13 cities
Fuel and vehicle tech	ALT-I	Introduction of BS-IV all across the country by 2015
	ALT-II	Introduction of BS-IV all across the country by 2020
	ALT-III	Introduction of BS-IV all across the country by 2015 and BS-V in 2020
	ALT-IV	Introduction of BS-IV all across the country by 2015 and BS-VI in 2020
Alternate fuel	CNG	Converting 70% buses, cars, and 3-wheelers to CNG
In-use vehicle management	RETRO	Retro-Fitment of 50% of existing BS-III/IV truck/lmv/bus with DPF wigth 90% efficiency
	FM	Fleet modernisation of 50% existing vehicle to BS-VI vehicles
	I&M	Implementation of existing I&M system

Public transportation	PTS	Shifting 50% PKM demand from Cars to bus
	MRTS	Shifting 10% PKM demand Bus and 10% from cars to Metro rail
Reduced mobility demand	RMD	Reduce travel demand by 20% (through different mechanism)

Emission reductions that can be achieved through adoption of different strategies is estimated and presented in Table 5.

Table – 5: Emission reductions (kt/yr) that can be achieved through adoption of different strategies

	NOX		**PM2.5**		**CO**		**VOC**	
BAU2030	9987		297		6963		931	
ALT-I	7553	-24%	170	-43%	6058	-13%	877	-6%
ALT-II	8367	-16%	209	-30%	6409	-8%	905	-3%
ALT-III	6483	-35%	156	-48%	5868	-16%	798	-14%
ALT-IV	5260	-47%	134	-55%	5616	-19%	591	-37%
CNG	8396	-16%	240	-19%	5918	-15%	896	-4%
RETRO	9987	0%	206	-31%	6963	0%	931	0%
FM	5493	-45%	158	-47%	6422	-8%	679	-27%
I&M	7558	-24%	228	-23%	5622	-19%	775	-17%
PTS	9799	-2%	283	-5%	6746	-3%	941	1%
RMD	9506	-5%	280	-6%	6319	-9%	836	-10%
MRTS	9784	-2%	291	-2%	6808	-2%	913	-2%

% Red is reduction achieved in the scenario wrt BAU

It is evident from the analysis that in the BAU scenario (where no further action is assumed till the year 2030), the emissions from transport sector are going to grow about three folds for PM2.5, and five folds for NOx. Black carbon emissions which are the subset of PM2.5 only can also be assumed to grow with similar rates. This also means that air quality concentration levels in the present context are going to worsen in future and could show with much more health impacts. Higher Ozone formation due to increase NOx emissions may also severely impact the agricultural productivities.

The alternative paths shown in Table depict reductions in different proportions. Highest PM2.5 reductions can be achieved through strategies of introduction of diesel particulate filters (DPF) for controlling emissions from heavy duty sector. This could be achieved through adoption of a road map which adopts BS-VI (Euro -6 equivalent) standards by the year 2020 (ALT-IV). Adoption of BS-V standards (ALT-III) may reap reductions of 48%. A fleet modernisation program (50% vehicles replaced with newer BS-VI vehicles) could be a difficult option to implement but could theoretically reap reductions of 47% in PM2.5 emissions from the sector. Implementing BS-IV norms (ALT-I) by 2015 and an effective I&M program both individually could reduce the PM emissions by about 25% in 2030.

5. Key findings and recommendations

Analysis of emissions at National scale shows that in order to reduce emissions from transport sector in the next two decades in India, we must start with making provisions for supply of BS-IV quality fuels (50 ppm sulphur) all cross the country latest by 2015. This is also in-line with the ideology of 'One country, one fuel and one standard' in India. However, for the optimal functioning of the most advanced emission control devices like DPFs (diesel particulate filters), supply of BS-V fuel (sulphur content below 10 ppm) nationwide will be necessary. Hence, while the reach of BS-IV fuels should be expanded to the whole country, the refineries should be upgraded to supply BS-V fuels by 2017. Advanced vehicle emission standards should accompany improvements in fuel quality. Eventually, with introduction of 10 ppm sulphur fuels, India should plan to move to BS-VI standards by the end of this decade. For two-wheelers, a strict adherence to the Euro-IV and Euro-V levels should be observed, while developing the road map and the norms for HC and NOx should be separately adopted for better control of both the pollutants.

Additionally, improvements in the inspection and maintenance systems should go hand in hand for continued improved performance of vehicles in real world conditions. A move towards world harmonized driving procedures'' will also help in improving real world compliance of emission norms. The existing fleet of old high emitting vehicles can then be renewed with cleaner BS-VI vehicles with proper financial mechanisms in place.

Other than emission control measures, important steps need to be taken to reduce energy demand from the sector. These include introducing fuel efficiency standards, enhancing public transport and non-motorized transport, and implementing strategies to reduce vehicular growth and usage.

A summary of recommendations is provided below:

- Implementation of BS-IV fuel quality and vehicle emission standards by 2015 across the country
- Adoption of BS-V fuels and vehicular emission standards by 2017
- Adoption of BS-VI vehicular emission standards by 2019
- Commissioning of an effective I&M system across country to replace or enhance the current PUC system
- Move towards world harmonized driving cycles
- Development of a fleet modernization programme
- Measures for reducing energy demand from the sector

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Monitoring

Introduction

Delhi National Capital region (NCR) is one of the severely polluted regions of the world. In addition to anthropogenic sources (transport sector being the most dominant), natural aerosols are also transported to the region every year during the pre-monsoon to monsoon seasons leading to degradation of air quality. A major air quality mitigation step was taken in the year 2001 when the public transport sector was converted from diesel/petrol to CNG. Despite all the efforts, air quality remains poor in this region. Recently Ramanathan (2013) has shown drastic reduction in Black Carbon (BC) concentration across California due to technological interventions and policy measures introduced during previous decades. Building on the experiences learnt from California, a joint initiative-India California Air Pollution Mitigation Program (ICAMP)- has been taken by University of California San Diego, The Energy Research Institute and California Air Resource Board involving various stakeholders such as Government, Academic and Non Profit institutions from India and US and World bank for mitigating air pollution in India, particularly from the transportation sector. Here we propose a framework for establishing a monitoring network to evaluate the changes in vehicular emission and ambient air quality in a city in response to mitigation measures. We consider the city of Delhi as an example.

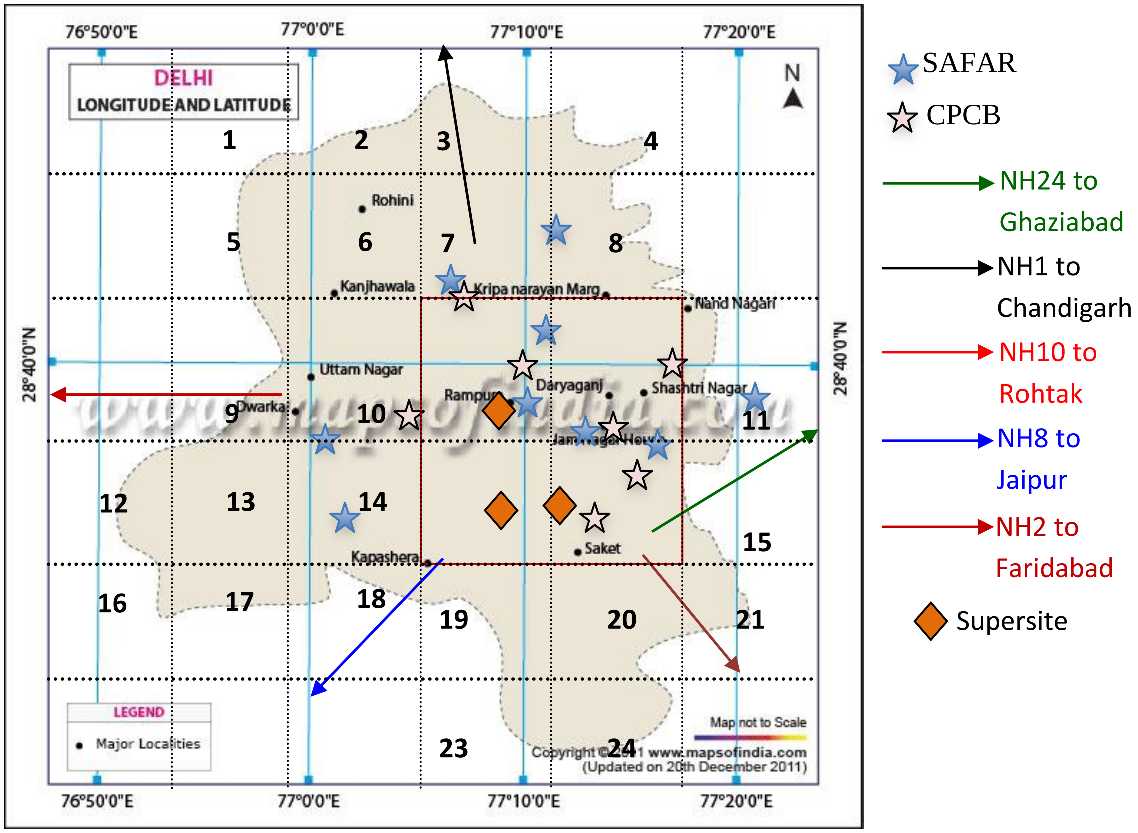

Figure 1: Map of Delhi National Capital Region (NCR) and the proposed observations overlain with existing air quality measurements networks (some well-known places are marked for reference).

Proposed Monitoring Network We propose to develop a network to monitor PM2.5, Ozone (O3) and black carbon (BC) to cover the Delhi city as well as other nearby polluted (e.g. Noida, Gurgaon and Faridabad) and relatively clean areas. The network will leverage existing networks, supplement existing sites, or create new sites where needed.

Existing Networks Two networks, one maintained by Central Pollution Control Board (CPCB) and the other maintained by Indian Institute of Tropical Meteorology, Pune (System of Air Quality Weather Forecasting and Research, SAFAR network) are in operation (Fig. 1) in the Delhi NCR. Some criteria pollutants are being measured on a regular basis. For example, NO2, CO, O3, PM2.5 and PM10 are monitored in the SAFAR network, while SO2, NO2 and PM10 are measured in the CPCB network. CPCB and SAFAR data (quality control may be an issue) are freely available from their website.

Plan Five major National Highways connect Delhi metropolitan area to other states - NH1 to Gurgaon and Jaipur, NH2 to Faridabad and Agra, NH24 to Ghaziabad, NH1 to Chandigarh and NH10 to Rohtak.

Entire NCR may be divided into 10 km by 10 km area (as shown by grid nos. in the figure). A total of 24 sites is proposed to measure BC, O3, CO and PM2.5. The central part of Delhi (shown by red box) should have more concentrated measurements - at 12 sites. These sites will be made operational at Institutions within that zone (Research institutes, schools or colleges).

Five additional sites will be chosen (Grid 9, Grid 3, Grid 15, Grid 21 and Grid 18 or 19) to monitor vehicular emission, as these are the major entry points for the heavy-duty vehicles. Highly time resolved (e.g., 1 Hz) measurements of CO2, BC, and NOx concentrations would be ideal at these locations to enable quantification of emission factors for the heavy-duty vehicles that pass the sampling locations. Using a carbon balance method, the measured CO2 is related to the amount of fuel burned to compute fuel-normalized emission factors: g pollutant emitted per kg fuel burned. If an increase in diesel particle filter use is likely during the study, the additional measurement of NO or NO2 would be of interest because these filters have been shown to increase NO2 emissions and the NO2/NOx emission ratio. Additional information about the passing heavy-duty trucks, such as engine model year and installed emission control equipment (e.g., if the truck was retrofitted with a diesel particle filter), would add value to the study. Site selection should aim to place the point of air sampling as close as possible to the exhaust of the trucks. A mobile sampling platform, such as a van outfitted with the air pollution monitors, has proven useful in past studies of vehicular emissions.

Three supersites are proposed (shown as diamond in the figure) at IIT Delhi, TERI and IITM-Delhi campus.

Total proposed sites = 24 (to maximize the coverage of Delhi NCR) + 12 (within the core zone) + 5 (outlet points) = 41

Cell Phone Monitoring Network for Black Carbon Monitoring For all 41 sites, a cell phone monitoring network will be set up at each site in order to collect immediate measurements of black carbon from filters [Ramanathan et al, 2011]. Each 24-hour filter sample can be photographed with a cellphone camera, and submitted by email to a server, which will automatically analyze the filter image for black carbon loading, store the result in a centralized database, and make the data available via a website. Since the cell phone soot monitors cost only about $500 each, it is possible to have about 200 sensors in each major city to collect unprecedented data to examine the health impacts of black carbon and PM.

Instrumentation In all the proposed sites, the following instruments will be used:

1. Aethalometer (AE 42) – to measure BC at 5 min interval
2. Gas-analyzer – to measure O3 and CO at 1 min interval
3. EBAM PM sampler – to measure PM2.5 at 15 min interval
4. UPS will be required at each site as back up in case of power failure

The proposed three supersites will have the additional instruments:

a. Bulk filter sampler – to collect 8 hourly samples on filter for the 24-hour duration every third day. The samples will be utilized for chemical measurements.
b. EC-OC analyser – to measure OC
c. Seven-wavelength Aethalometer - to measure the absorption spectra

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Health Impact of Air Pollution

Health Effects of Emissions Air pollution has remained a major health concern in India. Fumes from vehicular exhausts constitute particulate matter (including black carbon) and gaseous pollutants like CO, HC, SO_2, and NOx. Each of them is associated with a variety of health effects, which are summarized in Table 1.

Table 1. Health effects of different pollutants

Pollutants	Effects
Nitrogen dioxide (NOx)	Bronchitis in asthmatic children. Reduced lung function growth
Particulate Matter ($PM_{2.5}$, PM_{10})	Cardiovascular and respiratory diseases, lung cancer, ALRI, COPD.
Carbon monoxide (CO)	Reduces the oxygen carrying capacity of blood, causes headaches, nausea, and dizziness. Can lead to death at high levels
Sulfur dioxide (SO_2)	Affects respiratory system and lung function. Coughing, mucus secretion, asthma and chronic bronchitis. Causes acid rain.
Lead	Affects intellectual development of children, and at very high doses poisoning, brain and organ damage can occur.
Benzene	Exposure over a long time can lead to cancer
1, 3 Butadiene	Exposure over a long time can lead to cancer.
Ozone	Breathing problems, asthma, reduce lung function. Ozone is one of the most damaging pollutants for plants.

Air pollution causes cardiovascular and respiratory diseases, damages crop quality, reduces the biodiversity of plants, and contributes to global warming (UNECE, 2012). The decisive factor for the quality of life and health, however, is not primarily the total emissions of air pollutants but their concentration in urban areas.. It is likely that within any large human population, there is such a wide range in susceptibility that some subjects are at risk even at the lowest end of the concentration range. The elderly and people suffering from cardio-respiratory problems such as asthma appear to be the most susceptible groups. Children and newborns are also sensitive to the health effects of air pollution since they take in more air than adults for their body weight and consequently, a higher level of pollutants. An important point in this context is that socio-economic conditions play an important role in health effects of air pollution. People who are poor and less educated are more vulnerable to illness and death from air pollution exposures (Pope et al., 2002).

Literature survey reveals that long-term (chronic) exposure to high concentrations of particulate matter (PMs) in the air may cause a wide spectrum of adverse health effects, ranging from reduced lung function and development of chronic respiratory disease (Naeher et al. 2007), severe pulmonary inflammation and hemorrhage, high degree of alveolar and interstitial edema, disruption of epithelial and endothelial cell layers, cardiopulmonary problems (Brunekreef and Forsberg 2005; Mar et al. 2005; Harrabi et al. 2006; Naeher et al. 2007), cardiovascular diseases (CVD; Anand 2000; Sugathan et al. 2008), cancer (Vinzents et al. 2005), to death (Peters et al. 1997; Oberdörster 2000). This exposure has been found to be associated with increase in hospital admissions for cardiovascular and respiratory disease and mortality in many countries (Samet et al. 2000; Dockery 2009) including India (Kumar et al. 2010; Balakrishnan et al. 2011; Rajarathnam et al. 2011). It may also lead to a marked reduction in life expectancy. Each 10 µg/m3 elevation in fine particulate matter has been associated with approximately a 4%, 6%, and 8% increased risk of all-cause, cardiopulmonary, and lung cancer mortality, respectively (Pope et al., 2002; Vineis and Husgafvel- Pursiainen, 2005; Vineis et al., 2006; Gallus et al., 2008). Lung can be injured directly by air pollutants as it is the primary route of entry. Reduction of lung function has been linked to vehicular pollution (Ingle et al., 2005) and ambient ozone (Walker, 1985; Tager et al., 2005). Urban air pollution is known to trigger asthma (Behera et al., 2001; Mishra, 2004; Halonen et al., 2008) and has also been associated with chronic obstructive pulmonary disease (COPD), which is projected as the third leading cause of total mortality and the fifth leading cause of disability by 2020 (Murray et al., 2004; Mannino et al., 2006).

Cardiovascular diseases:

Chronic exposure to air pollution is an established risk factor for morbidity and mortality from CVD (Brook et al., 2004; Miller et al., 2007). Traffic-related Particulate Matter (PM) is a risk for CVD (Peters et al., 2004) and even death from the disease (Hoek et al., 2002). Epidemiological studies have shown that chronic exposure to moderately elevated levels of particulate air pollution enhances the risk of hypertension and systemic atherosclerosis (Brook, 2007). Even short-term exposure to PM2.5 over a few hours can trigger myocardial infarctions, cardiac ischemia, arrhythmias, heart failure, stroke, exacerbation of peripheral arterial disease, and sudden death (Brook, 2007). For every 10 µg/m3 increase in PM2.5 in ambient air, the risk of a cardiovascular event increases by 24% and death from CVD by 76% (Miller et al., 2007). Smaller particles (PM2.5 and UFPs), due to their higher surface area and reactivity (Mills et al., 2005; Schlesinger et al., 2006; Tornqvist et al., 2007), were found to be more potent than larger particles. Recent studies from India have reported that residents of Delhi (Banerjee et al. 2012) and Kolkata (Dutta and Ray, 2012) are at increased cardiovascular risk from exposure to ambient air pollution. PM exposure can increase the risk of CVD by a multitude of mechanisms that include increased production of C-reactive protein (CRP), blood coagulation proteins, (Barregard et al., 2006; Rückerl et al., 2006), and fibrinogen (Schwartz, 2001; Ghio et al., 2003) , increased plasma viscosity (Peters et al., 1997), increased neutrophil and platelet numbers (Salvi et al., 1999, 2000), over-expression of adhesion molecules on leukocyte or in plasma (Rückerl et al., 2006; O'Neill et al., 2007), and oxidation of proteins and lipids in plasma (Sørensen et al., 2003; Barregard et al., 2006).

Reproductive system:

The female reproductive cycle is a sensitive hormone-synchronized process controlling fertility and related reproductive outcomes. Vehicle-related emissions are associated with dysmenorrhea in pre-menopausal women (Mavalankar et al., 1991; Mishra et al., 2004), and increased risk of various adverse pregnancy outcomes like selected cardiac defects and oral cleft formation in the growing fetus and early childhood defects (Kristensen et al., 1997; Farr et al., 2004; Mishra et al., 2005), significant increase in the risk of first tri-semester miscarriages, stillbirths, reduced birth-weight of infants (Liu et al., 2003, 2004; Salam et al., 2005; Sram et al., 2005; Wilhelm and Ritz, 2005; Bell et al., 2007; Ritz et al., 2007; Siddiqui et al., 2008; Windham and Fenster, 2008; Hansen et al., 2009; Woodruff et al., 2010; Yildiz et al., 2010), preterm births, intrauterine fetal growth retardation and decreased fetal head circumference in pregnant women (Bean et al., 1979; Cooper et al., 1996; Lipfert et al., 2000; Arbuckle et al., 2001; Ozbay et al., 2001; Boy et al., 2002; Gilboa et al., 2005; Lacasana et al., 2005).

Cancer:

Particulate matter, especially traffic-related airborne particles, contains a large number of genotoxic/ mutagenic chemical substances which are capable of causing DNA damage and promoting carcinogenesis (Cooper, 1980; Alfheim et al., 1983; Zhang and Smith, 1996). Vehicle emissions are associated with the development of cancer, particularly lung cancer (Vineis et al., 2006; Parent et al., 2007). Early life exposure to traffic emissions may be associated with breast cancer in women; higher exposure to traffic-related emissions at menarche was associated with pre-menopausal breast cancer while emissions exposure at the time of a woman's first childbirth was associated with postmenopausal breast cancer (Nie et al., 2007). A study in

Finland among individuals occupationally exposed to diesel and gasoline exhausts showed an association between ovarian cancer and diesel exhaust (Guo et al., 2004).

Air Pollution and the Burden of Disease:

According to the most recently published 2010 Global Burden of Disease (GBD 2010), published in The Lancet in December 2012, outdoor air pollution in the form of fine particles is a much more significant public health risk than previously known − contributing annually to over 3.2 million premature deaths worldwide and over 74 million years of healthy life lost. It now ranks among the top global health risk burdens. In Asian countries, overall GBD 2010 estimates over 2.1 million premature deaths and 52 million years of healthy life lost in 2010 due to ambient fine particle air pollution, and this represents fully 2/3 of the burden worldwide. Among other risk factors studied in the GBD, outdoor air pollution ranked 4th in mortality and health burden in East Asia (China and North Korea) where it contributed to 1.2 million deaths in 2010, and 6th in South Asia (including India, Pakistan, Bangladesh and Sri Lanka) where it contributed to 712,000 deaths in 2010. The GBD quantified health losses from a wide array of diseases and injuries. These losses are expressed in units of disability-adjusted life-years (DALYs: YLLs + YLDs), which account for both premature mortality - measured as years of life lost (YLLs: number of deaths at age ‘x’ multiplied by the standard life expectancy at age ‘x’), and time spent in states of reduced health - measured as years lived with disability (YLDs).

GBD 2010 analysis showed that the large burden of disease is attributable to particulate matter pollution in ambient environments. The magnitude of disease burden from particulate matter is substantially higher than estimated in previous comparative risk assessment analyses. Previously, ambient particulate matter pollution was estimated to account for 0.4% of DALYs in 2000 compared with 3.1% in GBD 2010. The self-proclaimed limitation of this report though, is that it does not address how the different sources of particulate matter in terms of effects. The report emphasizes the need to implement more stringent regulation of vehicle and industrial emissions, reduce agricultural burning or land clearing by fire, and curb and reverse deforestation and desertification to reduce ambient particulate matter from dust.

A comparative analysis of the top 20 mortality risk factors from GBD 2010 shows that ambient particulate matter pollution ranks 8th in US and 5th in India (Fig. 1 and Fig. 2). Nearly 103,027 deaths in US and 627.426 deaths in India have been attributed to ambient particulate matter pollution in 2010, a 6-fold difference (Fig. 3). COPD and ARI account for 24% of the mortalities due to ambient air pollution in India, but it is just 7.5% in US, which less than 1/3 that of India. . All cohort studies of $PM_{2.5}$ and mortality from chronic disease have been conducted in the US and Western Europe and new models are therefore needed to estimate exposure-response functions at high levels of PM in Asia and other regions. The International Agency for Research on Cancer, a specialized cancer agency of the World Health Organization has recently classified ambient air pollution as being carcinogenic (Group I) to human. PM, which is a major component of outdoor air pollution had been evaluated separately and has also been classified ambient air pollution as being carcinogenic (Group I) to human.

Size of Air Pollutants:

One of the important determining factors of harm from particles is the aerodynamic size and the translocation in airways. Figure 4 gives the site of deposition of the particles (Brown et al., 2013). The distribution disposition of the particles is very much dependent on aerodynamic diameter of the particles. The inhaled particles are deposited in the airways and lungs and clearance is related to concentrations, characteristics of air contaminants and the toxic doses. In the case of particles which are soluble in the respiratory tract fluid, a systematic absorption may be almost complete and there could also be local toxic or irritant affects in the respiratory tract. On the other hand, the particles which are slowly deposited in the airways, are moved up to muco-ciliary ladder. Eventually these particles reach the pharynx from where they are swallowed or spit out. In case of particles which are deposited in non-ciliated region, which have a large surface-to-volume ratio, the clearance occurs by the process of dissolution for materials that are generally insoluble. The particles may also be cleared as free particles either by the process of phagocytosis when alveolar macrophages engulf the particles or by the process of passive transport along surface liquids. When the particles pierce the epithelium or are engulfed in macrophages, these may be sequestered within cells or may enter the lymphatic region and transferred to pleural, and more distant lymph nodes.

The small size of $PM_{2.5}$ and $PM_{0.1}$ allow them to be inhaled deeply into the airways and the lungs. A fraction of these particles is deposited in alveoli, that are the gas exchanging region of the lungs, and another part enters the pulmonary circulation and presumably the systemic circulation. The main pathway by which PM contributes to increased cardiac risk is by initiating and promoting atherosclerotic progression, the underlying cause of most cardiovascular diseases. Atherosclerotic lesions can lead to ischemia of the heart, brain, or extremities. Air pollution may induce atherosclerosis in the peripheral arteries, coronary arteries, and aorta. The changes that occur following exposure to air pollution are depicted in figure 5.

Conclusion:

Air pollution is a major cause of mortality and morbidity in India. The sources of pollution are diverse but diesel fuel is one of the important contributors to air pollution in urban areas in India. It has been shown through numerous studies that air pollution is directly related to respiratory, cardiovascular diseases and cancer. However, these studies are mostly from the more developed countries with limited levels of air pollution. There is limited understanding of the health impact from high concentrations of air pollution such as that in India. The Global Burden of Diseases does demonstrate a several folds higher mortality and morbidity in India compared to the US. These studies are based on estimates from models developed from data collected from the more developed countries such as the US. There is a need to demonstrate the impact on health that is specific to the Indian population. The size of the air pollution particles have an important impact on health; the smaller the size of the particulate the higher the health damage. The improvement of measurements of such exposures and PM in India will help document the level of health impact that is specific to the Indian population.

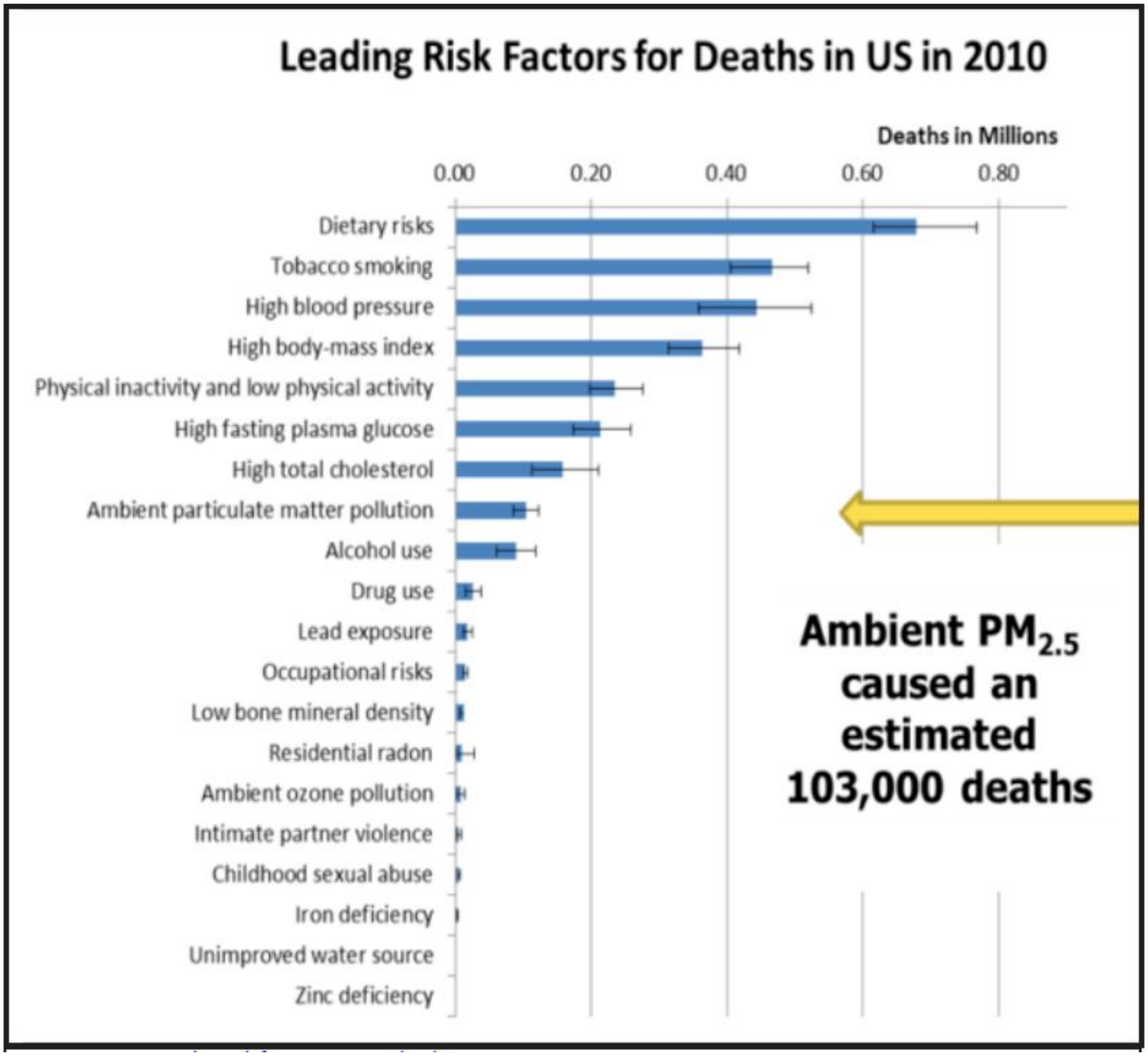


Fig. 1: Top 20 mortality risk factors in US and India Sources: GBD, 2010

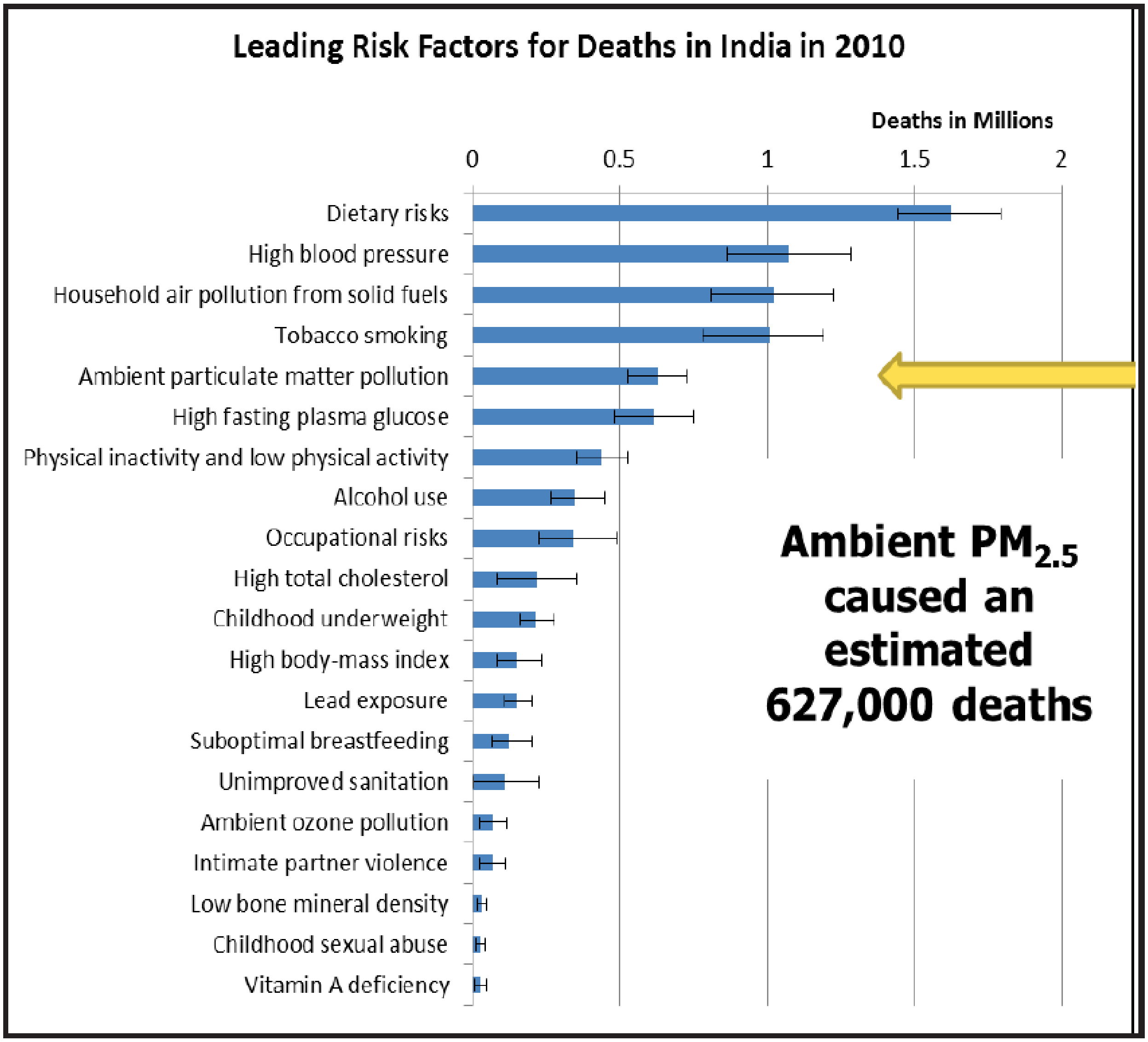


Fig. 2: Top 20 mortality risk factors in US and India Sources: GBD, 2010

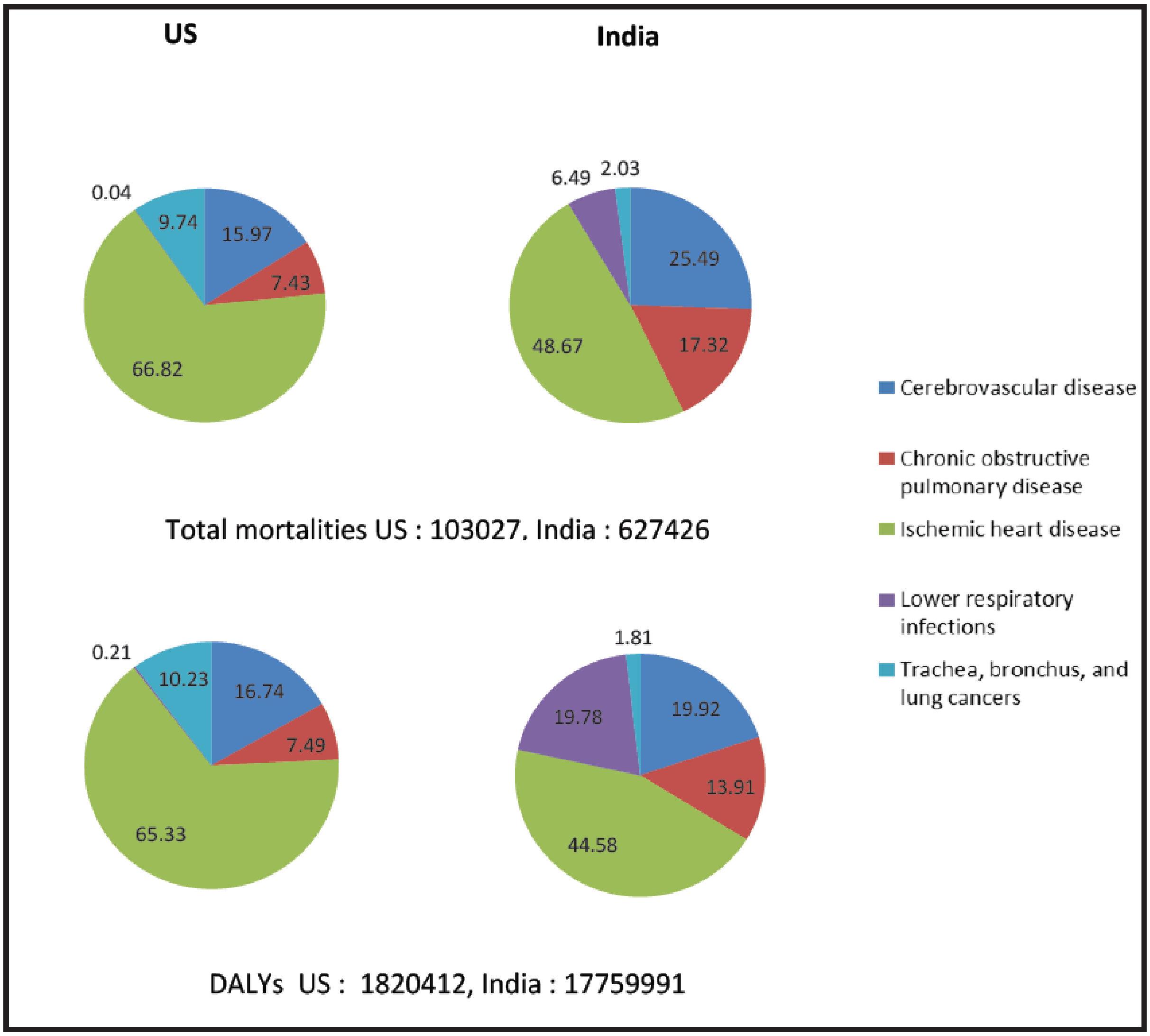
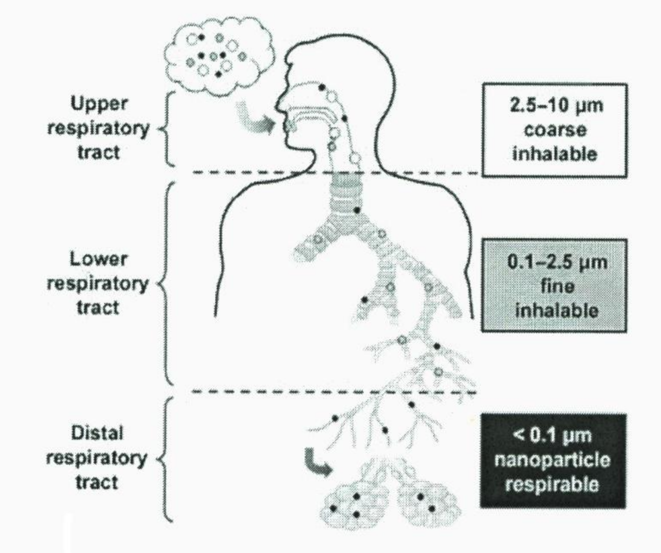


Fig. 3: Disease-wise distribution of deaths and DALYs (%) attributable to ambient particulate matter pollution in US and India



Diagrammatic representation of the translocation patterns of coarse (inhalable), fine (thoracic) and ultrafine/nanosized (respirable) particles in the human respiratory system.

Fig. 4: Translocation of inhaled particles in human lungs

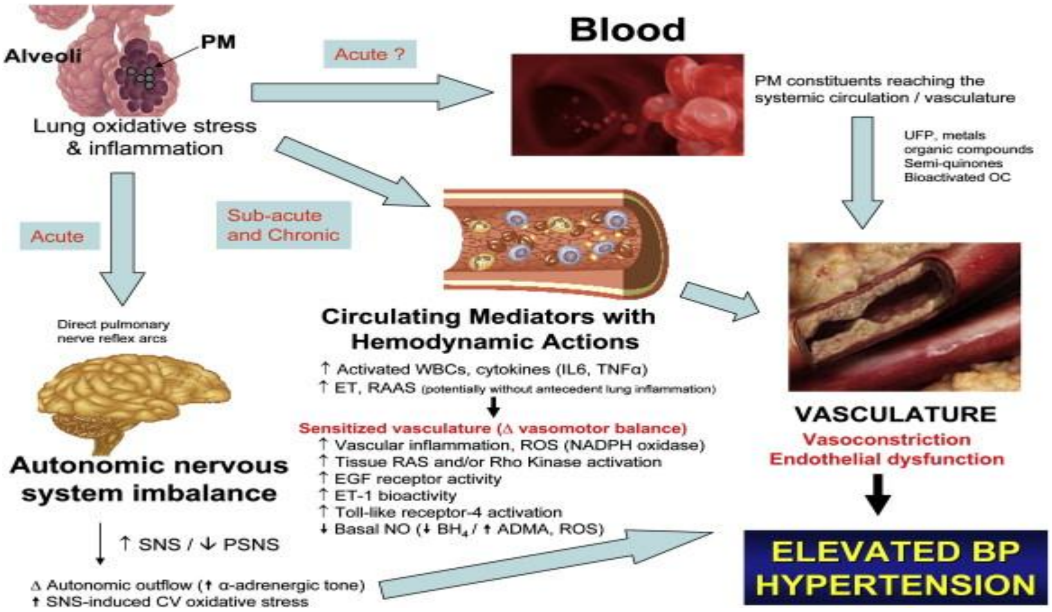


Fig. 5: Underlying Molecular Mechanism of Cardiovascular Impact

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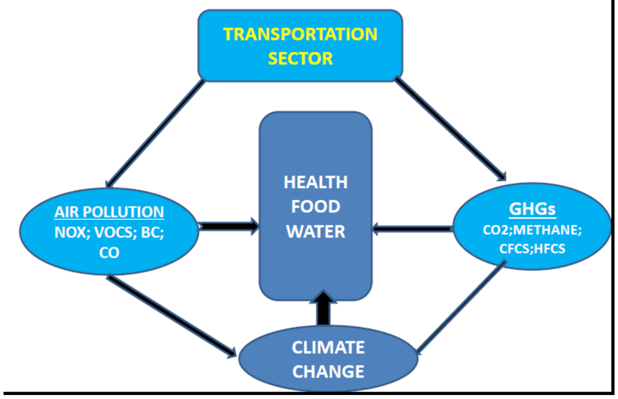
Climate Change Mitigation in India

1. *Air Pollution – Climate Nexus: A Primer*

As is well known, CO_2 is the most important global warming pollutant gas. With respect to the air pollutants: Ozone and methane are greenhouse gases and contribute to surface warming. PM on the other hand has complex climate effects including cooling, warming, decreased rainfall and increased precipitation intensity. There are several types of manmade PM: sulphates, nitrates, black carbon, organic carbon, dust). Their climate effects arise because they interact with sunlight in complex ways and in addition interfere with formation of cloud and raindrops. Sulphates, formed from emissions of SO2, primarily reflect sunlight back before it can reach the surface and cause cooling. However, the reduction of sunlight at the surface, the so-called dimming, is a major source of decreased rainfall due to human activities. The primary source of sulphates is coal combustion in power plants. In India, power plants contribute 60%, followed by industry (31%). The transport sector contributes a negligible amount (<0.1%). Nitrates, formed from NOx gas, is also an important source of PM. Nitrates, like sulphates reflect sunlight and cause dimming which can lead to surface cooling and decreased precipitation. NOX emissions are about a factor of 2 less than SO_2 emissions. However, NOx also leads to surface ozone formation which is a greenhouse gas. The transport sector contributes about 44% to total NOx emissions in India.

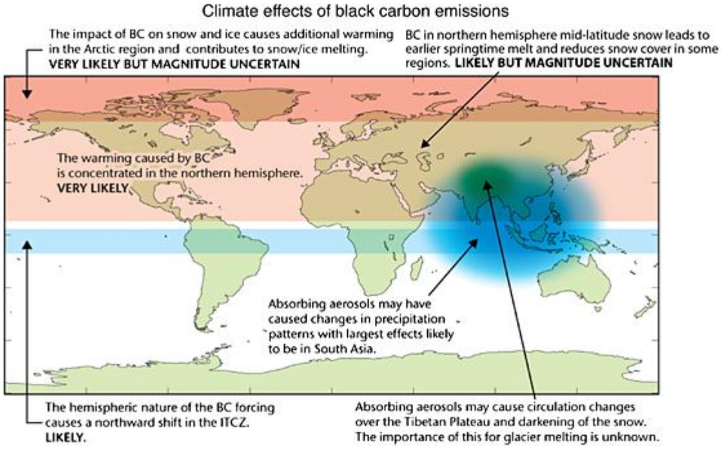
THE TRANSPORTATION SECTOR



The other major PM source is Black carbon (BC) and organic carbon (OC) aerosols. The transport sector contributes 10% of India's BC emissions. In Indian cities however, its contribution is about 50%; furthermore 75% of the PM emissions from diesel engines is black carbon. Black carbon, by itself, is the second largest contributor to global warming. However, black carbon, is usually emitted with organic carbon (OC). OC both absorbs and reflects sunlight and nucleates cloud drops which scatter sunlight and causes cooling. On the other hand, OC as well as nitrates can suppress precipitation from low clouds. For diesel combustion, the OC emission is low and thus the warming effects of BC dominate as shown by California data. The greenhouse gases emitted by the transportation sector include: CO2; methane (fugitive emissions); CFCs and HFCs used as refrigerants. Some gases such HFCs are super greenhouse gases having about 2000 to 4000 times more potent than CO_2 on a 50 to 100 years time scale.

Climate Change: CO_2 and BC

Although both CO_2 and BC warm the atmosphere, they do it in different ways. While CO_2 absorbs outgoing long wave radiation, and adds heat energy to the atmosphere as well as the surface, BC absorbs the incoming solar radiation, which warms the atmosphere but leads to solar dimming at the surface. Because of short life time of BC (weeks or less), its radiative effects is concentrated close to the sources; whereas CO_2 is globally distributed and its effects are more globally uniform. Figure 2 summarizes the major climatic effects of BC. It has also been recently shown that controlling BC may be a faster way of reducing Arctic ice loss and climate warming than other options including CO_2 reduction (Jacobson, 2010). It should be noted that mitigation of CO_2 is required to limit global warming below 2 ^{0}C as agreed upon in Copenhagen accord hence all controls must be adopted.



Climate effects of black carbon emissions

The impact of BC on snow and ice causes additional warming in the Arctic region and contributes to snow/ice melting. **VERY LIKELY BUT MAGNITUDE UNCERTAIN**

BC in northern hemisphere mid-latitude snow leads to earlier springtime melt and reduces snow cover in some regions. **LIKELY BUT MAGNITUDE UNCERTAIN**

The warming caused by BC is concentrated in the northern hemisphere. **VERY LIKELY.**

Absorbing aerosols may have caused changes in precipitation patterns with largest effects likely to be in South Asia.

The hemispheric nature of the BC forcing causes a northward shift in the ITCZ. **LIKELY.**

Absorbing aerosols may cause circulation changes over the Tibetan Plateau and darkening of the snow. The importance of this for glacier melting is unknown.

Figure – 2: Climatic impacts of BC emission (Adapted from Bond et al., 2013).

Considerations for BC Mitigation Based on Climate Forcing

Radiative forcing (RF), which is defined as the change in vertical irradiance at tropopause, does not factor in the rapid adjustment processes in the climate system caused by changes in clouds and snow cover. When these adjustments are incorporated, the resulting forcing is termed as climate forcing ($W\ m^{-2}$). Fig. 2 (a) summarizes the climate forcing by BC-rich sources entirely exerted in the first year of the emission. The climate forcing from on- and off-road diesel is positive (with high confidence) leading to climate warming with largest contribution from heavy-duty trucks (Fig. 2b). The control of BC from on-road diesel engine thus offers an effective means of mitigating near-term climate change. In addition, sulfur content in on-road diesel source is low in developed countries and lowering elsewhere. Organics also form a lesser constituent of diesel particulate matter (PM) compared to other BC sources. Therefore, control on diesel PM will reduce BC without affecting the emission of sulfate and organic carbon (OC) resulting in net cooling. Recently, this fact has been established in California (Ramanathan, 2013).

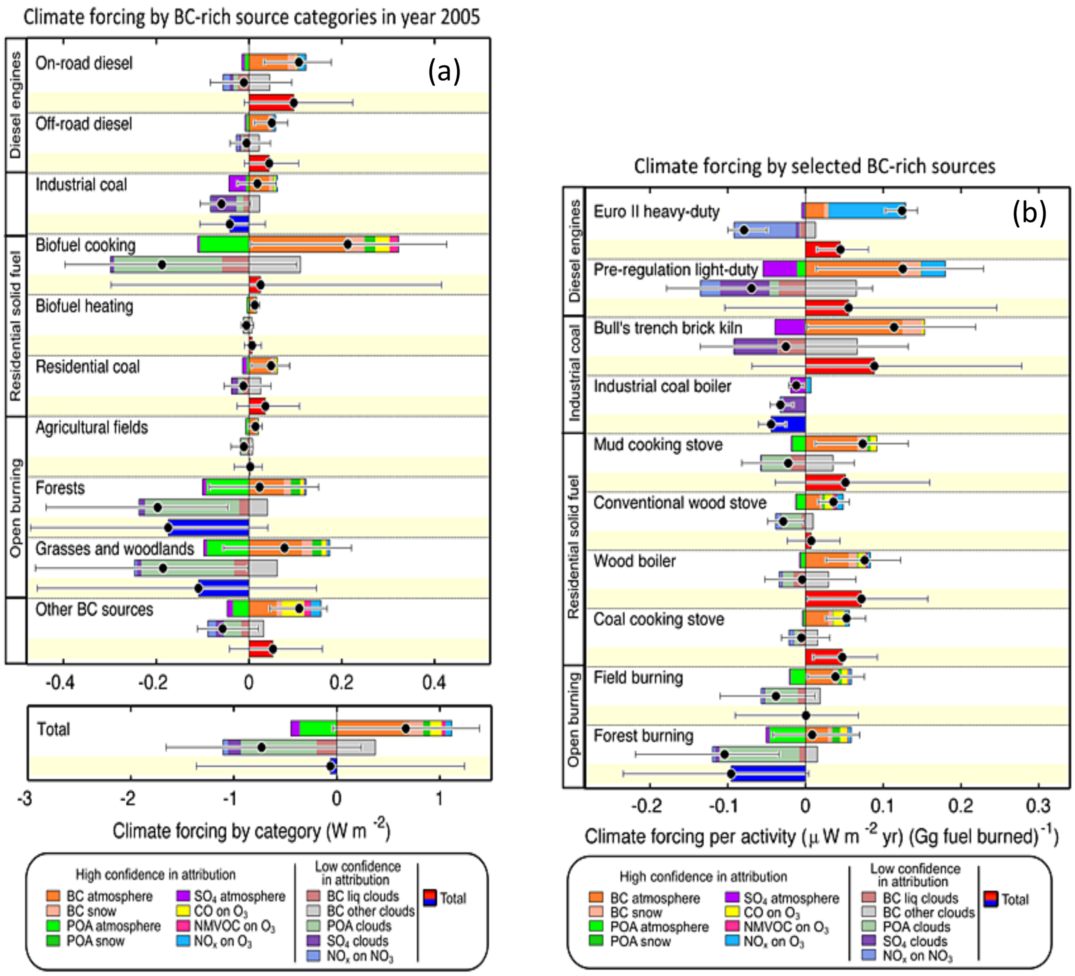


Figure – 2: Climate forcing by (a) BC-rich sources and (b) their sub set. The bottom color key should be used for three sets of bars with black dots as the best estimate with uncertainties (Adapted from Bond et al., 2013).

Mitigation in Indian Transportation Sector

India's transport with more than 100 kT BC emission per year is the fourth largest sector, next only to Biofuel. Within transportation sector, Heavy Duty Trucks are largest BC emitters (40 kT) followed by Bus, which is followed by 3-wheelers. As far PM$_{2.5}$, Heavy Duty Trucks emit most (100 kT) followed by 2-wheelers followed by 3-wheelers. City wise transportation also stands as the largest emitter of PM$_{2.5}$ in Bangalore (followed by DG sets), Pune (followed by secondary formation) and Kanpur (followed by domestic). Heavy Duty Trucks are largest BC and PM$_{2.5}$ emitters in states such as Maharashtra and Gujarat as well as cities such as Delhi and Chennai. Whereas two wheelers emit maximum PM$_{2.5}$ in Delhi.

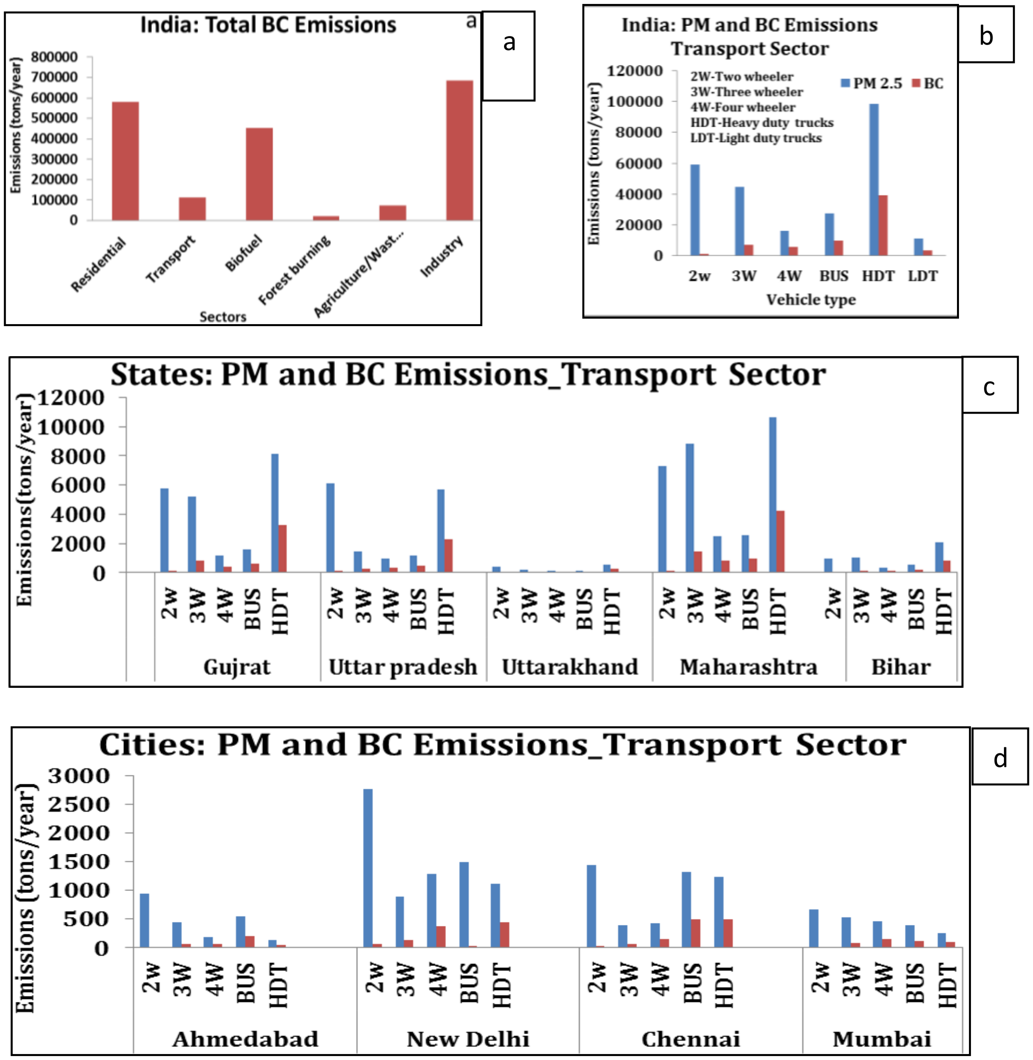


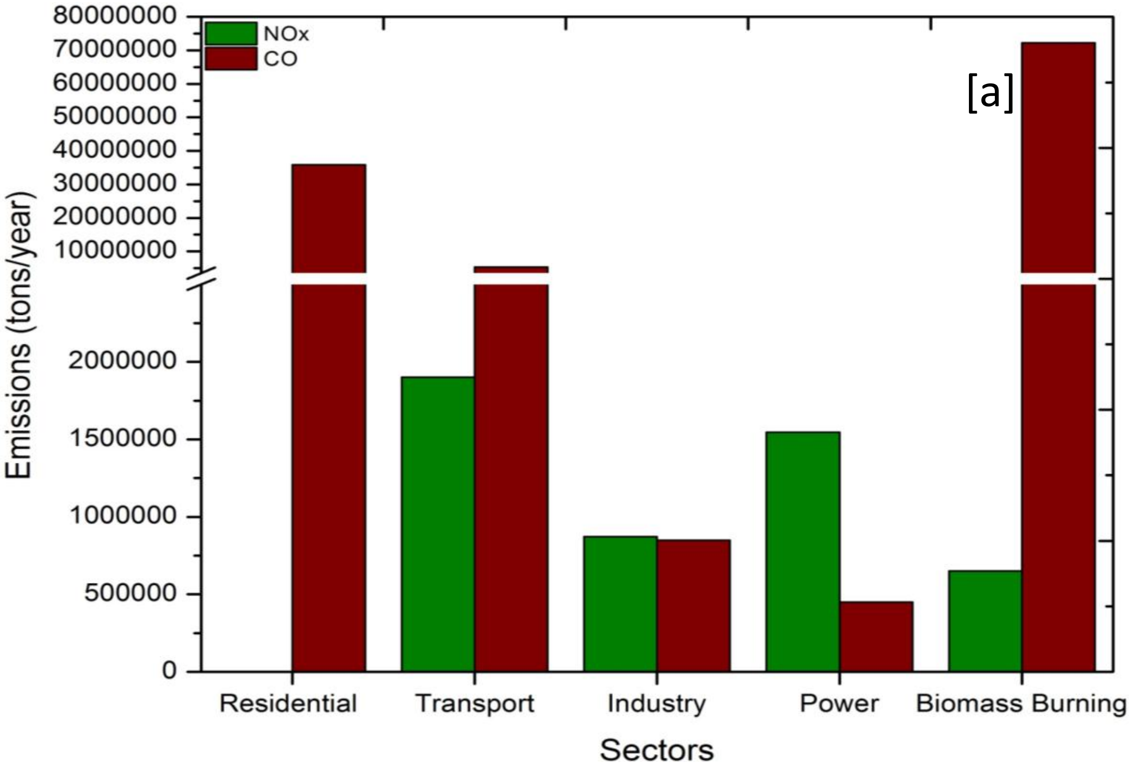
Figure – 3:(a) Total BC emissions from different sector in India. (b) Total $PM_{2.5}$ and BC emissions from transport sector in India. (c) $PM_{2.5}$ and BC emissions from transport sector in selected states of India (d) $PM_{2.5}$ and BC emissions from transport sector in selected cities of India. Data source: Guttikunda and Jawahar (2012) and Sloss (2012).

Tropospheric ozone, an outcome of photochemical reactions between precursors such as NO_x, CO and VOCs, has been shown to be an important Short Lived Climate Pollutant (SLCP). The emission data on these precursor gases, particularly VOCs, in India is scarce. Figure 4(a) and (b) show total CO and NO_x emission from various sectors in India and transportation sector for various cities, respectively. Transportation sector appears to be the largest emitter of NO_x and second largest for CO, next to biomass burning, which is an unorganized sector. Therefore any policy and/or technological intervention will likely have little impact on the emissions from the biomass burning.

Mitigation Strategies

On-road diesel vehicles in general and Heavy Duty Trucks (and to certain extent two wheelers) in particular should be targeted to reduce BC emissions in India to slow down climate warming in short time scale. The associated reduction in $PM_{2.5}$ will have co-benefits in terms of human health and air quality.

From the ozone precursor point of view, transportation sector should also be targeted. Due to the lack of detailed data on geographical and vehicular emission pattern of ozone precursors, more specific recommendation cannot be made.



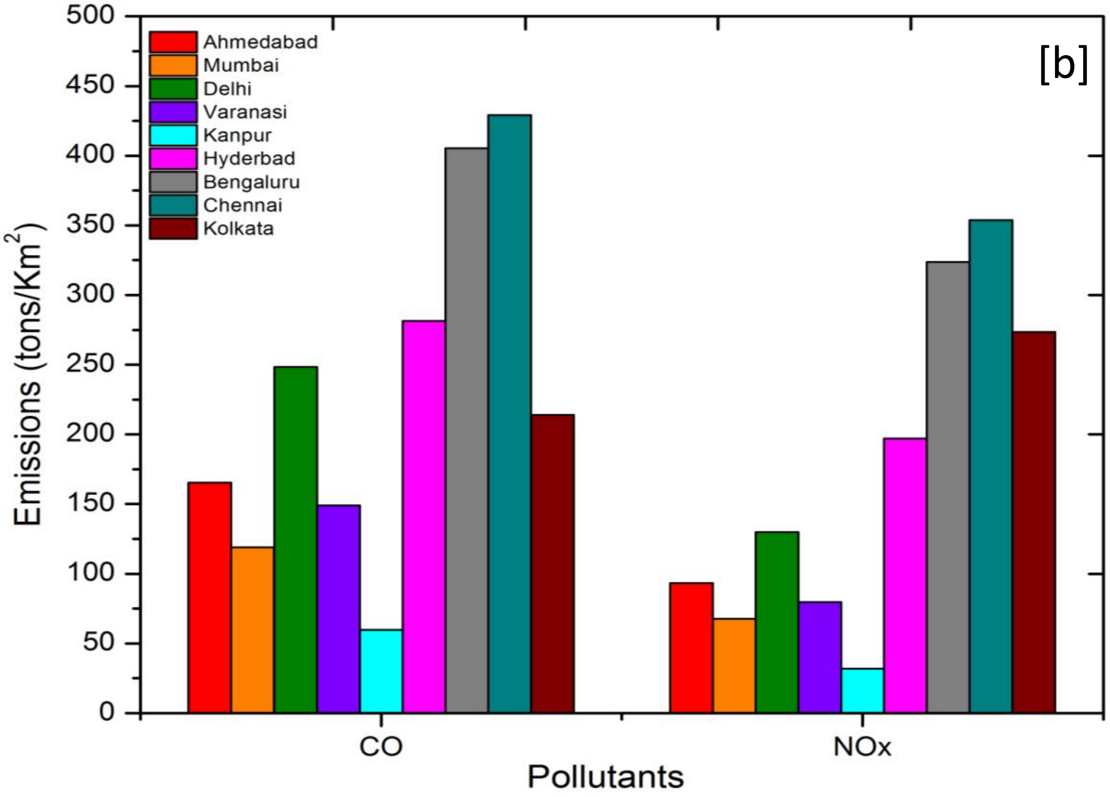


Figure - 4: Total CO and NO$_x$ emissions In India (a) from different sectors (b) from transport sector in major cities. Data source: Garg at al., (2006); Galanter et al., (2000) and Ramachandra and Shwetmala (2009).

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II. TECHNOLOGY MEASURES

R. Harnish, A. Bandivadekar, A. Aggarwal, M. Waugh,
J. Kubsh, N. Iyer, S. Yeh.

Technical Summary

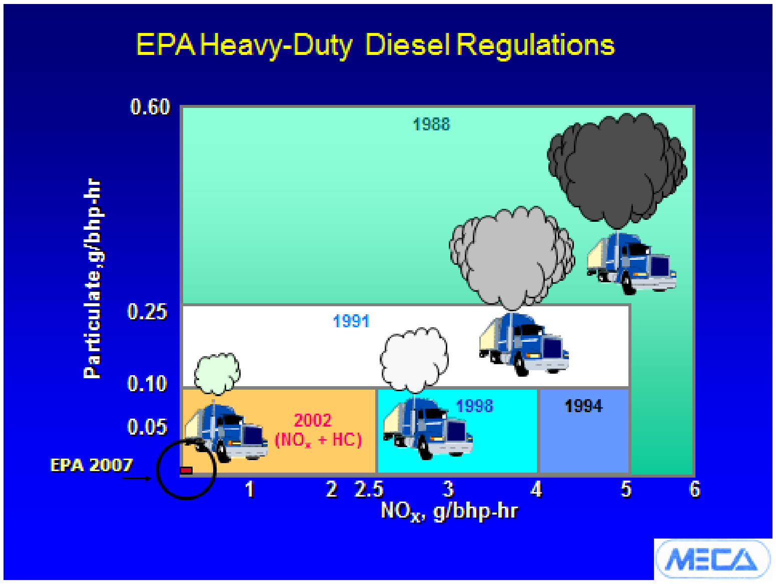
In this section we examine technology being used and technology that could be used to reduce air pollution in India. Technology issues at the upstream or refinery end of the diesel fuel production chain include reduction of sulfur content, limitation of aromatic content, lubricity additives and recoupment of capital and operating costs. Technology issues at the downstream end can be resolved with a wide range of solutions dependent upon use, costs and selection of pollutant to be reduced. The menu of choices for reduction of ultrafine particulate matter and oxides of nitrogen include selective catalytic reduction, exhaust gas recirculation, variable geometry turbos, NOx adsorbers, diesel particulate filters and oxidation catalysts. Next we offer a broad overview of engine technology changes and aftertreatment systems being employed by Indian manufacturers of two- and three-wheel vehicles to meet the emission standards (Bharat Stage III) in place for a range of fuels, including petrol, diesel, CNG, and LPG, followed by an assessment of the technical options available to reduce emissions to meet the proposed Euro 4/5/6 equivalent limit values in the respective years of their likely adoption and implementation in India. We also take a brief look at the use of diesel particulate filters in diesel stationery engines and some of the outcomes. We are reminded that there is no “best path” for technology change in transportation, which depends upon many things not least the use of the engine and the relative costs of materials.

A recent, important policy step for technology change was the Government of India decision to gradually phase out subsidies on diesel fuel. A policy barrier to technological progress on air pollution mitigation in India is the continued delay in implementing the supply of ultra-low-sulfur fuels. ULSF would enable the sale of vehicles meeting more stringent emission standards and adoption of diesel particulate filters (DPFs) and other advanced vehicle aftertreatment systems in India. Refinery capital and operating costs in California for the transition to low PM fuel produced minimal price changes to the consumer. Another barrier is the patchwork of fuel standards in city and rural areas, which prompts some analysts to call for “one country, one fuel”. Two and three wheeled vehicles produce roughly 40 percent of PM2.5, and 35 percent of PM10, of the emissions inventory for road transport in India. But there are no particulate matter emission standards for two and three wheeled vehicles. Finally, because they constitute the overwhelming majority of vehicles in India, they also produce 40 percent of carbon monoxide and 70 percent of volatile organic compounds.

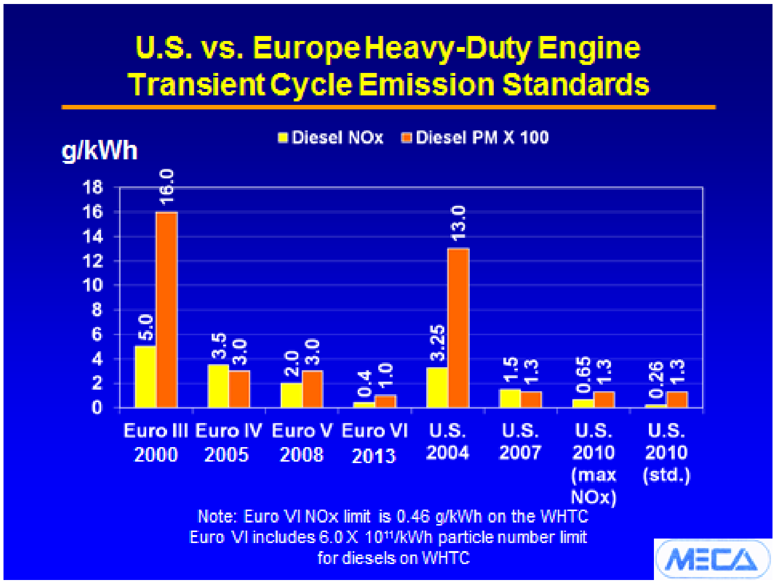
Key Points

- The biggest barrier to progress in India is the continued delay in implementing the supply of ultra-low sulfur fuels, which would enable the sale of vehicles meeting more stringent emission standards and adoption of diesel particulate filters (DPFs) and other advanced vehicle aftertreatment systems in India.
- The adoption of Bharat Stage (BS) VI emission standards would reduce per vehicle PM2.5 emissions by over 90 percent from today's levels.
- In a determined campaign to reduce premature death and agricultural loss in India, it may be cheaper for society to remove older vehicles from service rather than attempt to regulate retrofit technologies.
- The refinery investments needed to transition to ULSFs in India will be less than 2 percent of the present fuel price.
- Different operating conditions and economic factors can and do influence the technology path which is most appropriate for each market.
- Technologies to reduce NOx include selective catalytic reduction (SCR), advanced combustion, cooled exhaust gas recirculation (EGR) and variable geometry turbochargers.
- Two and three wheeled vehicles produce roughly 40 percent of PM2.5, 35 percent of PM10, 40 percent of carbon monoxide and 70 percent of volatile organic compounds in the emissions inventory for road transport in India.
- A major improvement in the PUC system for two and three wheelers would be the adoption of the Automotive Research Association of India Two Wheeler loaded mode test for the periodic vehicle inspection.
- Due to limited availability for vehicular usage, CNG and LPG will remain niche market solutions and cannot be considered for widespread usages.
- Diesel generators and agricultural tractors are an important source of diesel emission in India. PM standards are being tightened. The level of emission performance can be achieved with 50 ppm sulfur diesel, but will not require DPFs.

History of Technology and Fuel Measures in Europe and USA


EPA Heavy-Duty Diesel Regulations

PM emission standards for heavy-duty trucks in both the U.S. and Europe have been tightened a number of times since the late 1990s. As seen in the U.S. HD emissions chart, between 1988 and 1994, PM standards for heavy-duty highway diesel engines were decreased from 0.6 g/bhp-hr to 0.1 g/bhp-hr, about an 80% reduction.


U.S. vs. Europe Heavy-Duty Engine Transient Cycle Emission Standards

Note: Euro VI NOx limit is 0.46 g/kWh on the WHTC
Euro VI includes 6.0 X 10^{11}/kWh particle number limit for diesels on WHTC

These reductions were achieved largely through improved engine combustion technologies that did not require the use of ultra-low sulfur diesel fuel. U.S. PM standards did not change again until 2007 when the PM standard was reduced an additional 90% to 0.01 g/bhp-hr. To achieve this level of PM performance required the introduction of ultra-low sulfur diesel fuel (in mid-2006) and the application of catalyzed diesel particulate filters on new highway diesel engines in the U.S. The turnover of the heavy-duty fleet to newer, cleaner engines of this 20+ year time frame contributed to the decrease in ambient PM levels observed in California (and the rest of the U.S.). In the second chart Euro vs. U.S. heavy-duty emission standards are compared.

India is currently at the Euro III/Euro IV limits (Euro IV in large metropolitan areas with 50 ppm diesel sulfur limits and Euro III for the rest of the country with 500 ppm diesel sulfur limits). The Euro III limits are roughly equivalent to U.S. 2002/2004 limits (which also utilized 500 ppm sulfur diesel fuel). Currently in India with this bifurcated set of emission limits, not many Euro IV trucks are being purchased since cheaper Euro III trucks can be purchased outside of the metropolitan areas (the exception are a few Euro IV bus fleets that have been put in place in some Indian cities). From Euro III/Euro IV limits, the next big step in reducing PM is getting DPFs on new trucks/buses and getting the fleet to turnover to these newer, extremely low PM DPF-equipped trucks. The Euro VI limits (with ultra-low sulfur diesel fuel) force the use of DPFs on heavy-duty truck and bus engines in much the same way that EPA's 2007-2010 emission standards did here in the U.S. Some lower PM levels could be achieved through engine combustion modifications associated with Euro V trucks in India, but DPFs are needed to get significantly cleaner (PM wise) trucks into the Indian market place.

Vehicle Emission & Fuel Quality Standards

India's vehicle population has grown from approximately 50 million in 2003, when the last Auto Fuel Policy was adopted, to 130 million in 2013. Heavy-duty vehicles (trucks and buses) are responsible for 56% of all PM_{10} and 70% of all NOx emissions from on-road vehicles. It is estimated that nearly 40,000 premature deaths each year are caused by vehicle $PM_{2.5}$ emissions in India's cities alone[1].

There is a large potential to reduce diesel particulate matter (PM) emissions by implementing stricter vehicle emission and fuel quality standards. Implementing ultra-low sulfur fuels (ULSF – fuels with under 10 ppm sulfur content) would enable the adoption of Bharat Stage (BS) VI emission standards, which would require all four-wheeled vehicles in India to be fitted with diesel particulate filters (DPF). DPF implementation would reduce per vehicle $PM_{2.5}$ emissions by over 90 percent from today's levels. Additionally, ULSF and BS VI standards would also reduce NOx, HC, and CO emissions, all of which are problematic for air quality in India.

Although BS IV fuel is supplied to about thirty cities, Bharat Stage (BS) IV emission standards are applicable only in thirteen cities. Outside of these thirteen cities, Bharat III emission standards are applicable. BS IV standards require fuel sulfur content to not exceed 50 ppm, while BS III standards allow for up to 150 ppm sulfur gasoline and 350 ppm sulfur diesel.

Theoretically, vehicles should also meet standards in the same way as fuels, meaning the cities with BS IV standards should only sell BS IV vehicles while BS III vehicles are sold in the rest of the country. In reality, most new passenger vehicles meet BS IV standards, while most light-commercial vehicles (LCVs) and heavy-duty vehicles (HDV) meet BS III standards, as they are almost all sold and registered outside of urban areas.

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[1] International Council on Clean Transportation. (2012). *Costs and Benefits of Cleaner Fuels and Vehicles in India.* http://www.theicct.org/costs-and-benefits-cleaner-fuels-and-vehicles-india

Barriers for Adoption of Cleaner Fuels and Vehicles India did not convene a new Auto Fuel Policy Committee until 2013, a full three years after the previous auto fuel policy road map was carried out. A clear road map for emission standards and fuel quality is needed urgently. The technological know-how to achieve the needed improvements in vehicle and fuel quality is already available in the marketplace.

The biggest barrier to progress in India is the continued delay in implementing the supply of ultra-low-sulfur fuels, which would enable the sale of vehicles meeting more stringent emission standards and adoption of diesel particulate filters (DPFs) and other advanced vehicle aftertreatment systems in India. While regions with advanced regulations such as Europe, the United States, and Japan implemented low-sulfur fuels years ago, and developing countries like China, South Africa, Mexico, and Brazil have plans to reduce fuel sulfur levels further in the near future, India is making minimal progress on this front. Apart from expanding the supply of 50-ppm sulfur fuel to about 60 cities by 2015, there is no plan as of yet to supply that essential fuel to the whole country, nor to reduce fuel sulfur content to 10 ppm. Supplying 50-ppm fuel only to urban areas will not benefit the majority of vehicles in India, especially as vehicle sales become dispersed away from large urban centers. The situation will not get better for commercial trucks—which are the largest emitters of NOx and PM— since they often operate and refuel in rural areas.

Hart Energy and MathPro found the refinery investments needed to transition to ULSFs in India to be around \$4.2 billion[2]. Summing investments and increased operational costs, and normalizing them to a per liter basis, Indian refineries would pay an extra 0.70-0.88¢ per liter of fuel produced. Thus, ultra-low sulfur fuels would cost only about 50 paise per liter. Even after including tax impacts, the net increase in fuel price due to ULSFs will be less than 2 percent of the present fuel price.

India's central government has long arranged for kerosene, diesel, and certain other fuels to be sold at a fixed rate lower than their market value to support agriculture, the transport of goods, and weaker sections of society. The downside of this has been under recoveries for oil companies. Continuing under recoveries have diminished the appetite of the oil industry to invest in fuel sulfur reduction technologies, and investment seen by the oil industry as providing no economic benefit to them.

Recently, the government agreed to raise diesel prices by Rs. 0.50 (US 1 cent) per liter every month until the full diesel subsidy is eliminated. This is a tremendous step forward for India's oil

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[2] Hart Energy; MathPro. (2012). *Technical and Economic Analysis of the Transition to Ultra-Low Sulfur Fuels in Brazil, China, India and Mexico.*
http://www.theicct.org/sites/default/files/publications/ICCT_ULSF_refining_Oct2012.pdf

industry, and is freeing up capital for investments in ultra-low-sulfur fuel production technologies. One extra month of on-going monthly Rs. 0.50 per liter diesel price increase will ensure that investments made by oil sector in producing ultra-low sulfur fuels will be recouped.

Fuel Quality Improvements and Refining

Reducing sulfur levels in diesel fuel is an effective means of reducing PM emissions from diesel engines, especially when lower-sulfur fuel allows for the deployment of effective aftertreatment technologies such as DPFs—the combination of which can reduce PM emissions by about 90 percent. Furthermore, regulations that limit emissions from new diesel engines require low-sulfur diesel to be effective. Significant capital costs may be required for refiners to produce low-sulfur diesel fuel, and lubricity additives may be needed in higher concentrations, but the widespread use of diesel fuel keeps the cost-per-gallon impacts relatively low. Reducing the aromatic content of diesel fuel reduces both PM and NOx emissions and also requires capital investment.

One of the most effective means of reducing fine particulate matter from diesel combustion is to reduce the sulfur content of the diesel fuel. Not only do lower sulfur levels reduce direct particulate matter (PM) emissions, they also allow for after-treatment technologies, such as diesel particulate filters (DPFs), to be deployed for even greater PM reductions. Furthermore, limiting the aromatic content of diesel fuel reduces emissions of both PM and oxides of nitrogen (NOx).

Reduction of Diesel Sulfur Levels in California. In July 2003, the California Air Resources Board (ARB) approved a 15 parts-per-million (ppm) sulfur limit for diesel fuel used in on-road and off-road engines. The previous diesel fuel sulfur limit had been 500 ppm. The 15-ppmw limit was needed for two primary reasons: to enable the effective use of the emissions control technology that is required by heavy-duty diesel vehicles and engines that must meet the PM and NOx emission standards adopted by both the United States Environmental Protection Agency and ARB; and to enable the use of the exhaust gas treatment technologies that are required by new and retrofitted diesel engines to meet the diesel PM reduction targets identified in ARB’s Diesel Risk Reduction Plan.

The phase-in of the 15-ppm standard began in June 2006 and was fully implemented for motor vehicles and off-road diesel engines in September 2006. Beginning in January 2007, the standard also applied to harbor craft and intrastate locomotives. With the implementation of the cleaner diesel fuel, there have been no reported problems with its use, and staff estimates that overall direct diesel PM emissions have been reduced by about 25 percent. Coupled with a DPF, total PM emissions can be reduced by 90 percent. Moreover, lower fuel sulfur levels also reduce sulfur dioxide emissions that may form secondary PM emissions, such as ammonium sulfate.

Cost of Reducing Diesel Sulfur Levels. Requirements for low-sulfur diesel fuel may necessitate changes in the way diesel fuel is produced. Refiners may need to perform modifications to their facilities to ensure that they are capable of producing sufficient and consistent quantities of low-sulfur diesel fuel.

When ARB adopted the 15-ppm diesel sulfur limit in 2003, eight of the 12 large refineries in California reported that capital expenditures to produce low-sulfur diesel fuel would be minimal. Three refineries reported significant costs involving the installation of new hydro-desulfurization units. The refinery cost estimates included total capital investment for the purchase, installation, associated engineering, permitting, and start-up costs for necessary equipment. Based on survey responses, staff estimated that refiners would incur capital expenditures of approximately $170 to $250 million to comply with the low-sulfur diesel requirements.

Along with the initial capital investment, annual operating and maintenance (O&M) costs must also be considered. Most of the survey responses included annual O&M costs. Usually, these are costs associated with labor, material (such as catalysts, etc.), sulfur disposal, maintenance, insurance, and repairs associated with the new or modified equipment. The O&M costs were estimated to range from $50 to $60 million per year for all California refineries.

Amortizing the capital costs over ten years and adding those costs to the annual O&M costs, and considering that California annual demand for diesel fuel was 3.5 billion gallons, staff estimated that the cost-per-gallon impact of the lower diesel fuel sulfur requirements were about 2.5 cents per gallon.

The total cost impact of lower-sulfur diesel fuel may be much higher if refiners need to make significant capital expenditures for hydro-sulfurization equipment. Furthermore, additional hydrogen production capacity may need to be installed to support that hydro-desulfurization. Hydrogen production, via steam-methane reforming, emits some of the highest levels of carbon dioxide emissions in a refinery. Finally, additional sulfur recovery equipment may need to be installed to accommodate the increased sulfur removal.

Lubricity Issues. Diesel fuel lubricity can be defined as the ability of diesel fuel to provide surface contact lubrication. Adequate levels of fuel lubricity are necessary to protect the internal contact points in fuel pumps and injection systems to maintain reliable performance. Natural lubricity of diesel fuel is provided by trace levels of oxygen- and nitrogen-containing compounds, and certain classes of aromatic and high molecular weight hydrocarbons in diesel fuels. When diesel fuel sulfur levels are lowered through hydro-desulfurization, some of the naturally occurring compounds in diesel that help with lubricity are also removed, so lubricity additives are usually required.

Lubricity additives are available in today's market, are effective, and are in widespread use around the world. These additives must be applied carefully, as they can have issues in pipelines used for several hydrocarbon products. Common carrier pipeline harm effects can be a result of surface-active species in the lubricity additives that plate out on pipeline walls. Other fuels following diesel fuel treated with lubricity additive through the pipeline can become contaminated with these surface-active species. Jet fuel contaminated with these species can have an increased affinity for water. This can result in the jet fuel being out-of-specification for moisture content. Pipeline contamination of jet fuel can be addressed by pipeline protocol, such as additizing at the rack or fuel terminal. Another option would be to follow shipments of diesel fuel with gasoline prior to running jet fuel.

Aromatic Content of Diesel Fuel. ARB reduced the aromatic content of diesel fuel in 1988 from 35 percent to 10 percent by volume (20 percent for small refiners). Hydro-processing can reduce aromatics content by as much as 70 percent. Staff estimated in 1988 that reducing the aromatics content of diesel fuel to 10 percent would cost about 11 cents per gallon for large refineries and 19 cents per gallon for small refineries, which is why ARB set a less stringent standard for small refiners who would have to invest significant capital for necessary hydro-processing equipment. Aromatics also reduce cetane number, so lower levels are beneficial for diesel performance without additional cetane-improving additives.

The aromatic hydrocarbons in diesel fuel play an important role in PM formation. During the combustion process, aromatic hydrocarbons produce chemical species that contain a high carbon-to-hydrogen ratio, making them unstable. These species, because of their instability, tend to react with each other to agglomerate and produce highly carbonaceous PM.

Aromatic compounds in diesel fuel also increase flame temperatures during combustion, contributing to NOx emissions. Reducing total aromatic content in diesel fuel from 30 percent to 10 percent reduces NOx emissions by about 3 to 5 percent and reduces polycyclic aromatic hydrocarbons (PAH) in diesel exhaust. PAH compounds have attracted considerable attention because of their known mutagenic and, in some cases, carcinogenic character.

Reducing sulfur levels in diesel fuel is an effective means of reducing PM emissions from diesel engines, especially when lower-sulfur fuel allows for the deployment of effective after-treatment technologies such as DPFs—the combination of which can reduce PM emissions by about 90 percent. Furthermore, regulations that limit emissions from new diesel engines require low-sulfur diesel to be effective. Significant capital costs may be required for refiners to produce low-sulfur diesel fuel, and lubricity additives may be needed in higher concentrations, but the widespread use of diesel fuel keeps the cost-per-gallon impacts relatively low.

Reducing the aromatic content of diesel fuel reduces both PM and NOx emissions and also requires capital investment.

Future Diesel Technology

For controlling emissions, there are several technology options available. What is important is to develop the right technology for each application and market served. Different operating conditions and economic factors can and do influence the technology path which is most appropriate for each market. While developing multiple emission solutions requires broader and deeper investment in Research and Development, it has to ensure that the customers have engines that deliver optimum performance and reliability at the lowest possible cost of operation.

A second, but no less important part is to involve original equipment manufacturers (OEMs) as early as possible in the development and integration process. This open exchange of information is instrumental in developing vehicles and equipment that perform at the highest level of efficiency, durability, reliability and productivity.

It is required to work in combustion research, fuel systems, air-handling systems, controls and after-treatment for providing the most appropriate emission control solution. For example, on-highway standards of Euro-IV were met using Selective Catalytic Reduction (SCR) aftertreatment. SCR was the best customer solution for the European market, because fuel prices relative to urea were very high and use of urea made economic sense by reducing fuel consumption. This was in contrast with the U.S. on-highway truck market, where application of cooled exhaust gas recirculation (EGR) made most economical sense to comply with U.S. EPA 2002/2004 heavy-duty highway emission standards. The other technologies used are a combination of advanced combustion, flexible fuel systems and controls, base engine capability and variable geometry turbocharging.

Looking at 2007 - 2010, the emission levels were reduced dramatically for heavy-duty trucks under U.S. EPA on-highway regulations. NOx was reduced to 0.2 g/hp-hr by 2010, while PM was reduced to 0.01 g/hp-hr in 2007. In addition to NOx and PM exhaust levels, crankcase gases were also included in the emission measurement. In support of the new emissions standards, the U.S. EPA lowered the limit for diesel fuel sulfur from 500 ppm to 15 ppm. Implementation of the federal 15 ppm sulfur cap on highway diesel fuel began in the U.S. in October 2006. This ultra-low sulfur fuel has several benefits. It inherently produces less PM from combustion. It enables NOx adsorber technology to be highly effective, improves the effectiveness and durability of catalyzed diesel particulate filters, and reduces the production of sulfuric acid. It also can have a positive effect on the oil drain intervals.

New specifications of lubrication oil are required to be compatible with the low emission solutions. The primary focus is to make oil compatible with after treatment devices. The requirement is to reduce ash in order to enable extended maintenance intervals on the diesel particulate filter while maintaining the important lubricity capability of the lubricant.

Coming to NOx reduction technologies, we have advanced combustion, cooled EGR, variable geometry turbochargers, EGR and various aftertreatment solutions.

Advanced combustion systems reduce engine out emissions at the source – inside the combustion chamber. This requires optimizing fuel injection system parameters and combustion geometry.

Cooled EGR is very effective for NOx control. The EGR system takes a measured quantity of exhaust gas, and passes it through a cooler before mixing it with incoming air to the cylinder. The EGR adds heat capacity and reduces the oxygen concentration in the combustion chamber by diluting the incoming ambient air with the cool exhaust gases. During combustion, EGR has effect of reducing flame temperature, which in turn, reduces NOx production as NOx is proportional to flame temperature.

In order to control both NOx and particulate emissions accurately, the amount of re-circulated exhaust gas and air must be precisely metered into engine under all operating conditions. Variable Geometry (VG) Turbos have been developed that continuously vary the quantity of air delivered to the engine. Aftertreatment strategies to reduce NOx include Selective Catalytic Reduction (SCR), NOx adsorbers and Lean-NOx catalysts. SCR uses urea, which is converted to ammonia in the exhaust stream and reacts with NOx over a catalyst to form harmless nitrogen gas and water. In an SCR system, the urea injection rate must be tightly controlled. The urea-SCR system consists of three basic elements – the catalyst, urea in liquid form in a storage tank, and the urea injection and control system. For reduction of each 1-g/hp-hr reduction in NOx, an SCR engine consumes urea at approximately 1.5% of the amount of fuel used. Thus, the cost of fuel verses urea is one of the driving factors in selecting the NOx solution.

The NOx Adsorber Catalyst (NAC) uses a combination of base metal oxide and precious metal coatings to affect the control of NOx. The base metal components, for example, barium oxide, reacts with NOx to form barium nitrate. When available storage sites are occupied, the catalyst is operated briefly under “rich” exhaust gas condition where air-to-fuel ratio is adjusted to eliminate oxygen in the exhaust. This releases NOx from the base metal storage sites, and allows it to be converted to nitrogen and water vapor. This process is called regeneration. Sulfur poses challenges for NOx adsorbers. This is because in addition to storing NOx, NAC also stores sulfur, which reduces its capacity to store NOx. A periodic de-sulfation process to remove sulfur from the catalyst is required in addition to the regeneration process.

A Lean-NOx catalyst uses unburned hydrocarbon to reduce NOx over a catalyst. The catalyst typically contains platinum with a zeolite. The successful operation of lean-NOx catalyst requires continuous injection of fuel upstream of catalyst. The NOx conversion efficiency depends on may factors, but typical values of 10%-25% are in use over practical duty cycles.

Coming to PM reduction technologies, we have advanced combustion, oxidation catalysts and Diesel Particulate Filters (DPF). In order to reach tight PM standards, active diesel particulate filters are needed. Filtration of exhaust gas to remove soot particles is accomplished by using porous media generally made from cordierite or silicon carbide. Soot accumulates in the filter, and when sufficient heat is present, a “regeneration” event occurs, oxidizing the soot and cleaning the particulate filter. The challenge of particulate filter design is to enable reliable and consistent regeneration so that soot can be removed in all types of duty cycles - be it a fully loaded truck on the highway or that bus on a stop-and-go operation inside the city. It must also work under all ambient conditions. That is why “active” controls are required. The use of “active” methods involves monitoring the particulate filter backpressure and regeneration events and managing the temperatures entering the filter. There are several methods to control or raise the exhaust temperature to actively manage the DPF. One, for instance, is to add an oxidation catalyst. This will allow regeneration to take place under low-ambient / low-load conditions when exhaust temperatures are low, as well as during normal operations.

DPF challenges include potential maintenance. Metals in the lubricating oils become ash and collect on the filter. Low ash oils are therefore needed. A discussion of DPF maintenance practices and experience is available in report from the Manufacturers of Emission Controls Association (MECA) at: http://www.meca.org/resources/reports (Diesel Particulate Filter Maintenance: Current Practices and Experience, June 2005).

Additional information on diesel exhaust emission control technologies including oxidation catalysts, diesel particulate filters, lean NOx catalysts, and selective catalytic reduction catalysts is also available in report from the Manufacturers of Emission Controls Association (MECA) at: http://www.meca.org/resources/reports (Emission Control Technologies for Diesel-Powered Vehicles, December 2007).

Two and Three Wheel Vehicles

Motorcycle sales in India have been growing at double-digit rates, and recently passed the million-vehicle-per-month mark. With annual sales five times those of passenger cars, motorcycles dominate the on-road passenger vehicle fleet. Meanwhile, three-wheelers, which play a critical role in providing point-to-point as well as feeder service in India's urban and semi-urban areas, are on a path to surpass half a million annual sales. Given the importance of these vehicles to personal mobility in India, reducing their emissions and fuel consumption must be a priority for health, environmental, and energy policy. In the Road Transport in India 2010-30 Synopsis Report by Guttikunda and Jawahar dated November 2012, two and three wheeled vehicles produce roughly 40 percent of PM2.5, 35 percent of PM10, 40 percent of carbon monoxide and 70 percent of volatile organic compounds in the emissions inventory for road transport in India.

In 2007, the ICCT published an initial assessment of technologies to control air pollution from motorcycles, followed shortly after by a more comprehensive review of opportunities to reduce emissions and fuel use. These reports set the stage for a detailed India-specific assessment of technology and policy opportunities for realizing on-road emission reduction from two- and three-wheelers http://www.theicct.org/two-and-three-wheelers-india-iyer-report

Technology Being Used to Reduce Emissions Most of the two-wheeled vehicles in India, up to the year 2000, were powered by 2-stroke engines with high levels of Hydrocarbons and Carbon Monoxide emissions, though, in comparison, emission of oxides of nitrogen was almost insignificantly low. Solutions adopted by vehicle manufacturers to meet the emission standards, progressively tightened over the years, beginning with the year 1991, and up to the year 2000, consisted of design improvements, optimizing the air-fuel ratio and ignition timing and, in some cases, use of simple after-treatment devices, mostly oxidation catalytic converters. A major tightening of emission limits in the year 2000 led the manufacturers to gradually shift from two-stroke to four-stroke engines.

The process of shifting to four-stroke engines gained further momentum in the years 2005 and 2010**.** Manufacturers attribute this shift not only to the need to meet the emission standards but also to changing market preferences – from predominantly two-stroke-powered metal-bodied scooters to fuel efficient four-stroke motorcycles. As a result, the two-stroke engines have all but been eliminated from the Indian market. A small number of two-stroke engines are still used in a few models of mopeds and scooterettes. All other vehicles – scooters and motorcycles of all capacities sold in the market are powered by single cylinder 4-stroke engines. The relative share of 2-stroke engines is now only around 6% of the total powered two-wheeled sales in the country.

In case of four-stroke engine powered two and three-wheeled vehicles, tuning and recalibration - mostly to lean air-fuel ratios - combined with secondary air injection are used to comply with the emission standards for the year 2000. Lean air-fuel mixtures led to improved fuel efficiency desired by the customers albeit with a loss in acceleration, which is acceptable to most of the Indian users of two-wheeled vehicles. Some models of four-stroke powered two-wheelers also use oxidation catalytic converters to control Hydrocarbon (HC) emission to compensate for the increased Oxides of Nitrogen (NOx) emission resulting from lean air-fuel mixtures so that the composite (HC+NOx) standard can be met without sacrificing fuel efficiency. The alternative to the catalytic converter is to switch to richer air-fuel ratio to reduce NOx emission that would adversely affect the fuel efficiency.

Certain manufacturers have used innovative (some of them patented) technologies to partially offset the loss of acceleration without sacrificing fuel efficiency. “Digital Twin Spark Ignition System” and “Automatic Ignition Advance” with respect to speed and load are two such technologies successfully introduced in the market, both aimed at reducing the “engine out” emissions.

The approach for three-wheeled vehicles using two-stroke petrol engines was the same as for two-wheeled vehicles. However, the shift to four-stroke engines did not reach the same proportions as in case of two-wheeled vehicles. Manufacturers attribute this to the lower market pressure due to the fact that the substantial fuel efficiency benefit that attracted the two-wheeled vehicle customer to the four-stroke engine was not achieved in three-wheeled vehicles. Besides, the perception of the owners/operators (who mostly used the three-wheeled vehicles for commercial purposes, such as passenger auto-rickshaws and goods carriers) that the four-stroke vehicle was more complex and costly to maintain was also a contributing factor.

In case of three-wheeled vehicles using compression ignition engines, the primary approach consisted of optimization and recalibration of injection parameters.

Further Tightening of Indian Emission Standards. Further tightened emission standards for two and three-wheeled are likely to be enforced in India to be made applicable from the year 2015. As a member of the United Nations, India is committed to transpose the standards formulated by the UNECE under Global Technical Regulation No 2 into its own laws. India has already adopted the driving cycle (World Motorcycle Test Cycle), the test procedure and the UNCEC proposed limits as an alternative to its own limit values and test procedure. It will further be obliged to transpose the new emission standards, which are being formulated by the UNECE.

In the absence of any official indication regarding further progression of Indian emission standards beyond the year 2015, the present assessment of the potential emission reduction technologies has been done assuming that the future standards would broadly follow the progression of the proposed Euro IV and Euro V (which may eventually be adopted by the UNECE) limit values. It is further assumed that Euro IV and Euro V limit values will be promulgated in India from the years 2015 and 2020 respectively.

Potential Technology to Achieve Further Reduction in Emissions. An assessment of the compliance levels of present vehicle models with the proposed limit values, and possible technology solutions that could be used to meet the proposed Euro IV equivalent standards shows that some of the present vehicle models may meet these using optimization and calibration techniques along with improved after-treatment systems, while many others may require use of advanced technologies such as fuel injection to bring about significant reduction in “engine-out” emissions. Fuel injection systems for small engines are of different types (A) Air Assisted Direct Injection and (B) High Pressure Direct Injection for two-stroke engines, and, (C) Port Fuel Injection, (D) Direct Injection and (E) Air Assisted Direct Injection for 4-stroke engines. Other emerging technology options are Electronic carburetor and the Pulse Count Injection

(PCI). The most promising of these are Air Assisted Direct injection for two-strokes and Port Fuel Injection for four-stroke engines.

The main barrier in the widespread use of fuel injection technologies is the high cost relative to the cost of the whole vehicle and a higher level of complexity from the point of view of the users. Efforts are afoot to reduce the costs of these systems so that they become more affordable to the buyers of the low cost motorcycles.

From a further analysis of the compliance levels of present vehicle models with the proposed limit values, it appears that meeting the proposed Euro V equivalent standards will be more challenging and may require many models to adopt fuel injection as well as improved oxidation catalysts or three-way catalysts in a closed loop system. In this case also, the best-suited injection systems will be the Air-Assisted Direct Injection for 2-stroke engines and Port Fuel Injection for 4-stroke engines. Significant reduction in fuel consumption is achievable on two-stroke engines with Air Assisted Direct Injection on two-stroke engines. Fuel efficiency gains by using Port Fuel Injection in case of 4-stroke engines may be limited by the fact that the basic Indian engines are already calibrated for high fuel efficiency.

It is indicated that catalytic aftertreatment will continue to remain an important component of the emission control strategy for the next levels of emission standards. While many two and three-wheeled vehicles currently use oxidation catalytic converters, the technologies of fuel injection, electronic carburetor and PCI will help to improve the efficiency of these oxidation catalysts and also permit the efficient use the three-way catalytic converters. With a judicious combination of technologies to reduce “engine out” emissions and aftertreatment devices, it seems highly probable that it will be possible to meet the proposed emission standards for the proposed Euro IV and Euro V equivalent levels effectively and at reasonable costs. Additional information concerning the application of exhaust emission controls such as three-way catalytic converters to two and three-wheel vehicles is available in a report from the Manufacturers of Emission Controls Association at: http://www.meca.org/resources/reports (Emission Control of Two and Three-Wheel Vehicles, August 2008).

A few fuel injection versions of 4-stroke motorcycles have already been introduced in the market. The difference between the market prices of these models and those of their original versions (assuming that the difference essentially represents the incremental cost of the fuel injection system) when compared with the approximate costs of the fuel injection systems, show that the former are higher than the incremental price of the fuel injection systems. A major southward impact on the prices can also be expected when the volumes grow.

Control of PM Emissions. Vehicles using two-stroke engines are a major source of Particulate Matter (PM) emission. Four-stroke engines, like their counterparts in four-wheeled vehicles, are not presently considered as significant contributors of PM emissions. Presently, there are no emission standards for PM from two and three-wheelers. Studies recently carried out on PM emissions from two-stroke engines have shown that the oil and fuel quality have considerable influence on the particulate emissions, which are mainly oil condensates. Use of synthetic or semi-synthetic lubricating oils in lower proportions with respect to the fuel can reduce PM emissions. It has also been shown that the oxidation catalytic converters that are now invariably used on all 2-stroke engines also help to reduce the PM emission very significantly.

Two-stroke engines in which Air Assisted Direct Injection is applied are equipped with a separate pump to supply the lubricating oil. This cuts the proportion of oil-to-fuel by half – from 1:50 recommended for carbureted engines to 1:100. Recent research on the emission of PM from 2-stroke engines equipped with air-assisted fuel injection showed that the particulate mass decreased significantly when the oil-to-fuel ratio was decreased from 1:50 to 1:100. Further reduction of the oil-fuel ratio to 1:400, a rate of oil consumption equal to that of 4-stroke engines, the reduction of PM occurred more slowly. This indicated the predominance of combustion generated PM over the oil derived PM. This shows that the application of air-assisted fuel injection can help to reduce PM emissions to the levels of four-stroke engines.

Other studies have shown that, engine technology influences nanoparticle emissions by mixture preparation, mixture tuning, oil consumption, post-oxidation, quality and condition and temperature of the catalyst. The study concludes that, since particulate emission of the 2-stroke engines consists mainly of lube oil condensates, the minimization of oil consumption stays always an important goal.

Fuel Consumption Reduction. There are no fuel efficiency standards for two and three-wheeled vehicles in India. However, on account of the pressure from the market, the Indian vehicles are tuned and optimized for fuel consumption, which is among the lowest in the world. Studies show that Air Assisted Direct Injection employed on 2-stroke engines can reduce fuel consumption significantly, say 25 to 30%. This could help to bring the fuel consumption to a level comparable to that of four-stroke engines. As regards the 4-stroke engines, using Port Fuel Injection can reduce fuel consumption by around 5 to 10% depending upon the model.

Technical Measures Other than Tail Pipe Emission Standards

Evaporative Emissions. There have so far been no standards for evaporative emissions in India for two and three-wheeled vehicles. It is now proposed to introduce a limit of 2g/test using the SHED test method along with the next set of mass emission standards. Evaporative emission standards have been in place for motorcycles sold in California and the rest of the U.S. for some time. In general, these U.S. motorcycles have adopted automotive evaporative emission control technologies such as carbon canisters for meeting U.S. EPA and CARB evaporative emission requirements. Additional information on evaporative emission control technologies for gasoline vehicles is available in a report from the Manufacturers of Emission Control Association (MECA) at: http://www.meca.org/resources/reports (Evaporative Emission Control Technologies for Gasoline Powered Vehicles, December 2010.

Durability Requirements. Although durability requirement of 30,000 km is specified for two and three-wheeled vehicles in India, there is also a need to review the present provisions and revise them suitably. The main area of improvement to be addressed pertains to the need to introduce a system that makes it mandatory for the manufacturers to demonstrate the durability of emission control in a suitable manner and the second aspect is to consider the feasibility and benefit of enhancing the durability mileage from the present 30,000 km to, say, 50,000 km.

Management of In-Use Vehicles. Managing emission control of in-use vehicles (for all categories of vehicles) includes the following steps: (A) Conformity of Production (COP), (B) Periodic Vehicle Inspection (named as 'Pollution Under Control' - PUC), (C) In-Use Conformity Testing (IUC) and (D) On Board Diagnostics (OBD). Among these, the COP system being presently implemented seems to be quite satisfactory and does not need any major changes. The deficiencies of the existing PUC system (for all categories of vehicles) are well known. In addition to a complete revamping of the existing system, a major improvement, particularly in relation to two and three-wheelers, can be achieved by adopting the (Automotive Research Association of India) ARAI Two-Wheeler loaded mode test as a part of the regular procedure for periodic vehicle inspection. It will be necessary to institute further development work to fine-tune the ARAI system and gain more experience. In-use Conformity Testing (IUC), which is not included in the present Indian regulations for any vehicle category, may be introduced after a comprehensive study of the feasibility and effectiveness. Since the study will require considerable expense and time, it would be worthwhile to begin the process based on the experience of the system in Taiwan, the only country to have an IUC system for 2 and 3-wheeled vehicles. The OBD system should be considered for being mandated for vehicles using fuel injection or any other form of electronic fuel management system.

Fuel Quality Requirements of Two and Three-Wheeled Vehicles. Specific literature on the problems faced by motorcycles that could be attributed to fuel properties is extremely scarce. A broad observation is that the characteristics of fuel required for satisfactory performance of four-wheeled vehicle engines are also adequate for two and three-wheeled vehicle engines.

Use of Alternative Fuels such as CNG and LPG. Presently the usage of CNG and LPG is mostly restricted to three-wheeled vehicles. Their use in two-wheeled vehicles, though technically possible, is not practically feasible due to limitation of space in the vehicle for installing the cylindrically shaped gas tank and the various valves and regulators. Due to their gaseous nature at ambient conditions, these fuels burn cleanly in the engine thus producing low PM emissions. However, their impact on the emission of other pollutants is variable. Test results show that there is a reduction in CO emissions – up to 20%, but the Total HC and NOx may show increase in some cases. In fact, catalysts are required to be used on LPG engines to meet the BSIII standards for Total HC. The use of CNG in 4-stroke engines improves its fuel efficiency over the petrol version though the impact in other cases is variable. Looking at the future, due to limited availability for vehicular usage, both of these fuels will remain niche market solutions and cannot be considered for widespread usage.

CNG Vehicles in India and Impacts on Air Pollutants Emissions and Air Quality[3]

In response to a citizen lawsuit initiated in 1985 over poor air quality in Delhi, the Supreme Court issued a series of resolutions instructing the government to ensure that all public transportation, buses, taxis, and auto-rickshaws switch to clean alternative fuel. Its 1998 resolution called for CNG in Delhi, and its 2003 resolution applied to 11 other cities. In spite of several hitches, including supply uncertainties and long waiting lines at refueling stations, by the end of 2003 more than 87,000 vehicles—mainly public-transit vehicles, taxis, and three wheelers—in Delhi alone were using CNG (De, 2004). In 2007, more than 204,000 vehicles in India run on CNG. A more recent update puts total number of CNGVs (including buses, auto, RTV, and others) at 344, 250 in 2010.

Although the environmental factor is undoubtedly one of the main considerations for governments promoting NGVs, some of the emission results have been disappointing or even poorer than those of gasoline vehicles, due to poor conversion, maintenance, and system integration of NGVs (Dondero and Goldemberg, 2005; Flynn, 2002; Gwilliam, 2000; Matic, 2005; Zhaoa and Melaina, 2006). Air quality improvements from introducing CNG vehicles can take place at three levels: local, regional, and global. Local air quality is most affected by particulate emissions from diesel and by photochemical smog that arises from ozone and non-methane hydrocarbons (NMHCs). NGV in general improves tailpipe emissions of particulate matter and NMHCs; the push for NGV buses, for example, is often targeted to improve particulate emissions. Regional emissions are primarily relevant to hydrocarbons (HCs), nitrous oxides, and carbon monoxide. Here the picture on NGV is more complex and depends in large part on the type of conversion system installed on the vehicle. North American OEM vehicles will have a high standard of emission control, while the literature indicates that traditional carburetion-type conversion kits shift but do not reduce emissions, because they are often ‘‘tuned’’ to nonstoichiometric air/fuel rations. Dondero and Goldemberg (2005) compared the emissions of converted CNG vehicles with when they ran on gasoline and found them to exhibit average reductions of 53%, 55%, and 20%in CO, NMHCs, and CO2 emissions, respectively, but average increases of 162% and 171% in HC and NOx emissions, respectively.

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[3] Materials largely extracted from Sonia, Y., An empirical analysis on the adoption of alternative fuel vehicles: The case of natural gas vehicles. *Energy Policy* **2007,** *35*, 5865-5875.

Several studies examined the impacts of air quality after the introduction of CNG found mixed results (Chelani and Devotta, 2007; Goyal and Sidhartha, 2003; Kathuria,

2004; Ravindra et al., 2006). Goyal and Sidhartha (2003) compared the air quality in Delhi during the years 1995–2000 (without CNG) with the year 2001 (with CNG) and found decreases in ambient air concentration of CO, sulphur dioxide (SO2), suspended particulate matter (SPM), and NOx emitted from the transport sector. Kathuria (2004) used a simple linear regression model and a dummy representing CNG implementation (one after December 1, 2002 and zero otherwise) on daily air quality data from 1999 to 2003 in Delhi. No significant effect of CNG conversion was found for SPM, PM10 (particles with aerodynamic diameter smaller than 10 μm), or NOx. The author attributed the lack of improvements to improper retrofitting of liquid-fueled engines to run on CNG.

Global emission issues are related to greenhouse gases (GHGs). Therefore, a comparison should be based on lifecycle GHG (or so called well-to-wheel) emissions, which take into account the entire fuel cycle including emissions from fuel extraction at the well through emissions occurring during the operation of the vehicles, and the global warming potentials (GWPs) of non-CO2 GHGs. Methane has 25 times the GWP of CO_2, according to the IPCC Forth Assessment Report (2007). Compared with the life-cycle GHG emissions of a gasoline-fueled vehicle, a CNG bi-fuel vehicle has roughly 25% less total CO_2-equivalent emissions (Hekkert et al., 2005). Recent political efforts to reduce GHG emissions from the transport sector, such as the Low Carbon Fuel Standard in California (S-1-07, January 18, 2007; Sperling and Yeh, 2009), have stimulated new interest to include natural gas-fueled buses, trucks, taxis, and fleet vehicles as part of the solution to global warming. It remains to be seen, however, whether this will result in higher penetration as well as improved emissions, especially for converted vehicles.

Diesel Stationery Engines

Diesel generators are an important source of diesel emissions in India (as are agricultural tractors). There are PM standards for diesel generators and currently those are in the process of being tightened. Even after the current round of tightening, the emissions from diesel generators will be at the same level as those in Europe Stage IIIA or US Tier 3 off-road diesel engine emission norms. This level of emission performance (0.3 g/kWh) can be achieved with 50 ppm sulfur diesel, but will not require DPFs.

The US and Europe are both in the process of implementing Tier 4/Stage IV off-road emission standards for off-road diesel engines, which will reduce the PM emissions by an order of magnitude (0.025 g/kWh) compared to Tier 3/Stage IIIA levels. These Tier 4/Stage 4 emission limits require ultra-low sulfur diesel (10-15ppm). Unlike the situation with US 2010 or Euro VI heavy-duty highway emission limits, Tier 4/Stage 4 off-road diesel engine compliance strategies will not universally adopt DPF+SCR technologies. Depending on the engine power rating, some

manufacturers are intending to achieve Tier 4/Stage 4 PM emission limits without DPFs, utilizing advanced engine combustion technologies with SCR to achieve the lower Tier 4/Stage 4 PM (and NOx) standards. The implications of Tier 4 compliance without the use of a DPF is discussed in a new report available from the Manufacturers of Emission Controls Association (MECA) at: http://www.meca.org/resources/reports (Ultrafine Particle Matter and the Benefits of Reducing Particle Numbers in the United States, July 2013). Indian DG set manufacturers may be willing to go to Stage IV norms, but they cannot do so without the 10-15 ppm diesel.
Shakti Sustainable Energy Foundation has recently funded a study of the efficiency improvement and emission reduction potential of the DG sets. The preliminary results of the Shakti funded study reinforce the need to go to low sulfur fuels to enable DPF deployment on the DG sets. Kunal Sharma, kunal@shaktifoundation.in, is the contact person at Shakti, and the study itself is being carried out by ICF India.

Low sulfur diesel and DPFs can be applied to diesel generators and have the same impact on diesel PM as DPFs on diesel trucks. DPFs with ultra-low sulfur diesel fuel have been employed on a variety of diesel stationary engines here in the US. A case study report is available from the Manufacturers of Emission Controls Association (MECA) that describes the application of DPFs (and in some cases a combined DPF+SCR emission control system) on U.S.-based stationary diesel engines. This case study report is available at: http://www.meca.org/resources/reports (Case Studies of Stationary Reciprocating Diesel Engine Retrofit Projects, November 2009). The California Air Resources Board in November 2003 adopted an airborne toxic control measure (ATCM) to reduce public exposure to diesel particulate matter (PM) and to control criteria pollutants emitted from new and existing stationary diesel-fueled, compression-ignition engines. The control measure reduces diesel PM and controls criteria pollutant emissions through a combination of limits on annual operating hours and application of best available control technology: DPFs for most types of stationary engine applications. This ARB ATCM also required stationary engines > 50 hp to utilize 15 ppm max. diesel fuel by no later than January 1, 2005. ARB's verified diesel emission control strategies listing includes a number of manufacturers that have verified DPF applications for stationary diesel engines: http://www.arb.ca.gov/diesel/verdev/vt/cvt.htm. At the federal level, the US EPA has also put emission standards in place for new diesel stationary engines that are comparable in stringency and timing to EPA's Tier 4 off-road diesel engine emission standards.

Final Point

The diesel particulate filter technology in transportation is primarily applicable to new private, light duty and heavy-duty vehicles. Technology to be retrofit is custom built and therefore expensive. In California, small transport companies argue that retrofit of their trucks and buses is not possible if they are to remain in business. In a determined campaign to reduce premature death and agricultural crop damage in India, it may be cheaper for society to remove

older vehicles from service rather than attempt to regulate retrofit technology. Additional information on diesel retrofit technologies including oxidation catalysts, diesel particulate filters, and SCR systems, is available from a report from the Manufacturers of Emission Controls Association (MECA) at:
http://www.meca.org/resources/reports (Retrofitting Emission Controls for Diesel-Powered Vehicles, October 2009).

III. Governance

J. Seddon, A. Lloyd, B. Croes and S. Sundar. Thanks go to P. Reddy as well as M.and U. Panwar who made valuable comments on the draft but are not responsible for the results.

Technical Summary

The previous sections have laid out the scientific analysis of the state of air quality in India and its impacts and the various emissions control technologies available. The potential gains from action are significant, in financial, wellbeing, and food security terms. The International Council for Clean Transport (ICCT, 2012), for example, estimates that the gains from investing in cleaner fuels and vehicle emissions control technology to reduce PM2.5 emissions would be at least three times the costs of even stringent control measures.

This chapter focuses on ways to integrate this information into policymaking and implementation as well as public investment planning. The subsections correspond to the elements of successful air pollution control programs in California, the United States, the European Community, and Asia: clear, publicly supported goals and the information base to assess progress; technology-enabled and technology-forcing emission limits for all major contributing sources, and enforcement programs to ensure that the emission standards are met.

Key recommendations include:

- **Invest in building the information basis (monitoring network and source apportionment) for prioritization of investments in air quality improvement and evaluation of progress in air quality.**

- **Upgrade India's fuel supply to provide nation-wide access to Euro – IV (<50ppm sulphur) Ultra Low Sulfur Fuel (ULSF) by 2015 and Euro-V (<10ppm sulphur) by 2017. BS-VI emission norms should be in place by 2019.**

- **Upgrade India's in-use vehicle testing program through a combination of additional staffing, investment in emissions testing, and alteration of registration procedures to strengthen enforcement and thus adoption of vehicle-level emissions control.**

While upgrading fuel quality must be a national government effort given the industry ownership, scale of supply chains, and national movement of fuels and vehicles, we note that other aspects of government require both national and state government participation.

Introduction

“Governance” is commonly defined as the process of integrating public priorities and expert information to effectively allocate public financial and human resources toward development and welfare goals. It has both policy making and policy implementation dimensions – “governance” does not stop with a decree, but includes developing and maintaining the ability to ensure that policies are enforced and updated to achieve the desired ends.

The first subsection touches on the politics of air quality and investments that could be made to increase the incentives for and effectiveness of action to reduce emissions from transport (and other sources). India has ambient air standards as well as emissions limits for vehicles. Public awareness of air pollution and its effects is growing. Moving to the next step of tightening and enforcing standards, however, will require more detailed, up to date, and accurate information about air quality and sources of pollution. The key recommendation in this section, therefore, is to invest in building the information basis for prioritization of investments in air quality improvement and evaluation of progress in air quality. The Central Pollution Control Board (CPCB) has made a significant effort to improve the national network; this trend should continue and include close interaction with the State Pollution Control Boards to optimize investments in building a network that can be used for credible monitoring of ambient air as well as detailed source apportionment.

The following three subsections discuss governance investments to support specific action priorities that emerge from the scientific and technical assessments. Upgrading India’s fuel supply to provide nation-wide access to Euro – IV (<50ppm sulphur) Ultra Low Sulfur Fuel (ULSF) by 2015 and Euro-V (<10ppm sulphur) by 2017 is a necessary first step. BS-VI emissions norms should be in place by 2019. A recent study by Hart Energy and MathPro, commissioned by ICCT, estimated the total costs at $4.2billion, or about Rs. 50 paise per litre at the current volume of production. Informal estimates shared by state-owned Indian oil companies and conferences and other discussion venues are much as two to three times higher. The basis for these estimates should be further explored and analyzed, but in either case the investment could be mobilized through existing public finance mechanisms. Additional steps will also be required to ensure that the distribution network for lower-sulphur fuels is in place and to protect the fuel supply chain from adulteration after refining.

Reducing the full spectrum of health, agriculture, and climate- damaging emissions will also require adoption of vehicle emissions control technologies, especially diesel particulate filters. There may be scope for innovation in emissions control technology to allow the development of an indigenous pollution control industry. Emissions control targets can be mandated and relatively easily enforced in factories or at the points of sale or registration for new vehicles sold into the Indian market; motivating changes to existing vehicles is more of a challenge. Subsection three focuses on strategies for upgrading India’s in-use vehicle testing program to strengthen enforcement and thus adoption of vehicle-level emissions control. International experience demonstrates that strict, consistently implemented regulations focused on emissions outcomes are also likely to drive innovation in emissions control technology.

Emissions control technology and fuel quality go hand-in-hand: diesel filters and current emissions control technologies perform best when they are used with fuel of at most 10ppm (BS-V). Lowering sulfur content in fuel also reduces sulfate aerosols, which mask warming. It is important to simultaneously reduce darker particulate matter to avoid regional warming.

The delay in mandating and enforcing stricter standards may only increase the costs of implementation and reduce health benefits leading to a lose-lose situation. It is then ideal to take actions on the recommendations to reduce per-vehicle emissions without further delay.

The penultimate section moves from the focus on “Improving” vehicles to reduce emissions to the two other legs of a strategy for building a sustainable transport system - one that provides mobility for individuals and supports freight movement for business with minimum emissions. “Avoid” and “Shift” require first, strategic urban planning to reduce amount of travel required; and second, investment in creating attractive, competitive lower emissions options for passenger travel and freight movement. With more than $3 trillion worth of investment in transport infrastructure called for over the next two decades, India has an opportunity to develop a sustainable transport system. “Avoid” and “shift” are both well-recognized options for reducing India’s need for energy imports and the fiscal burden of fuel subsidies as well as climate and health damaging emissions. They feature prominently in Government of India transport strategy statements such as the Ministry of Urban Development’s National Urban Transport Policy, the National Habitat Mission and the interim report of the Prime Minister’s National Transport Development Policy Committee (NTDPC). However, strengthening metropolitan transport governance is a longer run endeavor. Subsection Four reiterates the recommendations of the interim report of the NTDPC and the National Urban Transport Policy in laying the governance groundwork for investing available funds into sustainable transport systems.

The concluding subsection summarizes key points with reference to India’s federal structure. While upgrading fuel quality must be a national government effort given the industry ownership, scale of supply chains, and national movement of fuels and vehicles, we note that other aspects of government require both national and state government participation.

We draw on lessons from California’s experience throughout the document, from insights into political momentum for action to experience enforcing vehicle emissions norms for fleets on the road. The California Air Resources Board (CARB) has had notable success in reducing transport emissions even as the vehicle fleet grew. [Ref. Text Box on CARB] The Indian context is obviously distinct from that of California in many ways, not least because one is a country and the other a state within a federation. The two areas have widely varying income levels, states of the transport infrastructure, and political and administrative jurisdictions. Nevertheless, there are important lessons to be learned from California's experience in formulating and enforcing laws and other initiatives to reduce emissions from transport.

India states do have the legal authority to act on various aspects of transport emissions reduction. Section 17 (1)(g) of the Air Act empowers a state to prescribe vehicular emission standards. This would imply that Indian states have been given by law the powers to notify vehicle emission standards that may be more stringent than the national standards, a power that appears to have been given to California by special dispensation. No Indian state has, however, exercised its powers.

However, these lessons from experience do highlight important elements of the pathway to reducing transport emissions as well as provide an example of the kinds of successes that are possible.

It is also important to emphasize that this document seeks to reinforce rather than supplant the normal process of policy evaluation and prioritization among India's many other pressing development objectives.

About CARB

CARB works with public, business sector and local (city) governments to find solutions to California's air pollution problem. It has an annual budget of $150 million and oversees 35 local and regional air pollution control districts. In addition it receives $166 million per year from fees on vehicle registration and new tire sales. It has a staff of 1100 employees state-wide, most are engineers and scientists and at about 20% have advanced degrees (PhDs and Masters). The state of CA as a whole has 4,000 air quality professionals including officials in local government.

CARB draws on the world renowned scientific expertise in the state's academic institutions including, Stanford, Caltech, University of California and many state colleges in the system by funding researchers to address mission-specific research questions. CARB funds extramural research at a level of $5 million per year, taking advantage of the strong academic community in California and other states. It also funds the development of state-of-the-art emission, air quality and macroeconomic models and conducts its own vehicle testing programs. CARB also has state of the art monitoring systems for most air pollutants.

The governor of California, with the consent of the State Senate, appoints the 12 members of CARB. It is an independent board when making regulatory decisions. Six of the members are experts in fields such as medicine, chemistry, physics, meteorology, engineering, business and law. Six others are elected officials who represent regional air pollution control agencies – one each from the Los Angeles region, the San Francisco Bay area, San Diego, the San Joaquin Valley, Sacramento, and another to represent other, more rural areas of the state. The first chairman was Professor Arie Haagen-Smit, who discovered how urban smog was created and the latest, Ms. Mary Nichols, is an environmental lawyer with extensive experience in leadership positions at non-governmental, state and federal organizations.

Except for the Chairman, the Board only meets once per month and relies on its staff for technical input. The Board oversees a $150 million budget and a staff of over 1,100 employees located in Northern and Southern California. CARB oversees the activities of 35 local and regional air pollution control districts. These districts regulate industrial pollution sources. They also issue permits, develop local plans to attain healthy air quality and ensure that the industries in their area adhere to air quality mandates. CARB provides financial and technical support to the 35 local districts. It is funded by vehicle registration fees and fees on stationary sources and consumer products. It also receives up to $166 million per year in incentive funds from fees on vehicle registration and new tire sales. This goes to diesel engine retrofits, car scrappage, and agricultural, port and locomotive projects.

Emission reduction initiatives at the local level also play a critical role in air quality management. Local governments can contribute to cleaner air through emission reduction measures aimed at corporate fleets, energy conservation and efficiency measures in municipal buildings, public education to promote awareness and behaviour change, transportation and land use planning; and bylaws (anti-idling etc). The South Coast Air Quality Management District (SCAQMD), the district regulatory agency in charge of the South Coast Air Basin, which includes Los Angeles, is authorized to develop stationary source regulations and to set fines for violators. Thus, the biggest polluters pay the most toward funding the air pollution control effort. Also, businesses must pay annual fees for their operating permits. However, since motor vehicles account for more than half of this region's pollution, a surcharge was added in 1991 to the vehicle registration fee. Part of the surcharge goes to the SCAQMD to be used for air quality improvements involving mobile sources such as those promoting ridesharing, developing clean fuels, and as grants for programs intended to reduce vehicle emissions.

Over the past four decades, California has been a test bed for fuel and motor vehicle emission standards that have been copied by the U.S. EPA and the European Union, and are now being adopted in many developing countries, particularly in Asia. Two of the keys to CARB's success are the technical evaluations that go into its regulation development and the very open public process. CARB develops new emission test methods, and in some cases, proves that more stringent emission standards are achievable by funding or conducting technology demonstrations. It encourages participation by all stakeholders, including the public, industry and communities that may be impacted by air pollution disproportionately from others. CARB meets with many stakeholders to hear concerns and to provide a mechanism for addressing their issues. It holds workshops that solicit suggestions and comments on initial issues. The technical data and assumptions are published in advance of the workshops.

Regulations are first proposed in an initial report and additional workshops are held for public comment. CARB change its proposal once significant issues are raised that warrant a revision. Once the regulation is adopted, it issues a formal response to all issues raised. The public has a chance to air their concerns directly to Board members. The Board reviews the technology and enforceability of regulations when necessary to make sure that the regulations meet the expectation held at the time of adoption. CARB considers economic impacts of its regulations on California businesses and individuals, and regulations do not advantage or disadvantage California manufactured products over products manufactured elsewhere in the United States or in the world.

CARB also has a requirement that the scientific underpinnings of all its regulations undergo scientific peer review. This is normally done by the University of California. Underlying this science-based approach is the willingness to move ahead in the face of some uncertainties.

1. Politics & Policy: Motivating Action

Policy initiative in democracies requires public support for momentum as well as technical knowledge and policy analysis for direction. This section discusses options for governance actions that contribute to both political salience and policy analysis. The key recommendation is for further investment in air quality monitoring and more detailed, metropolitan-region specific emissions inventories and source apportionment studies. Selected action should not wait - California acted many times when all the information was not available based on the "precautionary principle" of avoiding likely harm. This information infrastructure is an essential foundation for increasing political awareness and public salience of air quality, supporting evidence-based effective mitigation actions, and monitoring changes in air quality. Credible monitoring of changes in ambient air quality also enables various governance mechanisms, such as performance-linked or specific-purpose grants from the national government, to be created to accelerate policy and administrative action.

Air Quality as an Emerging Political Issue

The scientific evidence regarding the significant impact of air pollution on geographically immediate issues such as public health and agricultural yields as well as regional and global climate change is quite clear.

The public and political salience of air quality as a development priority in India is emerging. TERI (2013)'s survey of over 4000 residents of India's 6 largest cities found a widespread perception that air quality has remained poor or gotten worse over time. (Figure 1) Perceptions about the underlying causes varied, but transport was widely recognized as an important contributor. (Figure 2)

Figure 1

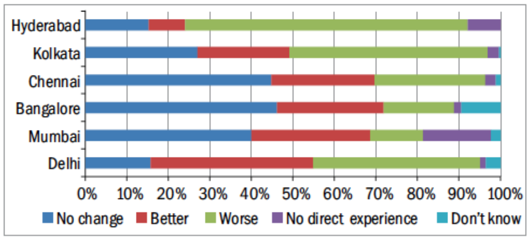

Figure 3.1: Changes in the State of Air Quality in the Past Five Years

Figure 2

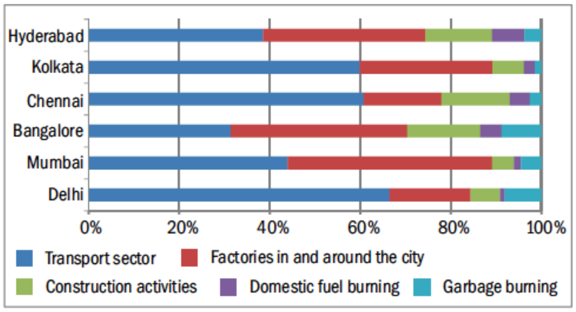

Figure II: Sectors Contributing the Most to Air Pollution in the Six Cities

Ambient air quality standards (AAQS), the legal framework for emissions control, have been progressively tightened. National Ambient Air Quality Standards (NAAQS) were notified by the Central Pollution Control Board (CPCB) in the year 1994 under the Air (Prevention and Control of Pollution) Act, 1981 for seven parameters i.e., suspended particulate matter (SPM), respirable particulate matter (RPM), sulphur dioxide (SO_2), oxides of nitrogen (NO_x), carbon monoxide (CO), ammonia (NH_3) and lead (Pb). The central Government further notified NAAQS for six parameters in the year 1996 under the Environment (Protection) Act, 1986. Most recently, Ministry of Environment and Forests (MoEF) announced the notification of the revised National Ambient Air Quality Standards, 2009 in the official Gazette. The new standards are are common across industrial and residential areas, and more stringent standards are prescribed for some pollutants in residential areas and ecologically sensitive areas. The SPM standard has been replaced with a particulate matter ($PM_{2.5}$) standard which is considered to be more relevant from public health point of view and new parameters, such as, ozone, arsenic, nickel, benzene and benzo(a)pyrene (BaP) have been included for the first time under NAAQS.

Although the general administrative underpinnings for acting on these standards must be strengthened – a challenge we revisit several times in this note – there is some evidence of political responsiveness to air quality. Delhi's winter smog generally makes the headlines, but

November 2012's particularly severe episode provoked more specific actions ranging from a special meeting of Chief Ministers across affected states as well as a short-lived increase in citations that police issued for vehicles without up to date pollution under control (PUC) certificates. It is not clear what longer-run impact these activities had on air quality, but they are a demonstration of emerging political responsiveness to air quality.

India is potentially at an inflection point – in other contexts, episodic action has been the precursor of more sustained investment in air pollution control. In the "western" world air pollution has been a recognized problem for centuries. In the 1600s London was described as having a "Hellish and dismall cloud of sea-coale." London's air continued to get worse due to increases in population and increased use of coal. Finally, in December 1952, dense smoke-filled fog shrouded London for four days. Cattle died at a livestock show. The smoky fog could be seen indoors, interfering with patrons views in movie theaters. A subsequent Ministry of Health report estimated that 4,075 more people died than would have been expected to under normal conditions.

The United States had its own wake-up call in Donora, Pennsylvania. In October of 1948, a strong inversion trapped pollutants in the valley of the Monongahela River. Twenty people asphyxiated and over 7,000 were sickened by the air pollution

The first recognized episodes of smog in Los Angeles occurred in the summer of 1943. Visibility was limited to only three blocks and residents suffered from smarting eyes, respiratory discomfort, nausea, and vomiting. The phenomenon was termed a "gas attack," and was blamed on a nearby butadiene plant, but the situation did not improve when the plant was shut down. Smog events continued to plague Los Angeles, and its residents experienced the highest levels of ozone ever recorded as total oxidant (ozone plus nitrogen dioxide) approached 800 ppb. PM_{10} concentrations exceeded 600 $\mu g/m^3$ in Los Angeles and 1800 $\mu g/m^3$ in desert areas.

Public consensus and a broad commitment to meeting environmental goals are essential if policies are to be successfully developed and implemented. In the first half of the 20th century, pollution was not unrecognized, but the polluting industries had great political clout and the public at large was largely indifferent. It took calamities such as those in London and Donora, Pennsylvania, and the pervasive smog in Los Angeles, to galvanize public support.

The City of Los Angeles began its air pollution control program in 1945, establishing the Bureau of Smoke Control in its health department. On June 10, 1947, California Governor Earl Warren signed into law the Air Pollution Control Act, authorizing the creation of an Air Pollution Control District (APCD) in every county of the state. The Los Angeles County APCD was then established—the first of its kind in the United States. During the 1940s and 1950s, air pollution control focused on obvious sources, such as backyard burning and incinerators, open burning at garbage dumps, and smoke emissions from factories (SCAQMD, 1997). California's legislature formed CARB in 1967. California led the way in the United States, as California legislation and CARB regulations have typically led to similar approaches by the federal government.

The visibility reduction experienced by rapidly developing economies, whether Los Angeles during its post-World War II boom period or India today, provides the populace with a measure of impaired quality of life, and is a valuable risk communication tool for pollution-induced health problems, lost productivity, avoidable mortality, and their collective costs. Temporary emission controls, such as occurred during the 1984 Los Angeles and 2008 Beijing Olympics, showed that it's possible to have dramatic environmental improvement, accelerating public support for clean air policies.

Converting the similar growing awareness in India into sustained action to reduce emissions, however, involves what is known as "entrepreneurial politics."[4] The gains from emissions reduction are dispersed among a broad group of constituents, while the costs of emissions control are (at least initially) concentrated among particular groups such as auto-manufacturers, fleet owners, and oil marketing companies. Smaller, well-defined groups tend to be better able to overcome collective action problems to advocate for their policy position. Building a broader coalition of beneficiaries requires political entrepreneurship. Efforts to build a coalition around investments in transport emissions reduction is further complicated by the fact that transport is an important but not the only contributor to air quality. It is easy to shift blame to other jurisdictions or sources (e.g. brick kilns, road dust, trash burning, construction dust) that other departments must pay to mitigate. Even within efforts to reduce transport emissions, there is room to shift blame from vehicle emissions to the public sector for inadequate public transport infrastructure.[5]

Such politics are not unique to India. Polluting industries have always contended that cleaning up emissions will threaten their livelihood. In free market economies, it is necessary to show a compelling need for pollution controls, typically in the form of negative human health or environmental effects, to gain public and political support for controls. In managed economies, such as the former USSR, environmental protection was generally seen as a bourgeois luxury and a drag on production. In both cases, it is important that society realize that the costs of

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[4] The term refers to one form of politics described in the "Wilson-Lowi matrix," a widely used tool in non-market strategy analysis. See Baron (2012), for example.

[5] We should also note that the emerging movement for "sustainable transport" rests on benefits other than air quality, including: traffic reduction, safety, energy security, and climate change mitigation. See Ghate and Sundar (2013) for a recent summary. While policy proposals seeking to achieve these goals point in the same direction as those seeking to improve air quality, air-quality-motivate policies are likely to go further in reducing emissions beyond CO_2.

pollution are borne by the society at large, through loss of worker productivity, increased health costs, material damage, and degradation of resources.

Political entrepreneurs seeking to strengthen policy must be able to make the case for specific investments in emissions reduction, going beyond the broad air quality impacts on health and agriculture to build public confidence regarding the link between transport and air quality as well as policy-relevant knowledge about what changes are most effective. These "cases" are also important for evidence-based policy to use scarce public resources for effective air pollution mitigation.

Recommendation: Invest in upgrading ambient air quality monitoring and creation of locally specific emissions inventories, particularly, but not limited to, congested metropolitan areas.

Ambient air quality is monitored and different pollutants present in the air are measured across the country at a number of locations (342 operating stations covering 127 cities/towns in 26 states and four 4 union territories of the country) under the National Air Quality Monitoring Program (NAMP) run by CPCB with the help of state pollution control boards, pollution control committees, and the National Environmental Engineering Research Institute. (NEERI) These are primarily chosen to represent areas of high traffic density, industrial growth, population density, emission source, land use pattern and public complaints, if any. Most commonly the pollution source and the pollutant in question are the key deciding factors for designing the monitoring network.[6] If the monitoring results on two consecutive days of monitoring exceed the limits specified in the norms for a given pollutant, it is considered as adequate reason to institute regular or continuous monitoring and carry out further investigations (as per the official gazette).[7]

This network, however, continues to have important gaps in coverage. The System of Air Quality Forecasting and Research (SAFAR) initiative under the Ministry of Earth Sciences has established high-resolution air quality monitoring systems in Delhi and Pune and similar networks are underway in Mumbai, Chennai, Kolkata, and Ahmedabad[8], but other cities (including 47 other urban agglomerations of over a million people each) continue to have limited networks. More importantly, emissions inventories are, for the most part, lacking. Concentrations of respirable suspended particulate matter (RSPM) violate the standards in more than 80% of cities leaving major sections of the urban population exposed to poor air quality. The sources of RSPM are many, however, and require research to establish their exact contributions.

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[6] http://www.cpcb.nic.in/newitems/7.pdf

[77] http://cpcb.nic.in/National_Ambient_Air_Quality_Standards.php

[8] Status according to the SAFAR Home Page: http://pune.safar.tropmet.res.in/Home.aspx

India should ideally have a combination of top-down and bottom-up inventories. (ESMAP, 2011) Top-down inventories would require an expanded monitoring network, collection of samples, and analysis to allocate what's found to different sources. It would also be important to create local source profiles in order to match what's collected in samples to various sources. Bottom-up inventories, that identify sources of pollution and estimate emissions factors using dispersion models, provide important additional information. They may be inaccurate for various reasons - dispersion models and meteorology assumptions may be inaccurate, or sources may be outside of jurisdiction and/or under-reported given incentives of polluters to avoid fines, remediation costs. However, they are important for differentiating between some sources of pollution that have different behavioral/social roots but similar chemical signatures and cannot be distinguished by top-down apportionment (e.g. cooking and heating, soil and road dust).

This kind of information foundation exists for a few of India's largest cities. The Indian Oil Corporation Ltd (IOCL) and the Automotive Research Association of India (ARAI) supported the National Environmental Engineering Research Institute (NEERI) and the Central Pollution Control Board (CPCB) under the Ministry of Environment and Forest (MoEF) to undertake integrated studies combining source and receptor modeling in Bangalore, Chennai, Delhi, Kanpur, Mumbai and Pune. (CPCB, 2010). Guttikunda and Jawahar (2012) summarize the limited range of other local and regional studies.

There are also tools for rapid first-pass assessments based on existing data that can then be fine-tuned. SIM-Air modules, available for free, are designed to estimate emissions and to simulate the interactions between emissions, pollution dispersion, impacts, and management options. The underlying data and emissions factors can be updated by state and city leaders as new information is collected. Guttikunda and Jawar (2013) report on results of a separate emissions inventory undertaken for Pune, Chennai, Ahmedabad, Surat, Rajkot, and Indore.[9]

Several studies have also included technical capacity-building to enable states to maintain and update information for air quality management. The World Bank-funded Hyderabad Source Apportionment Training and Demonstration Project included collaboration between the Andhra Pradesh Pollution Control Board (APPCB), US National Renewable Energy Laboratory (NREL), US Environmental Protection Agency (USEPA) (ESMAP, 2011, Chapter 5). The Indian National Environmental Engineering Research Institute (NEERI) has also provided technical support for building air pollution monitoring and source apportionment capabilities in various cities including Delhi and Pune.

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[9] Guttikunda, Sarath, and Puja Jawahar (2012). "Application of SIM-air modeling tools to assess air quality in Indian cities," Atmospheric Environment 62 (2012) 551e561

Enhanced monitoring and more detailed emissions inventories enable a number of existing governance mechanisms to work more effectively for air quality improvements.

They would, for example, make existing legal standards actionable. The Right to a Pollution-Free Environment has been held to be a part of Art. 21 of the Constitution, which guarantees the right to life. In Subhash Kumar v. State of Bihar, AIR 1991 SC 420, the Supreme Court, while dealing with a Public Interest Litigation, held that:

> "Right to live is a fundamental right under Art 21 of the Constitution and it includes the right of enjoyment of pollution free water and air for full enjoyment of life. If anything endangers or impairs that quality of life in derogation of laws, a citizen has right to have recourse to Art, 32 of the Constitution for removing the pollution of water or air which may be detrimental to the quality of life. A petition under Art. 32 for the prevention of pollution is maintainable at the instance of affected persons or even by a group of social workers or journalists."

This holding is significant as it empowers citizens or NGOs to approach the Supreme Court directly to enforce this right to clean air. The emissions inventories provide an evidence base to inform concrete redressal plans.

The information would also enable more effective federal collaboration, and ideally action, on air quality mitigation by clarifying progress on ambient air outcomes as well as informing state-level strategies. Improved monitoring networks would be essential, for example, if India chose to emulate China's recent move to set specific provincial and local government air quality performance standards. Performance-linked intergovernmental transfers have been used by the national government to motivate a variety of state actions, ranging from reform of State Electricity Boards to devolution of power to local governments to investment in social services. The success of such programs rests on the ability to measure outcomes while leaving local decision-makers to innovate on inputs.

2. Fuel Supply: Upgrades

Status Quo:

As discussed elsewhere in this report, Indian policy on air quality and vehicle efficiency continues to be undermined by its reliance on two parallel standards: Bharat Stage (BS) IV for a handful of cities and BS III for the rest of the nation.

The Mashelkar Committee had recommended that a new Auto Fuel Policy Committee be formed every five years to review progress and the 2013 Auto Fuel Policy committee has been established to develop a road map for vehicular emissions and fuel quality norms through 2025. However, there has been no progression or tightening of the vehicle emission norms since

2010; nor has there been a progression in the supply of Bharat IV fuel in any significant manner beyond the initial 13 cities. A total of 63 cities are planned to receive Bharat IV fuel by 2015 and oil industry representatives speaking to the press in 2012 confirmed the feasibility of this expansion, noting that "We are ready to extend this to 50 cities by 2015. We are prepared. The investment has already been done by the refineries. Now it is only a matter of logistics."[10] However, at present some cities in India have better quality fuel and lower emission norms as compared to the rest of the country, a distinction that is untenable. There clearly cannot be two categories of Indians.

The patchwork of fuel creates confusion, and treats consumers and businesses outside of major cities inequitably. Further, it weakens the logic of the policy overall, since all heavy-duty trucks (the highest contributors to PM loads from the transport sector) meet BS III (350 ppm) standard only. Nothing prevents BS IV vehicles requiring low-sulfur fuels for optimal operation of their emissions control technologies from refueling in high-sulphur fuel areas and thus damaging the vehicle emissions control technologies. The distinction also reduces pressure for to lower emissions from commercial vehicles, since fleet owners have a incentive to purchase and register vehicles outside the BS IV-designated areas because these are less expensive. Since many emissions control technologies require low sulphur fuel to function correctly, Bharat IV vehicles refueling on Bharat III fuel are likely to be emitting more than they are designed to. India has also taken steps to reduce sulphur content in petrol, however, India remains well behind international best practices for both fuels.

Gaseous fuels like CNG and LPG have been introduced in an effort to reduce PM emissions in some of the hotspot cities like Delhi and CNG is now being supplied in 25 cities of the country (MoPNG, 2012a). In Delhi, all the buses, auto-rickshaws, and taxis have been switched over to CNG. Some gasoline driven cars are also being retrofitted with CNG kits. In Bangalore, all the auto-rickshaws are retrofitted with LPG kits. However the overall penetration of these fuels, and the prospects for significant scaling up given supply factors remain slim. Traffic management measures including construction of transport management infrastructure have been taken up in some cities for reducing congestion and hence corresponding idling emissions.

Engine design and combustion processes improvements have already led to a significant decline in PM emissions from vehicles since the introduction of BS-I to BS-IV standards in India. The number of vehicles in Indian cities is growing at a rapid pace and is expected to grow more in the next two decades. The enormous growth of vehicles is negating the benefits accrued by introduction of earlier norms (BS-I to BS-IV), For an example, in Delhi after a decrease observed

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[10] Quote from "a senior executive at state-controlled Hindustan Petroleum Corp. Ltd requesting anonymity." In Raj, Amrit. "Twenty Indian cities to switch to BS IV emission norms by 1 Mar," *Mint* February 26, 2012. http://www.livemint.com/Politics/jSbTuZc2uJysn8pXD399BN/Twenty-Indian-cities-to-switch-to-BS-IV-emission-norms-by-1.html

in the ambient PM_{10} levels during 2004-2007, they have increased to unprecedented annual average of about 250 ug/m3. Further, growth is going to worsen the air quality in future. TERI estimates show that the total number of on-road vehicles are going to grow from about 100 million to about 350 millions in 2030 in India. This will increase the PM2.5 emissions from vehicles from about 100 kt/yr in 2010 to 280 kt/yr in 2030 in a business as usual scenario assuming BS-III all across country and BS-IV in some cities.

Recommendation: The Government of India should without further delay mandate the refineries to upgrade their facilities. The timeline for fuel supply improvements should be tightened as follows:

- *"One country-one fuel" at Euro-IV (50 ppm sulphur) standards all over the country by no later than 2015.*
- *Advancement to Euro –V (10 ppm sulphur) fuel by 2017.*
- *Emissions standards should leverage the opportunities that these cleaner fuels create for high-performing vehicle emissions control technologies and India should achieve BS-VI by 2019.*

Substantial technical analysis undertaken by TERI and ICCT and reported in their submissions to the Auto Fuel Policy Committee shows that refineries can upgraded, existing ULSF production capacity shifted from exports to imports, and/or imports arranged to supply BS-IV (50 ppm) fuel to the entire nation by 2015. Industry experts have concurred that the shift is possible, provided that funds can be arranged.

India should also benefit from advanced technology options like diesel particulate filters (DPFs) to reduce vehicular emissions and improve air quality. This calls for supply of even cleaner fuel (BS-V) at the earliest.

The rapid progression to nation-wide Euro-V (10 ppm) fuel by 2017 will be essential to prevent a recurrence of the ethically untenable current system of dual fuel standards. As emphasized throughout the report "one nation, two fuels" creates challenges for auto manufacturers which then have to produce two types of vehicles, and erodes the gains to be had from optimal functioning of vehicle emissions controls such as DPFs. Having two standards effectively dilutes the impact of the tighter emissions standard, lowering the public health, agricultural, and environmental returns on the investment. The mandate could also encourage refineries to explore the possibility of leapfrogging and thus reducing costs of upgrading fuel quality.

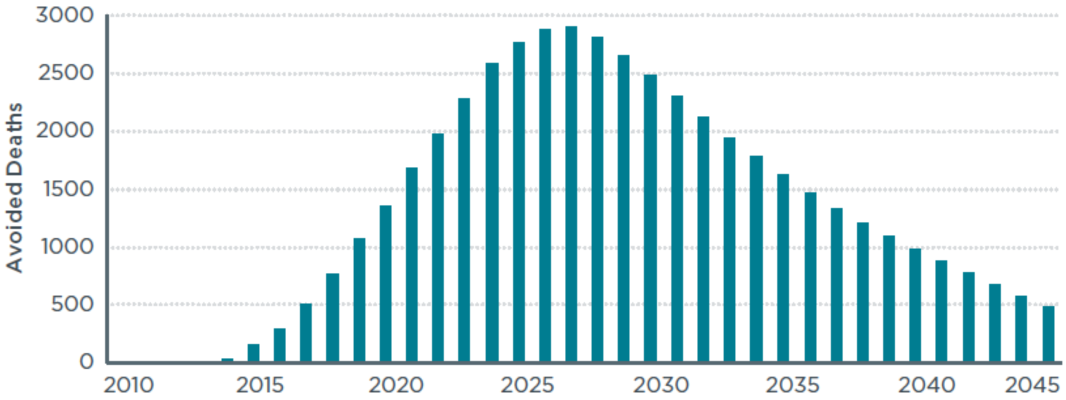
Rapid action is important for air pollution beyond particulate matter. Earlier standards focussed more on PM reduction and less on NOx which is observed to be rising in almost all the major cities in the country. Introduction of ULSF (10 ppm) along with BS-V/VI norms would reduce the NOx emissions (and subsequently O3 in the longer run) substantially along with the reduction in

PM. NOx itself has significant health impacts (next high relative risk after PM), and also causes acid and Ozone formation, and also leads to secondary particulates formation that further add to PM concentration.

This clearly emphasise the need for further advancement of emissions norms to up to BS-VI levels which can bring down the PM and NOx emissions considerably.

Figure 3 below from ICCT (2013) illustrates the potential development gains from enacting the recommended timeline. Shifting fuel supply upgrades forward by just a few years from a trajectory of nationwide BS-IV by 2016 and BS-V by 2020, with BS-VI emission standards in 2025 results in nearly 50,000 avoided deaths by 2045.

Figure 3:



The investment required for this shift to cleaner fuels will be significant overall given the scale of India's refineries, but the capital and operational costs per litre will be a small fraction of the current price. A 2012 study by Hart Energy and Math Pro, commissioned by the International Council on Clean Transport (ICCT), estimated the total cost of upgrading India's refineries to produce diesel with less than 10ppm of sulphur at $4.2 billion dollars, or .9 to 1.1 cents per litre. The dollar costs of investments may be higher today, given the 2013 depreciation of the rupee as well as potentially increased domestic and external borrowing costs as India's macro-economic fundamentals evolve. However, even if these figures were updated, estimates informally cited by the state-owned oil companies that would be affected by a mandatory fuel upgrade project costs of 2-3 times the published study. The roots of these differences are not clear, nor are all of the assumptions behind the calculations currently available in the public domain for comparison. This difference needs to be better understood and the basis for all estimates placed in the public domain for comparative evaluation.

In any case, a range of investment of \$4.2 - \$12 billion for upgrading India's state-owned refineries to supply ULSF of <10ppm sulphur would require significant additional capital investment relative to current plans. According to the 12th Plan Working Group on the Petroleum and Natural Gas Sector, the planned public sector investment investments in refining over 2012-2017 was 88,211 crore, or about \$14.7 billion at today's exchange rates. Overall investment by public oil companies was anticipated to be \$26 billion over the same period.

Much of this investment would need to be provided to the downstream oil marketing companies as an up-front infusion of capital. State-run oil marketing companies, the largest of which are also "corporatized" and listed on public stock exchanges, are currently bearing much of the bill for fuel subsidies as the Finance Ministry seeks to contain the fiscal deficit in government accounts. Imposing additional requirements on the oil marketing companies is unlikely to be financially or politically viable, particularly given competing needs for investment in oil exploration and production.

Capital funding of this magnitude, however, is unlikely to be raised without some form of fiscal-institutional innovation. One possibility would be to earmark part of the ongoing monthly increases in fuel prices (50 paise/litre for diesel, 75 paise/litre for petrol) for a ring-fenced fund that could then be used as collateral for borrowing, similar to the approach followed for the Central and State Road Funds. Alternatively, it may be possible to draw upon the funds accumulated in the National Clean Energy Fund. The NCEF is primarily meant for research and development in non-fossil-fuel sources of energy, so some changes in the guidelines would be required but the aim of reducing transport emissions is consistent with the spirit of the NCEF.

Dispersing the required investment would also require institutional design innovation. The costs of shifting to ULSF include both one-time capital costs and ongoing operations and maintenance (O&M). Even if there were a budgetary or Plan allocation to cover the capital costs, the ongoing current expenditures would effectively raise the fuel subsidy to be absorbed by oil companies unless price increases could be passed on to consumers. The government's current program of steadily increasing fuel prices has demonstrated that such gradual increases are politically viable, but it will be challenging to convey political commitment to extending the increases during and after the 2014 election period.

It is also important to note that India does have substantial capacity to produce ULSF already, but much of this capacity is owned by private refineries that produce ULSF for export. Reliance Industries Ltd's Special Economic Zone refinery in Jamnagar, one of two RIL refineries in the area with a combined capacity of 60MMTPA (compared to 120 MMTPA in the public sector), was the first plant in India to produce Euro-IV fuel.[11] Private owners may require some form of

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[11] Government of India, Ministry of Petroleum (2013. See http://petroleum.nic.in/refinery.pdf, accessed Jan 27, 2014

compensation for investments made to shift business focus to serve domestic markets, and the terms of this compensation could take time to negotiate.

Beyond refineries, it will also be important to secure the fuel supply chain. As discussed in the inception note fuel quality standards can break down in many places along the supply chain. Compliance with fuel quality standards is overseen by the Ministry of Petroleum and Natural Gas, but the oil companies implement the testing. MoPNG representatives are legally required to be present at refineries and depots to sign off on each batch of fuel as it is tested at refineries and oil depots but it is not clear that this actually takes place. The state governments issue permits to fuel transporters, who are also required to maintain lists of the retailers whom they supply. Morris et al (2006) found that recordkeeping was limited in practice and that fuel shipments were not tracked to ensure that the transporters were going to their assigned destinations. The study also found high levels of corruption among transporters' employees as well as those overseeing their compliance. Roychoudhury (2002) also found adulteration of fuel to be widespread. An anti-adulteration cell within the Ministry was established in 2001 but shut down in 2004. Independent labs do exist, but these do not have the authority to obtain samples or to punish actors in the fuel supply chain for any violations detected.

There are a variety of ways to reduce adulteration, with varying levels of financial and administrative costs:

- Increasing the price of kerosene, the most common adulterant relative to diesel and petrol, would reduce the incentives to mix it with higher-grade fuels. The fuel is currently subsidized as part of efforts to improve energy access for the poor, but it is also an important contributor to health-damaging indoor air pollution.

- Controlling the supply of subsidized kerosene to reduce leakage from intended beneficiaries, through tighter beneficiary identification as may be enabled by the Aadhar program or by using dyes or other chemical markers that allow subsidized kerosene to be more easily tracked (as has been attempted already). This would also reduce the fiscal impact of subsidies.

- Investing in improved security systems all along the fuel supply chain. Some of the oil marketing companies are already issuing tenders for improved locks for facilities and tankers. Tenders for shipment services also currently specify locking systems and security capabilities.

- Increasing penalties for bulk and retail dealers found to be supplying adulterated fuel products. The penalties along with a clear system for assigning liability would create incentives for dealers to invest in fuel testing, potentially making the problem more visible. The inception note argued for a national program to test fuel quality throughout the fuel supply chain, including retail stations, by April 1, 2015. A national fuel-testing lab has already been commissioned in Noida, but as planned that facility would not have authority to take action against noncompliant fuels. Regional fuel testing labs should be established in all regions of the country and given authority to take legal action against fuel handlers dealing with noncompliant fuel.

3. Emissions Control Technology

As discussed elsewhere in this report, vehicle-level control technologies provide the bulk of per-vehicle emissions reduction. The technology chapter notes that California's switch from 500pm to 15ppm sulfur in diesel delivered a 25% reduction in diesel PM emissions, while the cleaner fuel coupled with a diesel particulate filter could reduce emissions by around 90% of the emissions occurring with the use of 15 ppm fuel.

The challenge introducing fleet-wide emissions control technology can be broken into two components: setting and enforcing standards for new vehicles entering the fleet, and either retrofitting or incentivizing faster phase-out of existing vehicles. The relative role of these two components depends on the size of the fleet, average vehicle operational lifetime, and the anticipated rate of growth.

Standards for new vehicles are in many ways easier to enforce at the point of manufacturing and are especially effective in situations of high-expected fleet growth (as is the case in India.)

Emission standards for new vehicles are set by the Ministry of Road Transport and Highways (MoRTH) under the Motor Vehicles Act 1988 and Central Motor Vehicles Rules 1989. The standards are in respect of $PM_{2.5}$, HC, NO_x ,SO_2 and CO. They are European standards modified to meet Indian requirements; Euro III as modified in India for instance, is termed as Bharat Stage III. The roadmap for introducing these standards was last set by the Auto Fuel Policy chaired by Dr. Mashelkar in 2002. That roadmap envisaged that Euro III equivalent standards would apply to all vehicles, including two wheelers, all over the country by 2010 and that Euro IV equivalent standards would apply to vehicles in 13 cities which were then considered to be the most polluted by 2010. The implementation of the roadmap also envisaged that Euro III equivalent fuel (with sulphur less than 350 ppm) would be made available all over the country by 2010, and that Euro IV equivalent fuel (i.e. with sulphur less than 50 ppm) would be available in 13 cities. This roadmap has been achieved. Euro III equivalent standards now apply to all new vehicles, including two wheelers all over the country and Euro IV equivalent standards in 13 cities.

The technology options for tightening vehicle emissions standards go hand in hand with fuel options available; the most effective emissions control technologies require fuel of 50 ppm or less sulphur.

The mass emission standards i.e. BS-III, BS-IV etc prescribed by MoRTH also include deterioration factors. The compliance of new vehicles to these standards is tested by agencies authorised under the Motor Vehicles Rules through Type Approval and CoP tests. These agencies are also required to carry out aging tests from samples taken from in-use vehicles of different vintages. However, the aging tests are not carried out and there is no program for recall of vehicles that do not pass the aging test.

The magnitude of the challenge of reducing emissions from vehicles on the road is difficult to estimate given ambiguity about the size of India's vehicle fleet. Data on vehicles come from recorded registrations, but these registrations are based on a system of life-time registration. When a car is registered in India it is given a registration certificate valid for 15 years, but it may not actually be on the road for this length of time. The figures on fleet size may thus overestimate the size of the existing fleet and the extent to which retrofitting and/or incentives for accelerated phasing out would be required.

Nevertheless, some attention to reducing emissions from the existing fleet will have to be considered. Some of the instruments for checking emissions from on-road vehicles exist in principle. Passenger vehicles may be difficult to detect given the long registration period, but commercial vehicles need to obtain a fitness certificate initially after 2 years after registration and subsequently every year.

Separately, idling emission standards have been set under Rule 115 of Central Motor Vehicles Rules to measure Carbon Monoxide and hydrocarbons. The Rule also prescribes standards for maximum smoke density for diesel vehicles and mass emission standards for CNG and LPG vehicles (distinct from standards set for criteria pollutants for new vehicles or with deterioration factors). Rule 115 also specifies the procedure for carrying out the tests and the instruments to be used. Sub Rule (7) of the CMVR empowers the state governments to prescribe the validity period for such tests. In terms of this provision, the Government of Delhi has made it mandatory to carry out a PUC test every three months, whereas elsewhere in India a PUC test is required only twice in a year.

One of the suggestions made by the Expert Committee set up under the chairmanship of Mr Sundar to revamp the Motor Vehicles Act was that Indian states should abandon the current practice of registering a vehicle for its lifetime and introduce a rigorous system of computerized emission testing at given periodicities.

The frequency of the test, however, is less important than the quality of the test and, the efficacy of controls on false certifications, and the extent to which test failures are followed up with fines or other sanctions.

Recommendation: Strengthen state enforcement capabilities through a combination of additional police staffing, procedural changes in vehicle registration, and investment in vehicle testing stations.

In principle, state governments have adequate powers to ensure that vehicle pollution is contained and all the in use vehicles comply with the idling emission standards set under Rule 115. Street-level enforcement, however, comes down to the Regional Transport Offices (RTOs) where vehicles are registered and in principle re-certified as meeting emissions standards, and the police force, which has the power to issue citations for vehicles without valid pollution under control (PUC) certificates.

The police force is currently overburdened. They would be the ones in charge of pulling over and fining polluting vehicles, and they do currently issue fines to vehicles emitting visible smoke or without a yearly pollution certificate. These same officers also check for licenses, driving safety, observance of traffic laws, and other compliance as well as step in to manage traffic.

PUC testing also requires additional investment. A study of PUC testing undertaken by TERI in Delhi over a period of August 2012 – July 2013 shows that barely 20% of the total registered vehicles (about 74 lakhs) take the test. The failure rate is also very low giving rise to the suspicion that the tests are not carried out with integrity. There is also evidence to show that the instruments used for testing are not periodically calibrated and the personnel carrying out the tests are not trained. It is entirely within the competence and jurisdiction of the state governments to ensure that the PUC Centres are properly equipped and manned; it is also for the State governments to ensure that all the in use vehicles come for PUC testing through strict enforcement. It is also within the competence of state governments to set up computerised testing facilities that reduce human intervention in the measurement of pollutants.

Credible enforcement of standards for both new vehicles and those in-use is important for driving innovation that may lower the cost of vehicles. Entrepreneurs and industry respond to certainty - certainty that action/regulations are coming and that they will be enforced. Tighter policy can drive innovation and create economic opportunities for local firms. Technology-based or technology-forcing emissions target allow industry to to pursue the most cost-effective strategy targets. As a result, actual control costs are generally less than originally estimated. In the United States, total air pollution control costs are about 0.5% of GDP, although this has not necessarily resulted in overall job and income loss because the air pollution control industry is about the same size. In 2001, the air pollution control industry in California generated $6.2 billion in revenues and employed 32,000 people (EBI, 2004). The United States figures are $27 billion in revenues and employment of 178,000 people (Ibid).

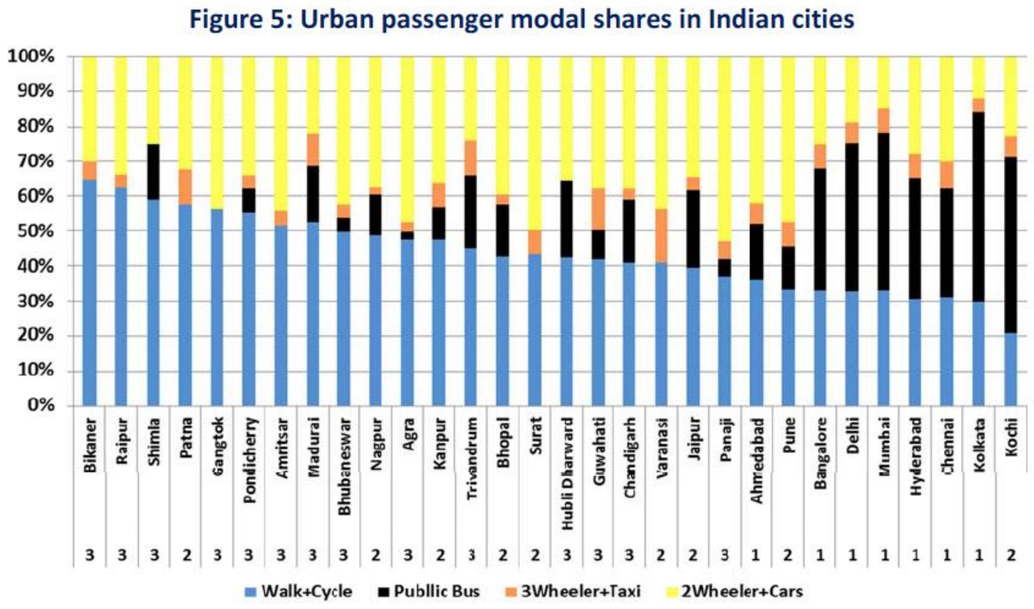
State emission standards set by CARB continue to outpace the rest of the nation and have prompted the development of new control technologies for industrial facilities and motor vehicles. In 1975, the first oxidizing catalytic converters to reduce CO and hydrocarbon tailpipe emissions came into use as part of CARB’s Motor Vehicle Emission Control Program. This is the state’s first example of “technology forcing” regulations, compelling industry to develop a new pollution control capability by a set deadline. Other examples include the first three-way catalytic converter to control hydrocarbons, nitrogen oxides, and CO (1977), “on board diagnostic" (OBD) computer systems to monitor emission performance and emission control equipment (1994), Cleaner Burning Gasoline resulting in gasoline composition changes that reduced vehicle emissions and enabled advances in catalytic converter technology (1996), ultra-low sulfur diesel fuel (15 ppm) in 2006, and the Low-Emission Vehicle regulations, which set stringent emission standards for most mini vans, pickup trucks, and sport utility vehicles (SUVs) to reduce emissions of these vehicles to the level of emissions from passenger cars by 2007.

4. Transport Investment: Avoiding and Shifting

India's National Urban Transport Policy espouses an approach of "Avoid (transport use), Shift (from high to lower-emission forms of transport), and Improve (transport technology to reduce emissions). The lessons for India from California are clearest on the means to "Improve," but Avoid and Shift are also part of India's stated action plan and we discuss them here.

India has an important opportunity to build a transport system in which public and non-motorized transport become the first choice for mobility. Vehicle ownership is just 13 cars/84 two-wheelers per 1000 people. Car ownership is concentrated in the urban areas[12], but a substantial portion of passenger-kilometres traveled in urban India are still by public or non-motorized transport.

Figure 4(Source: Guttikunda & Jawahar, 2012[13])



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[12] Delhi has an ownership level of 157 cars per 1,000 population, followed by Chennai (127) and Coimbatore (125), while cities like Pune (92 cars per 1,000 population), Thane (98), Bangalore (85), and Hyderabad (72) are fast approaching the 100 cars per 1,000 population mark (GoI 2011; MoRTH 2012 cited in Ghate and Sundar (2013).

[13] Guttikunda and Jawahar (2012). "Road Transport in India 2010-2030: Emissions, Pollution, and Health Impacts," Working Paper November 2012.

Travel by foot, bicycle, and bus, however, does not reflect choice as much as necessity at this point – those who can afford two-wheelers or cars typically do buy them.[14]The challenge is to channel the anticipated investments into public transport that remains competitive with private vehicles when people have a choice. TERI (2013) found a high percentage of respondents who used public transport (Figure 4) as well as general public support for "sticks" to discourage vehicle use as well as "carrots" to attract riders to public transport. (Figure 5)

Figure 5

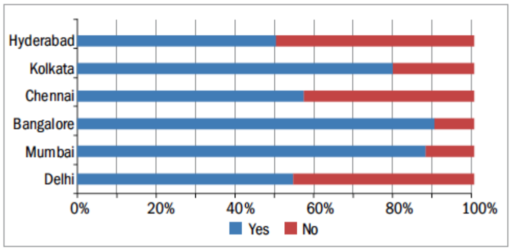

Figure 3.16: Usage of Public Transport

Figure 6

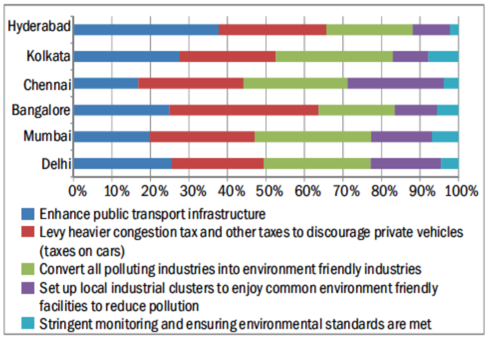

Figure III: Strategies Government Should Adopt to Improve Air Quality in the Six Cities

However, many in the same pool of respondents noted that they use public transport because it is lower cost. Those who do not use public transport – presumably those who can afford not to – cite inconvenience, delay, safety, and other concerns that are common but not intrinsic features of public transport. (Figure 7)

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[14] TERI (2006) shows that vehicle ownership increases faster than per capita income, rising by 1.7% for a 1% increase in per capita income.

Figure 7

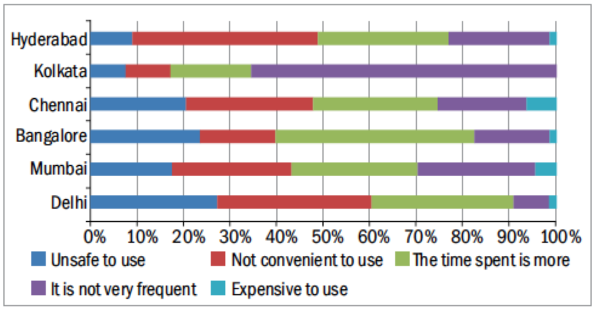

Figure 3.18: Reasons for Not Using Public Transport

Recommendation: *Implement Existing Recommendations*

There are no simple “silver bullets” for quickly converting investment into high-quality urban transport. We highlight some of the relevant recommendations emerging from the background papers for the NTDPC Report. The report will discuss governance changes extensively.

These are:

- Consolidate the fragmented jurisdiction over urban transport to create entities at the city and metropolitan level that have the expertise and authority to direct investments across modes, between infrastructure and service innovation, and other aspects of the transport system as a whole. These responsibilities are currently divided among and between three levels of government, with urban transport acknowledged to be a “constitutional orphan.”

- Ensure that investment in urban infrastructure is technology neutral, if not actively encouraging improved public transport. The national government will inevitably provide much of the capital investment even if metropolitan and state governments develop transport plans, but the terms of urban infrastructure funding have not always been neutral across technology.

- Take advantage of less capital-intensive ways to improve the customer functionality of existing public transport, including: unified ticketing; provision of feeder services and/or policy incentives to support private provision of feeders such as auto-rickshaws; lighting, toilets, and other “amenities” in and around stations; transparent scheduling and communication about routes via SMS and other widely accessible formats.

- Consider some measures to ensure that drivers internalize externalities (e.g. air pollution, traffic, noise, and accident hazards), including congestion pricing, limiting parking spaces (rather than mandating construction of additional parking), and quotas on vehicle registration. There is also an equity argument for such measures: the minority of people with vehicles occupies a majority of road space. Hong Kong's early investments in public transport, for example, were in part motivated by a finding that three-quarters of the road space was used by one-quarter of the population. (Ghate and Sundar (2013))

- Introduce demand management measures to reduce the use of personal vehicles.

India may also reduce emissions by enacting the National Urban Transport Policy's call to integrate ambient air quality goals into the urban planning process. This would require revision of States' Town and Country Planning Acts and Development Acts to include ambient air or related outcomes as part of the objectives for land use planning. It would also require building state and metropolitan governments' capacity to estimate the emissions impact of plans.

California's Sustainable Communities and Climate Protection Act of 2008 offers one example of a policy effort to support coordinated transportation and land use planning with the goal of more sustainable communities that have less vehicle miles traveled, thus reducing fuel consumption and saving money. Under the Sustainable Communities Act, CARB sets regional per capita targets for greenhouse gas emissions reductions from passenger vehicle use. In 2010, CARB established these targets for 2020 and 2035 for each region covered by a metropolitan planning organization. CARB will periodically review and update the targets, as needed. Each of California's metropolitan planning organizations must prepare a "sustainable communities strategy" as an integral part of its regional transportation plan. The sustainable communities strategy contains land use, housing, and transportation strategies that, if implemented, would allow the region to meet its per capita greenhouse gas emission reduction targets. Once adopted by the metropolitan planning organization, the sustainable communities strategy guides the transportation policies and investments for the region. CARB reviews the strategies to confirm that, if implemented, they would meet the regional targets. The Sustainable Communities Act also establishes incentives to encourage local governments and developers to implement the sustainable communities strategy. Developers can get relief from certain environmental review requirements if their new residential and mixed-use projects are consistent with a region's sustainable communities strategy, for example. This regulation is still a new policy and its impacts have yet to be assessed, but may be relevant for India as its urban planning framework evolves.

CARB is also guiding an effort to develop a Sustainable Freight Transport Initiative that will outline the needs and steps to transform California's freight transport system to one that is more efficient and sustainable. This strategy will be a collaborative effort with key partners in the fields of air quality, transportation, and energy. The goals of the strategy include:

- Move goods more efficiently and with zero/near-zero emissions

- Transition to cleaner, renewable transportation energy sources
- Provide reliable velocity and expanded system capacity
- Integrate with national and international freight transportation system
- Support healthy, livable communities

This effort builds upon CARB air quality planning and modeling work that has shown the growing contribution of emissions from freight-related sources and the need to transition to zero- and near-zero emission technologies over the next several decades. This transition will likely need to include widespread use of alternative transportation fuels such as grid-based electricity, hydrogen, and renewable fuels which will have significant impacts for energy providers in California.

5. Conclusion

Various government articulations of transport strategy for India emphasize the importance of enabling people and goods to move freely throughout the nation, but doing so in ways that minimize the environmental and other costs of doing so.

The four parts of the governance strategy outline here work together to support India in achieving this goal. The information base increases the salience of air pollution and guides efficient use of constrained financial resources to improve air quality. It enables informed discussion of costs and benefits and trade-offs between competing goals. Cleaner fuel and vehicle control technology manage emissions from a fleet that will grow. People will have more options for transport as incomes rise, and some of them will inevitably choose cars. These choices may continue to be reinforced by policy incentives: automobile manufacturing is an important and employment-generating business for India and depends in part on growth in the domestic market. Developing transport governance institutions seizes an opportunity to create a sustainable transport system that delivers mobility with the lowest possible environmental cost. Investing in public transport ensures that more environmentally friendly options remain competitive with vehicles as more people can afford cars. Public transport can be faster, safer, and more convenient than private vehicles – if it is well-designed and integrated into urban planning.

Air quality is a national-scale challenge, but much of the ostensive authority to act lies with states. This authority has yet to be activated and requires national effort to build states' air quality management capabilities by investing in air quality monitoring networks and emissions inventories to inform policy, using incentive funding to motivate state action to link national ambient air quality with state urban planning and land use strategy, funding training and expert staff expansion for state pollution control boards, and expanding police forces to enable more on-road enforcement, among other measures. State governments in India have enormous potential as the locus for comprehensive, integrated air quality management, but building state leadership will require national funding to both motivate and enable action.

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