INDIA-CALIFORNIA AIR POLLUTION MITIGATION PROGRAM (ICAMP)

Options to reduce road transport pollution in India

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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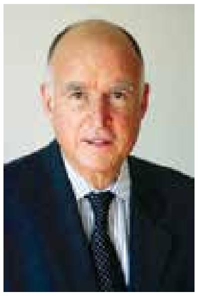


OFFICE OF THE GOVERNOR

Foreword

The Honorable Edmund G. Brown Jr.
Governor of California

I welcome the India California Air Pollution Mitigation Program and the growing cooperation between India and California to improve air quality. This initiative and the 12-point action agenda that emerged from this cooperation promises better health, increased food production, and meaningful reduction of air pollution as well as greenhouse gas emissions.

California has spent five decades as a leader in improving air quality, primarily because California had some of the worst air pollution levels in the world dating back to the 1940s. We are pleased to share our experience and success in reducing particulate and other pollution by 90 percent over that time, with the expectation that India can achieve similar results much more quickly. We can also make progress together to reduce greenhouse gases.

I inaugurated and participated in the first meeting of the India California Air Pollution Mitigation Program during a workshop in Oakland last year and sent my staff to the meeting last February in Delhi. I support this proposal for action in four Indian cities. It is essential that we increase our efforts to reduce particulate and short-lived climate pollutants like black carbon and ozone. California will continue to work directly with India through the California Air Resources Board and my Office, along with The Energy Resources Institute, the University of California San Diego, and the World Bank as we move this initiative forward.

Sincerely,

Edmund G. Brown Jr.

GOVERNOR EDMUND G. BROWN JR. • SACRAMENTO, CALIFORNIA 95814 • (916) 445-2841

Preface

R K Pachuari, Director General of The Energy and Resources Institute, and Mary Nichols, Chairman of the California Air Resources Board

The partnership between India and California is grounded in the fact that both partners face a set of common local and global challenges as they grow. India and California are two of the largest economies in the world, and both face severe, ongoing air quality problems. Both are experiencing dangerous impacts of emissions from pollutants on health, global climate, and economic productivity. It only makes sense that India and California work together to find solutions.

Collaboration on both technology and policy solutions for air pollution and climate change can help improve regional air quality and protect public health. California's long history of reducing air pollution can provide valuable insights for India as it works to mitigate air pollution, even as its population of people and vehicles grow.

In the 1960s, California faced an unprecedented public health challenge. California had air pollution levels among the highest ever recorded, due to large increases in population, traffic, diesel trucks, coal-burning industries, and agricultural burning – all fueled by an economic boom following World War II. Despite a doubling in the number of people and cars, and a tripling in the number of miles driven, California has succeeded in reducing levels of all air pollutants by 75 per cent to 90 per cent over the past 50 years. Now, economic activity, vehicle population, and resultant emissions are similarly growing in India; Indian states and the Union Government can learn from California's experiences.

The *India-California Air Pollution Mitigation Program (ICAMP): Options to reduce road transport pollution in India* lays out a practical strategy to reduce air pollution in India. It will help to improve air quality in India, and reduce the deleterious effects of air pollution on death and disease rates, crop yields, and global temperatures – while continuing to grow India's economy. Many of the solutions to air pollution are the same as those needed to mitigate the impacts of global warming. Subnational partnerships, like those being developed through ICAMP, are emerging as critical elements of a concerted, international effort to adequately address the challenge of global climate change.

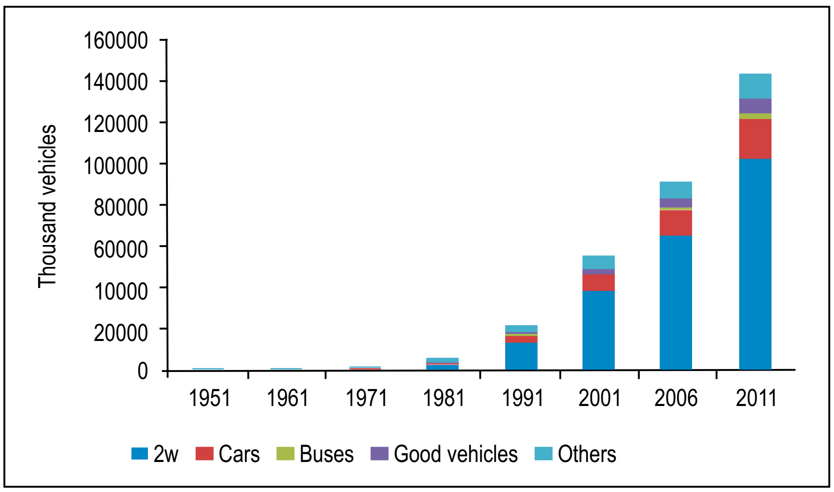
ICAMP is a partnership that draws on the scientific, technical, and policy expertise of academic and government partners, including The Energy and Resources Institute (TERI), Scripps Institution of Oceanography at the University of California at San Diego (SIO-UCSD), and California Air Resources Board (CARB). This partnership is facilitated by the World Bank, and will not succeed without its active participation. TERI is one of the largest non-profit policy research organizations in India and a scientific leader in the field of air pollution. Scientists and engineers at TERI are constantly engaged in fundamental research to help policymakers understand the environmental problems and potential solutions. SIO-UCSD is one of the leading air pollution and climate research institution in the world.

ICAMP grew from conversations between Dr R K Pachauri, the Director General of TERI, and Professor Veerabhadran Ramanathan, of SIO-UCSD, one of the world's foremost atmospheric scientists. The operating principle of ICAMP is to bring these researchers together with other US scientists and CARB to help transfer to India, California's experiences and successes on reducing particle and ozone pollution from the transportation sector. ICAMP facilitates knowledge transfer and capacity building to accelerate integration of air pollution reductions with ongoing transportation development initiatives in India. Through meetings in California and Delhi, and the authoring of this report and a prior one, officials from the Indian Union government and state governments met with academics and officials from California to explore key issues and solutions to deal with environmental impacts from transportation.

The World Bank is interested in working to reduce black carbon emissions and ozone – pollutants with multiple impacts on public health, crop yields, and global climate change. The efforts under ICAMP to reduce these pollutants in India can provide critical benefits on a local and global scale. The partnering organizations are grateful for strong support from the World Bank.

II.

India's vehicle fleet is growing rapidly. In 1991, there were 20 million vehicles in the fleet, in 2011, the number had skyrocketed to 140 million, and by 2030, it is expected to reach a staggering 400 million vehicles.

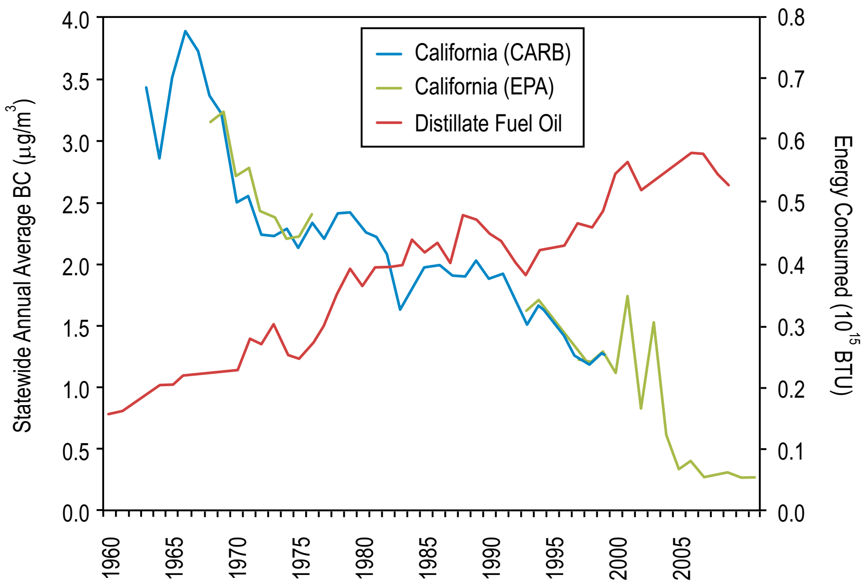


Along with this rapid growth in vehicles has come a rapid growth in emissions, particularly from trucks in urban areas. Vehicle emissions have become a substantial contributor to outdoor air pollution in India, bringing critical public health consequences. The World Health Organization estimates that of the 67 risk factors studied in their Global Burden of Disease project, outdoor air pollution ranked 5th in mortality and 7th in health burden in India, contributing to 627,000 deaths and 17.7 million healthy years of life lost in 2010. The World Health Organization also found that thirteen of the twenty most polluted cities in the world are in India, with New Delhi at the top of the list.

California's air pollution problems in the 1940s and 1950s have many similarities to India's current situation. Large increases in population, traffic, diesel trucks, coal-burning industries, and agricultural burning led to air pollution levels among the highest ever recorded in the world. But California demonstrated that economic growth can be decoupled from air polluting emissions. For 40 years, despite claims that it would destroy the automotive industry, CARB has pushed cleaner vehicle standards, and today, cars in California are 99 per cent cleaner and diesels are 98 per cent cleaner than they were in the 1970s, while the vehicle industry continues to flourish.

In the 1990s, CARB pushed clean fuel standards forward – despite false claims from the oil industry that they would lead to gas price spikes and cripple consumers – and today, California has the cleanest fuel in the world. California's clean fuel standards are single-handedly responsible for reducing air pollution emissions by 15 per cent and cancer risks from vehicle pollution by 40 per cent – for pennies per gallon. Now, California is again proving conventional wisdom wrong and showing that it is possible to dramatically reduce emissions of greenhouse gases while growing its economy. The average Californian spends significantly less money on household electricity and gasoline than the average American, and California gets twice the economic output for every unit of electricity that it uses than the rest of the country does.

California's successes can provide elements of a template for India. The costs of emissions control are outweighed many times over by large public health benefits, improved crop yields, and job creation. Since California first began regulating vehicle emissions 50 years ago, the state's economy has grown twentyfold, from $100 billion to $2 trillion.



California's actions for reducing air pollution – and improving public health and crop yields – have also had large climate co-benefits. Professor Ramanathan and his fellow investigators found that California's emissions policies have also reduced black carbon emissions by 90 per cent over the past 45 years. This dramatic, unique reduction in black carbon has come from reduced diesel tailpipe emissions, improved engines, and California's mandated low sulphur fuel – even while diesel consumption has increased fourfold. The climate cobenefits of these actions to improve public health immediately are equal to 513 per cent of California's total greenhouse gas emissions over the past 20 years, alone.

Short-lived climate pollutants like black carbon and ozone represent the ultimate nexus of air quality and climate. CARB continues to reduce diesel emissions from trucks and the ports of California to further improve air quality and tackle climate change. By 2015, CARB will also complete a comprehensive plan with detailed actions to further significantly reduce emissions of short-lived climate pollutants in the coming years and deliver important, immediate benefits for public health and climate.

III.

India's policy for reducing air pollutants from transportation is Avoid, Shift, and Improve. The ICAMP authors recommend 12 action items that support the three elements of Avoid, Shift, and Improve and form a strategic framework for reducing India's air pollution from the transportation sector in the future.

National fuel quality must be improved. This single step underlies much of the Improve element of the ICAMP Action Options. The Auto Fuel Vision and Policy 2025 has already done strong technical work to identify options. Now, it is up to the Government of India to move forward on this issue.

Refinery improvements can be financed by continuing to reduce subsidies on diesel fuel and kerosene. Indian government has announced to stopped subsidizing diesel. What originally may have been intended as a welfare transfer to poor and rural India must now be seen as a socio- economic loss, as refineries in India claim to be without funding for producing the lower sulphur fuel that directly reduces the emissions that lead to premature death and also enables the cleanest diesel technologies.

Another fundamental step is to build a national air quality monitoring network. Without adequate and accurate monitoring, a scientific approach to improve air quality in India and track progress is limited. More monitors and more frequent calibration are needed.

India, like California, mandates emissions standards for new vehicles, but its program is still relatively new. With decades of experience, CARB can share best practices for enforcing vehicle emissions standards through rigorous laboratory certification and monitoring of in-use vehicles, including random onroad inspections in collaboration with traffic police.

The successful enforcement of vehicle regulations in California also includes the imposition of statutory fines, which increase with the severity of non-compliance and the size of a business deemed to be in violation. Adapting this practice to India's fiscal system could be an important element of knowledge transfer and capacity building with CARB. CARB could advise India on how to set up an incentive program, a financial one if possible, to remove old vehicles from the road and encourage retrofitting diesel vehicles in the existing fleet. California is one of the few places that is cleaning up in-use diesel vehicles, a practice that has been essential in achieving a rapid large reduction in emissions and black carbon levels.

California's aggressive efforts to curb air pollution were driven by broad public support and recognition that air pollution poses a threat to public health, economic growth, and quality of life. India may be reaching a similar tipping point. A 2013 survey by TERI of over 4,000 residents in India's six largest cities found a widespread perception that air quality has remained poor or gotten worse over time. Perceptions about the underlying causes varied, but transportation was widely recognized as an important contributor.

The action items identified in this report should be tried in several cities of India to gather evidence on measures that are most effective under a given circumstance. Just as California's actions provide a template for actions replicated throughout the United States, this program could function as a national laboratory for India.

IV.

We hope that the new Government of India will welcome our report and incorporate it into a broad strategy to address a number of critical environmental issues in India, including air pollution and climate change. As California has shown, improvements in environmental and public health can be achieved alongside rapid economic growth. Increasingly, it appears that they not only *can* coexist, but they *must*. This report lays out a practical strategy to improve the health of India's citizens, increase agricultural production and food security, and ensure sustained growth by slowing the pace of global climate change and growing clean technology industries.

Contents

Executive Summary

I. About this Report

The India-California Air Pollution Mitigation Program (ICAMP) focuses on the transportation sector and explores practical and proven pathways for mitigating air pollution. 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 particulate matter (PM) and pollutant gases that produce ozone in the lower atmosphere. In the atmospheric science literature, PM or particles are referred to as aerosols. PM and lower atmosphere ozone are the two dominant pollutants that impact human health. The cost of reducing emissions, 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 cleanup costs. In addition, mitigation of particles and lower atmosphere ozone has huge co-benefits for food security and mitigation of climate change. The fundamental issue that the authors of ICAMP confronted was the following:

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

We decided to focus on the pollution from the road transportation sector. Strong economic growth and competitive markets have led to tremendous growth in the number of motor vehicles. Due to relatively low levels of vehicle ownership per capita, there is high probability of further growth of private vehicle demand in the country. Therefore, in this report where we use the term transportation sector we are referring to road transportation (both on-road and off-road) and does not include air or water transportation. Heavy-duty vehicles have major shares of 52 per cent and 83 per cent respectively in particulate matter (PM2.5) and oxides of nitrogen (NOx) emissions from transport in India. The transportation sector energy projections for the year 2030 show that under the business as usual (BAU) scenario, the emissions from the transportation sector will grow by about threefold for PM2.5 and fivefold for NOx. Black carbon (BC) emissions are a subset of PM2.5. Various estimates suggest that at the national scale, the transportation sector has contributed 7-34 per cent to overall B C emissions across different years. However, the contributions may increase from urban centers, e.g., in Bangalore the contributions are as high as 56 per cent from the transportation sector. We can only assume that BC will grow at a rate similar to that of PM2.5. This means that air quality concentration levels in the present context are going to be worse in the future.

We pursued these questions through a year-long process of review and synthesis of the literature, assisted by a great number of scholars and government officials who contributed their ideas. Communication among the stakeholders was facilitated by a workshop in Oakland, California in October 2013 and a policy conclave in Delhi, India in February 2014. The two key institutional partners of ICAMP are The Energy and Resources Institute (TERI) and The Scripps Institution of Oceanography of the University of California, San Diego. Key sources of wisdom and experience included participants from the Government of India and from the Government of California, particularly the Air Resources Board. Through the process of research, authorship and face-to-face meetings we gradually formed a network committed to the reduction of air pollution from the transport sector in India.

None of this could have happened without the generous support of the World Bank. The World Bank is keenly focused on the problem of short-lived climate pollutants in South Asia and for that we are thankful. The World Bank Initiative is supported in turn by grants from the Government of Australia and the Asia Sustainable and Alternative Energy Program.

II. 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 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, which is the focus of this report, vehicles have grown from 20 million in 1991 to 140 million (includes all road vehicles) in 2011 and the fleet is projected to grow to more than 400 million vehicles by 2030. While this growth in vehicle fleet has contributed significantly to the mobility and economic growth, the development has come at a huge cost to human well-being and sustainability.

- First, the transport sector is 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 some of the precursors for ozone in the atmosphere. In this report, when we discuss health effects of aerosols we will refer to them as PM to be consistent with the practice of the air pollution community. Aerosols come in a variety of sizes ranging from nanometers to tens of micrometers. We are primarily concerned with aerosols smaller than 2.5 micrometers. Although the largest sources of air pollution are residential burning of solid fuels (biomass and coal), power generation and industry and open burning of crops, the transport sector is also a major contributor. The relative fractions of these sources vary from region to region and from nation to nation within each region. However, in many major urban areas with high population density, the transportation sector contributes 40 per cent to 50 per cent to PM sources and even larger percentages to pollutant gases (e.g., nitrogen oxides, NOx) that produce Ozone. This fact is important because, currently 52 per cent of the global population live in cities and that share is projected to grow to 75 per cent in the coming decades.
- Next, the transport sector is also responsible for about 25 per cent of all energy related carbon dioxide (CO_2) emissions and about 20 per cent of global emissions of black carbon (BC), the second largest contributor to warming of the planet, next to CO_2.

The negative impacts of these pollutants embrace all aspects of human well-being: Health, Food, and Water.

Health: Ambient PM from all sources, including the transport sector, lead to about 3.2 million premature deaths every year globally. 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 premature deaths in 2010. The corresponding estimate for the US is 103,000 deaths.

Food: The ground level ozone produced by pollutant gases (such as NOx) released during combustion of fuels leads to over 5 million tons of crop damages(primarily wheat and rice) which could be as high as 25 million tons in India every year.

Water: Although not widely recognized, air pollution has significant effects on water directly and indirectly through climate change. Aerosols (sulphates, nitrates, organics, and dust) reduce sunlight (known as dimming) reaching the ground which reduces evaporation and hence precipitation. Some of the aerosols also nucleate copious amounts of cloud drops, which reduce the precipitation efficiency of low-level clouds. In addition, some of the aerosols cause surface cooling and alter land-ocean differential heating, which also leads to reduced rainfall. In addition, ozone and black carbon are two important short-lived climate pollutants (SLCPs) that cause surface warming (see Scientific Basis chapter for more details) as well as warming of elevated regions of the Himalayas. Lastly, these two pollutants have been shown to have expanded the tropical circulation, which determines the regional locations of precipitation in the low latitudes and deserts in the sub tropics.

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 parts per billion (ppb). Between 1968 to 2008, California reduced emissions of ozone precursor gases (carbon monoxide [CO], nitrogen oxide [NOx] and sulphur dioxide [SO_2]) by 75 per cent to 90 per cent and cut its black carbon (major part of diesel PM) emissions by 90 per cent while its population increased by 100 per cent, the number of vehicles increased by 175 per cent and its diesel consumption as well as miles travelled increased by 225 per cent. The cost of control was about 0.5 per cent of gross domestic product (GDP) and brought in $10 to $30 of health benefits for each $1 spent in control and added 30,000 jobs in the air pollution control industry and 123,000 jobs in the clean energy industry.

The University of California at San Diego (UCSD) led a study (Ramanathan et al, 2013), which analyzed the comprehensive statewide measurements of ambient black carbon and other particles, and demonstrated the success of the improvements in improving air quality (Figure below):

The climate-change mitigation effects of reduction in diesel black carbon (BC) emissions from 1989 to 2008, is equivalent to California reducing its CO_2 emissions by 21 to 50 million metric tons annually, i.e., it is equivalent to taking 4 million cars off the road. The primary message from the California experience is that (Ramanathan et al, 2013):

Targeting air pollution emissions from the transportation sector has huge benefits for human health, water 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) and are important contributors to global warming and regional climate change such as retreat of glaciers, disruption of tropical precipitation patterns and extreme weather.

The California Air Resources Board (CARB) is not done improving air quality. New regulatory steps will emerge in the area of above ground storage tanks and enhanced vapour recovery and are now in the stage of public comment. CARB is also developing a Sustainable Freight Strategy. California has a state of the art scientific monitoring system for air pollution that should serve as a baseline for the monitoring system recommended for India (Action Option 1). The University of California at San Diego (UCSD) has developed one of the largest and most agile university based micro-grids for electricity (with solar and fuel cells) that generates 42 megawatts and saves the campus $800,000 per year in energy costs. It now has started a program for electric cars using "smart" system to access the micro-grid (Action Option item 10) in collaboration with Mercedes-Benz, RWE (Germany's second biggest utility), and K2Ngrid, a local company and the California Energy Commission. The electric vehicle smart grid program is documented in Chapters 2 and 4. Specific cases will produce other areas of cooperation. Several of India's coastal cities with ports (Chennai, Mumbai, Kolkata, for example) could benefit from the California experience on reducing emissions in ports and drayage. UCSD also has an outstanding program in aerosol, air pollution, and climate change research and can set up joint programs with institutions in India for education and training.

The state government of California along with UCSD and CARB are keen to share the knowledge and regulatory experience with India at the central and state government level as well as at the institutional level, as India moves forward with the 12-Action Options outlined below.

India has a great opportunity to benefit from the *Improvement* in the transportation sector demonstrated by California and leapfrog to a sustainable transportation system by adopting and implementing a holistic path of:

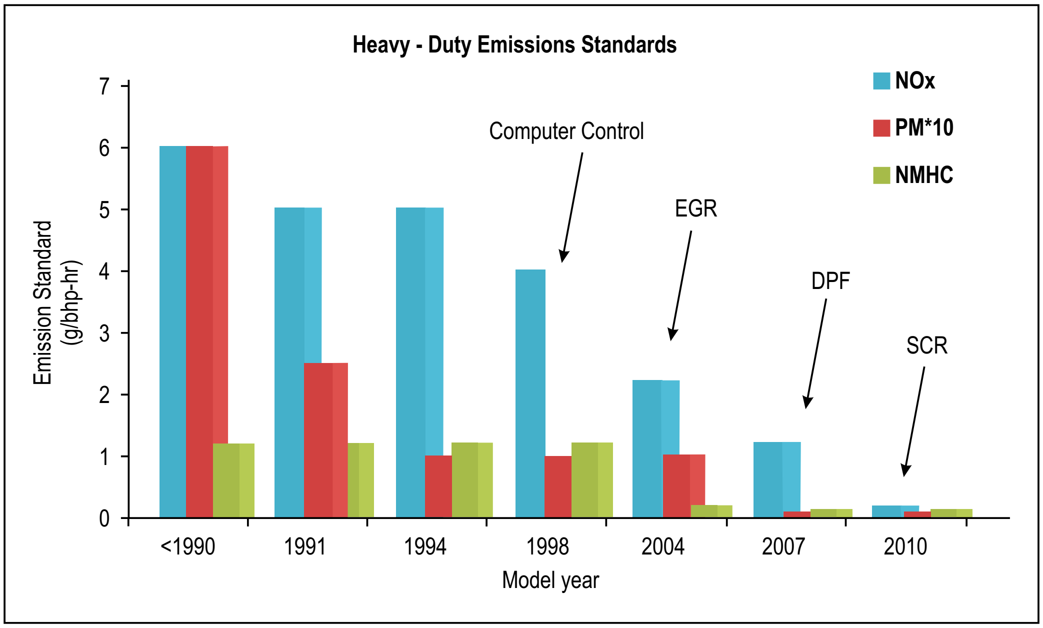


Figure 0.1: History of engine and fuel improvements in California and impacts on emissions of NOx, PM and volatile organics (non-methane hydrocarbons [NMHC])

Source: B. Croes (CARB, 2013)

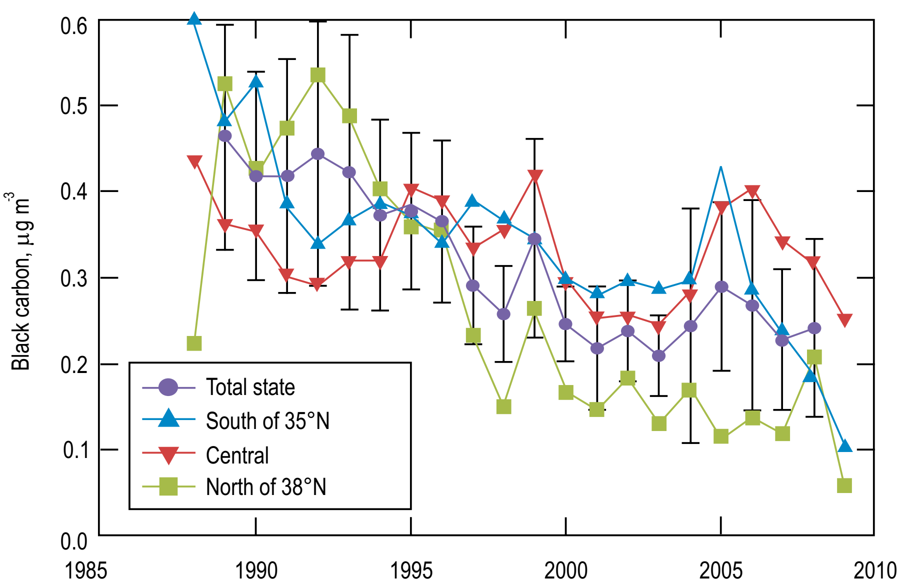


Figure 0.2: Trends in Black Carbon over south, central and north California in response to emission reductions from diesel engines (on-road and off-road).

Source: Ramanathan et al (2013).

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 land-use planning to reduce the amount of travel and transport required for a given level of economic activity; 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

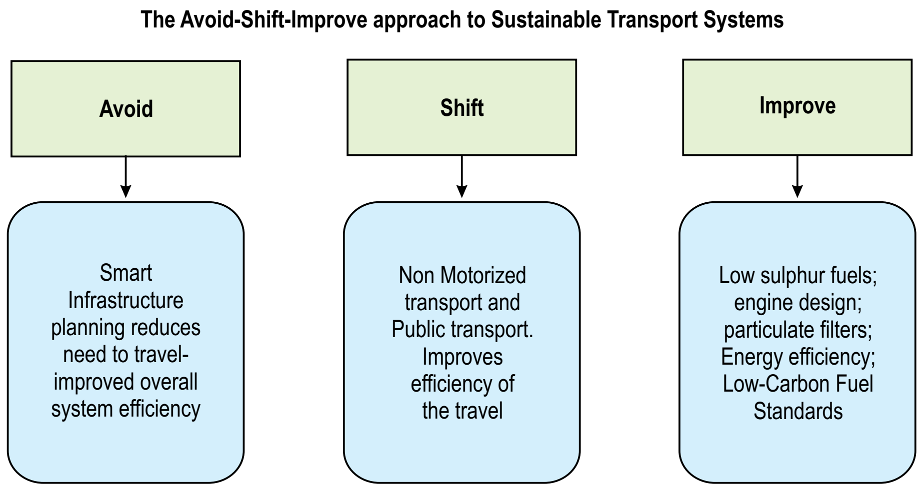


Figure 0.3: Avoid, Shift and Improve (ASI) System
Source: UNEP

Commission, Government of India 2013), India has a great opportunity to develop a sustainable transportation system. This document lays the groundwork for implementing the Avoid, Shift And Improve (ASI) approach.

This relies heavily on "Science and Technology informing Policy," but this report is also focused on implementation of the policy and hence Governance is given a prominent role in the report. The whole process of Science, Technology, Policy and Governance to implement intervention requires dynamic and adaptive management, for which we need pilot projects in several locations to evaluate the performance of the interventions.

The first of five chapters describes the scientific basis of the proposed Action Options. It calls for a balance between field studies and monitoring stations to determine compliance and health exposure studies (see Action Options item 1), 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 that air pollution has a large impact not only in urban situations but also on regional climate. Health impacts take the central role in our criteria for air pollution mitigation.

The second chapter delves into technology measures required to drastically cut emissions of PM and ozone precursors, focusing on technologies that have high potential for emission reduction. In order to achieve a >95 per cent reduction in tailpipe emissions from a mobile source, it proposes: Cleaner engines (see Action Options item 3); After-treatment such as filters (see Action Options item 5); Cleaner gasoline and diesel fuel and Alternative fuels. The focus of the chapter is largely on diesel vehicles since, it is dominant source of PM. However, some of the steps like introduction of catalytic converters are applicable to petrol car as well. To achieve an 80-90 per cent reduction in emissions from stationary sources, it prescribes: Low-NOx burners, selective catalytic reduction and cleaner fuels. All of these changes follow California's path and fall under the 'Improve' part of ASI transportation system.

In the third chapter, the report outlines strategies for Policy and Governance of the ASI transportation system. Governance is defined as the process of integrating public priorities and expert information to effectively allocate public financial and human resources toward development and welfare goals.

In the fourth chapter, we present our recommendations in 12-Action Options. The Action Options is composed of twelve specific steps in priority order that form a coherent strategy for reducing emissions from the transportation sector, and thereby improving human health, agricultural productivity, and climate change. The action areas draw freely from the list of California actions and include the three categories of action, improve, avoid and shift sources of emissions. Each action area is presented with contextual information, suggested lead figures and other initiatives that might contribute to the achievement of this program.

In the last chapter, the ICAMP authors delineate a way forward. We have tentatively chosen four cities (Ahmedabad, Chennai, Bangalore, and Dehradun)for pilot projects and will reconfirm this in mid-November 2014 workshops. The pilot projects would be based on detailed multi-discipline analysis and designed to evaluate the success of the twelve steps included in the Action Options and dynamically modify or improve them as necessary. Obviously this requires Memoranda of Understanding between the state governments of India and ICAMP and approval from the Government of India. In addition, California and the Indian States of Gujarat, Punjab, and Uttarakhand are discussing the possibility of collaboration in various areas including vehicular emission control.

ICAMP and CCAC Complementarity

The India-California Air Pollution Mitigation Program (ICAMP) is funded by the World Bank. The primary objectives are to improve human health and crop yields through reduction of air pollution (PM2.5, ozone, and black carbon), particularly from the road transportation sector. The secondary objective is to mitigate negative effects of regional climate change such as reductions in precipitation, warming, and melting of Himalayan glaciers. Towards this latter objective, ICAMP has a goal to target those air pollutants that also reduce radiative forcing of global warming. Such air pollutants (e.g., black carbon and gases that produce ozone) are referred to as short-lived climate pollutants (SLCP). It is built on the premise that California has successfully reduced SLCP in diesel transport and that knowledge might be a pathway for India to walk at a greater pace than California did. Crucially, California did not suffer any loss in economic growth and this should be an attractive feature of the program to Indian government and business figures striving for sustainable development.

The United Nations Environmental Program, Climate and Clean Air Coalition (CCAC) aims to reduce radiative forcing of SLCPs. One of the directions for the CCAC is the heavy-duty diesel initiative. This initiative has some 75 members, some governmental and some companies or non-profit organizations. The International Council on Clean Transportation (ICCT) is the non-state lead partner in the heavy-duty diesel initiative. ICCT is also participating in the ICAMP by drafting segments and providing comments on others. In common, the CCAC heavy-duty diesel initiative and the ICAMP report focus on the benefits of their initiatives on climate change and human health. The CCAC additionally focuses on fuel economy and energy security. The ICAMP report additionally focuses on crop loss.

Similarly the CCAC and the ICAMP report have an overlap in their action steps. Both initiatives promote a policy of improvement of the vehicle fleet. The parties would encourage their partners to adopt low sulphur fuel, the uptake of emission reducing technologies, retrofits or scrappage for the existing vehicle stock based on a strong program of inspection and maintenance. However, the ICAMP approach opts for a number of action steps that fit under the rubric of avoid and switch. ICAMP's approach would shift road transport to other modes, increase the cooperation between California state programs and those of the Indian states, encourage the use of non-motor transportation and the spread of electric vehicles.

ICAMP's report is expected to be published by November 2014. The CCAC heavy-duty diesel initiative is aiming for a Green Freight Action Plan in December 2014 to coincide with the next Conference of the Parties of the United Nations Framework Convention on Climate Change.

The CCAC heavy-duty diesel initiative cooperates with countries that become members. Their work is concentrated in Mexico, Peru, Bangladesh, Chile, and Vietnam. ICAMP might be expanded to other countries e.g., Nepal or Bangladesh. The CCAC seeks to bring projects to the Multilateral Development Banks, e.g., on refinery upgrades in countries, which they are assisting. The ICAMP on the other hand recommends the reduction of the diesel fuel subsidy in India, freeing up funds for refinery and fleet modernization.

III. Major Findings & Recommendations

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

- *The transport sector is experiencing significant growth in India. Vehicle population has grow sevenfold in the last two decades. It is expected to grow from 140 million in 2011 to about 400 million during the next two decades. Clearly, Indian citizens are on the move and are prospering from the growth. But this growth will worsen the air pollution problem in India and will come at a huge cost to public health and crop yields. It also has consequences to monsoon rainfall, Himalayan glaciers, and regional climate (see Chapter 1).*
- *Vehicle emissions contribute to particulate matter (PM) smaller than 2.5 micrometers (PM2.5) and to Nitrogen oxides, NO and NO_2 (NOx). NOx in turn lead to production of ozone. PM2.5 is the dominant contributor to premature deaths and numerous other illnesses, followed by ozone and NOx, the other two major contributors to health impacts. Under current trends in growth of vehicles with current fuel and emission standards, the transport sector emissions of PM2.5 will increase by a factor three and emissions of NOx by a factor of five.*
- *Exposure to ambient PM2.5 leads to 627,000 premature mortalities in India, according to a recent international assessment. The role of transport sector in such estimates has not been reliably estimated yet. The transport sector contributes about 15 per cent to 50 per cent of the PM2.5 emissions in cities and is a dominant contributor to NOx emissions (Chapter 1).*
- *Drastic reduction (more than 90 per cent) of particulate matter (PM) and nitrogen oxides (NOx) from the transportation sector, primarily diesel vehicles (on-road and off-road) and buses, will have the largest and most immediate beneficial impact on human health and food supply. More than 75 per cent of the PM2.5 particles (also known as aerosols in the climate literature) from diesel vehicles is black carbon aerosols (or particles), a major contributor to global warming and melting of Himalayan glaciers. Drastic reductions in PM2.5 and NOx emissions will also mitigate impacts of black carbon and nitrate aerosols (resulting from NOx) on precipitation and regional climate change. It is a win-win action for all aspects of sustainability.*
- *The dose response curves used to link PM2.5 with mortalities are mostly based on data collected outside India. Since both the composition and the amount of PM2.5 are highly dependent on the region, we urgently need India-specific epidemiological studies of both mortalities and morbidities. Likewise, climate and meteorological model studies used to assess the impacts of aerosols (black carbon, sulphates, organics and nitrates) on monsoon rainfall are based primarily on models developed outside India, whose simulations of dominant regional phenomena such as the Indian monsoon and the Himalayan glaciers are deficient. We urgently need reassessment of these fundamental effects of aerosols (PM) and ozone on regional precipitation & cloud formation and the effects of black carbon on the melting of Himalayan glaciers with models developed nationally so that dedicated efforts can be expended to properly simulate the dynamics of the Indian monsoon and the dynamics of the Himalayan glaciers.*
- *The California experience demonstrates that technologies to improve engine emissions and to distill ultra-low sulphur fuels (ULSF) are available and can be implemented successfully on a large scale. The California example demonstrates that these technologies can accomplish massive reductions (>90 per cent) in air pollution. Sulfur levels in fuels used in vehicles play an important role in defining the emissions. The efficiency of tailpipe treatment devices depend heavily on the sulphur content of the fuels. These devices work with their optimal efficiencies when provided with fuels with ULSF, i.e., sulphur content of 10 ppm or less. Their optimal performance can drastically reduce PM and NOx emissions from vehicles.*
- *More importantly, California has demonstrated that such drastic reductions in air pollution can be accomplished without slowing down economic development. On the contrary, California's population,*

vehicles, and economy grew dramatically during the period (1968 to now) of the mitigation actions. In India the cost of cleaning up emissions at the refinery and the individual vehicle probably run to tens of billions of dollars. The benefits for human health and agriculture productivity could reach hundreds of billions of dollars (See Appendix-B).

- *There is a large potential to drastically reduce diesel particulate matter (PM) emissions as well as emissions of NOx from diesel and petrol vehicles by implementing stricter vehicle emission standards and fuel quality standards. These standards are defined in Appendix-A. They are referred to as Bharat Stage I (BS-I) to Bharat Stage VI (BS-VI). Much of India is currently at BS-III. The BS-IV to -VI standards correspond approximately to Euro IV to VI standards followed in the European Union. The European Union is transitioning now to Euro VI standards.*
- *ICAMP (In what follows, ICAMP refers to the authors from the three core partner institutions, TERI, UCSD, and CARB) recommends that the Government of India (GOI) should without further delay mandate and facilitate the refineries (see Action Options Item 2) to upgrade their facilities and supply BS-V fuel all over the country no later than 2018. The BS-V fuel standards reduce the sulphur content of fuels from the current high levels (50-350 ppm) to the ULSF (ultra low sulphur diesel) value of 10 ppm.*
- *The ICAMP authors recommend that GOI immediately set up an expert group to prescribe BS-VI vehicle emission norms by 2017 and introduce them by 2020-21 in all of India, as BS-V fuel (10 ppm), which is adequate for BS-VI emission standards, will be available throughout the country by 2018.*
- *The new standards would enable diesel particulate filters (DPF) to function with maximum efficacy. Such filters, if retro-fitted onto existing vehicles, would help reduce per vehicle PM2.5 (particulate matter less than 2.5 microns) emissions by over 90 per cent from today's levels (see Action Options item 5). Considering that the share of diesel in the transportation of passengers and freight is about 70 per cent, a reduction of this magnitude in emissions from diesel vehicles would have a significant benefit to public health.*
- *The Auto Fuel Vision 2025 (AFV2025) Committee set up by the Government of India released its report in June 2014. Their recommendations are broadly consistent with the recommendations above. However, the time scales for the introduction of the new standards recommended by AFV2025 are slower by two to three years in the case of BS-IV and four years in the case of BS-VI emission standards, compared with the time scales prescribed bythe ICAMP authors above. These delays will put India ten years behind Europe.*
- *AFV 2025 recommends BS-IV and BS-V fuels across the country by 2017 and 2020, respectively. The ICAMP authors, on the other hand, recommend leapfrogging from BS-III (the current standards) directly to BS-V by 2018. Each year delayed will result in an addition of about 15 million more polluting vehicles on the road. We believe that BS-V fuel can be supplied all over the country by 2018 if the refineries are mandated, funded, and facilitated to move from BS-III/IV to BS-V fuels.*
- *We therefore urge the Government of India to consider urgently and comprehensively the earlier introduction of BS-V fuels than those recommended in the Auto Fuel Vision (AFV 2025) Report, by requiring and enabling the Indian refineries to leapfrog from BS-III to BS-V fuels by 2018. Alternately, GOI can divert the current exports of Reliance Industries Limited – Special Economic Zone (RIL-SEZ), taking into account the contractual committments that the company may have, and arrange for marginal imports. However, if there is no possibility whatsoever of advancing the timelines recommended by the AFV 2025 Committee, then these timelines should be notified to refineries and vehicle manufacturers immediately, to avoid further delays in introducing the fuel and emission norms.*
- *We urge for introduction of stricter emission norms for two and three wheelers also, with separate standards for HC and NOx for effective control of both the pollutants.*
- *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) (see Action*

Options item 4) as well as enforcement facilities across the country, especially in cities with a population of one million or more. Indian states should also consider modifying vehicle registration requirements to ensure that all vehicles, including cars and two-wheelers are periodically checked for compliance with the emission norms.

- *Overall, dedicated simulation studies conducted by TERI for this ICAMP report reveal that, a combination of BS-VI standards, effective inspection and maintenance (I&M) and a fleet-modernization program that replaces older vehicles with newer models, or when feasible, retrofitting vehicles with after-treatment devices (e.g. DPF), would result in a massive reduction of 79 per cent in PM2.5 emissions and 74 per cent reduction in NOx emissions compared with the 2030-BAU scenario of 3-fold increase in PM2.5 emissions and five-fold increase in NOx emissions.*
- *While this is a major accomplishment, the study shows that in spite of the drastic mitigation actions, Indian cities will still be more polluted than the present by 2030 simply because of the massive increase in vehicle population. Thus, to avoid worsening of the pollution situation, additional steps are required as described below.*
- *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 (fuel refining technology & transport engine 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 (see Action Options figure following) since India has an important opportunity to build a transport system in which public and non-motorized transport becomes a significant choice for mobility. India could break away from the private vehicle based path that the developed countries took in their process of growth.*
- *State governments in India have enormous potential as the focus for comprehensive, integrated air quality management (see Action Options item 12). While building state leadership will require national funding to both motivate and enable action, state governments should also be encouraged to invest in effective Avoid-Shift-Improve interventions to place transport systems on a sustainable path.*
- *A coordinated (between academia and government) observational and modeling effort is required to develop national capability for assessment of pollution impacts as well as science based policy directives and to monitor the effectiveness of mitigation actions (see Action Options item 1) in improving ambient air quality, human health and other parts of the ecosystem. We have articulated (Chapter 1) a state-of-the art monitoring facility for Delhi which will serve both as a model for a base-line system to be replicated in other cities in India and for monitoring the evolution of air pollution in India's capital city, considered now to be one of the most polluted Indian cities.*

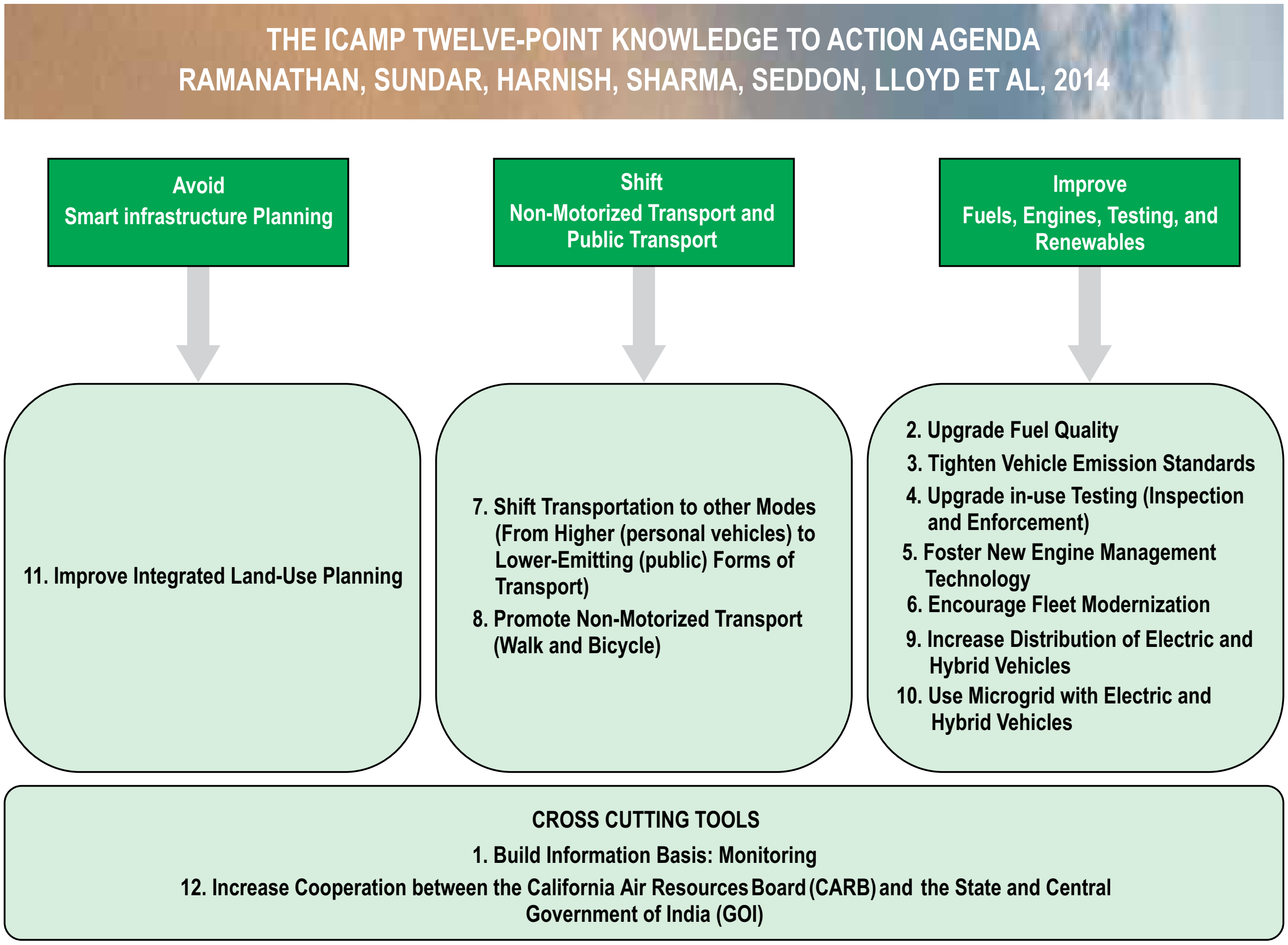
These major findings and recommendations led to a 12-Action Options for implementing the Avoid-Shift-Improve approach as described in the next section.

IV. The 12-Action Options

We have arrived at a set of 12-Action Options (Figure 0.4) to implement the findings and the recommendations from the chapters dealing with: Scientific Basis, Technology Measures, and Policy and Governance chapters. A cost benefit analysis for some of the Action Options is also carried out and is presented in Appendix C. The Action Options focusses on the following three objectives:

1. Reduce premature mortality and morbidity through the reduction of PM emissions,
2. Reduce crop loss through the reduction of oxides of nitrogen, and
3. Reduce the pace of climate change through reduction of black carbon and other short-lived climate pollutant emissions.

1. **BUILD INFORMATION BASIS: MONITORING** – An extensive network of monitoring stations providing representative data for air quality in India is missing. The ICAMP authors recommend strengthening and expanding the network through addition of new stations and capacity to monitor the full range of pollutants. Towards this end, we have proposed a base-line monitoring system for Delhi, similar to or even better than the one in California. ICAMP also recommends carrying out studies on source apportionment, epidemiology and emission inventories using the Delhi city monitoring system, to develop an extensive database for research and development purposes. Such studies can then be extended to the four pilot cities (See next section).
2. **UPGRADE FUEL QUALITY** – The participants in ICAMP recommend that the Government of India should require cleaner fuel particularly by reducing sulphur content. Without further delay it should mandate the refineries to upgrade their facilities and to supply ultra low sulphur (10 ppm) fuel known as BS-V fuel. The BS-V fuel should be available all over the country by no later than 2018. Admittedly this is earlier than the agenda recommended in the Auto Fuel Vision and Policy 2025 (MoPNG 2014) Report. The government could also divert to domestic use, current exports of Reliance Industries Ltd – Special Economic Zone (RIL-SEZ) taking into account the contractual committments that the company may have, and arrange for marginal imports. However, if this is not possible then the timelines recommended by the AFV 2025 Committee should be notified immediately, so that there are no further delays in introducing the fuels.
3. **TIGHTEN VEHICLE EMISSION STANDARDS** – The ICAMP authors recommend that India reduce the emission of pollutants from vehicle engines. As per the road map suggested by AFV 2025, the whole country should move to BS-IV norms by 2017. However, if BS-V fuel were introduced by 2018, the auto industry could reach US/European emission standards (BS-VI) by 2020. This would facilitate the retrofitting of after-treatment devices (such as exhaust gas recirculation (EGR), diesel particulate filters (DPF), and selective catalytic reduction (SCR).
4. **UPGRADE IN-USE TESTING (INSPECTION AND ENFORCEMENT)** – The participants in ICAMP recommend the replacement of existing Pollution Under Control (PUC) centers with a smaller number of modernized and automated centers that can be effectively monitored by the state governments. ICAMP participants can work with CARB and state governments to provide technical assistance as may be required to setup the modernized and automated emission testing centers. The current in-use testing procedures are handicapped by inadequate infrastructure and scarce opportunities to conduct verification procedures.
5. **FOSTER NEW ENGINE MANAGEMENT TECHNOLOGY** – The participants in ICAMP recommend retrofitting of after-treatment devices (such as exhaust gas recirculation (EGR), diesel particulate filters (DPF), selective catalytic reduction (SCR) into diesel vehicles as early as 2015. This would allow for significant reductions in PM emissions. Participants in ICAMP will seek the support of the United Nations Environment Programme (UNEP) Partnership for Clean Fuels and Vehicles (PCFV).
6. **ENCOURAGE FLEET MODERNIZATION** – The ICAMP authors recommend that the government of India should institute incentives that will encourage the elimination of older vehicles from road transportation.
7. **SHIFT TRANSPORTATION TO OTHER MODES (FROM HIGHER** (personal vehicles) **TO LOWER-EMITTING** (public) **FORMS OF TRANSPORT)**– participants in ICAMP will encourage a shift from higher to lower-emitting forms of transport by using public transport and rebalancing road and rail transport which can reduce congestion as well as lower PM emissions.
8. **PROMOTE NON-MOTORIZED TRANSPORT (WALK AND BICYCLE)** – The ICAMP authors endorse walking and bicycling whenever feasible. This will be beneficial to the atmosphere since it is the cleanest form of transport. They produce zero emissions and provide exercise giving positive health benefits.
9. **INCREASE DISTRIBUTION OF ELECTRIC AND HYBRID VEHICLES**– The use of electric and hybrid vehicles is a cleaner transport alternative with zero emissions (provided electricity is produced by renewables or natural gas) and can reduce dependency on petroleum products. Electric vehicles have a very high end use



efficiency, about a factor of four higher than internal combustion engines. ICAMP participants will work with electric vehicle (EV) manufacturers to build a supportive environment for EV in India. ICAMP recommends an increased share of electric and hybrid vehicles in India through incentives and regulations.

10. **USE MICROGRID WITH ELECTRIC AND HYBRID VEHICLES**– The ICAMP authors propose to apply the tested University of California, San Diego (UCSD)model of building micro-grids in smaller Indian cities for renewable fuel vehicles.

11. **IMPROVE INTEGRATED LAND-USE PLANNING** – ICAMP participants recommend the integration of transport plans, including concerns for air quality in the city development plans and encourage through policy measures and/or fiscal incentives, e-governance telecommuting e-trades, etc.

12. **INCREASE COOPERATION BETWEEN THE CALIFORNIA AIR RESOURCES BOARD (CARB) AND THE STATE AND CENTRAL GOVERNMENT OF INDIA (GOI)**– The ICAMP urges the use of the experience of CARB to give insightful lessons into the design and implementation of effective policy through field-tested governance protocols. California's experience should also form the basis for technical cooperation.

V. Next Steps

The suggested Action Options have taken California's proven interventions to improve air quality and identified those that are relevant for India. While some of the actions can only be taken by the National government, there are others which can be taken by the States. The strategies identified for India can reduce vehicular emissions in all Indian cities. In the second phase of the project, we aim to measure the impacts of these strategies at the city scale. The second phase is proposed to verify and validate the effect of interventions on prevailing air quality in some pilot cities.

Based on detailed study, the State governments with the assistance of ICAMP participants will make appropriate requests to the World Bank for technical and financial assistance to test and implement the 12-Action Options and setup monitoring stations as required to continuously and effectively monitor air quality improvements flowing from these interventions. After discussions with the State Governments and other important stakeholders, four cities namely Ahmedabad, Dehradoon, Bangalore, and Chennai have been identified for initiating the demonstration projects. The air quality in all four cities is not acceptable, has violated the standards consistently, and the leadership is open to change. Some cities have shown improvements due to measures taken in the past, however growing activity levels have kept air pollutant concentrations above the permissible limits. These cities are appropriate choices for initiating the demonstration projects, largely because of their strategic importance to India's development and also in part because of the excellent infrastructure (state governments, colleges and research institutions) in place to deploy the technologies and to undertake state-of-the art monitoring system to determine the impacts of the intervention. In the first instance, it will be necessary to make a detailed assessment of the transport systems in these cities and carry out feasibility studies of the interventions that will be most relevant for a particular city. It is only thereafter that the cost involved in the implementation of interventions can be assessed. ICAMP partners will discuss the recommendations contained in the report, including pilot project proposals with the relevant governments to gain traction for their implementation.

Scientific Basis

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

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Air Pollution Impacts: Background

Air pollution is now globally perceived as an important issue. Emissions of various air pollutant species (particulate matter, oxides of sulphur, oxides of nitrogen, carbon monoxide, and volatile organic compounds) released from multiple sources mix, disperse and react in atmosphere to form pollutant concentrations. The receptors (humans, vegetation, materials, etc.) of these concentrations show negative effects once they cross certain threshold limits (WHO guidelines). Air pollutants not only impact the receptor due to their toxicities but are now also known to have effects over the global climate. A typical diagram of air pollutants classifications and their impacts is shown in Fig. 1.0a.

While, emissions from different sources include gases like SO_2, NO_x, CO, and VOCs, they also include particles of fractions less than 10 and 2.5 mm. The constituents of PM vary based on the source characteristics and may include carbon (black or

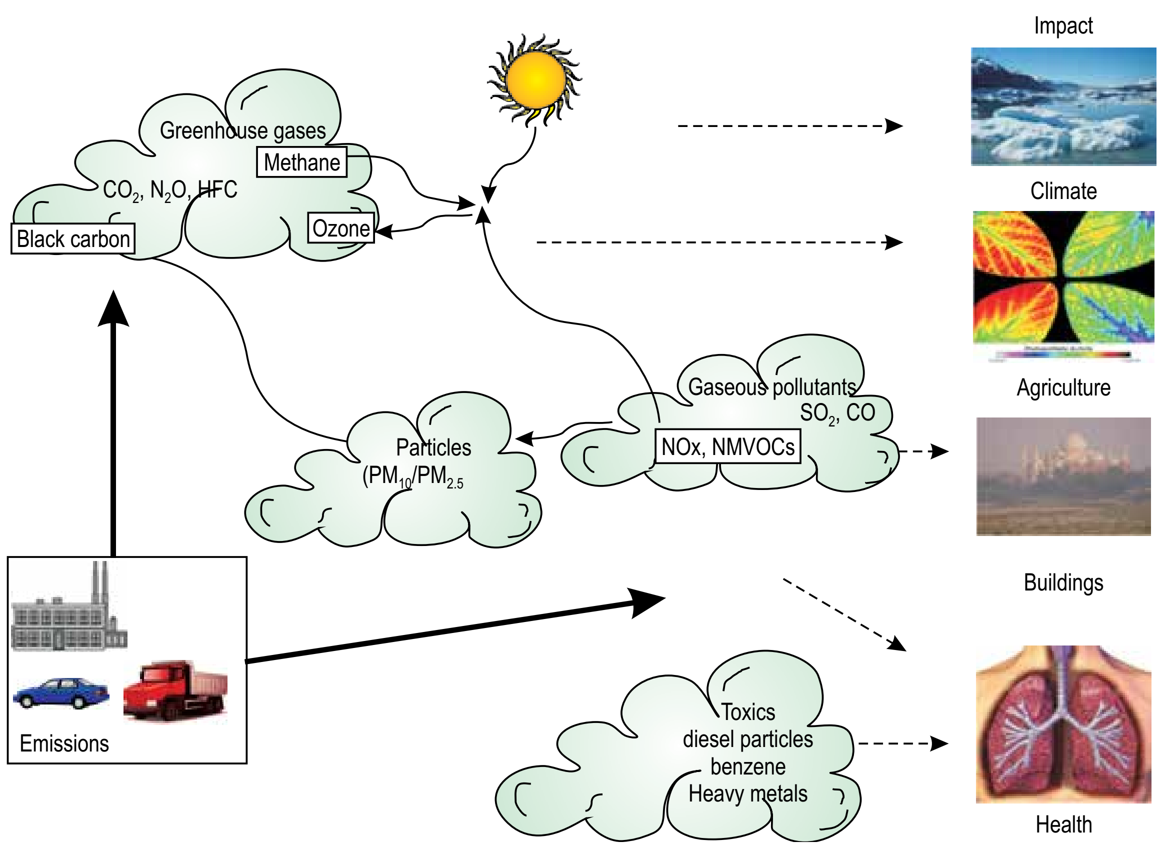


Figure 1.0a: Air pollutants classification and their major impacts

Box 1: What is black carbon?

Black carbon (BC) is a component of particulate matter formed by the incomplete combustion of fossil fuels, biofuels, and biomass. A complete combustion process should convert all the carbon in the fuel into carbon dioxide (CO_2), however due to inefficiencies in combustion processes, other substances like carbon monoxide (CO), volatile organic compounds (VOCs), organic carbon (OC) particles and BC particles are formed, along with CO_2.

While, it has the potential to cause severe health impacts, it is now also known to warm the atmosphere by intercepting the sunlight and absorbing it. It is also now linked with darkening of snow after its deposition and influencing the cloud formation. Over a period of 100 years, BC has 100-2000 times higher potential to warm the planet in comparison to CO_2, however in longer terms the effect of CO_2 dominates. The shorter life of BC particles suggests more immediate climate benefits due to its mitigation. The ratio of BC (warming) to other particles (cooling) defines the contribution of a source in climatic impacts.

Other than the climate effects, it contributes to significant health impacts by affecting the respiratory system and causing cardiovascular problems. Particulate matter emitted from diesel driven vehicles constitutes higher fractions of BC along with other harmful components, and hence has been identified as a cause of lung cancer by the California Air Resources Board (ARB) and the World Health Organization. Adverse health impacts from black carbon emissions are experienced to be higher in urban areas congested with vehicles and near highways with many heavy-duty vehicles based on diesel.

Box 2: What is tropospheric Ozone?

While there is a Ozone layer in stratosphere which protects us from UV fractions of the sunlight, there is Ozone formed in troposphere (near to the ground) which is known to have severe impacts over human health, agricultural productivities, and material. It is not merely a major component of urban smog but also has a significant radiative forcing* and hence acts as an important greenhouse gas. Ozone is primarily formed by the reaction of NOx and VOCs in presence of sunlight. With rise in precursor emissions of NOx and VOCs in the last 100 years, a threefold increase in the O_3 concentration has ben observed in the northern hemisphere. After, CO_2 and methane, it was known as third most important contributor to human-enhanced greenhouse effect. It is only recently, the research has shown to that black carbon has surpassed the radiative forcing of gases like methane and Ozone.

The effects of Ozone on human health are known to be lesser than those of PM, although still significant. However, its impacts over the agricultural productivities of important crop species like wheat, maize, cotton etc are extremely detrimental. Studies have shown to have highest Ozone concentrations in the most fertile Indo-gangetic plains in India. Impact of ground level Ozone on agricultural productivities is not only damaging to the economy of the country but also has grave implications over the issue of food security in future.

*Radiative forcing: Ramanathan et al. (1985), Ramaswamy et al. (2001) define it as 'the change in net (down minus up) irradiance (solar plus longwave; in W m–2) at the tropopause after allowing for stratospheric temperatures to readjust to radiative equilibrium, but with surface and tropospheric temperatures and state held fixed at the unperturbed values'.

organic), ions (sulphates, nitrates, etc.), heavy metals, and other crustal elements. There are two sources of particles: primary particles emitted directly from the sources such as black carbon and organic carbon from fires and diesel exhaust and secondary particles (sulphate and nitrate) formed through gas to particle conversion of gases such as SO_2 and NOx emitted by fossil fuel combustion. The primary and secondary particles are usually referred to as aerosols but in the public health literature, the particles are referred to as PM for particulate matter. Other than these, there are secondary gaseous pollutants formed (like Ozone) due to the chemical reactions between the primary pollutants in the atmosphere. In this document, our primary focus is on PM and ozone. For the purposes of this report, we are primarily concerned with ozone near the surface and within the lower atmosphere (surface to about 15 km). Unless otherwise stated, the word 'ozone' refers to ozone in the lower atmosphere and not to stratospheric ozone. Ozone is not emitted by human activities but is formed by photochemical oxidation of the pollutants: CO, NOx, VOCs and Methane. Brief descriptions of black carbon (which is a constituent of PM) and tropospheric Ozone are presented in Box–1 and Box–2.

We must also recognize the nexus between air pollution, health, and climate change (Figure 1.0b below).

Public Health: Both PM and ozone negatively affect human health. However, with respect to global

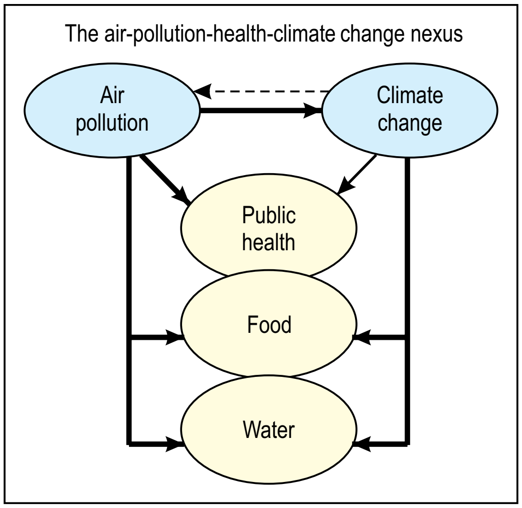


Figure 1.0b: Air Pollution-Health-Climate Change Nexus. Historically our concern for air pollution was primarily due to its impact on human health, ecosystem (i.e., acidity of rain) and on agriculture (ozone damage of crops). More recently, it has become clear that air pollution also has significant impacts on regional and global temperatures, precipitation, glacier retreat and sea ice retreat (see discussion below)

mortalities of about 3.2 million from ambient air pollution (see health section later in this chapter), 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 impact of PM on public health. Human activities produce several types of particles, the most notables are: Sulfates, organic carbon, nitrates and black carbon. Typically, PM will consist of all of these particles, and the relative proportion of each depends on location, season and time of day. Particles come in a variety of sizes ranging from nanometers, nm (10^{-9} m), to tens of micrometers, or simply microns (10^{-6} m). Typically, instead of measuring the sizes, the air pollution community measured just the mass of the total number of particles. Until about few decades ago, the air pollution communities were able to monitor particle mass only for particles less than 10 microns. This quantity is referred to as PM10. Since the larger particles dominate the mass, PM10 was dominated by particles larger than a micron. It was later realized, the smaller size particles (less than few microns) were more important for health impacts and measurements of mass of particle sizes less than 2.5 microns began. The latter is referred to as PM2.5. In the PM2.5 category, the transportation sector produces black carbon and organic carbon particles. In addition, the transport sector is the major contributor to NOx gas, which is oxidized to nitrate particles and which become part of PM2.5. NOx also is a dominant contributor to ozone.

Ecosystem: A major constituent of PM is sulphate particles (among others) and these are transformed into acids in precipitation and, when the acidic rain is deposited on forests it leads to destruction of forests. Major source of sulphates is coal combustion in power plants. The contributions of oil (petrol) and natural gas to sulphate particles are very small.

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

Climate: Ozone and PM have major influences on regional climate. Ozone is a greenhouse gas. The PM emitted at the surface gets transported vertically and is distributed throughout the lower atmosphere (or troposphere). Black carbon aerosols are the strongest absorber of sunlight and because of this solar absorption and because of its large sources (fossil fuel combustion and biomass burning) it is the second largest contributor to global warming (Ramanathan and Carmichael, 2008; Bond et al, 2013). Roughly 75 per cent of the PM2.5 from diesel vehicles consist of black carbon and hence diesel black carbon is an important contributor to global warming. Removing one ton of black carbon from diesel vehicles has the same climate change mitigation effects (on a 100 year time scale) as removing 2000 tons of CO_2 from fossil fuels (Jacobson, 2010; Ramanathan et al, 2013). The sulphates, nitrates and organic carbon aerosols primarily (with the exception of brown carbon) scatter solar radiation and hence have a cooling effect. In fact this cooling effect has masked as much as 40 per cent to 50 per cent of global warming by greenhouse gases (Ramanathan and Carmichael, 2008). In addition, the aerosols significantly (about 5 per cent to 15 per cent regionally) reduce solar radiation reaching the surface (dimming effect), which leads to reduction in precipitation regionally. Furthermore, the pollution aerosols nucleate significant amount of cloud drops, the net effect of which is to reduce the drop size and thus inhibit formation of rain drops. Lastly, black carbon deposits on snow, glaciers, and sea ice and darkens these bright surfaces leading to a significant increase in the absorption of solar radiation by snow and ice. The increased solar absorption accelerates the melting due to the global warming by greenhouse gases. In short, aerosols influence significantly the regional and the global hydrological cycle (Ramanathan et al, 2000; Ganguly et al, 2013; IPCC-AR5, 2013).

Short-Lived Climate Pollutants (SLCPs): Black carbon and ozone, along with methane and hydrofluoro carbons (HFCs) are referred to as short-lived climate pollutants by the climate and clean air coalition (http://www.unep.org/ccac/). They are called short-lived because their life time in the atmosphere ranges from a week (black carbon), month (ozone) to about a decade (methane and some HFCs). All the four SLCPs are potent global warming agents. Off-the-shelf technologies are available to reduce their concentrations significantly. Since the life times of SLCPs is short, the mitigation effect will be felt within a decade. It has been shown (Ramanathan and Xu, 2010; Shindell et al, 2013) that reducing the emissions of SLCPs can reduce the projected warming in the coming decades by as much 0.6 °C (50 per cent). Of significance to this report is the following: About 75 per cent of the PM from the diesel combustion is black carbon; and the transport sector is the largest NOx source and NOx produces ozone and also leads to nitrate aerosols. In addition to the aerosol effects, and the ozone greenhouse effects the transportation sector emissions also include: CO_2; methane (fugitive emissions during extraction and transportation of natural gas); refrigerants such as CHCs and HFCs.

Emission Scenarios

1. Background

India has followed a steep economic growth trajectory in the last two decades. 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 grown to more than 140 million in 2011 (MoRTH, 2012). Rapidly increasing consumption of energy in the cities and electrified rural regions has led to a tremendous increase in power demand. The power sector in India is coal dependent which is known to have high ash (30-45 per cent) and somewhat lower sulphur (<1 per cent)) 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 per cent of the rural households in India are still dependent on biomass for cooking and on kerosene for lighting (TERI, 2010). 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, and industrial activities have led to an 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 per cent of Indian cities violate the standards for air quality (mainly for PM) (CPCB, 2012).

The energy use scenario in India is presented in Figure 1.1. 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.

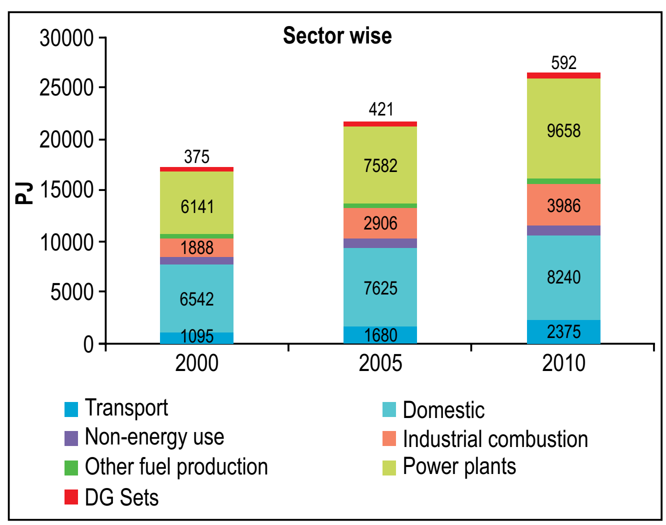


Figure 1.1: Sectoral Energy Use (in Peta Joules [PJ]) scenario in India.

Source: The Energy and Resource Institute (TERI, 2013a)

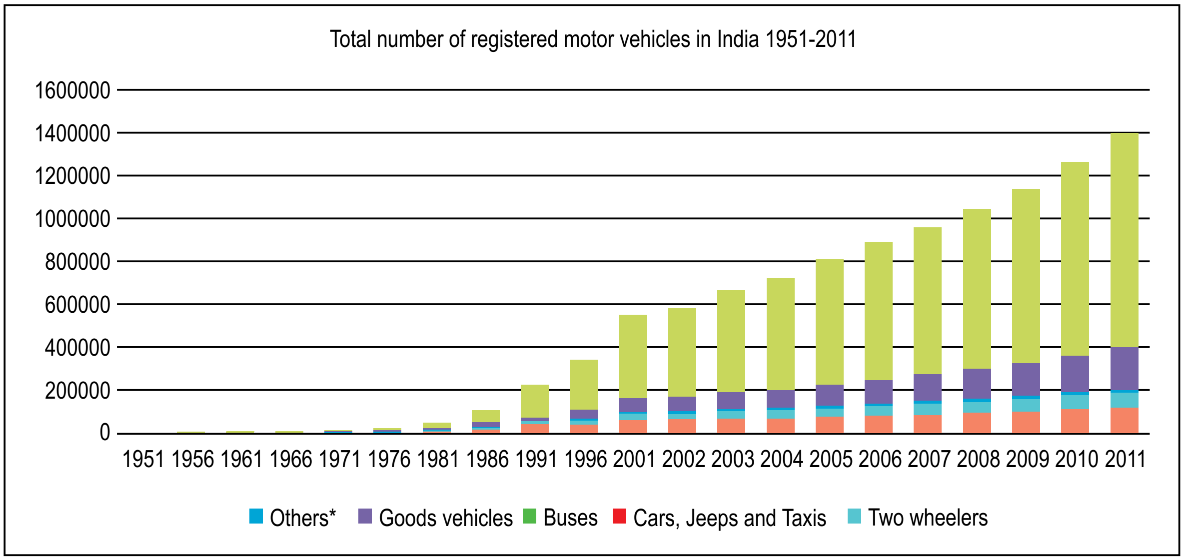


Figure 1.2a: Growth of Vehicles in India (1951-2011)
Data Source: MoRTH, 2011 and 2012

2. Transport Sector in India

The 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 28,000 two wheelers, and 4,200 cars are added to India's vehicular fleet daily (in 2011) (MoRTH, 2012). By 2011, India had already registered 141 million vehicles (Figure 1.2a).

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 per cent households have two wheelers whereas a meager 4.7 per cent have cars/jeeps/vans. India falls very low in per capita car ownerships and hence the vehicle fleet growth potential is huge given continued growth in economic activity.

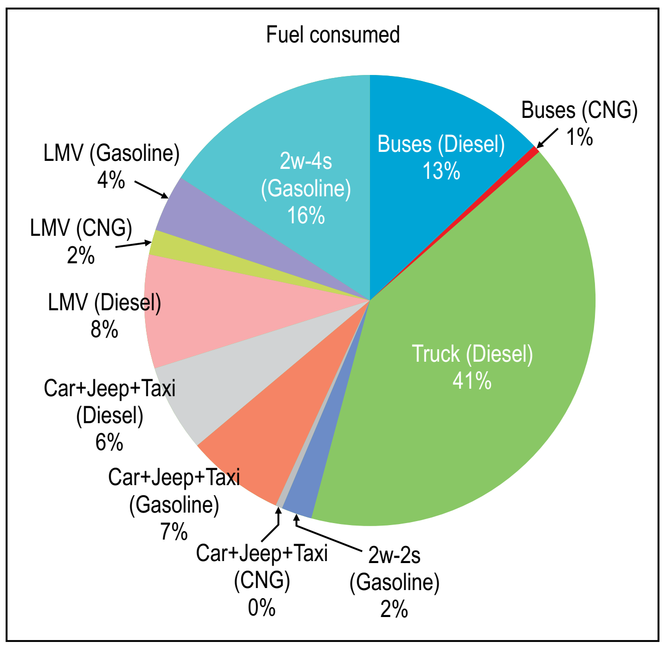


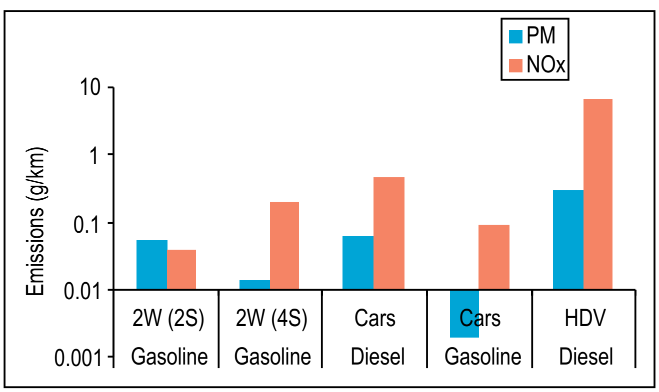
Figure 1.2b: Vehicle-wise share in overall energy consumption in the road transport sector in India (2010)
Source: TERI estimates validated with overall consumption in MoPNG, 2013

The vehicle-wise share in overall energy consumption in 2010 in the road transport sector is shown above in Figure 1.2b. Heavy-duty trucks for freight movement have the highest share (41 per cent), followed by two-wheelers (18 per cent), and buses (14 per cent).

3. Present Contribution of Transport Sector in Emissions and Air Quality

The contribution of the transportation sector to emissions and air pollutant concentrations has been significantly high in urban areas. Although, the per capita vehicle ownership is less in rural regions, the shift of older vehicles from cities to rural areas, improper maintenance practices, and infrastructural constraints in the villages lead to high emissions in the rural areas as well. However, due the presence of large populations in cities, actions need to be taken at these places on priority. Other than city-specific strategies, National scale strategies will help the cause at both urban and rural regions.

Emissions from the transport sector mainly depend 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 emit un-burnt hydrocarbons and carbon monoxide (CO), which are products 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 1.3a/b).



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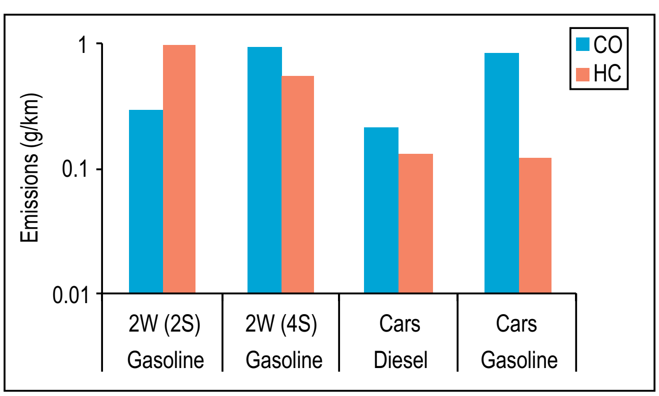


(b)

Figure 1.3a/b: Emissions (g/km) from different categories of vehicles running on different fuels.

Data Source: Based on Automotive Research Association of India (ARAI), 2010

Based on this, Table 1.0 summarizes the pollutant emissions and their impacts on air quality, health and others. Heavy duty diesel driven vehicles are known to emit the highest PM emissions among all classes. Two-stroke two-wheelers are also known for combustion inefficiencies and high PM emissions. Gasoline vehicles are comparatively less polluting, although they emit gases like CO and HC.

Vintage of vehicles is an important aspect for estimating emissions. In 2002, the Auto Fuel Policy (Ministry of Petroleum and Natural Gas (MoPNG, India), 2002) recommended a road map for advancement of vehicular emission norms in India (Table 1.1). Bharat Stage (BS) norms were introduced in India.

Figure 1.4a/b 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 before 2000 in India. CPCB, 2010 reported that almost 50 per cent of two-wheelers and car populations on Indian roads were less than 5 years old, whereas about 7–11 per cent were older than 15 years.

The road map was more or less successfully implemented with differentiation between some hotspot regions and the rest of the country; currently 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 BS-IV fuel standards. Emission estimates from the sector needs to take these developments into account.

Table 1.0

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

Type of vehicles	Fuel	Major primary pollutants	Secondary pollutants	Possible major impacts	Severity of problem
Two-wheelers (two stroke engine, 2S)	Gasoline	CO, PM, HC	Secondary Organic Aerosol (SOA)	Respiratory and cardiovascular health, Agriculture, Climate	High
Two-wheelers (four stroke engine, 4S)	Gasoline	NOx, CO	Ozone	Respiratory health, Agriculture	Low
Cars	Gasoline	CO, HC	SOA	Respiratory health	Low
	Diesel	PM (BC), NOx	Nitrates, Ozone	Respiratory and cardiovascular health, Agriculture, Climate	Moderate
Heavy-duty Vehicle (HDV) •	Diesel	PM (BC), NOx	Nitrates, Ozone	Respiratory and cardiovascular health, Agriculture, Climate	High
	Compressed Natural Gas (CNG)	NOx, HC	Ozone, Nitrates, SOA	Respiratory health, Agriculture	Low

Table 1.1

Road map for introduction of vehicular emission norms in India

Source: Based on MoPNG, 2002 (See Appendix A for definition of the BS and Euro norms)

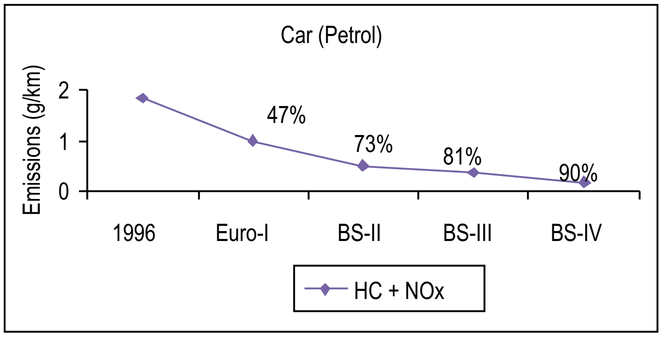
Coverage	Passenger Cars, light commercial vehicles, and heavy-duty diesel vehicles	2/3 wheelers
Entire country	Bharat Stage (BS) II – 1.4.2005	Bharat Stage-II- 1.4.2005
	Euro-III equivalent – 1.4.2010	Bharat Stage III -
11 major cities (Delhi/NCR, Mumbai, Kolkata, Chennai, Bangalore, Hyderabad, Ahmedabad,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

3.1 Emission estimates: share of transport sector

National level estimates of different pollutant emissions from the 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 International Institute for Applied Systems Analysis (IIASA), 2010 (Figure 1.5). It can be concluded that the domestic sector eclipses the contribution of other major sectors towards PM2.5 emissions. However, it is to be further noted that the majority of these domestic emissions happen in rural regions while the transportation sector contributes much more in cities.

Figure 1.6a/b (below) 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.

In case of combustion sources like transport, PM2.5 is more than 80 per cent in PM10. Black carbon has much higher share in PM2.5 fractions than in PM10 because its size is typically smaller than 2.5 microns.



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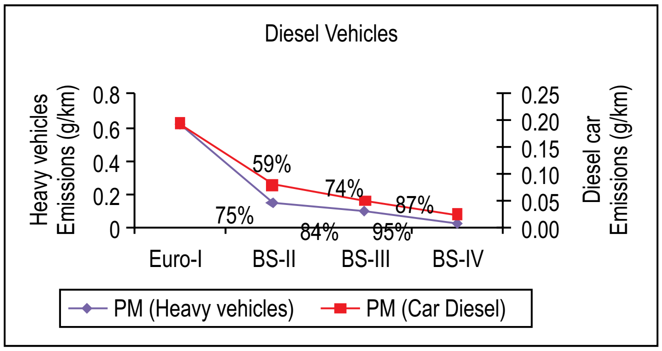

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Figure 1.4a/b: Emission norms of different vehicles as per the suggested roadmap in India
Data Source: MoPNG, 2002

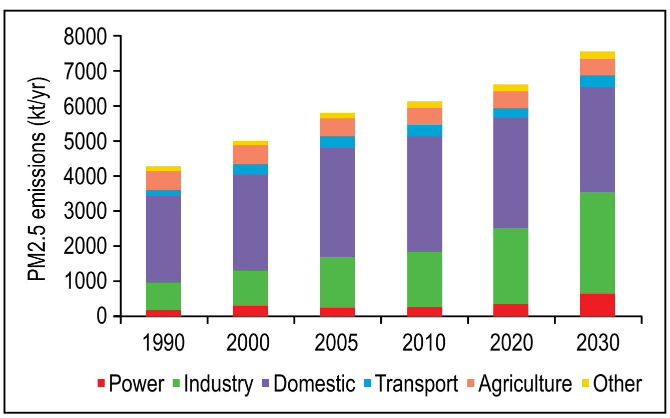
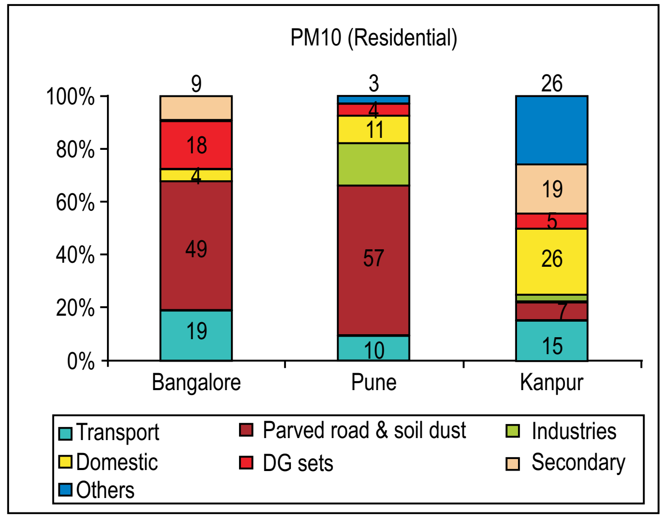


Figure 1.5: Estimates of sectoral PM2.5 emissions in India during 1990 to 2030
Data Source: IIASA, 2010



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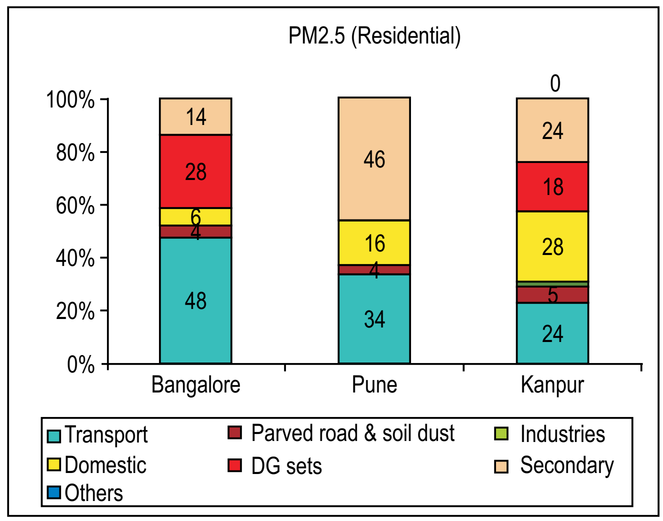


(b)

Figure 1.6a/b: Results of source apportionment studies for PM10 (a) and PM2.5(b) in Indian cities
Data source: Central Pollution Control Board (CPCB, India), 2011

The NOx emissions (caused due to high temperature combustion), the transportation sector has a dominant share at both National and Urban scales (Figure 1.7a/b). The share of transport is about 45 per cent at the National scale in 2010 and dominant across different cities except in Delhi where contributions were higher from power plants.

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 (2013a) showed very high sensitivities of NOx towards surface ozone formation in Indian conditions. Sensitivity of Ozone concentration with reduction of NOx emissions has been tested by TERI, 2013a. Figure 1.8 shows the possible percentage reductions in ozone concentrations due to 40 per

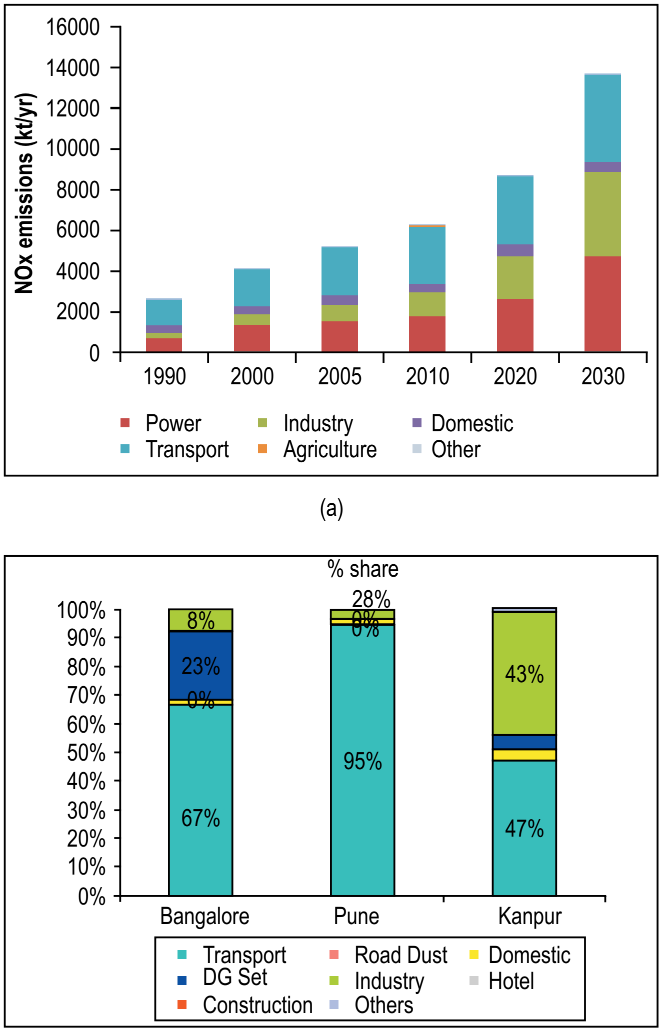


Figure 1.7a/b: Sectoral shares in NOx emissions at National and Urban scales in India

Data Source: IIASA, 2010, CPCB, 2011

cent reduction in NOx and non-methane volatile organic compounds (NMVOC) emissions in India. The reductions are to the tune of 15 per cent in the agriculture dependent Indo-Gangetic plains in India. It is to be noted that ozone concentrations may initially increase in the urban centers due to reduction of primary nitric oxide (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, 2013a estimated the NMVOC emissions for India and the contribution of the transportation sector was 12 per cent in 2010 (9 per cent tailpipe

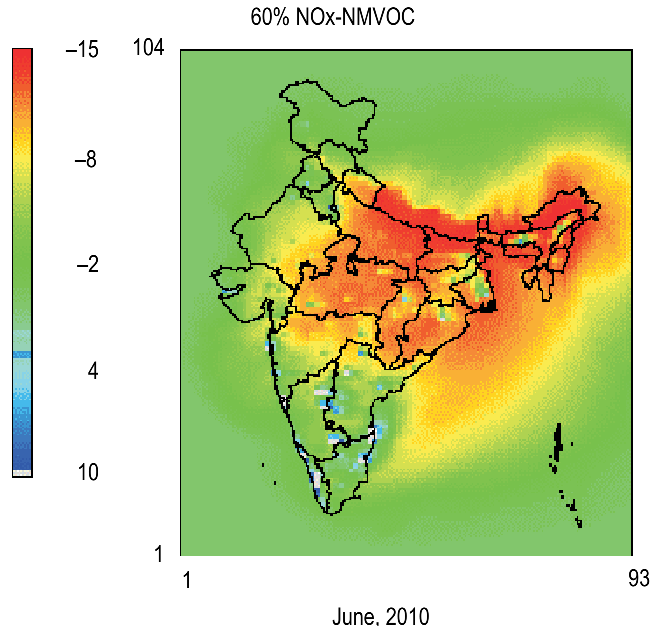


Figure 1.8: Percentage change in ozone concentrations across the Indian subdomain due to 40 per cent reduction in NOx and NMVOC emissions in 2030

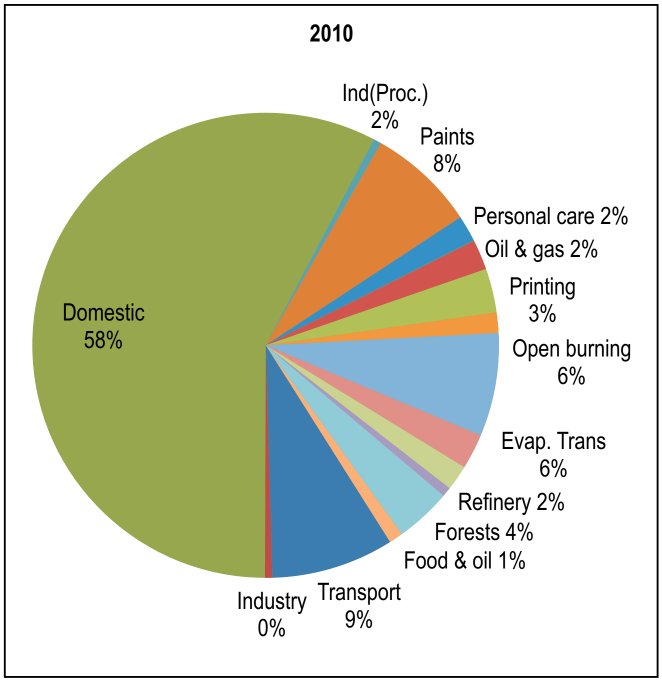
Source: TERI, 2013a

and 3 per cent evaporative). The projections for the year 2030 suggest further increase of share to 28 per cent (9 per cent tailpipe and 19 per cent evaporative) (Figure 1.9a/b). While tailpipe emissions will be somewhat controlled by increased proportion of BS-III/IV vehicles in the business as usual scenario (replacing old BS-III vehicles), evaporative emissions will continue to grow at the same pace.

3.2 Black carbon emissions

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, Beig Venkataraman et al. (2005), IIASA, 2010, Bond et. al, 2013). Table 1.2 shows the various estimates of BC emissions and the share of transport sector in India.

Several recent studies (Ganguly et al, 2009; Bond et al, 2013) have recently pointed out that published emission inventories (e.g, Reddy and Venkatraman, 2002 and Bond et al, 2004) of black carbon have underestimated black carbon mass by factors ranging rom 2 to 4 for India. Underestimation of emissions from transport sector in the region could be attributed to



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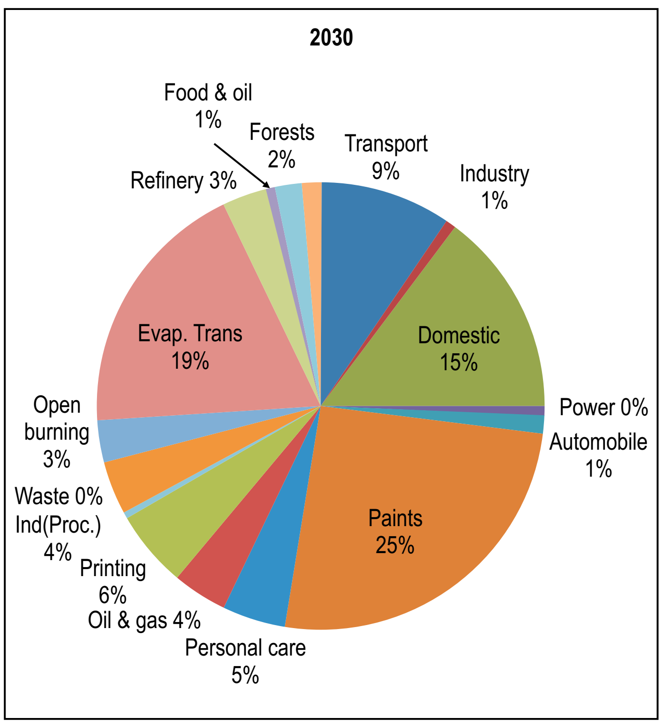

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Figure 1.9a/b: Sectoral shares of NMVOC emissions in India (2010 and 2030)
Source: TERI, 2013a

Table 1.2

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 teragrams (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%

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) Overloading of vehicles leading to increased emissions

d) Inaccurate information concerning on-road vehicles as very old vehicles still ply on the roads without re-registrations after 15 years

We urgently need significant new effort to refine estimates of black carbon over India. In the interim, published estimates suggest that at the National scale, the transportation sector has contributed to 7-34 per cent in overall BC emissions across different years. However, the contributions are much larger when we move to urban centers, e.g. in Bangalore, the contributions are as high as 56 per cent 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.

3.3 Rationale for focusing on transport sector

While the inventories show that industries and domestic sector emissions dominate at the National scale, the current study focusses on transport sector for the following reasons:-

a. Contribution of Transport sector is much more significant at the city level, where the population densities are many times higher.

b. WHO, 2012 classified diesel exhausts as potential carcinogens

c. Growth of the sector is much more than that of industries and domestic. Transport sector emissions are bound to grow faster if not controlled.

d. Being an organized sector, it is easier to implement strategies and reap quick benefits.

e. Share of black carbon in the PM is higher from transport than from domestic/industrial emissions; additional reason to reduce air pollution and control warming.

f. Many of the strategies to reduce vehicular emissions will also result in co-benefits of reduced congestion, savings on fuel, and impact on climate.

3.4 Vehicle-wise contribution in emissions from the transportation sector

The vehicle wise distribution of emissions of different pollutants in India for the year 2010 is presented in Figure 1.10

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

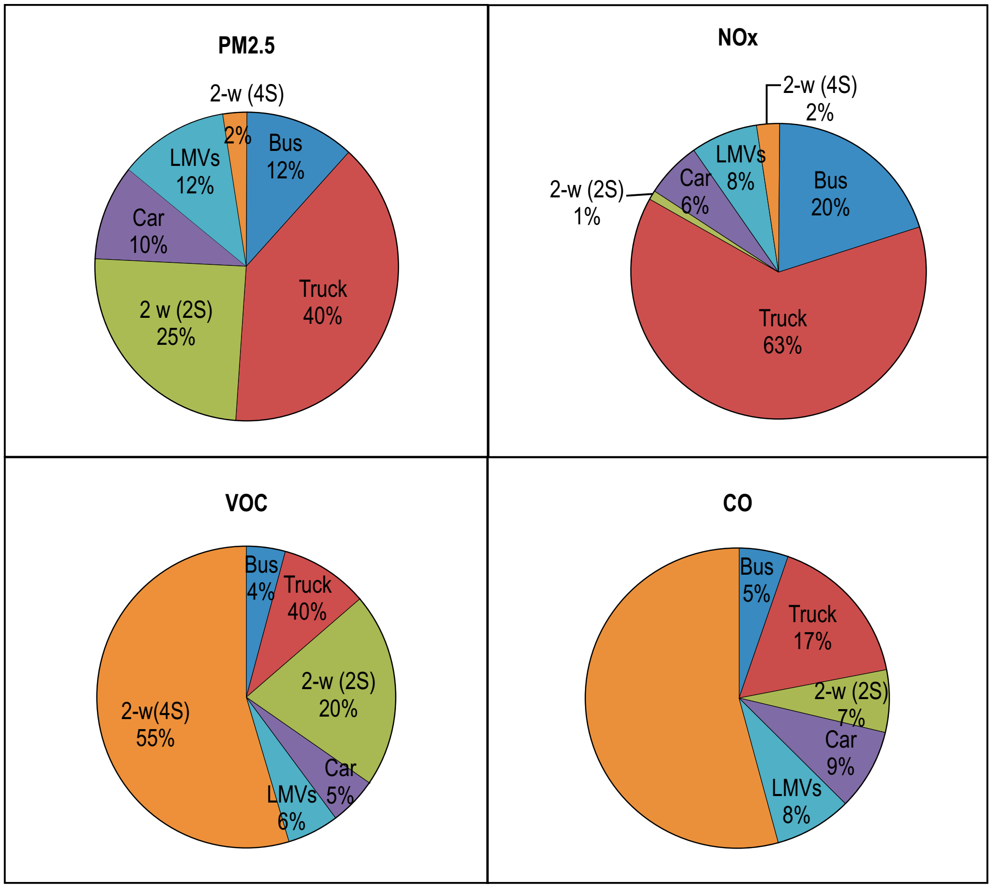


Figure 1.10: Vehicle wise distribution of emissions of different pollutants in India for the year 2010
Source: TERI estimates

3.5 City-wise contribution in emissions from the transportation sector

India's transport with more than 100 kT BC emission per year is the third largest sector, next only to industry and residential sectors (Figures 1.11 and Figure 1.12). Within transportation sector, heavy-duty trucks are largest BC emitters (40 kT) followed by Bus, which is followed by 3-wheelers. As for PM2.5, heavy-duty trucks emit most (100 kT) followed by 2-wheelers followed and then 3-wheelers. City wise, transportation also stands as the largest emitter of PM2.5 in Bangalore (followed by DG sets), Pune (followed by secondary formation) and Kanpur (followed by domestic). Heavy-duty trucks are

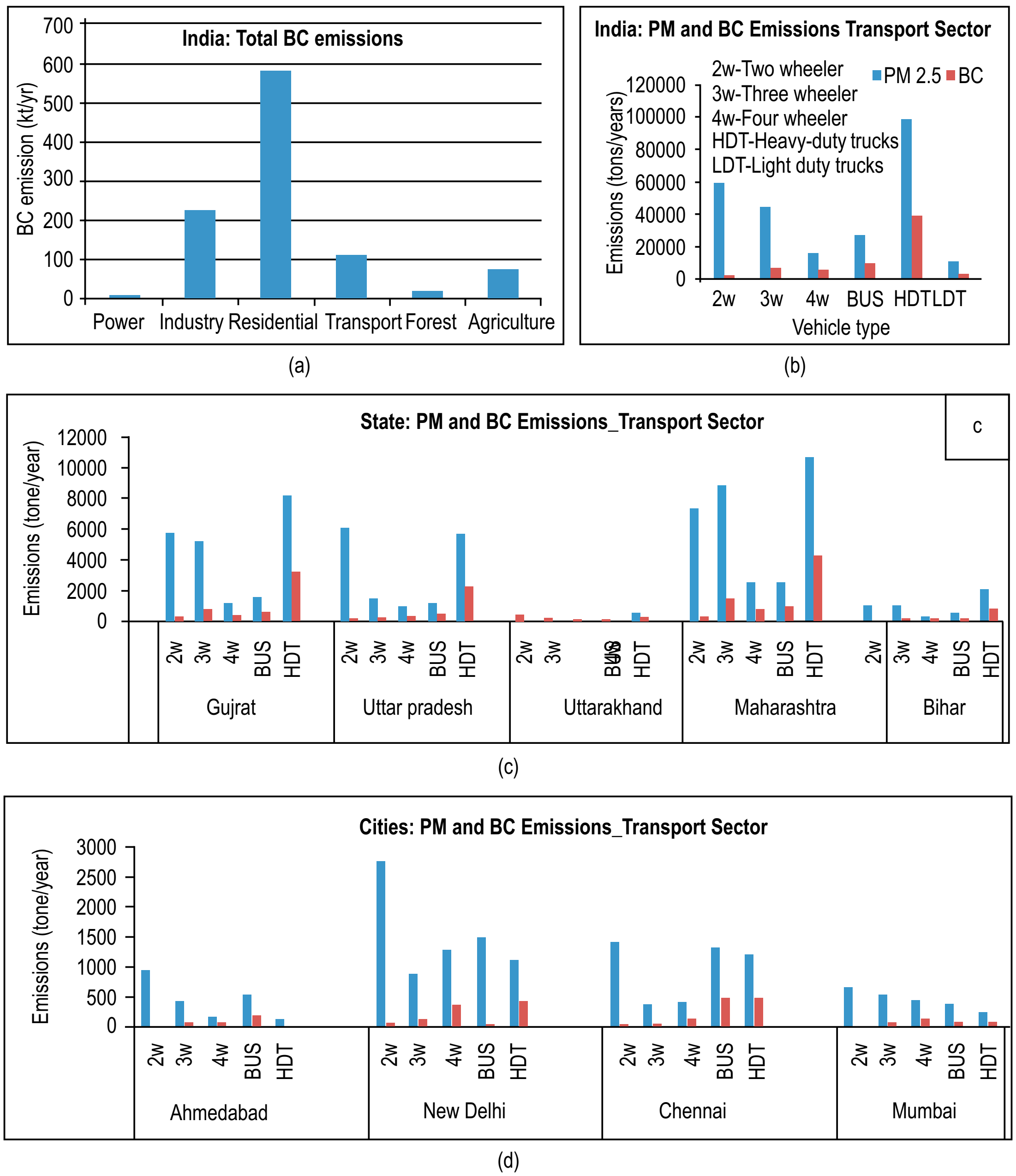


Figure 1.11: (**a**) Total BC emissions from different sectors in India. (**b**) Total PM2.5and BC emissions from transport sector in India. (**c**) PM2.5 and BC emissions from transport sector in selected states of India (**d**) PM2.5 and BC emissions from transport sector in selected cities of India

Source: Guttikunda and Jawahar (2012) and Sloss (2012).

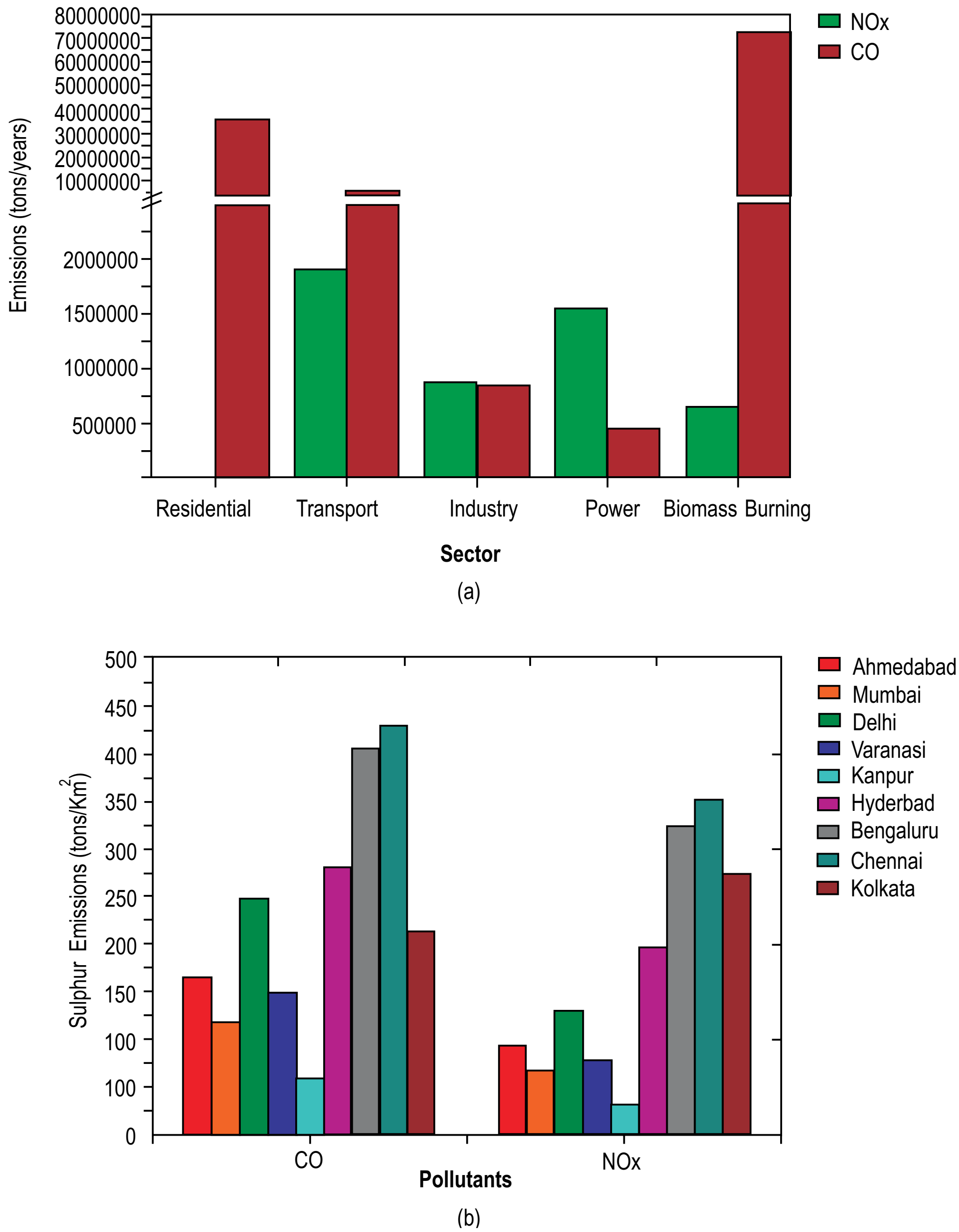


Figure 1.12: Total CO and NOx emissions In India (a) from different sectors (b) from transport sector in major cities.
Source: Garg et al., (2006); Galanter et al., (2000) and Ramachandra and Shwetmala (2009).

large sources of BC and PM2.5 emitters in states such as Maharashtra and Gujarat as well as cities such as Delhi and Chennai. Two wheelers are the largest sources of emit the maximum PM2.5 in Delhi.

3.6 Summary

In summary, transport emissions are more at urban scales due to the high volume of vehicular fleet. Among all different classes, heavy-duty diesel driven vehicles have the largest contribution in the PM emissions which are known to have a larger impact over human health. Measures need to be taken at the urban centres on a priority for control of vehicular emissions and most urgently from heavy-duty diesel driven vehicles. This will help reducing air pollutant concentrations at the urban centres which are currently heavily polluted. This could be followed upon by reduction in other vehicle categories and rural areas. Other than location specific strategies, some National scale interventions could help the cause at both urban and rural regions, simultaneously.

Emission Projection Scenarios and Impact of Interventions

There is a large potential to reduce PM and NOx emissions from the transportation sector. The major target should be heavy-duty vehicles (trucks and buses) which are responsible for 52 per cent of all PM2.5 and 83 per cent of total NOx emissions from on-road vehicles. This can be accomplished by implementing stricter vehicle emission and fuel quality standards, as defined by the Bharat Standards (BS) which are roughly equivalent to the Euro standards. Appendix-A defines and describes these standards in detail for the various vehicle category. The starting point is the sulphur content of diesel fuel. In India, generally the sulphur content of diesel is about 350 ppm, with some cities provided with 50 ppm diesel. The various engine technologies and filters for reducing pollution emissions require sulphur content of less than 10 ppm and these are referred to as ultra low sulphur fuels. Implementing ultra low sulphur fuels (ULSF – fuels with under 10 ppm sulphur content) would enable the adoption of Bharat Stage (BS)-VI emission standards, which would require all four-wheeled diesel vehicles in India to be fitted with diesel particulate filters (DPF). DPF implementation would reduce per vehicle PM2.5 emissions by over 90 per cent from today's levels. Additionally, ULSF and BS-VI standards would also reduce NOx, VOCs, and CO emissions.As detailed in the Technology Chapter, the BS-IV to BS-VI standards, in addition to specfying fuel quality, also require various engine improvements and catalytic converters to meet the emission standards.

We conducted a series of sensitivity studies with the TERI-MARKAL energy and WRF-CMAQ aerosol-chemical-transport model to assess the influence of various intervention strategies on emissions of PM and ozone precursor gases (NOX, CO and VOCs). 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 1.3.

Emission reductions that can be achieved through adoption of different strategies is estimated and presented in Table 1.4.

Table 1.3

Description of scenarios evaluated for possible emission reduction in the transport sector in 2030

Area	Scenario	Description
	(Business as usual) 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	(Alternate) 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/ light motor vehicle (LMV)/ bus with DPF with 90% efficiency
	FM	Fleet modernization of 50% existing vehicle to BS-VI vehicles
	Inspection and Maintenance (I&M)	Implementation of existing I&M system
Public transportation	Public transportation system (PTS)	Shifting 50% PKM demand from cars to bus
	Mass Rapid Transit System (MRTS)	Shifting 10% passenger kilometer (PKM) demand Bus and 10% from cars to Metro rail
Reduced mobility demand	RMD	Reduce travel demand by 20% (through different mechanism)

Table 1.4

Emission reductions (kt/yr) that can be achieved through adoption of different strategies by 2030

Source: TERI estimates

	NOX		PM2.5		CO		VOC	
BAU2010	1419		102		4305		738	
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%

% Reduction is reduction achieved in various scenarios with reference to 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 the transportation sector are going to grow about threefold for PM2.5, and fivefolds for NOx. Only Black carbon emissions, which are a subset of PM2.5 can 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 much more health impacts. Higher Ozone formation due to increased NOx emissions may also severely impact agricultural productivities.

The alternative paths shown in Table 1.4 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-VI equivalent) standards by the year 2020 (ALT-IV). Adoption of BS-V standards (ALT-III) may reap reductions of 48 per cent. A fleet modernization program (50 per cent vehicles replaced with newer BS-VI vehicles) could be a difficult option to implement but could theoretically reap reductions of 47 per cent 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 per cent in 2030. A combined program of introduction of BS-VI norms, effective I&M system and a fleet modernization program can result in massive reduction of 79 per cent and 74 per cent in PM2.5 and NOx emissions, respectively, when compared to BAU 2030 scenario. A cost benefit analysis for some of the scenarios Action Options is also carried out and is presented in Appendix C.

Monitoring

Introduction

It was because of the state-of-the art monitoring system with reproducible measurements and regional modeling capability that Ramanathan et al (2013) were able to demonstrate the efficacy of California's (California Air Resources Board, CARB) policies in drastically reducing ambient concentrations of black carbon and other pollutants. ICAMP authors are proposing a similar framework and capability within India for establishing a monitoring network to evaluate the changes in vehicular emission and ambient air quality in cities across India in response to the mitigation measures proposed in the ICAMP report. For reasons given below, we consider the city of Delhi as a baseline supersite that can be reproduced in other cities to be chosen for pilot projects (see Chapter 5).

- Delhi National Capital Region (NCR) is one of the most severely polluted regions of the world. In addition to anthropogenic sources (the transportation sector being an important source), natural aerosols are also transported to the region every year during the pre-monsoon to monsoon seasons leading to degradation of air quality. As a result, it is an excellent site to understand the relative roles of natural and manmade aerosols in public health.
- 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 one of the worst in this region. The baseline site can be used to undertake forensic style studies to understand

the problem and recommend effective policies to improve the capital city of India.

- Delhi has several high quality academic institutions (TERI, TERI-University, IIT-Delhi, JNU) and government laboratories (IITM-Delhi, National Physical Laboratory, Central Pollution Control Board), which can maintain state-of-the art measurements systems.
- Also Delhi is the location of world class research institution to conduct health impact studies: The All India Institute of Medical Sciences. Thus a super-site in Delhi will facilitate interdisciplinary studies on air pollution and its health impacts.
- Delhi has baseline instruments already in place and the supersite proposal of the ICAMP authors can build on it.

Proposed Monitoring Network

A model network would monitor PM2.5, size distribution of aerosols, chemical composition of PM2.5 including black carbon (BC), measurements to facilitate source apportionment and the vertical distribution of aerosols to determine the role of long range transport, to cover Delhi city as well as other nearby polluted (e.g., Noida, Gurgaon and Faridabad) and relatively clean areas. In addition, gaseous pollutants such as ozone, NOx, SO_2, VOCs and CO will be measured. The network would leverage existing networks, supplement existing sites, or create new sites where needed.

Existing Networks

Three networks, one each maintained by Central Pollution Control Board (CPCB) and the Delhi Pollution Control Committee, and the other maintained by the

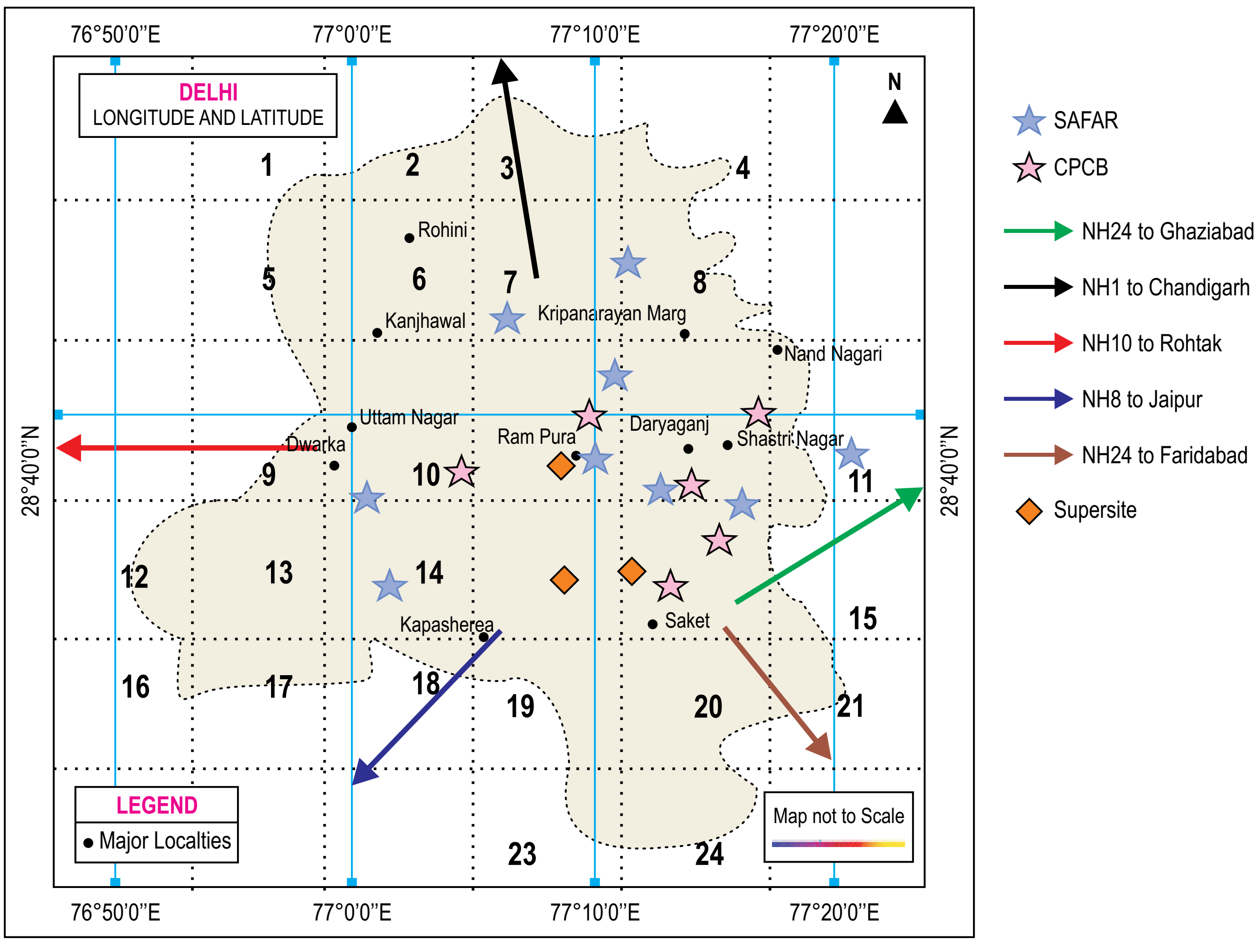


Figure 1.13: Map of Delhi National Capital Region (NCR) and the proposed observations overlain with existing air quality measurements networks (some well-known places are marked for reference).

Indian Institute of Tropical Meteorology, Pune (System of Air Quality Weather Forecasting and Research, SAFAR network) are in operation (Figure 1.13) in the Delhi National Capital Region (NCR). Some criteria pollutants are being measured on a regular basis. For example, NO_2, CO, O_3, PM2.5 and PM10 are monitored in the SAFAR network, while SO_2, NO_2 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 (NH) 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.

The entire NCR may be divided into 10 km by 10 km areas (as shown by grid nos. in the figure). A total of 24 sites might be proposed to measure BC, O_3, 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 heavy-duty vehicles. Highly time resolved (e.g., 1 hour) measurements of CO_2, BC, and NOx concentrations would be ideal at these locations to enable quantification of emission factors for 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: grams of pollutant emitted per kilogram fuel burned. If an increase in diesel particle filter use is likely during a study, the additional measurement of NO or NO_2 would be of interest because these filters have been shown to increase NO_2 emissions and the NO_2/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 a 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.

One supersite is proposed in one of the three locations (shown as diamond in the figure) at Indian Institute of Technology (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

Working closely with Nithya Ramanathan (Nexleaf) and the University of California at San Diego, for all 41 sites, a cell phone monitoring network will be set up at each site in order to collect daily measurements of black carbon from filters (Ramanathan et al, 2011). Each 24-hour filter sample can be photographed with a cell phone camera, and submitted by email to a server, which will automatically analyse 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. If such a system can be set up, it will be an unprecedented data set compared to anywhere in the world in order to undertake health impact studies.

Health Impacts

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 1.5

Air pollution causes cardiovascular and respiratory diseases, damages crop quality, reduces the biodiversity of plants, and contributes to global warming. The decisive factor for the quality of life and health, however, is not primarily the total emissions of air pollutants but

Table 1.5

Health effects of different pollutants

Pollutants	Effects
Nitrogen dioxide (NOx)	Bronchitis in asthmatic children. Reduced lung function growth
Particulate Matter (PM2.5, PM10)	Cardiovascular and respiratory diseases, lung cancer, acute lower respiratory infections (ALRI), chronic obstructive pulmonary disease (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.

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 per cent, 6 per cent, and 8 per cent 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 per cent and death from CVD by 76 per cent (Miller et al., 2007). Smaller particles (PM2.5 and ultrafine particles; 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 foetus 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 foetal growth retardation and decreased foetal 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).

Other impacts

Other than generally known respiratory and cardiovascular impacts of air pollution, it has now been linked with various other types of impacts also. Wang et al, 2014, linked the traffic pollution to higher levels of obesity hormone. An interquartile range increase (0.11 μg/m3) in annual mean residential black carbon was associated with 12 per cent higher leptin levels. The study reveals possible association of traffic pollution with adverse cardiometabolic effects. Additionally, air pollutants are also linked with impacts on eyes, and skin.

Air Pollution and the Burden of Disease

According to the most recently published 2010 Global Burden of Disease (Lim et al, 2012), in The Lancet, 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.

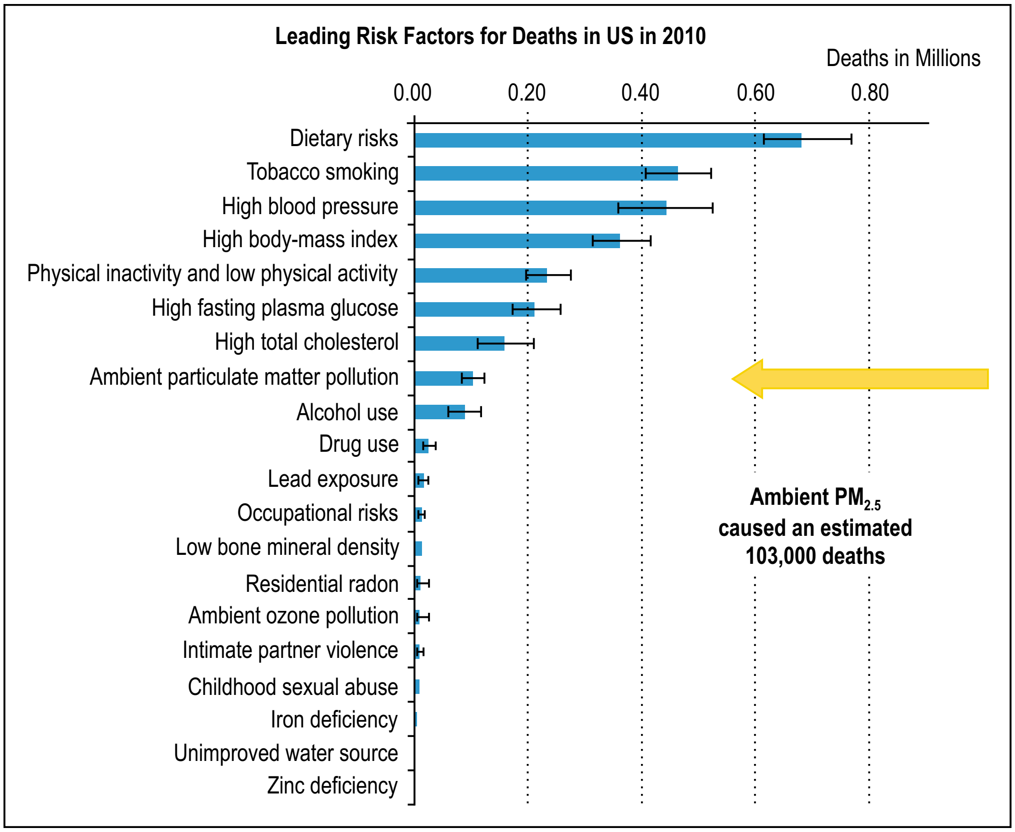


Figure 1.14: Top 20 mortality risk factors in US
Source: Lim et al, 2012

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 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 per cent of DALYs in 2000 compared with 3.1 per cent in GBD, 2010.

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 (Figure 1.14 and Fig 1.15). 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 (Figure 1.16). Reliable WHO approved estimates for the role of transportation sector is not available. One study has estimated that nearly 40,000 premature deaths each year are caused by vehicle PM2.5 emissions in India (International Council on Clean Transportation (ICCT), 2012). Chronic obstructive pulmonary disease (COPD) and acute respiratory illness (ARI) account for 24 per cent of the mortalities due to ambient air pollution in India, but it is just 7.5 per cent in US, which is less than 1/3 that of India. All cohort studies of PM2.5 and mortality from chronic disease have been conducted in the US and Western Europe and new models are therefore needed to

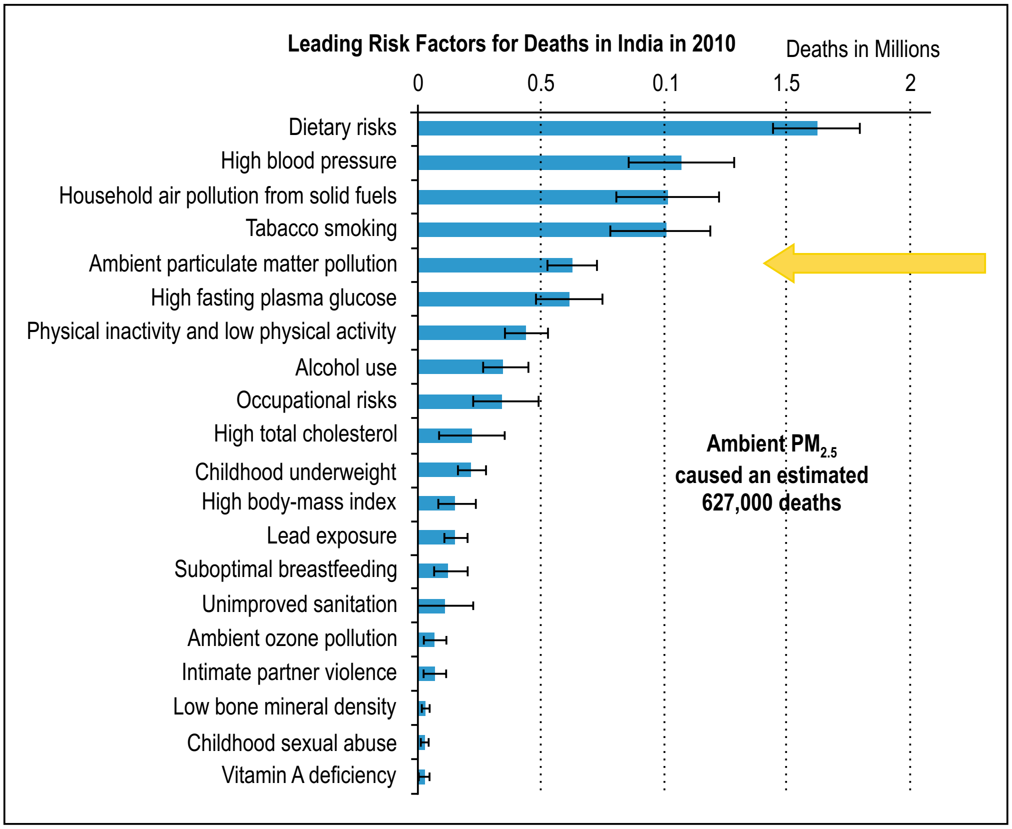


Figure 1.15: Top 20 mortality risk factors in India
Source: Lim et al, 2012

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 has been evaluated separately and has also 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 1.17 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 mucociliary 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 are then transferred to pleural, and more distant lymph nodes.

The small size of PM2.5 and PM0.1 allow them to be inhaled deeply into the airways and the lungs. A fraction of these particles is deposited in alveoli, that are

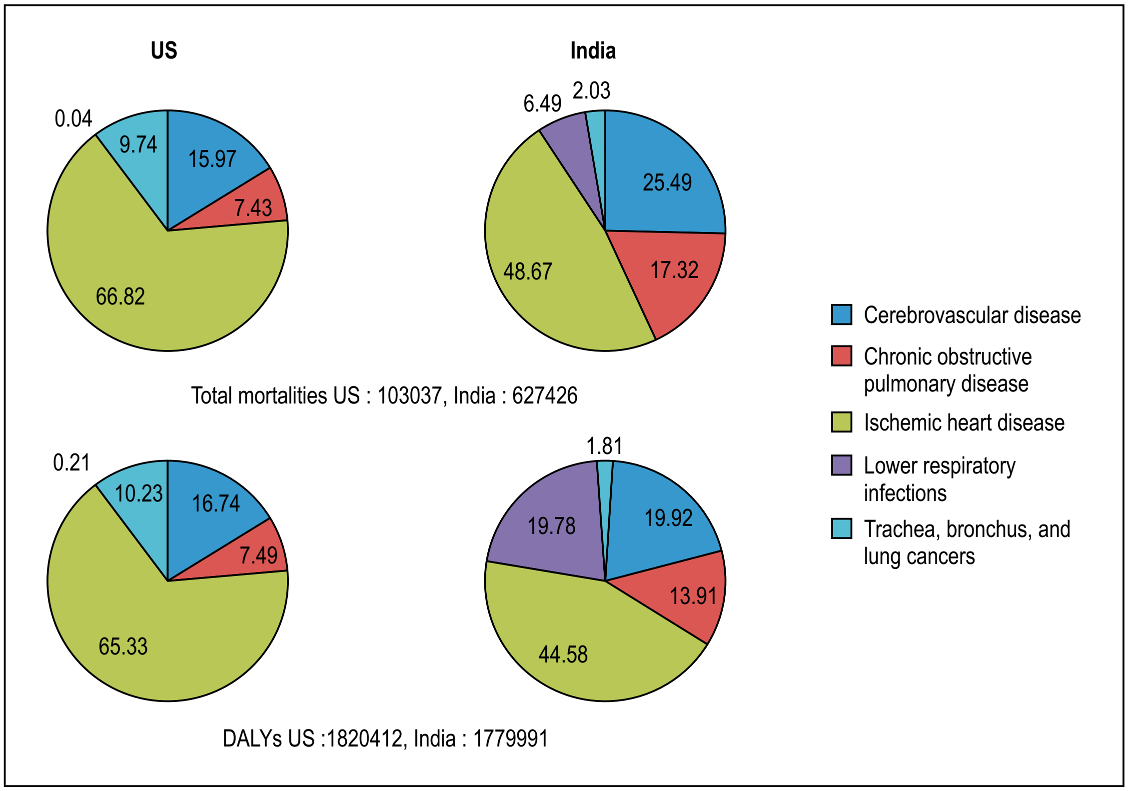


Figure 1.16: Disease-wise distribution of deaths and DALYs (%) attributable to ambient particulate matter pollution in the US and India

Source: Lim et al, 2012

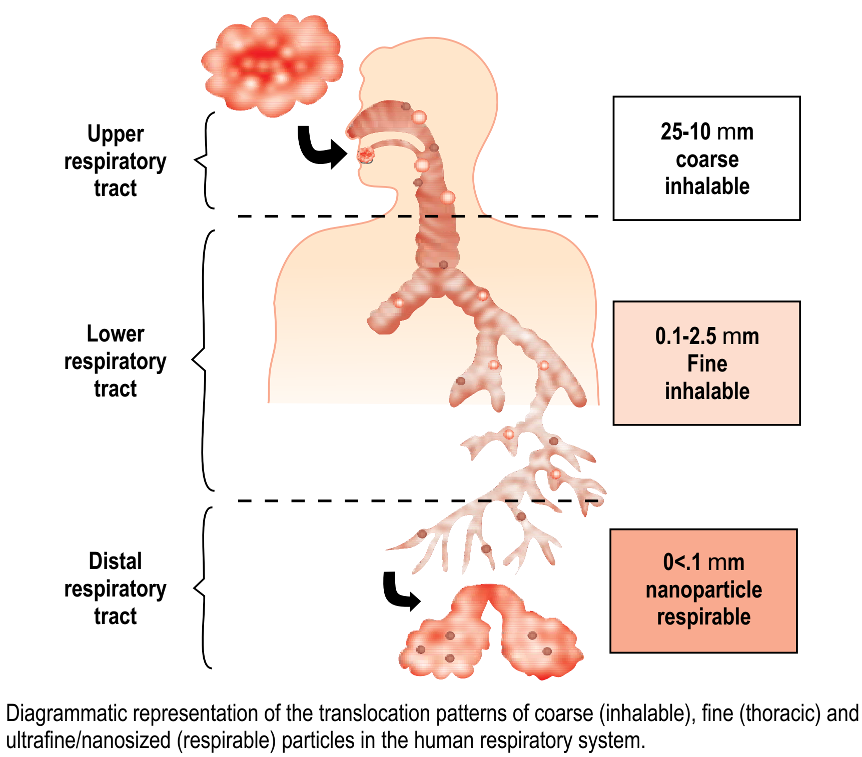


Figure 1.17: Translocation of inhaled particles in human lungs

Source: Brown et al., 2013

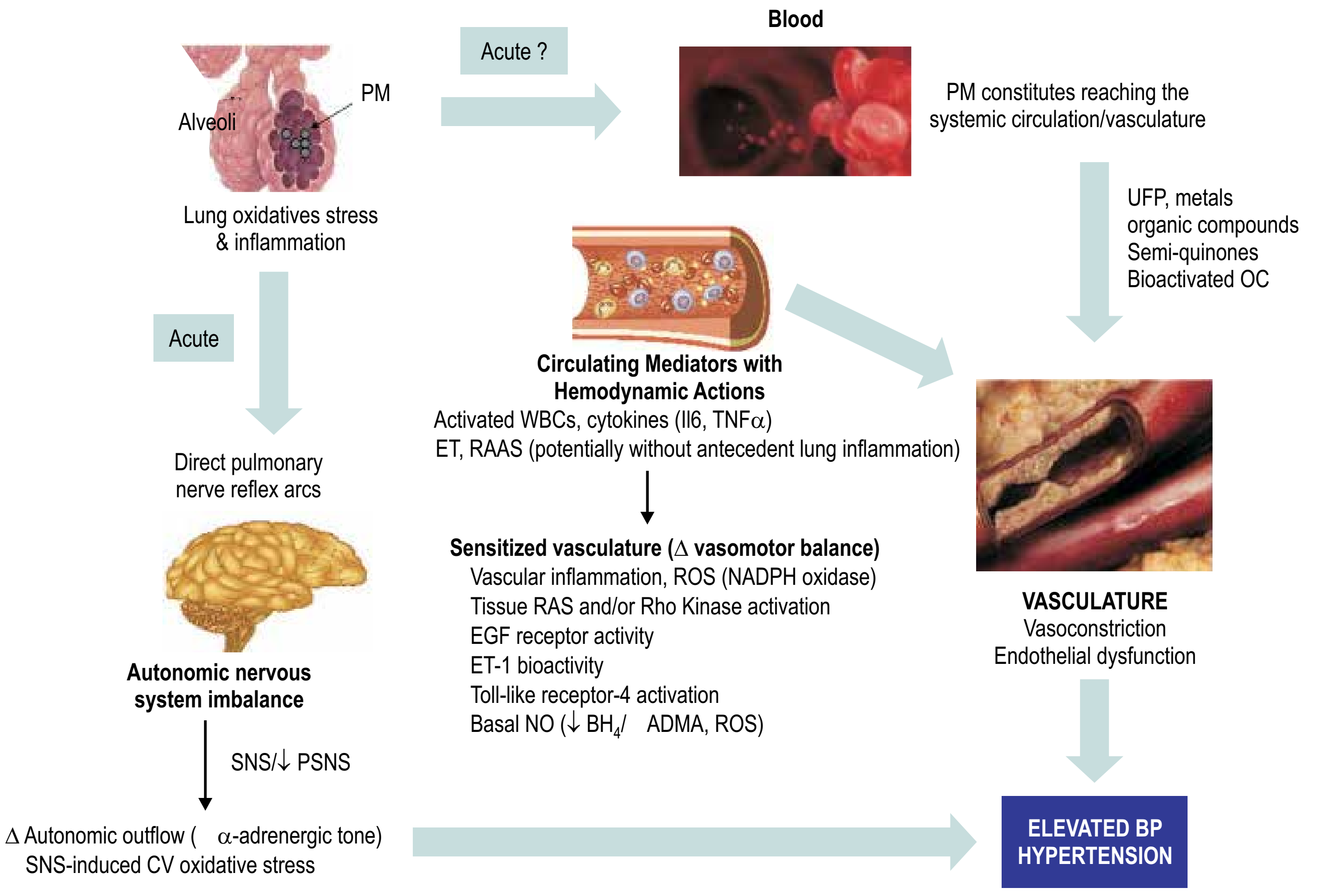


Figure 1.18: Underlying Molecular Mechanism of Cardiovascular Impact
Source: Brook, 2008

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 is depicted in figure 1.18.

Crop Impacts

1. India and Global Food Security

The four largest crops in the world – rice, wheat, maize, and soybeans – provide 75 per cent of all calories consumed by humans on the planet. While other crops – cereals, roots and tubers, fruits and vegetables, oil crops – are important for food and especially nutrition security, the ability to meet base caloric demand worldwide is largely a function of these four crops. Of these, rice and wheat are important for India, with other cereal and legume crops like sorghum, millet, lentils, barley, and peas playing important complementary roles.

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]. India's 1.2 billion citizens depend primarily on this production, although India exports a few million tons of rice and imports a few million tons of wheat each year. While these export amounts may seem trivial, they are key for many other south Asian (primarily Bangladesh) and African countries. Wheat imports are also highly valued and thus tremendously important for domestic food security. Rice in India is produced in two seasons:

85 per cent is grown in the kharif, or monsoon season, stretching from June-September; the remainder is grown in the winter rabi season. Wheat in India is a rabi crop, planted in November-December and harvested in April-May. Most rice is rained in India, most wheat is irrigated.

Wheat yields in India (and around the world) have begun to level off or even decline in some areas, even though actual yields remain well below theoretical yields in many regions. Rice yields in certain areas exhibit a similar slowing of yield growth over time, though to a lesser degree. With rising populations and increased demand from improved living standards, maintaining high wheat and rice yields is thus of paramount importance for Indian and global food security.

Climate change has important ramifications for agricultural production and food security. Crops are sensitive to solar radiation, soil moisture, ambient gas concentrations, temperature, and pests and pathogens, among other factors. Emissions of long-lived greenhouse gases (LLGHGs) and short-lived climate pollutants (SLCPs) affect all of these factors. The overall impact on crop yields from climate change is thus a complicated sum of many changes in a crop's ambient growing environment, some of which are positive and some of which are negative (and some of which differ on short versus longer time scales). The current state of knowledge of these impacts is summarized below, along with brief descriptions of the methodologies used to assess these impacts and major remaining sources of uncertainty.

2. Long-run Climate Trends

When considering the impact of climate on agricultural production, farmers and policymakers alike tend to focus on inter-annual variation: is this a hot or cool year relative to average; is this a wet or dry year relative to average? On a year-to-year basis, total precipitation and the potential for drought gets the most attention; however, over the long run, changes in average temperature have thus far had a stronger signature on agricultural production.

Most crops exhibit a non-linear relationship between growth and temperature (measured in any number of ways, from average daily temperature to cumulative exposure times at different temperatures). At low temperatures, growth (yield) increases slightly with increasing temperature, but above a critical temperature yields drop dramatically with increasing temperature. This critical temperature is determined empirically [e.g., Schlenker & Roberts 2009] through large panel analyses and in field trials. A rule of thumb is that, absent adaptation, each 1 °C increase in temperature would correspond to about a 10 per cent reduction in yields [Lobell et al., 2008].

Some of the impact of temperature is through soil moisture. In rain fed systems, soil moisture is largely a function of precipitation – both quantity and distribution over the season – although structural properties of the soil itself also matter. In irrigated systems, soil moisture is provided through applied surface or groundwater, which in turn depends on aquifer levels or abundance of runoff-fed surface sources like rivers and streams (discussed below).

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: national rice and wheat yields were several per cent lower in 2008 than they otherwise would have been absent the temperature and precipitation trends of the previous three decades [Lobell et al., 2011]. Studies like this one use historical data in multivariate panel regression analysis to tease out the relative impacts of climate, management practices, region-specific characteristics, etc.

These temperature and precipitation trends include the impacts of LLGHGs like CO_2 as well as SLCPs, which contribute to localized warming and changes in monsoon patterns. However, such studies do not take into account other factors like CO_2 fertilization, the impacts of SLCPs on radiation, the direct toxicity of ozone/ozone precursors to plants, co-emitted species (like SO_2), or the impact between SLCPs, their co-emissions, and pests and pathogens. These impacts are discussed below.

3. SLCP impacts

SLCPs – tropospheric ozone (O_3), methane, black carbon (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. However, the other SLCPs interact more complexly with agricultural production. Methane is both a greenhouse gas (contributing to warming) as well as a precursor to tropospheric ozone production. It is also emitted in flooded rice production (due to anaerobic decomposition in flooded paddy). It is thus difficult to tease out methane's net impact because it is both produced by and impacts crop production.

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), nitrogen oxides (NOx), and carbon monoxide (CO) – and since BC is often co-emitted or mixed in the atmosphere with other aerosols – like sulphates (mostly formed from sulphur dioxide (SO_2) emissions) and organic carbon (OC) – impact analysis necessitates discussion of broader aerosol impacts (BC + OC + SO_2/ sulphates) and joint analysis of O_3 and its precursors NOx, NMVOCs (non-methane VOCs), and CO.

4. 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. Organic carbon emissions have recently been shown to have mixed optical properties, with a net radiative impact of roughly zero (that is, they contribute some absorption and some scattering). Other aerosols, like sulphates, purely scatter incoming sunlight. These scattering aerosols also reduce the total radiation at the surface, but, since light is scattered rather than absorbed, it increases the fraction of diffused light on the surface. Plants may be able to more efficiently use diffuse light for photosynthesis [Mercado et al., 2009], so the net impact of aerosol emissions will depend on the relative amount of black carbon to other aerosols. Two studies have examined the historical impact of atmospheric brown clouds 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.

5. Ozone and Its Precursors

To date studies of ozone impacts have suffered from lack of data availability, as no long-run surface record of ozone measurements exists for India. Empirical statistical studies using historical data have thus not been possible. So studies have most often relied on extrapolation of exposure-response relationships and chemical transport models (to estimate exposures under present or future scenarios). However, results from such studies have been harrowing.

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 has lead 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 using flux measurements and chamber-scale observations have been used to derive cultivar-specific exposure-response relationships. Observational [Feng and Kobayashi, 2009; Fishman et al., 2010] and modeling studies have assessed the magnitude and distribution of ozone-induced production loss for major crops under present-day and future O_3 concentration scenario over various regions of the globe [van Aardenne et al., 1999; Aunan et al., 2000; Holland et al., 2006; Wang and Mauzerall et al., 2004; van Dingenen et al., 2009; Avnery et al., 2011a, 2011b]. All these impact assessment studies have raised concern about the O_3 impact on the magnitude of economic loss and food security [Teixeira et al., 2011].

Studies have projected that half of ozone-related crop yield loss in 2030 would be in India, absent adaptation [van Dingenen et al., 2009]. Both ground- and satellite- based measurements [Ghude et al., 2008; Bieg et al., 2006; Kulkarni et al., 2009] and regional ozone modeling using the atmospheric dispersion model MATCH [Engardt, 2008] have identified elevated concentrations across north eastern parts of South Asia, encompassing the fertile agricultural lands of the Indo-Gangetic Plain, one of the most important agricultural regions in the world. The highest ozone episodes were found during spring and early summer months which coincide with peak growing seasons for many important crops (most importantly, wheat).

A recent study [Bieg et al. 2013] made first estimates of the national risk to crop damage caused by surface O_3 pollution using regional chemical model (WRF-Chem) simulations, AOT40 exposure indices (an exposure-response relationship that measures the accumulated time a crop spends exposed to 40ppb or higher ozone concentrations) and district-wise crop production/ market price (daily) dataset for the year 2005 under present day NOx emission scenario. This assessment indicates significant production losses for four major crops, cotton, soybean, rice and wheat due to ozone exposure. The authors find that area of elevated O_3 concentration varies strongly between regions and timing of the crop season. The rainy season from June to September prevents the build up high surface O_3 levels and therefore kharif crops are less exposed to relatively low O_3 levels (particularly crops in Orissa, Chhatisgarh, Tamil Nadu, Kerala and western coastal strip) and are at low risk than the crops exposed during the winter season (rabi). The crop production shows higher output of rice and wheat in the western part of IG region, however risk associated with the O_3-induced crop damage is more for rice than wheat in this region. Present day fractional losses for cotton are estimated 5.3 (±3.1) per cent, 2.7 (±1.9) per cent for Soya bean, 2.1 (±0.9) for rice, and 5.0 (±1.2) for wheat. In terms of absolute production losses by weight, wheat (3.5 ± 0.8 million tons) and rice (2.1 ± 0.8 million tons) is found to be most affected by ozone-induced damage. Cotton and soybean suffered losses of 0.17 ±0.10 million tons and 0.23 ±0.16 million tons respectively. Translating the crop production losses into national economic losses for the four crop considered here, we estimate economic damage of 1.29 ±0.47 billion USD in 2005.

These results may have important policy implications for India where surface O_3 is expected to increase in future considering the recent upward trend in precursor emissions and implementation of National Food Security Bill. Recently, the Indian National Food Security Bill came into law (September 2013) to ensure availability of sufficient food grains to meet the domestic demand as well as access to adequate quantity of subsidies food to two third of India's 1.2 billion population. The result presented in this study show that national aggregated relative yield loss of wheat and rice totals 5.5 million ton in 2005. This loss is roughly about 12 per cent (92 million people) of 61.2 million tones (820 million populations) of cereals required every year for PDS under the provision of food security bill. In view of this the present study provides important assessment of the impact of present day air-pollution on agricultural crop yield reductions and extends first-hand important information to policymakers to propose or implement emission control measures to benefit more security on national food production.

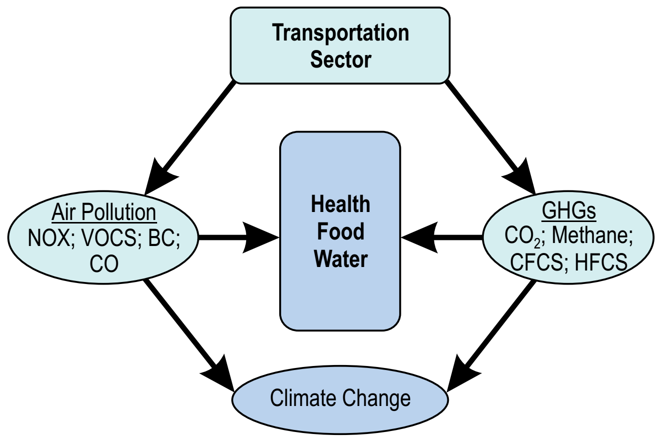
One shortcoming of current knowledge of ozone impacts is that the exposure-response framework considers only ozone (and not other climatic and regional factors). One recent study [Burney & Ramanathan, 2014] examined historical yields of rice and wheat in India over the past 3 decades and collectively teased apart the impacts of temperature, precipitation, and emissions (as opposed to concentrations) of aerosols and ozone precursors (as well as state-specific fixed and time-trending effects). This study found that wheat yields in India were 22 per cent lower (and rice yields 10 per cent lower) in 2008 than they otherwise would have been absent increases in emissions between 1980-2008. Over 80 per cent of this relative yield loss was attributable to the direct impacts of SLCPs (i.e., ozone exposure and, to a lesser extent, radiation changes) with the remainder due to long-run changes in average temperature and precipitation. These results suggested tens of millions of tons of crop loss and cleaning up the air in India could reclaim billions of dollars of revenue.

6. Other Mechanisms of Impact

SLCPs have additional impacts on crop yields through other channels (discussed elsewhere in this document). For example, localized warming, changing precipitation patterns, and direct deposition of black carbon on mountain snowpack and glaciers could drastically change the water security situation of India in the coming decades. Studies have shown dramatic reductions in water storage under India's breadbasket, the Indo-Gangetic Plains [e.g., Rodell et. al. 2009]. These withdrawals are mostly for irrigated agriculture. A short-run increase in glacial runoff/melting of snowpack might help with aquifer recharge and provide higher surface flow for human uses, but in the longer run, the decline in available water from the Himalayas (the Asian water tower) looms ominously [e.g., Menon et al., 2010].

Other research on the direct impact of deposition of aerosols on plants and the interactions between pollutants like ozone and sulphur dioxide and pathogens reveals some interesting connections that merit further research, but at present are difficult to convert into yield impacts. For example, direct deposition of particulate matter may disrupt photosynthesis by effectively reducing the active leaf area. The impact of NOx itself (beyond as a precursor for tropospheric ozone) may also be mixed. NOx is a strong oxidant and therefore damaging to plant tissues in a similar way to ozone; however, low levels of NOx might provide "free fertilizer" through soil deposition. Similarly, SO_2 emissions may result in radiation-blocking aerosol formation, but weakly acid rain may also provide "free sulphur" that farmers would otherwise have to purchase and apply. It is not known how these fertilization effects might offset some of the detrimental effects noted above, along with potential eutrophication and soil acidification. Finally research on pests and pathogens indicates that there is interplay between SO_2/NOx/Particulates and different plant pathogens — for example, some pests like low SO_2 while others prefer high levels. As such, more research is needed on the interplay between air pollution and yields, integrated into the broader climate/yield research agenda.

The Transportation Sector



Climate Impacts

1. Air Pollution - Climate Nexus Over India: The Transportation Sector

Globally, the transport sector accounts for 28 per cent of final energy demand, 70 per cent of which is from movement of people and goods on roads (Global Energy Assessment or GEA, 2012). Transport sector emits 6.6 Gt (giga tons) of CO_2 out of the 35 Gt from fossil fuels. Hence it is a major source of global warming. The transportation sector also has the highest rate of growth in CO_2 emissions. The other major GHGs (greenhouse gases) emitted by this sector is methane (fugitive emissions from natural gas processing and delivery), CFCs and HFCs. HFC contribution to warming is negligible now but it is the fastest growing GHG and at current rates can contribute as much as 0.1 °C by 2050 and 0.5 °C by 2100. Diesel vehicles (on road and off-road) are one of the major sources of black carbon aerosols, which is an SLCP. Diesel vehicles also emit organic carbon aerosols. In addition the transportation sector leads to increase of another SLCP, ozone. In addition, NOx emissions from the transportation sector contribute to nitrate aerosols in PM.

2. Impact on the Indian Monsoon and the Himalayan Glaciers:Water Security of South Asia

We want to highlight a potentially major impact of aerosols (PM) on the regional hydrological cycle of

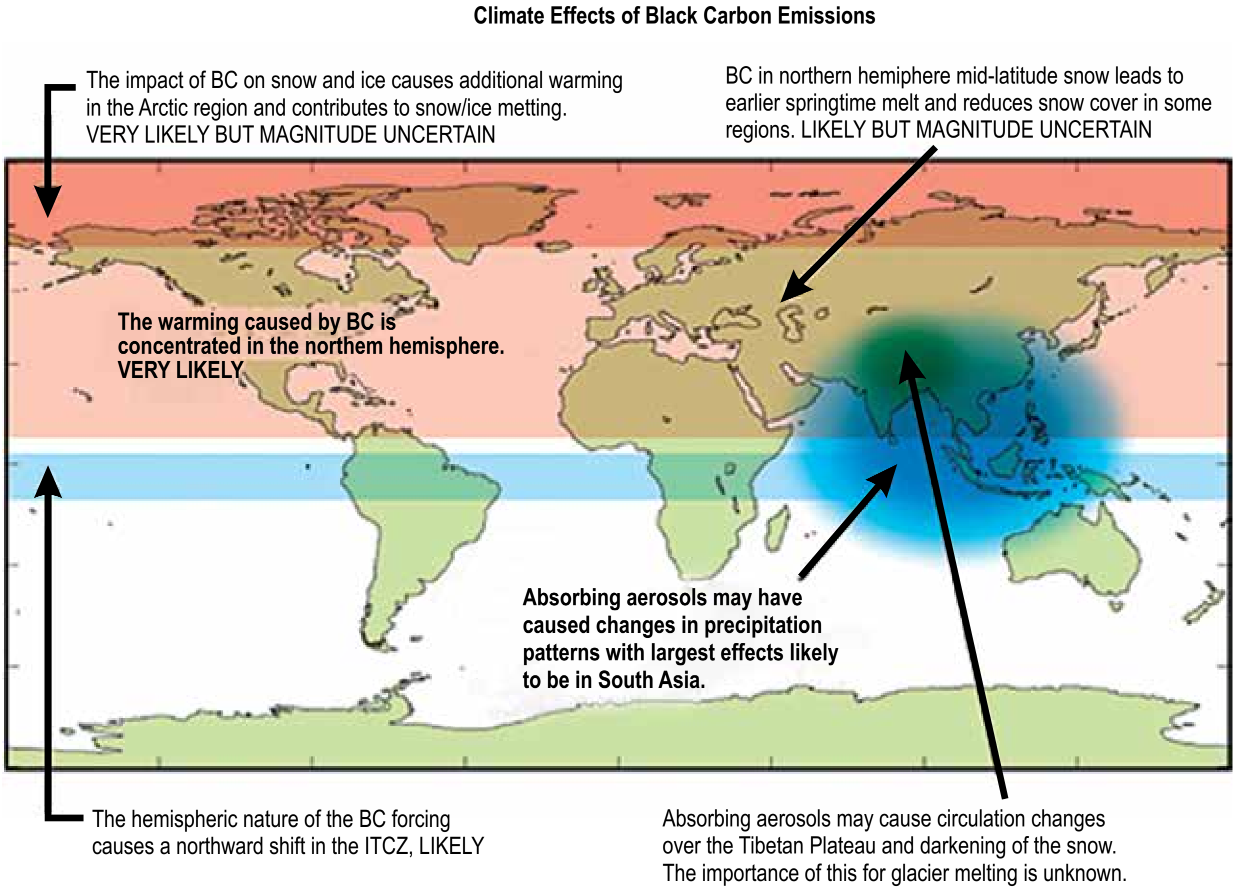


Figure 1.19: Climatic impacts of BC emission
Source: Bond et al., 2013

South Asia (Ramanathan et al, 2000; Ramanathan et al, 2005; Ganguly et al, 2013 IPCC-AR5, 2013). It has been shown that over the South Asian regions and the surrounding Indian Ocean, aerosols (sulphates, nitrates, organics and black carbon) contribute to significant dimming at the surface (UNEP-ABC-Asia report). The magnitude of the solar dimming is as much as 10 per cent over the oceans and 20 per cent to 30 per cent over the subcontinent. In addition, absorbing aerosols such as black carbon and dust (road and desert dust) absorb 10 per cent to 25 per cent of solar radiation within the atmosphere. This vertical redistribution of solar radiation along with alteration of the solar heating gradient between the land and oceans and between the north and the south Indian Ocean has been shown by several studies (Ramanathan et al 2005; Meehl et al 2009; see detailed review in Ganguly et al 2013) to weaken the monsoon circulation and reduce the summer time precipitation by 5 per cent to 10 per cent. In this regard, it is significant that observations show that the Indian monsoon precipitation has decreased by about 7 per cent from 1950 to 2005 (Ramanathan et al, 2005; Wang et al, 2008; UNEP-ABC Asia report, 2008).

In addition, the black carbon solar heating has been shown (by direct observations with UAVs and supporting model studies) to amplify the GHGs warming at elevated regions of the Himalayas by about 50 per cent to 100 per cent (Ramanathan et al, 2007; UNEP-ABC Asia report, 2008). In addition, direct deposition of black carbon over the bright snow and ice surfaces in the Himalayas, increases the absorption of solar radiation over the glaciers and snow packs, which also contributes significantly to the warming (Flanner et al, 2009; Qian et al, 2011; Menon et al, 2010; Ming et al, 2012). The two processes, black carbon direct warming of the atmosphere and the deposition over snow and ice, amplify the CO_2 induced warming over the Himalayas by as much as 100 per cent to 150 per cent (Xu, 2014). Observations of surface warming over the elevated regions of Himalayas and Tibet seem to support such amplification. Chinese glaciologists have shown (Liu et al, 2009) that the warming over the elevated regions of Himalayas is larger by a factor of two to three compared with the warming over the plains. The combined effects of CO_2 and black carbon on the Himalayan warming, contributes to the melting of numerous glaciers as reported in several studies (Kulkarni et al, 2007 &2013; Kulkarni an Karyakarte, 2014; Immerzeel et al, 2010; Bolch et al, 2012).

The monsoon and the Himalayan glaciers provide for the water needs of all of S. Asia. Air pollution aerosols have been shown (by model studies) to have a major negative impact on both the monsoon and the glaciers. The transport sector has a role in these effects since it contributes to black carbon, organic carbon, and nitrate aerosols but the magnitude has not yet been partitioned yet and awaits further studies.

Climate Change: CO_2 and BC

Because of short lifetime of BC (weeks or less), its radiative effects are concentrated close to the sources; whereas CO_2 is globally distributed and its effects are more globally uniform. Figure 1.19 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 black carbon cannot come at the expense of CO_2 mitigation.

Considerations for BC Mitigation: The importance of the Transportation Sector

Figure 1.20a summarizes the climate forcing by BC-rich sources. 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 (Figure 1.20b). The control of BC from on-road diesel engine thus offers an effective means of mitigating near-term climate change. In addition, sulphur 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 sulphate and organic carbon (OC) resulting in net cooling. Recently, this fact has been established in California (Ramanathan et al, 2013).

Summary and Conclusions

Air Pollution Impacts

- High population densities, mobility demands, and an 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) in Indian cities.
- Air pollution is a major cause of mortality and morbidity in India.The main air pollutant of concern is PM2.5 for human health impacts. 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. A recent WHO sponsored study concludes that ambient PM has caused 627,000 deaths (per year) in India. However, these studies are based on epidemiological data collected 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 has 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

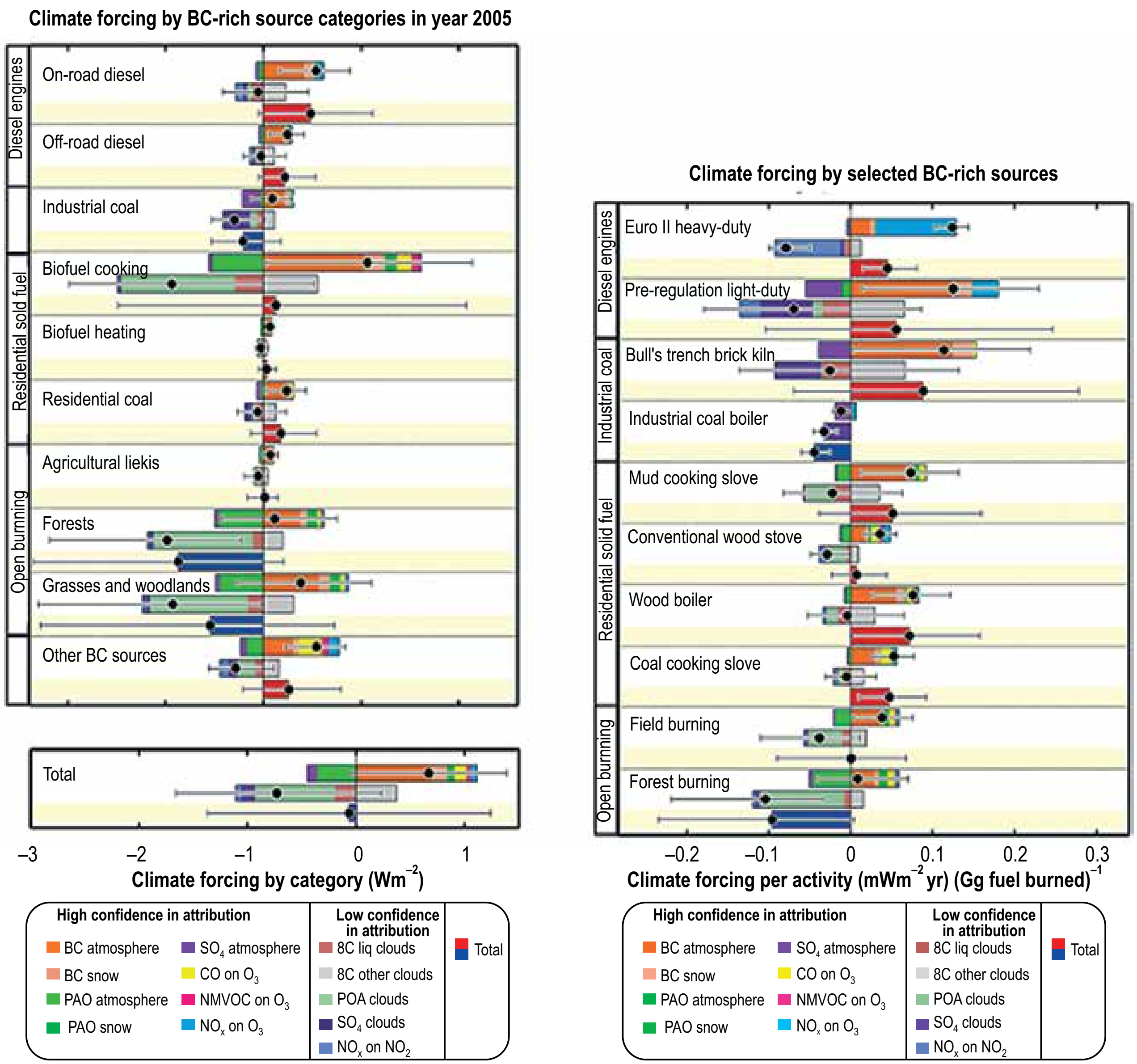


Figure 1.20a/b: Climate forcing by (**a**) BC-rich sources and (**b**) their sub set. The bottom color key should be used for three sets of bars with black dots as the best estimate with uncertainties

Source: Adapted from Bond et al., 2013

will help document the level of health impact that is specific to the Indian population.

- 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 beneficiaries in India for one year under the National Food Security Act. The loss is also about double the amount of wheat exported yearly and about 50 per cent of the rice exported annually. It has been estimated that India lost another 4 million tons of wheat due to climate change.
- Emission of CO_2 and the short-lived climate pollutants (Black Carbon, methane, ozone and HFCs) from the transportation sector contribute to global and regional climate change. In addition, emission of aerosols (black carbon, organics and nitrates) threaten the water security of

South Asia through their negative impacts on cloud formation, the Indian monsoon, and the Himalayan glaciers.

Transportation as a Source of Pollutants

- In cities, the transportation sector is a major contributor to PM2.5. In cities like Bangalore, Pune and Kanpur, the transport sector is a significant contributor to the concentrations of PM2.5. Within the transportation sector, heavy-duty trucks are the largest PM2.5 and BC emitters, particularly in states such as Maharashtra and Gujarat as well as in cities such as Delhi and Chennai. Transportation sector appears to be the largest emitter of NOx 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.
- Two and three wheeled vehicles produce roughly 40 per cent of PM2.5, 35 per cent of PM10, 40 per cent of carbon monoxide and 70 per cent of volatile organic compounds in the emissions inventory for road transport in India.
- The emissions from the transportation sector are projected to grow about threefold for PM2.5, and fivefold for NOx. Black carbon emissions, which are a subset of PM2.5, is likely to grow with similar rates. The dominant sources of PM within the transportation sector are diesel trucks and buses (52 per cent).
- 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.
- Trucks and buses are also the dominant source of NOx (83 per cent). 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 sulfate and ammonia loading), the negative impact of air pollution on India's precipitation will also decrease.
- The California example demonstrates that technologies are available to accomplish such massive reductions (>90 per cent) in air pollution.

Technology Measures

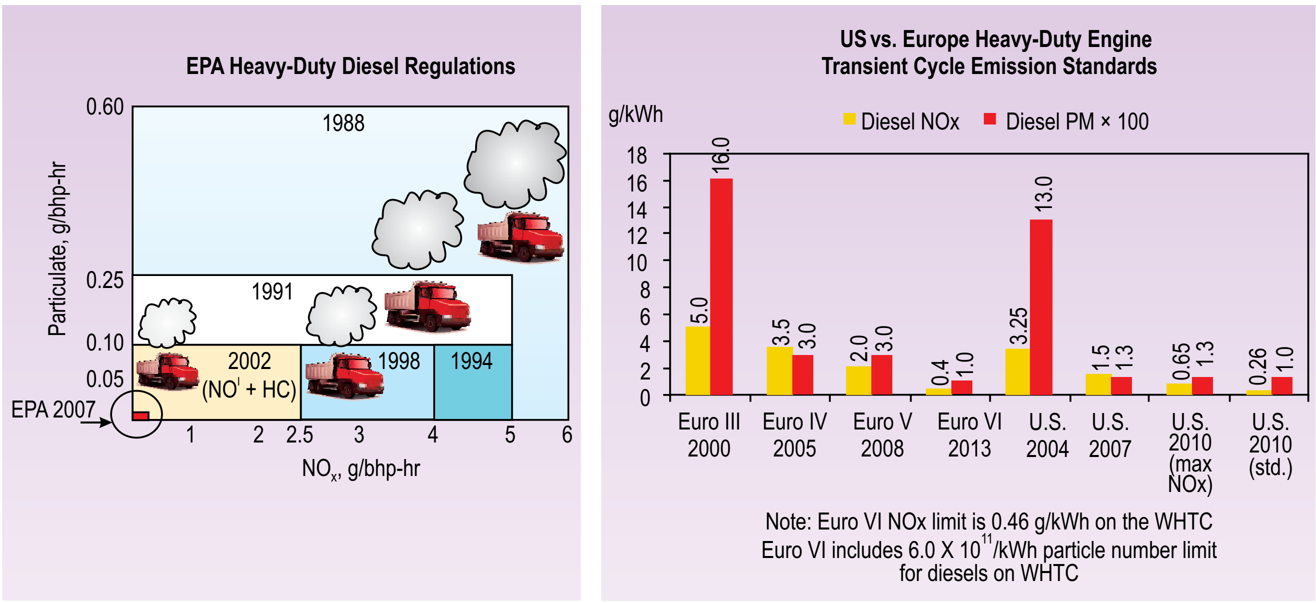
Harnish R, Bandivadekar A, Aggarwal A, Waugh M, Kubsh J, Iyer N, Yeh S, Davis S

History of Technology and Fuel Measures in Europe and USA

Particulate matter (PM) emission standards for heavy-duty trucks in both the US and Europe have been tightened a number of times since the late 1990s. As seen in the US 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, which amounts to about 80 per cent reduction.

These reductions were achieved largely through improved engine combustion technologies that did not require the use of ultra low sulphur (ULSF) diesel fuel. PM standards in the US did not change again until 2007 when the PM standard was reduced an additional 90 per cent to 0.01 g/bhp-hr. To achieve this level of PM performance required the introduction of ULSF (in mid-2006) and the application of catalyzed diesel particulate filters (DPFs) on new highway diesel engines in the US 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 US). In the second chart Euro vs. US 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 sulphur limits and Euro-III for the rest of the country with 500 ppm diesel sulphur limits). The Euro-III limits are roughly equivalent to US 2002/2004 limits



(a) (b)

Figure 2.1a/b: (a) Environmental Protection Agency (EPA) Heavy-duty diesel regulations. (b) US vs. Europe Heavy-duty engine transient cycle emission standards

Source: Manufacturers of Emission Controls Association (MECA), 2007 (which also utilized 500 ppm sulphur 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 exceptions 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 sulphur 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 in the US. 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.

The focus of the chapter is largely on diesel vehicles since, it is dominant source of PM. However, some of the steps like introduction of catalytic converters are applicable to petrol car as well.

Vehicle Emission & Fuel Quality Standards

Although BS-IV fuel is supplied to about thirty cities, 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 sulphur content to not exceed 50 ppm, while BS-III standards allow for up to 150 ppm sulphur gasoline and 350 ppm sulphur 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, 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.

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-sulphur fuels, which would enable the sale of vehicles meeting more stringent emission standards and adoption of diesel particulate filters and other advanced vehicle after-treatment systems in India. These advanced after treatment devices work at their best efficiencies when provided with fuels with sulphur content less than 10 ppm. Curently, the sulphur levels in diesel is about 350 ppm except in 20 cities where 50 ppm fuel is provided. While regions with advanced regulations such as Europe, the United States, and Japan implemented low-sulphur fuels years ago, and developing countries like China, South Africa, Mexico, and Brazil have plans to reduce fuel sulphur levels further in the near future, India is making minimal progress on this front. Apart from expanding the supply of 50 ppm sulphur fuel to about 60 cities by 2015, there is no plan as of now to supply that essential fuel to the whole country, or to reduce fuel sulphur 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 (2012) have estimated the refinery investments needed to transition to ULSFs in India to be around $4.2 billion. Summing investments and increased operational costs, and normalizing them to a per litre basis, Indian refineries would pay an extra 0.70-0.88¢ per litre of fuel produced. Thus, ULSFs would cost only about 50 paise per litre. Even after including tax impacts, the net increase in fuel price due to ULSFs will be less than 2 per cent 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 sulphur 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 ₹0.50 (US 1 cent) per litre every month until the full diesel subsidy is eliminated. This is a tremendous step forward for India's oil industry, and is freeing up capital for investments in ULSF production technologies. One extra month of on-going monthly ₹0.50 per litre diesel price increase will ensure that investments made by oil sector in producing ultra low sulphur fuels will be recouped.

Fuel Quality Improvements and Refining

Reducing sulphur levels in diesel fuel is an effective means of reducing PM emissions from diesel engines, especially when lower- sulphur fuel allows for the deployment of effective after-treatment technologies such as DPFs—the combination of which can reduce PM emissions by about 90 per cent. Furthermore, regulations that limit emissions from new diesel engines require low-sulphur diesel to be effective. In India, significant capital costs (on the order $4-$13 billion) are required for refiners to produce low-sulphur diesel fuel, and lubricity additives will be needed in higher concentrations, but the widespread use of diesel fuel should keep the cost-per-litre impacts at about $0.03. 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 sulphur content of the diesel fuel. Not only do lower sulphur levels reduce direct particulate matter emissions, they also allow for after-treatment technologies, such as diesel particulate filters, 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 Sulphur Levels in California

In July 2003, the California Air Resources Board (CARB) approved a 15 parts-per-million (ppm) sulphur limit for diesel fuel used in on-road and off-road engines. The previous diesel fuel sulphur limit had been 500 ppm. The 15 parts per million by weight (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 CARB; 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 CARB'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 harbour 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 per cent. Coupled with a DPF, total PM emissions can be reduced by 90 per cent. Moreover, lower fuel sulphur levels also reduce sulphur dioxide emissions that may form secondary PM emissions, such as ammonium sulphate.

Current Status in India

Presently, BS-III fuel (350 ppm sulphur) is being supplied throughout the country, except in 20 cities where BS-IV fuel (50 ppm sulphur) is available. There are many highly polluted cities other than these 20, which do not have the benefit of BS-IV fuel; also heavy-duty trucks have to be necessarily on BS-III norms, even if they are registered in the 20 cities, as they have to travel outside these cities.

Delay in the introduction of BS-III/BS-IV fuels across the country has been mainly due to inadequate availability of the fuel. Today, Indian refineries have production capacity of about 71 million tons for BS-III and 24.5 million tons for BS-IV quality fuels for supply in the domestic market. While, the Reliance refinery is producing BS-V fuel, this fuel is being exported. It is necessary for India to increase the production of BS-IV/V fuel and explore the option of diverting the fuel that is being exported to domestic use. Assuming that this diversion is not possible, the additional quantity of BS-IV/V fuel required in the country has to be produced by upgrading the Indian refineries.

Projected growth in the sector is expected to increase the transport sector energy consumption and emissions by about three times by the year 2030, and this would deteriorate the air quality further. The road map for further improvement in fuel quality and emission norms is under consideration of an Auto Fuel Vision Committee set up by the Government of India. The committee's recommendations on introduction of Euro-IV and Euro-V fuels are awaited.

It is certainly now on the government to mandate the refineries to upgrade their facilities and supply BS-V fuels (as a single fuel policy) at the earliest for supply across the country. The oil industry has indicated that it would be possible to upgrade the refineries within a span of 3 years. Also, the Indian automobile industry is exporting Euro-V equivalent vehicles, it has the necessary technology to upgrade the vehicles to advanced emission norms. On this basis, it is believed that BS-V fuels can be introduced across the country by 2018 and BS-VI emission norms by 2020. However, the AFV 2025 committee suggests a road map of providing BS-IV and BS-V fuels across the country by 2017 and 2020. This is delayed considering the loss of four years (2010-14) since the last road map ended.

We urge the Government of India to consider the earlier introduction of of BS-V fuels than those recommended in the Auto Fuel Vision and Policy 2025 Report, by requiring and enabling the Indian refineries to leapfrog from BS-III to BS-V fuels by 2018 or by diverting the current exports of RIL-SEZ and arranging for marginal imports. However, if this is not possible then the timelines recommended by the AFV 2025 Committee should be notified immediately so that there are nor further delays in introducing the fuels.

As per the road map suggested by AFV 2025, the whole country should move to BS-IV vehicular emission norms by 2017. However, if it is possible to introduce BS-V fuel by 2018, the auto industry could move from BS-III/IV emission standards to BS-VI emission standards by 2020 as recommended earlier. This will facilitate the use of after treatment devices at least for retrofittment as BS-V fuel is progressively introduced.

The corporate sector (oil and automobile manufacturing companies) need to respond to the mandate and upgrade their facilities to meet the advanced fuel quality and vehicular emission norms.

Cost of Reducing Diesel Sulphur Levels

Legal requirements for ultra low- sulphur diesel fuel necessitate changes in the way diesel fuel is produced. Unless they formerly produce ULSF diesel, refiners need to perform modifications to their facilities to ensure that they are capable of producing sufficient and consistent quantities of ultra low- sulphur diesel fuel.

When CARB adopted the 15 ppm diesel sulphur limit in 2003, eight of the 12 large refineries in California reported that capital expenditures to produce low- sulphur diesel fuel would be minimal. Three refineries reported significant costs involving the installation of new hydro-de sulphurization 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-sulphur 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 labour, material (such as catalysts, etc.,), sulphur disposal, maintenance, insurance, and repairs associated with 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 sulphur requirements were about 2.5 ¢ per gallon.

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 sulphur levels are lowered through hydro-de sulphurization, some of the naturally occurring compounds in diesel that help with lubricity are also removed, so lubricity additives are usually required.

Lubricity additives 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

CARB reduced the aromatic content of diesel fuel in 1988 from 35 per cent to 10 per cent by volume (20 per cent for small refiners). Hydro-processing can reduce aromatics content by as much as 70 per cent. Staff estimated in 1988 that reducing the aromatic content of diesel fuel to 10 per cent would cost about 11¢per gallon for large refineries and 19 ¢ per gallon for small refineries, which is why CARB 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 per cent to 10 per cent reduces NOx emissions by about 3 to 5 per cent 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.

Future Diesel Technology

When implementing Action Options item number 5, Foster New Engine Management Technology, 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 (R&D), it has to ensure that the customers have engines that deliver optimum performance and reliability at the lowest possible cost of operation. Equally important 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.

To design the most appropriate emission control solution, one must take into account combustion research, fuel systems, air-handling systems, controls, and aftertreatment. 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 US on-highway truck market, where application of cooled exhaust gas recirculation (EGR) made most economical sense to comply with US 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 US 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 US EPA lowered the limit for diesel fuel sulphur from 500 ppm to 15 ppm. Implementation of the federal 15 ppm sulphur cap on highway diesel fuel began in the US in October 2006. This ULSF 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 sulphuric 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 aftertreatment 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. After-treatment strategies to reduce NOx include 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 a 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 per cent 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 vapour. This process is called regeneration. Sulfur poses challenges for NOx adsorbers. This is because in addition to storing NOx, NAC also stores sulphur, which reduces its capacity to store NOx. A periodic de-sulphation process to remove sulphur 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 many factors, but typical values of 10 per cent-25 per cent are in use over practical duty cycles.

Coming to PM reduction technologies, we have advanced combustion, oxidation catalysts and DPFs. In order to reach tight PM standards, active diesel particulate filters are needed. DPF is already available in India on certain models of cars. With the introduction of Euro-V like standards in India (expected throughout India in 2020 according to the recently released Auto Fuel Vision and Policy 2025 report, MoPNG 2014) there will be a forcing effect on the development and manufacture of DPF in India. Probably multinational companies like Corning, Cummins, and Caterpillar will play an important role in technology transfer.

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 SCR 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 that are 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 per cent of PM2.5, 35 per cent of PM10, 40 per cent of carbon monoxide and 70 per cent of volatile organic compounds in the emissions inventory for road transport in India.

In 2007, the International Council on Clean Transportation (ICCT) published an initial assessment (Meszler D, 2007) of technologies to control air pollution from motorcycles, followed shortly after by a more comprehensive review (Kamakaté F, Gordon D, 2009) 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. (see: http://www.theicct.org/two-and-three-wheelers-india-iyer-report)

Technology Being Used to Reduce Emissions

Most of two-wheeler 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 aftertreatment 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 per cent 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 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 two-wheeled vehicle customer to 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 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 United Nations Economic Commission for Europe (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 UNECE 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 aftertreatment 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 (B) High Pressure Direct Injection for two-stroke engines, (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 after-treatment 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 of three-way catalytic converters. With a judicious combination of technologies to reduce "engine out" emissions and aftertreatment devices, it will be possible to meet the proposed emission standards for the proposed Euro-IV and Euro-V equivalent levels. Additional information concerning the application of exhaust emission controls such as three-way catalytic converters to two and three-wheel vehicles are 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 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 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. On 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 always stays 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 per cent. 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 per cent depending upon the model.

Technical Measures Other than Tailpipe 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 US for some time. In general, these US motorcycles have adopted automotive evaporative emission control technologies such as carbon canisters for meeting US 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 (IUC) Testing 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. IUC testing, 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 compressed natural gas (CNG) and liquid petroleum gas (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 per cent, 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 BS-III 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

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 CNG vehicles (including buses, auto, rugged terrain vehicles (RTV), and others) at 344, 250 in 2010.

Although the environmental factor is undoubtedly one of the main considerations for governments promoting natural gas vehicles (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 carbueration-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 emissions they ran on gasoline and found them to exhibit average reductions of 53 per cent, 55 per cent, and 20 per cent in CO, NMHCs, and CO_2 emissions, respectively, but average increases of 162 per cent and 171 per cent in HC and NOx emissions, respectively.

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 (SO_2), 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 life cycle GHG (or so called well-to-wheel) emissions which take into account the entire fuel cycle including emissions from fuel extraction at the well to emissions occurring during the operation of the vehicles, and the global warming potentials (GWPs) of non-CO_2 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 per cent 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) so it is important to keep them in mind when implementing Action Options item 5. 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 sulphur 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 sulphur 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 sulphur 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 sulphur 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 sulphur diesel fuel have been employed on a variety of diesel stationary engines 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 US-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 CARB ATCM also required stationary engines > 50 hp to utilize 15 ppm max. diesel fuel by no later than January 1, 2005. CARB'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.

Electric Vehicles

Transitioning to a low-carbon economy entails replacing traditional fossil-fueled generating stations for electric power with renewable zero-emission sources like wind and solar as well as decarbonizing transportation. Those implementing ICAMP can take a 'greenfield' approach to building a system based on the same principles laid out in California's integrated energy policy. Maintaining electric system reliability as intermittent renewable, like wind and solar sources, account for a growing share of the total portfolio and requires two key ingredients: dispatchable electric loads ("Demand Response") and energy storage. Sometimes referred to as "Non-Generator Resources" they can respond to periods of over or under-generation from wind and solar power sources. California's plan aims to leverage plug-in electric vehicles (PEVs) as a symbiotic compliment to its growing reliance on wind and solar power by making PEVs dispatchable. By doing so, these key goals cross-contribute:

- The State will reach 33 per cent Renewable Portfolio Standard by 2020
- California will reduce its GHG emissions (including Black Carbon and NOx)
- PEVs will contribute to electric system reliability by creating a virtual power plant (VPP) capable of responding to over or under-generation conditions or fluctuations in grid frequency.
- Grid operators can pay PEV owners to be "available for dispatch," thereby lowering the cost of the vehicle.
- Owners of distributed energy sources can create microgrids that rely on energy stored in the vehicle batteries during prolonged system outages or natural disasters.

Mature standards recently developed in Europe (International Organization for Standardization (ISO)/International Electrotechnical Commission (IEC) 15118) now enable vehicles from multiple manufacturers to become aggregated along with each other. Additionally, mature technology now exists to harmonize them with the grid and has been deployed across 21 countries in Europe and the United States. The ICAMP report proposal can leverage this technology being demonstrated on the UC San Diego campus today to help India reduce Black Carbon and NOx emissions from both its transportation and power generation sectors while reducing oil imports and increasing energy security.

The fastest approach to gaining market share for PEVs in metropolitan areas is EV car share. The city of

San Diego implemented a PEV car share program with 400 Smart "For Two" EVs and now has over 24,000 subscribers. Paris is now expanding their car share program into the suburbs due to its popularity as a compliment to public transportation.

Summary and Conclusions

In this chapter 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 sulphur 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-IV/V/VI 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 at some of the outcomes. We are reminded that there is no "best path" for technology change in transportation, which depends upon many things and not just on 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-sulphur fuels. ULSF would enable the sale of vehicles meeting more stringent emission standards and adoption of 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. Even if vehicles were fitted with DPFs, their control efficiency is just 50 per cent when 50ppm sulphur diesel is used and lower grades of fuel also damage the filter. The gains from investing in a DPF are attenuated unless the vehicle has consistent access to ultra low sulphur diesel (less than 10ppm). Two and three wheeled vehicles produce roughly 40 per cent of PM2.5, and 35 per cent 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 per cent of carbon monoxide and 70 per cent of volatile organic compounds

CHAPTER 3

Policy and Governance

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Introduction

The previous chapters have laid out the scientific analysis of the state of air quality in India and its impacts and the various emissions control technologies available. This chapter focusses on ways to integrate this information into policymaking and implementation as well as public investment planning. After a brief overview of the the institutional environment for transport governance, air quality management and their intersection, subsequent 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.

As described by Craig et al. (2008), while countries in Asia, the European Community, and North America each have a unique set of air pollution problems – and approaches and capacities to deal with them – there is a clear portfolio of comprehensive management strategies common to successful programs. These include the establishment of ambient air quality standards that define clean air goals, strong public support leading to the political will to address these problems, technology-based and technology-forcing emission limits for all major contributing sources, and enforcement programs to ensure that the emission standards are met. Some unique aspects of CARB's air quality management program are the authority to set emission standards more stringent than the national ones, the technical evaluations that go into its regulation development, and the very open public process.

Throughout the discussion we highlight measures that have been piloted or considered in India and from which lessons could be learned.

The chapter proposes both policy and governance changes that could reduce transport-related emissions. It is important to distinguish between the two. "Policy" comprises decisions to be considered by the Government of India and State Governments on the basis of available evidence of their merits. "Governance" is commonly defined as the longer-term process for integrating public priorities and expert information to effectively allocate public financial and human resources toward development and welfare goals. It is the foundation for ongoing policy formation as well as implementation. "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. In short, it generally refers to changes in the institutional environment than in turn enable and encourage more effective policies.

The first subsection provides an overview of the institutional environment for transport governance, air quality management, and their intersection.

The second subsection touches on the politics of air quality and ways in which the institutional environment could be catalyzed into further action. We focus in particular on informational and investmentsthat could be made to increase the incentives for and effectiveness of action, to reduce emissions from transport (and other sources). The case for reducing emissions from transport is clear – the costs of action may be concentrated on particular industries or sectors, but the gains from reducing emissions will ultimately accrue to the public, in the form of improved health, higher crop yields, and mitigation of regional and global climate change. The impetus to act will thus depend on building broader awareness of the gains from emissions reduction, mediating conflicts over costs of action, and building capacity to use public financial, human, and institutional resources to reduce emissions efficiently.

The following two subsections discuss important policy options that emerge from scientific and technical assessments. Upgrading India's fuel supply to provide nation-wide access to Euro-IV equivalent (<50 ppm sulphur) by 2015 (further defined in Appendix A, generally speaking Indian standards for vehicle emissions and fuel quality are similar to European standards) and Euro-V equivalent (<10 ppm sulphur) by 2018 should ideally be the first step. Comparable BS-VI emissions norms should be in place by 2020.

However, the recent report of Auto Fuel Vision 2025 (MoPNG, 2014) has recommended a road map of introducing BS-IV and BS-V fuels in the country by 2017 and 2020, respectively. It is much too late, and the options of requiring and enabling the Indian refineries to leapfrog from BS-III to BS-V fuels by 2018 or by diverting the current exports of Reliance Industries Limited-Special Economic Zone (RIL-SEZ) and arranging for marginal imports, should be explored. However, if we have to accept the road map suggested, the government should ensure that the timelines are adhered to and that there is no further delay.

A 2012 study by Hart Energy and MathPro, commissioned by ICCT, estimated the total costs of moving to nation-wide ultra low sulphur diesel at $4.2 billion, or about 50 paise per litre for a reference year of 2015. The analysis took into account the additional operating costs as well as capital investment involved in removing sulphur from fuel, considering India's refinery configuration, capacity, and the properties of crude fuel as of 2010. A parallel estimate of about $ 13 billion has been put forward by the Indian refineries as the capital cost of upgradation of refineries to produce BS-V fuels in India.

Reducing the full spectrum of health, agriculture, and climate-damaging emissions will also require adoption of vehicle emissions control technologies, especially diesel particulate filters. These devices work at their optimum efficiencies when provided with 10 ppm sulphur fuels and at lower efficiencies on 50 ppm sulphur fuels. There may be scope for innovation in emissions control technology to allow the development of an indigenous pollution control industry. Finally, after treatment devices should be mandated as OEMs.

Subsection Four focusses on strategies for upgrading India's in-use vehicle testing program to strengthen enforcement and thus adoption of more stringent emission control standards. 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 of sulphur (BS-V). Lowering sulphur content in fuel also reduces sulphate 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 focus in the penultimate section moves from "Improving" vehicles to reduce emissions to looking at options for "Avoiding" Transport and "Shifting" it to other lower-emission forms of transport. These are the two other legs of governance strategy for building a sustainable transport system - one that provides mobility for individuals and supports freight movement for business with minimum emissions. There is no single silver-bullet policy to reshape the patterns of transport use. "Avoid" and "Shift" require first, strategic urban planning to reduce amount of travel required; and second, investment in creating attractive, competitive lower emission 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 (NUTP), the National Habitat Mission and the Report of the National Transport Development Policy Committee (NTDPC).

Subsection five focusses on three types of measures that could contribute to "Avoided" and "Shifted" transport:

- institutional changes to enable more strategic urban planning including implementation of transit-oriented development (TOD) and integration of urban transport systems across modes;
- specific initiatives to help shift the patterns of freight use to lower-emission options as well as move towards TOD and improve bus systems (currently the core of India's public transport system) for passenger mobility; and
- initiatives outside of transport policy that could affect the level of transport demand. Many of these points reiterate recommendations of the Report of the NTDPC and the NUTP in laying the governance groundwork for investing available funds into sustainable transport systems.There is no one-size-fits-all way of implementing the broad policies of Transit Oriented Development in India's varied cities, nor is simply stating "follow TOD" sufficient to advance the practice. We therefore focus on the middle ground of discussing the kinds of governance reforms that would equip India's cities and states to design, implemenent, and maintain TOD (and integrated transport networks, land use planning, and other broad programmatic initiatives) in their areas.

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) were notably successful 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.

It is important to note that India's states, like California, have the potential to lead new initiatives in improving air quality. Indian states do have the legal authority to act on various aspects of transport emissions reduction. State government agencies overseeing urban infrastructure and industrial development policies (e.g., Development Authorities, Departments of Municipal Administration) have the power to influence infrastructure investment plans to support public transport investment. State Transport Departments oversee the registration process and verification of pollution under control certificates. For example, 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 to notify emissions standards.

California's 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 with concerted policy and investments in governance.

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.

Policy and Governance in California

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 1,100 employees statewide; most are engineers and scientists and at about 20 per cent have advanced degrees (PhD and Master's). 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 by-laws (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.

Visible pollution from diesel engines, coal-burning power plants, and fires for cooking and burning of trash provide a visceral measure of environmental degradation and impaired quality of life in California during the post-World War II industrial boon period, and in India today. Irritating substances like ozone, formaldehyde, and peroxyacetyl nitrate (PAN) make breathing difficult and eyes water. In the mid-1960s when pollution levels were first recorded, peak oxidant (ozone plus NO2) levels approached 800 ppb in Los Angeles and there were over 100 days of Stage 1 health alerts when all residents were urged to restrict their outdoor activities. 24-hour-average PM10 concentrations exceeded 1800 µg/m3 in desert areas and 600 µg/m3 in Los Angeles. Most Californians breathed unhealthy levels of lead, nitrogen dioxide, sulphur dioxide, carbon monoxide, ozone, particulate matter, and/or air toxics, which built strong public and legislative support, across political affiliations and socio-economic strata, for regulations and other actions to improve air quality.

Initially, California and other regions focused their air pollution control efforts on lead, ozone, and large particles (i.e., TSP, PM10). However, newer epidemiological studies of premature death, primarily conducted in the United States with cohorts as large as half a million participants, have made it clear that long-term exposure to PM2.5 is the major health risk from airborne pollutants. The ambient air quality standards and the regulatory authorities that result from public and political support have been the major driver of clean air progress (Craig et al., 2008).

Worldwide, command-and-control has been the primary regulatory mechanism to achieve emission reductions. CARB has a unique authority within the U.S. to set motor vehicle emission and fuel standards in California that are more stringent than the U.S. EPA in order to address "compelling and extraordinary" air quality problems. These standards can be adopted by other states, and California has demonstrated regulations and policies that are eventually adopted or otherwise influence regulations by the U.S. EPA and the European Union, and are now being adopted in many developing countries, particularly in Asia. Emissions of VOC and CO (and to a lesser extent NOX) from new passenger vehicles were reduced by a factor of a hundred in comparison to pre-control vehicles. Since 2010, emissions of heavy duty engines were reduced 98% compared to pre-control conditions. Implementation of reformulated gasoline and diesel fuels resulted in further reductions. Stationary source NOX and SOX emission standards were reduced by at least a factor of ten. Since the emission standards are technology-based or technology-forcing, industry has been able to pursue the most cost-effective strategy to meeting the emission target. As a result, actual control costs are generally less than originally estimated. Despite the increasing difficulty of pollutant emission reduction, technological advancements have kept control costs per unit of reduction fairly uniform for California's motor vehicle and fuel regulations over the past four decades (Craig et al., 2008).

A comprehensive enforcement program with mandatory reporting of emissions, sufficient resources for inspectors and equipment, and meaningful penalties for noncompliance ensures that emission standards are being met. While air quality management through standards for vehicles and fuels have resulted in measurable reductions in emissions, regulation of emissions for in-use vehicles through inspection and maintenance programs poses greater technical challenges (Craig et al., 2008).

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 changes 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 U.S. or in the world. Underlying this science-based approach is the willingness to move ahead in the face of some uncertainties.

Through decades of emission control success, these programs have significantly improved California's air quality, despite more than doubling the number of people and tripling the number of vehicles over the last four decades. The improvements in California and U.S. air quality over the past four decades have come at a modest cost to society. The total cost of U.S. air pollution control is estimated to be 0.5% of GDP during the time period 1990 to 2020. Air pollution control also has positive economic aspects. The benefits of controls include thousands fewer premature deaths and hospitalizations each year, and millions fewer lost school and work days. The value of these benefits is uncertain but ranges from $10 to $95 dollars for every dollar spent on control from 1970 to 1990, when lead reductions and other major control programs were implemented, and $30 from the period 1990 to 2020. Thus, air pollution control strategies are very cost-effective.

Much of the money spent on control stays in the state. The air pollution control industry in California generated around $6.2 billion, representing 0.5% of the economy, and employed 32,000 people in 2001. The industry grew 14 times its size from 1970 to 2001, a compounded annual growth rate of 9% and well ahead of the economic growth rate of the overall state economy during the same period. And the size of the California clean energy industry is even larger – $27 billion in 2009, 12% of the U.S. total and 2.5% of the global total, employing 123,000 Californians.

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.

The Institutional Context: Transport, Air Quality Management, and the Intersection

Transport

India's transport policy environment is fragmented. Responsibilities for infrastructure investment planning, policymaking, regulatory oversight, and financing are divided within and between levels of government. The country is unique in having separate national Ministries overseeing each mode of transport (road, rail, shipping, etc.,).

The erstwhile Planning Commission's Transport Division (PCTD) had been the main coordinating body on transport investment before the termination of the planning commission, but it focused more on aggregating projects into sector investment plans rather than long-range or multi-modal strategy. It is unclear what will replace this body. The National Transport Development Policy Committee (NTDPC), a high-level expert committee that submitted its report in April 2014, recommended the creation of an "Office of Transport Strategy" to be "primarily concerned with building the foundation for an integrated energy-efficient national infrastructure, reducing externalities from sub-national transport decisions, and leveraging transport as a contributor to national equity goals." (206) The OTS envisioned would serve as a system-level technical advisor to the government and the current group of agencies involved in transport to generate policy and investment options for consideration, and provide ongoing technical support once these are accepted. It would host and manage the country's transport data, making it available not only for its own analysis, but also for others to analyze and contribute. Finally, the OTS would also advise and evaluate longer-run institutional changes in transport governance such as initiatives to promote a "shift" to lower-emission forms of governance. Any new agency along these lines would be an important focal point for integrating air quality and other sustainability goals into India's transport system.

Civil aviation, railways, and shipping are primarily national responsibilities, while states play more of a role in road investment, regulation of road use, and road transport, as well as regulation of and investment in state-level ports. State-level divisions of responsibility across different tiers of roads (rural, major district roads, highways), policy and implementation, sources of finance (public, private, or intergovernmental transfer) vary across states. Many states have divided functions between Public Works and/or Rural Development for publicly financed roads, Road Development Corporations for privately financed roads, and Department of Municipal Administration for urban roads. Decisions about urban and peri-urban road networks, or about prioritizing investment in roads versus public transport often require several distinct agencies to coordinate.

Local governments play a limited role in creating and regulating the transport system. Links between transport strategy and land-use planning for industrial or urban development vary. Various agencies have been involved in development plans that link the two, including State-level infrastructure financing bodies (e.g., Karnataka Urban Infrastructure Development Finance Corporation), Urban Development Authorities (the agencies in charge of development planning for larger cities and their surroundings) and municipal corporations. The City Development Plans (CDPs), formally required as part of the planning process are not required to explicitly integrate decisions about transport and land use, though many of the recent ones have done so. The JNNURM, a national investment program for urban infrastructure also required all participating cities (India's largest cities) to write Comprehensive Mobility Plans and the most recent NUTP offers financial support for hiring transport planners and integrating transport plans into broader urban planning frameworks.

Urban transport, one of the key areas of interest for emissions reduction, has a particularly complex governance framework. It is a "constitutional and institutional orphan" (in the words of the Report of the Planning Commission Working Group on Urban

Transport) with many interested parents. National, state, and, to a lesser extent, city government agencies are involved in planning, financing, and maintaining projects. The Ministries of Railways and Urban Development play a key financing and oversight role in rail-based urban transport, and the Ministry of Road Transport and Highways is often involved in setting standards or providing other inputs for bus-based transport systems. State and local government share responsibility for road investment planning and implementation, and the local government undertakes maintenance. Public transport services are operated by a mix of state corporations (primarily focused on inter-city transport), municipal transport corporations (intra-city), and private providers of cabs, rickshaws, and mini-buses.

Capacity for integrating urban transport strategy across modes and with larger urban planning processes (particularly land use) also needs to be built. The Ministry of Urban Development's National Urban Transport Policy (2006) recommended that each city of more than a million residents form an Urban Metropolitan Transport Authority (UMTA). As of the 2011 Census, however, there are 53 cities of that size, but there are only 8-10 UMTAs existing in any form and available information suggests that even the older UMTAs are in the early stages of institutional development. Several of these committees play an important role in coordinating many state and urban participants in urban transport, but, at the time of writing, none have sizable permanent expert staff or independent budgets.

The recent promotion of "smart cities" reiterates the gaps in urban transport planning and urges more attention to public transport, noting: "So far, urban transport planning has emphasized providing for personal motor vehicle. Public transport systems have been planned in isolation with the result that a well-integrated multi-modal system has not come up."[1] The Smart Cities agenda recommends a "three pronged" approach that cuts across these agency divides, including: (1) Improvements in public transport – metro rail, BRT, LRT, Monorail, etc., (2) Improvements in infrastructure of other motor vehicles – ring roads, bypasses, elevated roads, improvements in the existing road ways, and (3) Improvements in infrastructure for walking, cycling and waterways.

Air Quality Management

India's emissions control standards are created and enforced by a range of government agencies, acting under several statutes and legal precedents regarding vehicle emissions, fuel quality and air quality standards. The following is a list of entities involved across national, state, and local governments and their respective roles:

National Government

- Ministry of Environment and Forests: This is the nodal agency entrusted with planning, promotion, coordination, and supervising the implementation of the country's environmental and forestry policies and programmes, which typically covers the conservation of flora, fauna, forests and wildlife, prevention and control of pollution, afforestation and regeneration of degraded areas, protection of the environment and ensuring the welfare of animals. (http://envfor.nic.in)
- Central Pollution Control Board: This is a statutory organization constituted under the Water (Prevention and Control of Pollution) Act 1974 and subsequently entrusted with the powers and functions under the Air (Prevention and Control of Pollution) Act 1981. Its primary functions include prevention, control and abatement, and water and air pollution in the country. It also organizes and coordinates the State Pollution Control Boards and resolves disputes between them. (http://cpcb.nic.in)
- Ministry of Power (Bureau of Energy Efficiency): The Bureau was set up under the Energy Conservation Act 2001 with the objective of developing policies and strategies, performing regulatory and promotional functions, thereby enabling the reduction of energy intensity of the Indian economy. (http://www.beeindia.in)
- Environmental Pollution (Prevention & Control) Authority: Environmental Pollution (Prevention & Control) Authority: This agency was set up by the

[1] Ministry of Urban Development, Government of India (2014). Concept Note on Smart Cities, version 25 Sept 2014. Available at: http://indiansmartcities.in/downloads/CONCEPT_NOTE_LATEST_25914.pdf, viewed 7 October 2014.

Supreme Court to look into pollution abatement measures for India's largest cities (initially the National Capital Region), recently expanded its jurisdiction and established state level reviews.[2]

- Ministry of Road Transport & Highways (MoRTH): This is the nodal ministry which formulates and administers policies for road transport, national highways, and transport research in consultation with the Central and State Governments. Its responsibilities include the administration of the Motor Vehicles Act 1988 and the enforcement of the Central Motor Vehicles Rules 1989 which lay out emission standards for new vehicles.(http://morth.nic.in)
- Ministry of Heavy Industries oversees vehicle-testing. It aims to achieve automotive excellence through the National Automotive Testing and R&D Infrastructure Project (NATRIP). NATRIP performs homologation and certification of vehicles under the Central Motor Vehicles Rules 1989 ensuring that the vehicles comply with the emissions and safety requirements. These projects are partially funded by automobile companies. (http://dhi.nic.in)
- Auto Fuels Policy Committee: The Government of India constituted this expert committee in 2001 (under the chairmanship of Dr R A Mashelkar, Director General, CSIR) to recommend an auto fuel vision and policy and provide a roadmap for its implementation. This committee recommended an Auto Fuel Policy upto 2010 and the recommendation have been implemented. There has been no progression since 2010 in the qulaity of fuel supply or in emission norms except that BS-IV fuel has now been supplied to more number of cities in addition to the 13 cities identified by the Mashelkar Committee. A subsequent Committee was formed in 2013 to provide a roadmap for auto fuel improvement up to 2025. It delivered its report (discussed below) in 2014.

State Government

- State Regional Transport Offices (RTOs): The State Transport Authority has been designated the task of issuing driving and conductor licenses, registration of motor vehicles, issuing fitness certificates and permits and laying down the do's and don't for transport vehicle owners, road users, and professional drivers. For every transaction with the RTO, the certificate of Pollution Under Control (PUC) will be checked.
- State Pollution Control Board (SPCB): The SPCBs have been set up with the objective of controlling, preventing and abating the pollution of streams, wells, land, and atmosphere in the States through effective monitoring and implementing of pollution control legislations.They enforce the regionally varied emissions standards set by the national policy for vehicles.
- Police: The Pollution Under Control (PUC) certificates have to be always carried while driving on Indian roads. Apart from the police (usually the traffic police), the transport department plays a bigger role in enforcing the holding of PUC certificates. In some states, remote sensing technology has been proposed to check the pollution levels of all types of vehicles without stopping them on the roads.

Local Government

- No direct authority over air quality management.

Courts

The Court system has emerged as a potentially important entity in air quality management. Public Interest Litigation enables members of the public to bring complaints about lack of government action on legal and constitutional mandates, even when not directly personally harmed. The series of decisions that led to the Supreme Court mandating conversion of public buses and transport vehicles to CNG began with a 1985 public interest litigation requesting implementation of the 1981 Clean Air Act in Delhi. The Right to a Pollution-Free Environment has also 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*

[2] http://envfor.nic.in/legis/ncr/ncrauthority.html

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 non governmental organizations (NGOs) to approach the Supreme Court directly to petition for enforcement of the right. The Court has heard such petitions and issued directives to the relevant governments to tighten emission standards and improve fuel quality. The Supreme Court issued notices to Delhi, Haryana, Uttar Pradesh, and Rajasthan in February 2014, for example, outlining a number of fiscal incentives and other steps toward promoting cleaner fuels. The Court's report also called for immediate implementation of BS-IV standards nation-wide.

Implementation of court orders, however, can be delayed by years or even decades depending on the level and complexity of investments required.

Intersection: Air Quality Management and Transport Policy

There are few points of intersection between the agencies tasked with managing India's air quality and those charged with planning, implementing, and regulating the transport system. There is a formal institutional infrastructure to enable "improvement" of emissions, or limits on per-vehicle emissions, but this is completely separate from the decision-making and enforcement of ambient air quality. Vehicles are treated as one more source to be controlled on a one-by-one basis, without any mechanisms for weighing the benefits of controlling the overall number of vehicles rather than the per-vehicle emissions. Similarly, there is no formal mechanism to link policy and infrastructure decisions focused on transport development to become consistent with ambient air targets given, other emissions sources.

Politics & Policy: Motivating Action

Policy initiative in democracies requires public support for momentum as well as technical knowledge and policy analysis for direction. This subsection 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 that can inform State and national action as well as raise public awareness of high-emitting activities and their impact on air quality. 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 3.1) Perceptions about the underlying causes varied, but transport was widely recognized as an important contributor (Figure 3.2).

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

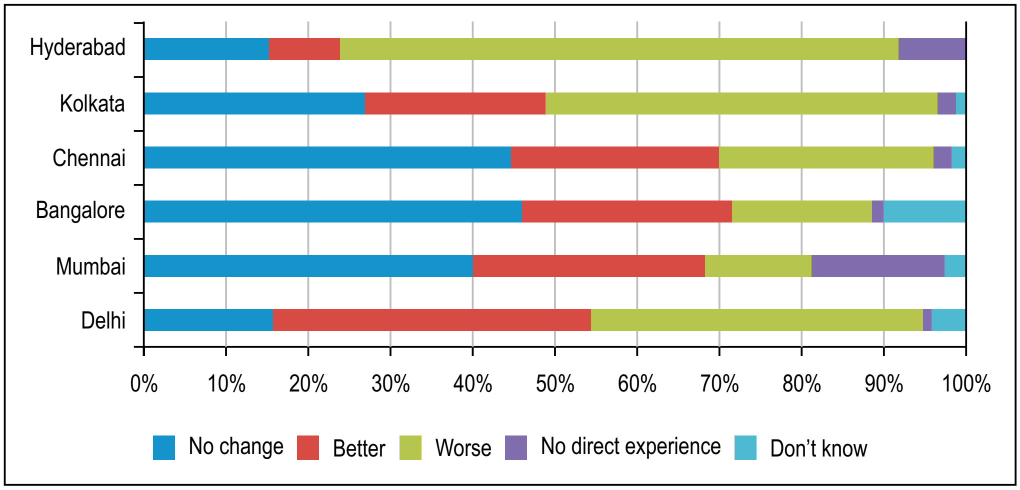

Figure 3.1: Perceived Changes in Air Quality in the Past Five Years (per cent of Respondents Giving a Particular Answer)
Source:TERI, 2013

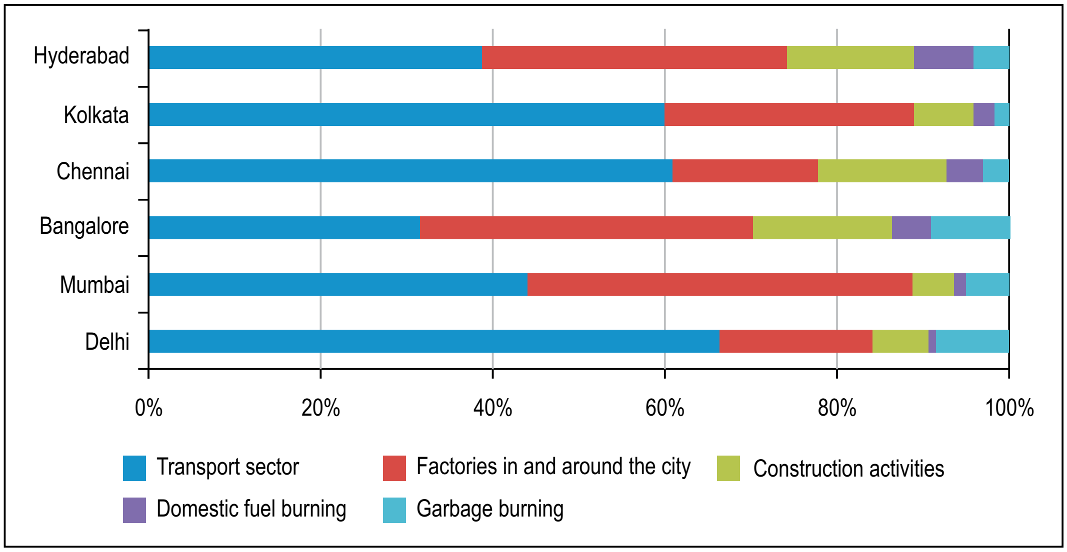

Figure 3.2: Sectors Perceived to be Contributing to Air Pollution (per cent of people listing activity as one of the top two contributors to air pollution in their city)
Source: TERI, 2013

for seven parameters i.e., suspended particulate matter (SPM), respirable particulate matter (RPM), sulphur dioxide (SO_2), oxides of nitrogen (NOx), 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 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 (PM2.5) 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 study – 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 for public awareness of air quality and demand for a response from relevant policymakers. 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 dismal cloud of sea-coal." 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. PM10 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, which 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." 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 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.[3] 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 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 reduction. State and urban leaders could, for example, find evidence on air quality impacts of infrastructure helpful when arguing for any additional costs of low-emissions plans.

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. If the results from regular sampling[4] consecutive days of monitoring exceed the limits specified in the norms for a given pollutant, it is considered as adequate reason to institute continuous monitoring and carry out further investigations (as per the official gazette).

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, 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 per cent 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.

India should ideally have a combination of top-down and bottom-up inventories. (Energy Sector Management Assistance Program (ESMAP), 2011) Top-down inventories would require an expanded

[3] 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.

[4] India's National Air Quality Monitoring Programme carries out 4-hourly sampling for gaseous pollutants and 8-hourly sampling for particulate matter. (http://www.cpcb.nic.in/air.php)

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, 2011). Guttikunda and Jawahar (2012) summarize the limited range of other local and regional studies. Major findings of these studies are presented in Chapter 1 (Scientific Basis).

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. State and city leaders can update the underlying data and emissions factors as new information is collected. Guttikunda and Jawahar (2013) report on results of a separate emissions inventory undertaken for Pune, Chennai, Ahmedabad, Surat, Rajkot, and Indore.

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 (EPA) (ESMAP, 2011, Chapter 5).

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 the existing legal standards mentioned above more actionable. While these intentions take time to implement, the emissions inventories provide an evidence base to inform concrete mitigation plans and track progress.

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 reward subnational governments for achieving ambient airtargets. 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.

Fuel Supply: Upgrades

Status Quo

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

The Mashelkar Committee had recommended in 2002 that a new Auto Fuel Policy Committee be formed every five years to review progress. The National Transport Development Policy Committee Report reiterated this recommendation in 2014. ICAMP authors are supportive of having a standing committee on Auto Fuels. This would certainly help to monitor implementation and also deal with any problems that may arise in introduction of advanced fuels and vehicles across the country. A Committee would also be helpful in conducting regular and timely reviews of the policy in future.

The 2013 Auto Fuel Policy Committee was established to develop a road map for vehicular emissions and fuel quality norms through 2025 and delivered its report in May 2014. However, before this report, there had 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" (Raj Amrit, 2012). However, at present, access to cleaner fuel is limited to a small number of urban areas.

The patchwork of fuel creates confusion in addition to treating 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. In practice, BS-IV vehicles requiring low-sulphur fuels for optimal operation of their emissions control are compelled to refuel in BS-III fuel areas, thus damaging the vehicle emissions control technologies. The distinction also reduces pressure to lower emissions from commercial vehicles, since fleet owners have an incentive to purchase and register vehicles outside the BS-IV designated areas because these are less expensive. Table 3.1 illustrates the significance of this incentive: just over 12 per cent of India's medium and heavy commercial vehicles are BS-IV compliant.

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.

Table 3.1

Number of Vehicles of Different Classes Sold in the Domestic Market Compliant with BS-III and BS-IV Fuel and Emmission Norms

Source: MoPNG (2014). Report of the Auto Fuels Vision 2025 & Policy Committee. May 2014.

	2010-11	2011-12	2012-13	2013-14*
Vehicles Sold in BS-III Regions in '000				
2 & 3 wheelers	8,810	12,086	12,372	9,815
Pass. Cars incl. MUV	1,463	1,805	2.069	1,418
LCV †	312	227	361	223
M & HCV †	276	312	237	127
Vehicles Sold in BS-IV Regions in '000				
2 & 3 wheelers ‡	1,658	1,695	1,853	1,419
Pass. Cars incl. MUV	276	312	237	127
LCV †	1,463	1,805	2,069	1,417
M & HCV †	312	227	361	222
Share of Vehicles Sold in BS-IV Regions of Total				
2 & 3 wheelers ‡	15.8%	12.3%	13.0%	12.6%
Pass. Cars incl. MUV	29.0%	22.7%	23.0%	22.5%
LCV †	17.0%	23.8%	24.2%	24.3%
M & HCV †	13.3%	12.0%	11.8%	12.3%

Note: ‡ For 2 & 3-wheelers applicable emission norms has been conforming to BS III even when sold in areas where BS IV norms are applicable to 4-wheelers.

* For the period April-December 2013-14

† Including goods and passenger carriers.

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 in the ambient PM10 levels during 2004-2007, they have increased to unprecedented annual average of about 250 µg/m3. Further, growth is going to worsen the air quality in future. TERI estimates show that the total number of on-road vehicles is going to grow from about 100 million in 2010 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. Alternate (ALT-I and ALT-II) scenarios, which envisage introduction of BS-IV norms all across the country by 2015 versus 2020 show reductions of 43 per cent and 30 per cent in PM2.5 emissions, respectively.

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:

- **The Government of India should without further delay mandate the refineries to upgrade their facilities and supply BS-V fuel all over the country by no later than 2018. This will call for earlier introduction of BS-V fuels than those recommended in the Auto Fuel Vision and Policy 2025 Report, by requiring and enabling the Indian refineries to leapfrog from BS-III to BS-V fuels by 2018 or by diverting the current exports of RIL-SEZ and arranging for marginal imports. However, if this is not possible then the timelines recommended by the AFV 2025 Committee should be notified immediately so that there are no further delays in introducing the fuels.**
- **Emissions standards should leverage the opportunities that these cleaner fuels create for high-performing vehicle emissions control technologies. As per the road map suggested by AFV 2025, the whole country should move to BS-IV norms by 2017. However, if it is possible to introduce BS-V fuel by 2018, the auto industry could move from BS-III/IV emission standards to BS-VI emission standards by 2020 as recommended earlier. This will facilitate the use of after treatment devices for retrofitment as BS-V fuel is progressively introduced.**

Substantial technical analysis undertaken by TERI and ICCT and reported in their submissions to the Auto Fuel Policy Committee shows that refinery production (see Table 3.2) can be upgraded by 2015 with existing ULSF production capacity shifted from exports to domestic supply, and/or imports arranged to supply BS-IV (50 ppm) fuel to the entire nation. Industrial experts have concurred that the fuel quality in the existing refineries can be advanced in the time-span of 3 years provided funds can be arranged. A possibility of 'Shift' of BS-V quality fuels from exports to domestic use has not been properly explored and the ICAMP team recommends exploring this option in case the existing refineries are not able to supply BS-V fuels by 2018. AFV 2025 reports that by 2020, against the total domestic demand of 106 million metric tons (MMT) of diesel, just about 50 MMT of BS-V will be available from existing refineries (excluding RIL-SEZ supplies of about 16 MMT). This clearly shows a shortfall of 56 MMT, which should either be arranged by mandating and facilitating the refineries or by diverting the exports or arranging imports.

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

The rapid progression to nation-wide Euro-V equivalent (10 ppm) fuel by 2017 will be essential to prevent a recurrence of the 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

Table 3.2

Automotive Fuels Sold in the Domestic Market Conforming to BS-III and BS-IV Fuel Standards All Oil Marketing Companies

Source: MoPNG (2014). Report of the Auto Fuels Vision 2025 & Policy Committee. May 2014.

	2009-10	2010-11	2011-12	2012-13	2013-14*
BS-III Fuel – MMT					
Motor Spiirit/ Gasoline	1.35	10.50	11.19	11.84	9.75
High Speed Diesel	0.10	50.30	53.54	57.02	42.30
BS-IV Fuel – MMT					
Motor Spiirit/ Gasoline	Nil	3.70	3.80	3.90	3.13
High Speed Diesel	Nil	9.57	10.27	11.09	8.29
Share of BS- IV Fuel of Total					
Motor Spiirit/ Gasoline	Nil	26.1%	25.3%	24.8%	24.3%
High Speed Diesel	Nil	15.9%	15.9%	16.0%	16.2%

Note: * For the period April-December 2013-14
† Most of the fuel sold in 2009-10 conformed to BS-II specifications

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 focused 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 O_3 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 emphasizes the need for further advancement of emissions norms to up to BS-VI, Euro-VI equivalent levels which can bring down the PM and NOx emissions considerably.

Figure 3.3 from ICCT (2013) illustrates the potential development gains from advancing the supply of BS-IV fuel from 2016 to 2015 and BS-V from 2020 to 2017, that would nearly result in 50,000 avoided deaths by 2045.

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

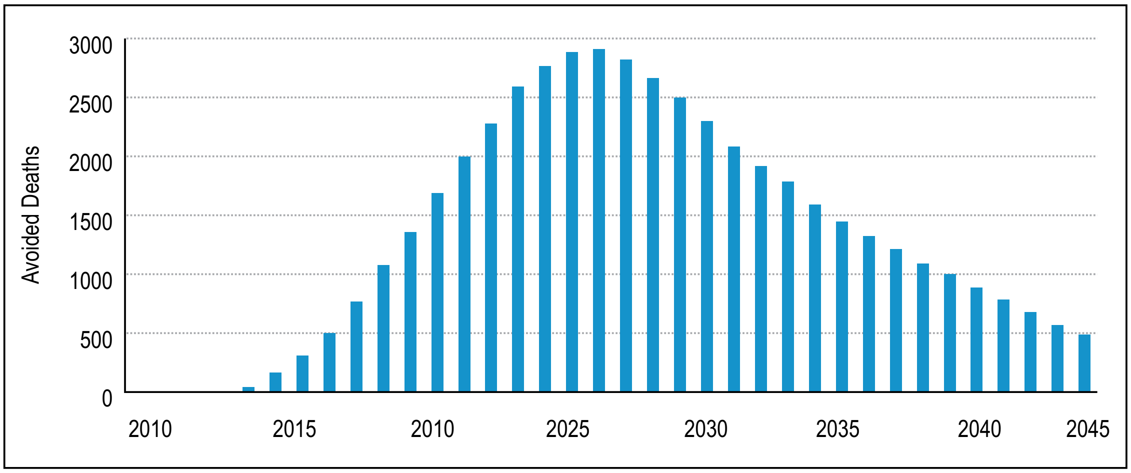

Figure 3.3: Number of avoided deaths

Source: ICCT, 2013

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 0.9 to 1.1 ¢ 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 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 or as ongoing financial support in the form of tax breaks, lower-cost access to capital, or revised arrangements for allocating the burden of fuel subsidies. 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.

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 (NCEF). 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.

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 which 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. Private owners may require some form of 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 well not have authority to take action against non-compliant 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 non-compliant fuel.

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 500 ppm to 15ppm sulphur in diesel delivered a 25 per cent reduction in diesel PM emissions, while the cleaner fuel coupled with a diesel particulate filter could reduce emissions by around 90 per cent 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).

As discussed above, emission standards for new vehicles are currently set by the Ministry of Road Transport and Highways (MoRTH) under the Motor Vehicles Act 1988 and Central Motor Vehicles Rules 1989. The NTDPC has recommended an updated structure: a standing National Automobile Pollution and Fuel Authority (NAPFA) that will be responsible for setting and enforcing vehicle emission and fuel quality standards in India.

Current standards are in respect of PM2.5, HC, NOx, 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 10 ppm or less sulphur for optimal performance.

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 authorized 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 lifetime 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 Central Motor Vehicle Rules (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 S Sundar of TERI and a chair of this report, is to revamp the Motor Vehicles Act and enure that Indian states 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 valid pollution under control 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 per cent 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 centers 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 computerized testing facilities that reduce human intervention in the measurement of pollutants.

Credible enforcement of standards for both new and in-use vehicles creates greater certainty about the demand for emissions control technology. Such certainty about the need to reduce emission, one way or another, is important for driving innovation that may lower the cost of low-emission vehicles. Standards that set and enforce clear goals are more effective in driving innovation than those that specify particular technologies – the race to meet the goals at lowest cost drives innovation that may ultimately lower the cost of achieving emissions reductions.

US and international experience has shown that tighter policy can drive innovation and create economic opportunities for local firms. Actual control costs in such settings are generally less than originally estimated. In the United States, total air pollution control costs are about 0.5 per cent 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 sulphur 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.

Transport Investment: Avoiding and Shifting

Much of this chapter has focused on the potential to "Improve" modes of transport. The other options of "Avoid" (transport use) and "Shift" (from higher to lower-emissions forms of transport) touch upon a broader set of policies that are intertwined with household and firm choices about location and means of transport. Transport use can be "avoided" through land-use planning that supports mixed-use development and avoids distorting industry choices about location of key facilities. "Shifting" transport from higher to lower energy intensive forms of transport will require addressing the balance of road and rail contributions to freight transport and in improving urban transport. While freight shipping is an important source of transport-related emissions overall, urban passenger and freight tend to be more visible contributors to poor ambient air quality given the concentration of vehicle movement. "Avoid" and "Shift" have been prominent in policy strategy discussions about transport in India ranging from the NTDPC to the National Urban Transport Policies to the more recent discussion of "Smart Cities." This section highlights some key requirements for turning the intentions into outcomes.

Avoid: Land Use Planning, Telecommuting, and Integrated Energy and Transport

There are two areas where the overall gains from action are clearer: reforming urban land policies to encourage mixed-used development and reduce urban land prices by allowing higher density development; and second, improving telecommunications infrastructure and to enable more effective telecommunications more telecommuting. Neither of these are strictly part of "transport" policy, but they do affect transport demand. Such policy priorities are not unique to India – they are standard parts of most "Avoid" toolkits (e.g. Low Emission Development Transport Toolkit - http://ledsgp.org/transport).

The National Urban Transport Policy highlights the role of urban planning in transport demand in particular, calling for "Encouraging integrated land use and transport planning in all cities so that travel distances are minimized and access to livelihoods, education, and other social needs, especially for the marginal segments of the urban population is improved." (3).[5]

India's cities are rapidly suburbanizing: both population and built-up areas are growing faster on the outskirts of cities than in the core business districts. (World Bank, 2013; Indian Institute for Human Settlements (IIHS), 2011)This trend is driven in part by the high costs of land in core business districts, which in turn is influenced by historic planning regulation that limit the "floor space index," or amount of housing area (floor space) that can be built on a particular plot.[6] The effect of suburbanization on transport is not entirely clear. To the extent that these new areas are integrated with the city economy and require residents to commute between the outlying areas and core business districts, the emerging urban geography increases transport demand. To the extent that these areas operate as more self-contained satellite areas with employment, shopping, schools, and other amenities, as prioritized in TOD, they may limit transport requirements. One thing is clear: urban planning that allows, much less encourages, mixed-use development is more likely to produce the latter.

California's Sustainable Communities and Climate Protection Act of 2008 offers an 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 travelled, thus reducing fuel consumption and saving money. 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 industrial development, infrastructure, and land use plans.

Telecommunication infrastructure that allows people to reliably work from home is another area that may reduce travel demand. India's broadband penetration in urban areas is relatively high (and the majority of broadband users are in the country's 30 largest cities), but is not yet widely affordable. Policies (e.g., tax incentives) that encouraged firms to subsidize worker access to Internet, through fixed-line or wireless broadband, may be one way to encourage more telecommuting.

A third area in which India could "avoid" transport is in its energy investment choices over the coming decade. The NTDPC found the movement of energy-related commodities sufficiently important for transport policy to include a working group on Integrated Strategy for Bulk Transport of Energy and Related Commodities in India. The group found that coal movement accounted for nearly half of the bulk freight transport on Indian railways. This proportion could be reduced by reallocating coal rights to match coal sources with closer-by generating facilities and/or by building future generating capacity in coal-rich areas and investing in transmission lines to move power rather than rail, to move coal. The choice between moving

[5] Ministry of Urban Development, Government of India. "National Urban Transport Policy," available at: http://moud.gov.in/sites/upload_files/moud/files/pdf/TransportPolicy.pdf, accessed, 7 October 2014.

[6] India's cities are some of the densest in the world in terms of population per square kilometer, but housing has not kept up with the density. Any changes that reduced the incentives to suburbanize.

power by transmission line versus coal by rail or coastal shipping, however, is a complex one that must consider federal political economy, fiscal regimes, generation technology, patterns of demand, and grid balancing among other factors. The NTDPC, in recognition of this fact, acknowledged the potential for investment in transmission to be an important way of reducing transport requirements and advocated investment in governance and inter-ministerial coordination to jointly evaluate investments in transmission and transport over time.

Shift: Road-Rail Balance and Urban Transport

Road transport accounts for nearly 70 per cent of freight and 90 per cent of passenger traffic after several decades of a steady shift from rail to road as the mode of choice. The potentially lowest-emission (per tonne-km) form of freight movement - inland waterways and coastal shipping – account for less than 10 per cent of total movement. Inland waterways are just 0.5 per cent of the shipping capacity. Shifting this balance will require significant (and faster) investment in rail infrastructure including attention to inter-modal connections at major and minor ports, urban hubs, and other points of interchange. It will require rebalancing rail pricing, and investing in inland waterways. The momentum for action on both counts is increasing as logistics costs increase and the price of energy inefficiency become more apparent.

India's rail network is highly congested, particularly in areas most important for freight. Only ¼ of the rail network is double track, and much of the signaling equipment and traffic management protocols are outdated. Expert reports and investment strategies over the past two decades have nearly universally recognized the challenge and investment in track management, capacity expansion on existing routes, and new track infrastructure as well as six dedicated freight corridors is underway. The economic stakes are high: NTDPC estimates losses as high as $45 billion annually from poor logistics. McKinsey (2013) estimates economic losses of up to $120 billion/year by 2020 without substantial improvement in rail freight and other investments in India's logistics infrastructure.

KPMG (2013) calls further development of inland waterways and coastal shipping "a game-changing opportunity."[7] There are currently 5 National Waterways and 3-4 regional ones (e.g., Mumbai and Goa Waterways) that are used for moving coal, steel, and other bulk commodities. While there has been substantial interest in developing these, including in National Action Plan on Climate Change (where it was the first item in the list for transport), and Planning Commission's Interim Report on Strategies for Low-Carbon Growth, investment and implementation has been slower. More recently, the Minister for Road Transport, Highways, and Shipping announced efforts to increase investment in coastal shipping and inland waterways infrastructure and re-emphasized the potential of the Ganga to serve as a major freight corridor.[8]

Recommendation: Enact NTDPC Agenda for Rail and IWT Development

The NTDPC Report's recommendations on rail and IWT development align well with this report's suggestion to improve the lower-emission networks so that they are competitive with road freight. Therefore, we reiterate them here rather than reinvent the kind of combination of investment and regulatory change that this transformation will require. The Committee acknowledges negative environmental and economic consequences of the increasingly high dependence on road freight and its recommendations, like our initiative, are focused on reversing that trend.

- It proposes the following broad recommendations aimed at increasing Railways' competitiveness with road freight. Create national action plan along the lines of the National Highways Development Project that created the Golden Quadrilateral as well as the North-South and East-West Corridors.

[7] KPMG (2013). *Logistics Game Changers*. CII and KPMG. Sector Report, 2013. Available at: https://www.kpmg.com/DE/de/Documents/Logistics_Game_Changers_Transforming_India_logistics_industry_2013.pdf

[8] Press Trust of India (2014). "Government to facilitate investment in inland waterways: Nitin Gadkari," *Economic Times* 11 September 2014. Available at: http://economictimes.indiatimes.com/news/economy/infrastructure/government-to-facilitate-investment-in-inland-waterways-nitin-gadkari/articleshow/42284195.cms

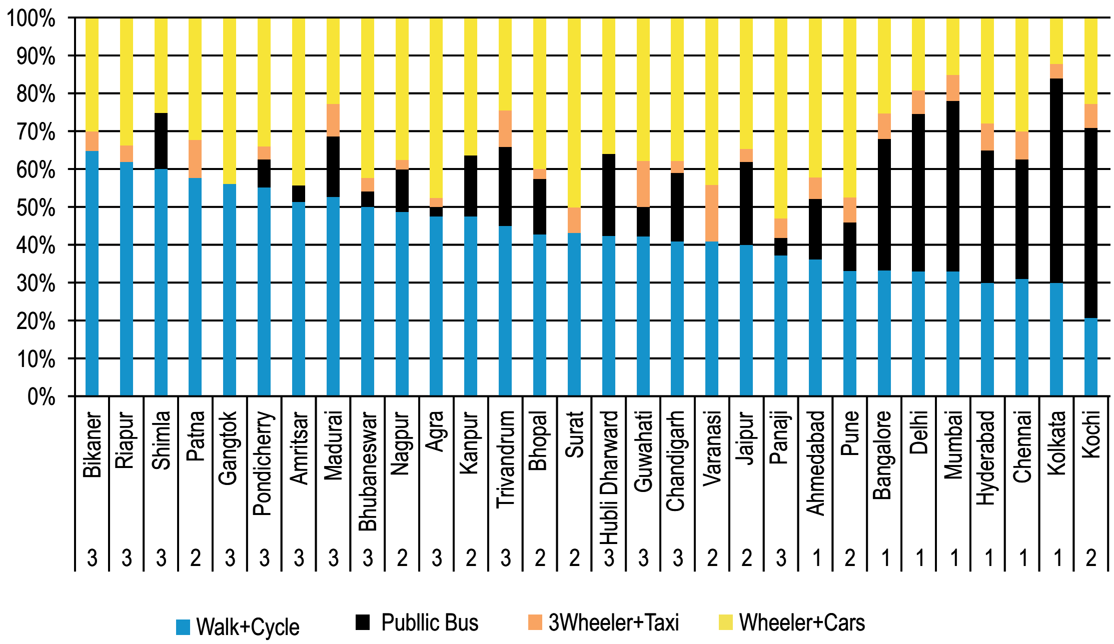

Figure 3.4: Urban Passenger Modal Shares in Indian Cities
Source: Guttikunda & Jawahar, 2012

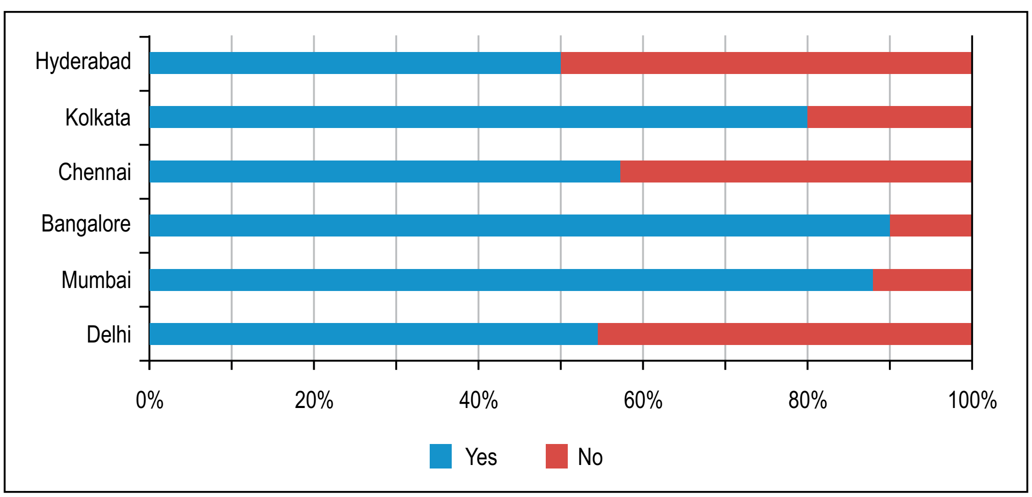

Figure 3.5: Usage of Public Transport
Source: TERI, 2013b

- Shifting public investment from roads to rails to enhance track capacity, speed, and in some critical corridors, density.
- Leveraging pricing and taxation policies to nudge transport demand towards more desirable model shares.

Similarly, the main recommendations for IWT and coastal shipping are to increase investment and direct it to addressing the main stumbling blocks to usage: ensuring navigability by maintenance of sufficient draft as well as bridge height throughout the waterways; straightening some stretches of waterway to reduce effective distance;

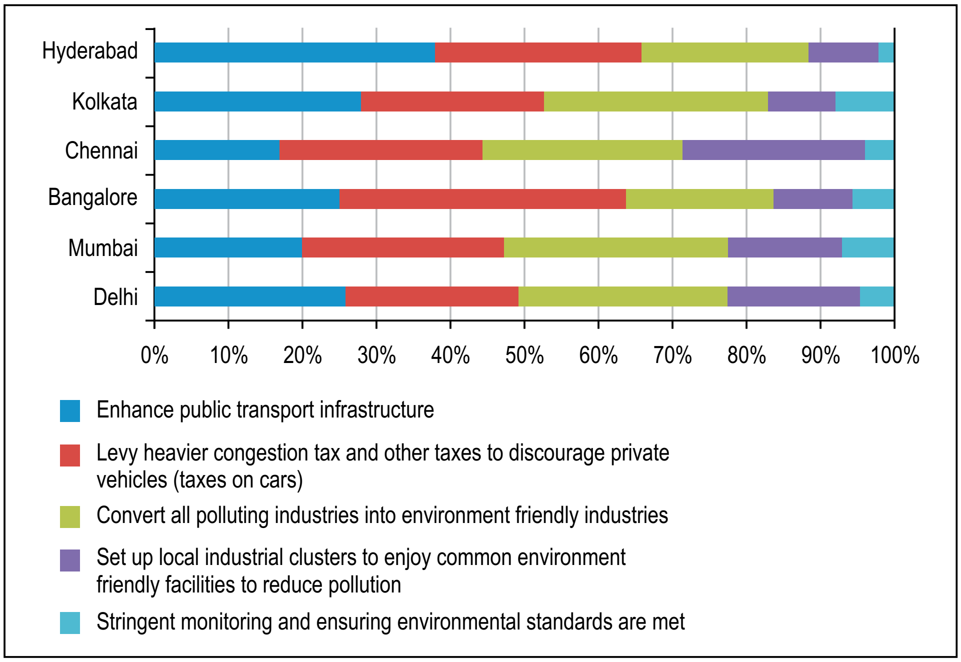

Figure 3.6: Strategies Government Should Adopt to Improve Air Quality in the Six Cities
Source: TERI, 2013b

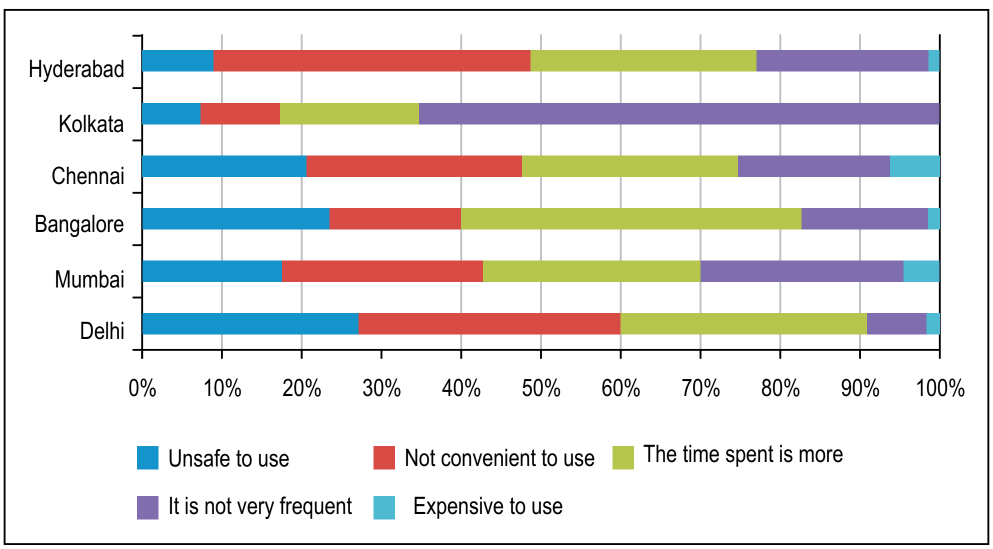

Figure 3.7: Reasons for Not Using Public Transport
Source: TERI, 2013b

development of inland freight offloading sites; dredging of minor ports to allow typical river-going vessels to dock; and developing a feeder network.

India's National Urban Transport Policy already 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 becomes the first choice for mobility. Vehicle ownership is just 13 cars/84 two-wheelers per 1,000 people. Car ownership is concentrated in the urban areas[9], but a substantial portion of passenger-kilometers travelled in urban India is still by public or non-motorized transport.

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. The challenge is to channel the anticipated investments into public transport that remains competitive with private vehicles when people have a choice. (TERI 2013b) found a high percentage of respondents who used public transport (Figure 3.5) as well as general public support for "sticks" to discourage vehicle use as well as "carrots" to attract riders to public transport (Figure 3.6).

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 3.7)

Governance Changes

While past NUTPs, the NTDPC, and nearly every other document on urban planning emphasizes the need to ensure adequate and quality public transport systems as well as safe Non-Motorized Transport options in every city, the detailed design of these systems will necessarily vary by city size, morphology, and anticipated growth. Similarly, the exact manifestation of Transit Oriented Developent (TOD), an approach to integrating land use and transport planning in ways that reduces transport requirements and maximizes access to public transport, will vary across cities.

Governance, is therefore an important first step. We highlight some key points for action here:

- Leverage national funding for urban infrastructure to encourage TOD and improvement of public transport systems. Although various urban reform templates such as the High Power Expert Committee on Urban Infrastructure envision more substantial local funding of infrastructure in the coming decades, the national government continues to be a important funder of transport projects as well as conduit for multilateral finance. It can leverage this position to build capacity and incentives for investing in public transport. The NUTP, for example, proposes to co-finance integrated transport-land use plans provided that "cities develop their willingness to act in accordance with them."
- There are no simple "silver bullets" for quickly converting investment into high-quality, locally appropriate urban transport and land use plans. It is therefore important to implement the NTDPC recommendation to consolidate the fragmented jurisdiction over urban transport to create statutorily and financially empowered Metropolitan Urban Transport Authorities (MUTAs). These should 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. As mentioned above, these responsibilities are currently divided among and between three levels of government.

Specific Initiatives

Even as governance changes are underway, there are a number of specific initiatives that could also start to shift India's urban mobility patterns.

First, India's public transport systems currently rely significantly on buses. The rider experience could be substantially improved with some relatively straightforward service upgrades, including scheduling to meet route demand and clearer publication of route maps and schedules. Some NGOs and citizen groups have stepped in to provide this information based on disclosure from the bus operators or citizen-collected data. More complex and costly reorganizations, such as moving from destination-based bus routes to trunk and feeder route maps, upgrading the rolling stock (passenger experience as well as cleaner fuels and emissions control), and moving to integrated ticketing and dynamic scheduling, require concerted effort from the operators themselves. These are possible, however, and the case of the Bangalore Metropolitan Transport

[9] 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).

Corporation provides one example. The BMTC was carved out of the larger Karnataka State Road Transport Corporation in 1997 and became one of the first public bus systems to overhaul its route planning, ticketing procedures, and operations starting in 2003.

Second, follow principles of TOD in newly expanding areas of cities, in development plans due for revision, or even in implementing and planning around ongoing infrastructure investments. Provisions such as expanded FSI (Floor Space Index) near transport corridors or incentives for pedestrian-friendly commercial development near public transport nodes can start to reshape cities even while larger-scale plans are being developed.

Third, smaller neighborhood projects to restore footpaths or invest in road furniture to improve pedestrian safety can become demonstration projects for larger initiatives, as has been the case in Chennai. The Institute for Transportation and Development Policy (ITDP) and the local Chennai City Connect Foundation (CCCF) have collaborated with the Corporation of Chennai on a series of pedestrianisation projects in specific areas and the initiative is scaling up.

Finally, in addition there can also be incentives to shift from personal vehicles to public transport.

- Some options for ensuring that drivers internalize externalities (e.g., air pollution, traffic, noise, and accident hazards), include 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)
- 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.

Promoting Electric and Hybrid Vehicles

Electric and hybrid vehicles have been seen as the technologies that can reduce dependence on oil. India has also been today looking at electric vehicles as one of the solutions and have come up with a clear road map for introduction of full range of electric vehicles (mild hybrids to full electric) in the next one decade. The National Electric Mobility Mission Plan (NEMMP) 2020 launched by the Government of India in 2013 is targeting energy security, climate change and pollution issues through promotion of electric vehicles in the country. The plan focusses on developing technologies, creating consumer acceptability and developing infrastructure to support ownership and use. The plan aims at penetration levels of 14-16 percent (5-7 million electric and hybrid vehicles) of the total vehicular fleet by 2020. There have been some efforts in this direction which provided financial assistance to EV consumers. It has now been recognized that subsidies are important for EVs to make a sizeable penetration into Indian markets. The issues to be tackled are development of cost effective electric vehicle batteries with high specific energy and support infrastructure such as charging facilities. For promotion of electric and hybrid vehicles, Department of Heavy Industries (DHI) has set up two new agencies, namely the National Council for Electric Mobility (NCEM) and the National Board for Electric Mobility (NBEM).

Electricity shortages are of important concern. In Tamil Nadu, power outages have almost driven EVs out of the market which highlights the importance of availability and quality of power. Moreover, the question of sources of power generation is also eminent, while we know India depends heavily on coal for power generation. However, electric or battery electric vehicles have zero emissions on ground as compared to petrol and diesel which release toxic pollutants right at the throat of the population. While comparing a gasoline and a electric car, some of the pollutants may turn to be higher from a electric vehicle on account of electricity developed through coal. Hence, electric vehicles which may solve the pollution problem in cities, may lead to more power generation and emissions form power plants. However, a shift from coal to renewable sources can make electric vehicles really less emitting than the ones dependent on petroleum products, and certainly the penetration of EVs need to start now so that enough EVs are on-road when more power is available from renewable sources in India. In the present context, EVs certainly provide an opportunity to reduce emissions at the hotspots cities and provide immediate relief to the residing populations exposed to toxic emissions from vehicles.

Summary and Conclusions

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 outlined 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 ostensible 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.

CHAPTER 4

Action Options

Harnish R, Sharma S, Sundar S, Seddon J, Ramanathan V

In the preceding chapters we have laid out the arguments why, how and by whom India and California can work to clean up ambient air pollution. The purpose of this chapter is to lay out practical steps to implement the recommendations that resulted from the Scientific basis, Technology Measures, and Policy and Governance chapters. We start first by re stating the vision for the ICAMP.

We then put forward twelve Action Options and each one is detailed in one or two pages. We hope these 12-Action Options will provide practical pathways for the union and state governments of India to drastically cut air pollution from the transportation sector. We hope further that the Action Options provide governments and other international funding agencies a context in which to evaluate the outcome of their assistance.

The Vision

Following a pathway walked by the California Air Resources Board (CARB), a substantial reduction in the air pollution from the transportation sector in India could protect the air, public health, food supply and water supply of India without harming the rate of economic growth. From this vision, there follow three objectives:

- Reduce premature death rate, disease, and morbidity through reduction of PM emissions
- Reduce crop loss through reduction of oxides of nitrogen which contribute to ground level ozone and
- Reduce the pace of climate change through reduction of black carbon and other short-lived climate pollutant emissions.

The ICAMP strategy is economically feasible. As witnessed by the California example and independent research from the World Bank, it will not affect India's economic growth. Indeed, in light of the California example, there is reason to believe it will create jobs and spur exports. The near term costs of refinery modernization appear to be modest, as does the cost of installing after-treatment devices in new and used vehicles. The near term benefits for human health and agricultural productivity are generally assessed in recent studies as being substantial. Harder to quantify but accepted by most scholars are the co-benefits of reduced global warming. Pilot projects recommended in the next chapter would provide data that will contribute to the black carbon benefit-cost analysis literature. A fuller accounting of economic feasibility appears as Appendix B. A cost-benefit analysis of pollution mitigation measures appears as Appendix C.

To achieve the three objectives, the California and Indian team members drew freely from the California experience on improved air quality. Output from our work will be applicable to Nepal, Bangladesh, and other South Asian countries with similar socio-economic and policy contexts.

Californian interventions	
Type of interventions	**Details**
Improvements in technologies and emissions standards	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. In 1977, the first three-way catalytic converter to control hydrocarbons, nitrogen oxides, and CO was introduced. In 1988, CARB adopted regulations to become effective from 1994 requiring that cars be equipped with an "on board diagnostic" (OBD) computer system to monitor emission performance and emission control equipment.
	In 2001, advanced standards were passed to reduce diesel soot and smog forming emissions by 90 per cent from new large diesel engines. The new standards were to take effect from 2007 and affect engines that power big rig trucks, trash trucks, delivery vans, and other large vehicles.
Improvements in Ambient air quality standards	In 2002, CARB promulgated new particulate matter standards. The new annual-average standard for PM10 is 20 μg/m^3 and for PM2.5 is 12 μg/m^3. The 24-hour standard of 50 μg/m^3 for PM10 is retained as well as the 24-hour average standard for sulphates at 25 μg/m^3. It also adopted airborne toxic control measures (ATCM) to reduce pollution from school bus idling.
Fuel quality improvements	Starting in 1970, the federal government phased out lead in gasoline. CARB pioneered a motor fuels specification enforcement program since 1977 and regulations were adopted to limit lead, sulphur, phosphorus, and manganese in gasoline, and to control the sulphur content of vehicular diesel fuel in Los Angeles. In 2003, CARB adopted new diesel fuel standards. The rule required greater than 95 per cent reduction in the amount of sulphur in diesel fuel. In 2006, California switched to new ultra low sulphur diesel fuel.
Congestion/ idling emission control	In 2004, CARB adopted heavy-duty diesel trucks (HDDT) idling controls. The regulation required heavy-duty diesel trucks and interstate bus operators to shut their engines down after five minutes of non-essential idling. The regulation affected more than 400,000 trucks and buses registered in CA and all out-of-state trucks and buses operating in CA.
I&M	During the late 1970s, Los Angeles and later the entire state required vehicle inspections for measuring emissions and inspections of emission control equipment, which in 1984 evolved into the California Smog Check Program administered by the state Bureau of Automotive Repair (BAR). In 2005, CARB adopted regulation requiring engine manufacturers to install on-board diagnostic systems on HDDT engines beginning in 2010. Also CARB signed a Memorandum of Understanding (MOU) with Union Pacific and Burlington Northern Santa Fe Railroads to significantly reduce diesel emissions in and around rail yards in CA.
Off-road vehicles	In 2007, shore power regulations require operators of certain types of ocean-going vessels to shut down their diesel auxiliary engines and hook up to shore power while docked at the state's busiest ports. Also, diesel port trucks that haul goods to and from ports and rail yards throughout the state will be required to have fewer emissions. CARB amends a landmark rule to reduce toxic emissions from the state's estimated 180,000 off-road vehicles such as tractors and bulldozers used in construction, mining and other industries. The amendments help business owners comply with the 2007 regulation.
Retrofitting	In 2008, CARB adopts two critical regulations aimed at cleaning up harmful emissions from the estimated one million heavy-duty diesel trucks. One requires installation of diesel exhaust filters or engine replacement and the other requires installation of fuel efficient tires and aerodynamic devices. State presents Proposition 1B Bond funds in the amount of $5.6 million to the San Joaquin Valley Air Pollution Control District to clean up 80 percent of smog forming and particulate matter emissions. Funds are used to retrofit older, dirty diesel fuel trucks with diesel particulate filters or replace engines.
Fleet modernization	In 2011, CARB offers funding assistance programs to truckers and buyers of on - and off-road clean vehicles. Business owners who took early action had a range of funding assistance options totaling hundreds of millions of dollars, and were able to tap into low-interest loans to operate clean vehicles.
E-highways	In 2014, a new road design project called the e-highway is being planned in Los Angeles to reduce emissions from heavy-duty vehicles. The e-highway will consists of an overhead catenary system which could provide power to hybrid or fully electric trucks. Once connected, the trucks will run on free emission mode using power from the overhead lines.

Each action option is set out in a few pages, which describe the problem, actions required, timeline and initiatives to build on and learn from. The idea of the program initiatives is to highlight a pathway that funding institutions such as the World Bank, Asian Development Bank, and USAID can follow to support businesses and state and union governments interested in implementing the Action Options outlined here. It is to be noted that Action options (2,3,4, and 5) are related to fuel quality and vehicular technological improvements and effective I&M systems. They are of utmost priority at the National scale to ensure long term reduction in vehicular emission in India. Then there are Action options (6,7,8,9,10, and 11) like promotion of avoid and shift measures which are more relevant at city scales, however, their priority varies with city characteristics, vehicular modal shares, and other important local factors. The Action Options 1st and 12th are more general and should be perused as long term agendas. A cost benefit analysis has also been carried out for some of the action options and is presented in Appendix-C. The twelve Action Options are described next.

1. Build Information Basis: Monitoring

Problem

The Scientific Basis section of this report has listed the negative impacts of air pollution on air quality, human health, and crops in India. In addition, air pollution also adversely affects water supply through various pathways, thus further impacting crop production. Therefore, it becomes imperative to suggest measures to mitigate air pollution in India, especially in cities like Delhi one of the most highly polluted in the world. Building upon the past experiences, proven technologies such as implementation of ultra low sulphur fuel (ULSF) followed by diesel particulate filter (DPF) fitting in vehicles is recommended to reduce target pollutants, namely PM and BC emissions from the transportation sector (see the Summary of Technology section). In order to measure the success of technology interventions, their effects on air pollution reduction need to be quantified. This requires the target cities to be equipped with a monitoring system to measure air pollutants before and after the implementation of mitigation measures.

Action Required

Currently there is a complete lack of a reliable air quality monitoring network in India. There are about 573 monitoring stations under the National ambient air quality Program of the Central Pollution Control Board. As per the criteria for minimum number of stations given in BIS, 2000, there is a requirement for 3300 monitoring stations in 605 Indian cities having more than 50 thousand residents. The density of the network will vary based on population, city characteristics and severity of the issue. There is a need to gradually build the existing network with enhanced coverage all across the country. In addition tomonitoring stations in urban regions, regional scale air quality also needs to be monitored(especially for pollutants like Ozone) at stations located outside the city limits.

The existing network also does not cover the whole range of pollutants; it currently monitors just RSPM, NOx, and SO_2. It limits the ability to study the space-time trend in fine PM, BC, and other important pollutants such as Ozone. A reliable network with additional observational capability of ambient PM2.5, BC, and Ozone will generate much required information that can be used by academia for scientific needs, government to take policy decisions, and civil society to create awareness in the public. According to the guidelines of requirements of monitoring stations in a region, the current network is inadequate. Hence, the Ministry of Environment and Forests (MoEF) should establish an adequate network of air quality monitoring stations across the country (including both urban and regional locations).

While there is some information on air quality trends in the cities, there is absolute dearth of knowledge on the source contributions towards prevailing air pollutant levels. Source apportionment studies have been carried out only in just six cities in the country, while there are 53 cities, which have a million plus population and where air quality is deteriorating. The MoEF with support from the corporate sector should commission source apportionment studies in all million plus population cities and make it a periodic exercise (five times annually).

Emission inventories at the national/regional and urban scales are presently lacking. There is a need to develop and maintain a dataset on national and urban scale emission inventories of different sectors and pollutants. This will call for a compilation of datasets on activity levels (vehicular movements, industrial fuel consumption, power generation, domestic fuels, etc.) and selection of appropriate indigenously developed emission factors.

There are very limited studies in India on assessing the dose response relationships of pollutants on human health and agriculture. The Ministry of Health, the Ministry of Agriculture, and the MoEF should jointly commission these impact studies and develop indigenous dose response functions. These studies could prove important in carrying out cost benefit analysis of various strategies that could be employed for air pollution control in India.

Above all, there is a need to sensitize the public on this important issue. MoEF along with CPCB should arrange for continuous dissemination of air quality data to educate the public on the need to maintain air quality.

Initiatives to Build On and Learn From

Example initiatives are: State of the art Air Quality Monitoring Networks similar to the system at CARB and System of Air Quality Weather Forecasting and Research similar to the capability at TERI, Delhi, and the Indian Institute of Tropical Meteorology, Pune. Semi-automated, low cost sensors to measure PM and BC being jointly developed by IIT Kanpur and Nexleaf will aid in the measurement with high spatial resolution requirement.

Timeline

The measurement of target species must be made before, during, and after the mitigation measures have been implemented. This means that such a network must begin measurement about one year prior to the action and continue to do so for several years to understand the trends in ambient PM and BC concentrations.

2. Upgrade Fuel Quality

Problem

Air pollution has emerged as a major problem in many countries across the world. About 3.2 million premature deaths are annually attributed to ambient air pollution in the world. Asia is a high-risk region with 2.1 million premature deaths, of which 0.6 million are in India. More than 80 per cent of Indian cities are violating the prescribed standards of air quality, exposing densely populated regions to high levels of health damaging air pollutants. The Science section (refer to section 3.1) clearly states the significant contribution of the transportation sector in prevailing air pollutant concentrations in India, more specifically at the urban scales. Diesel driven heavy-duty vehicles are found to be having the higher share in PM (and also BC) emissions, which are known to have severe impacts over respiratory and cardiovascular health. WHO has recently classified diesel exhausts as potential carcinogens. Moreover, vehicles also emit NOx, which is having its own impacts on health and is also known as an important precursor to ground level Ozone formation.

In response to the problem of vehicular pollution, India has progressively improved fuel quality (by reducing lead, benzene and sulphur). However, the level of sulphur in diesel, which is a bottleneck for emission control in vehicles, is still high. Ultra low sulphur fuel (sulphur less than 10 ppm) is a pre-requisite for the installation of advanced tailpipe treatment devices such as diesel particulate filters for effective control of emissions. Presently, BS-III fuel (350 ppm sulphur) is being supplied throughout the country, except in 20 cities where BS-IV fuel (50 ppm sulphur) is available. There are many highly polluted cities other than these 20, which do not have the benefit of BS-IV fuel; also heavy-duty trucks are on BS-III norms as they travel outside these cities. Projected growth in the sector is expected to increase the transport emissions by almost three times by the year 2030, and would deteriorate the air quality further.

In 2012, the Government of India set up an Auto Fuel Vision 2025 Committee to discuss and develop the road map for further improvement in fuel quality and emission norms in India. The committee has recommended BS-IV and BS-V fuels across the country by 2017 and 2020, respectively. BS-V emission norms will become applicable from 2020 and BS-VI emission norms are expected to come into effect from 2024. The timelines recommended in the report for the introduction of BS-IV and BS-V norms in India are delayed considering that we have already lost four years (between 2010-14) because of the delay in initiating the review since the last road map ended. Moreover, the report mentions about the possibility of implementing BS-VI vehicular emission norms in 2024, which is almost 10 years behind the timelines of Euro-VI introduction in Europe and similar Tier-3 norms in US.

In all, air pollution in Indian cities is significantly linked to the transportation sector emissions. Despite improvements in fuel quality, it is still inadequate to control the emissions from vehicles effectively. Further advancement of standards and uniformity in supply is required.

Action Required

India is presently facing the problem, which California has dealt with in the past. The region had several episodes of severe air pollution during 1940-70. In response to that, several measures were taken and one of the important measures was to reduce emissions from vehicles. As part of these measures, fuel quality was progressively improved. In tandem, measures were taken to improve engine technology. As diesel used in heavy-duty vehicles was a major contributor of air pollution, new diesel fuel standards were adopted in 2003, and a gradual shift was made to diesel with sulphur content less than 15 ppm by 2006. Introduction of low sulphur diesel also made it possible to employ DPFs and other tailpipe treatment devices to reduce emissions. Thus, over the years with progressive improvements in fuel quality, and in particular the use of low sulphur diesel together with tailpipe treatment devices, California succeeded in reducing black carbon emissions by 90 per cent despite an increase in number of vehicles and diesel consumption by 175 per cent and 225 per cent, respectively.

India now has an opportunity to learn from the Californian experience and introduce ultra low sulphur diesel (ULSD) across the country at the earliest date and mandate the use of advanced tailpipe treatment devices to bring about a significant reduction in emissions. As has been pointed out in the Scientific Basis section, this can bring down the PM emissions to less than half of the values projected for 2030 (refer to Table 1.5).

Delay in the introduction of BS-IV fuels across the country has been mainly due to inadequate availability of the fuel. Today, Indian refineries have production capacity of about 71 million tons for BS-III and 24.5 million tons for BS-IV quality fuels for supply in the domestic market. While, the Reliance refinery in Jamnagar is producing BS-V fuel, this fuel is being exported. It is necessary for India to increase the production of BS-IV/V fuel and explore the option of diverting the fuel that is being exported to domestic use. Assuming that this diversion is not possible, the additional quantity of BS-IV/V fuel required in the country has to be produced by upgrading the Indian refineries. Hart Energy and MathPro have placed the cost of this upgrade at US $4.2 billion. The Indian refineries themselves have estimated the cost at about US $13 billion. Taking the two different estimates into account, the range of incremental cost of diesel on account of upgradation from BS-III to BS-V quality will be less than 2 per cent of the current price of diesel (~Rs 60 per liter). The major difficulty in moving forward rapidly on the upgradation of refineries is the requirement of the upfront capital investments. The fuel cost of refinery upgradation should ideally be reflected in the cost of fuel. Financial support to the refinery in any other manner would result in subsidizing the rich at the cost of the poor. These funds can either be made available by earmarking part of the ongoing monthly increases in fuel prices (50 paise/liter for diesel, 75 paise/liter 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, the National Clean Energy Fund (NCEF) can be tapped. The fund is primarily meant for research and development in non-fossil-fuel sources of energy. It can be used with some changes in the guidelines (without altering the overall aim of reducing transport emissions). The AFV 2025 committee's recommendations to implement BS-IV and BS-V fuels and vehicular emission norms across the country by 2017 and 2020, respectively, are a step forward. However, the timelines are delayed considering the loss of four years (between 2010-14) since the last road map ended. During these years, there has been increase in air pollutant concentrations in many cities with increased vehicular activities. The report also not explored the options of diverting the exports of RIL-SEZ to domestic use, or importing the better quality fuels.

On these grounds, we urge the Government of India to consider the earlier introduction of BS-V fuels quality norms than those recommended in the Auto Fuel Vision and Policy 2025 Report. The government should require and enable the Indian refineries to leapfrog from BS-III to BS-V fuels by 2018 or by diverting the current exports of RIL-SEZ and arranging for marginal imports. However, if this is not possible then the timelines recommended by the AFV 2025 Committee should be notified immediately so that there are no further delays in introducing the fuels. The laws related to SEZ treats supplies from the SEZ to the domestic market as exports. However, the current exports from Reliance SEZ are likely to be under long term contracts which will make it difficult to divert the Reliance produce to the domestic market. ICAMP authors strongly urge the government of India to explore whether produce of Reliance SEZ can be made available to the domestic market at a negotiated price.

The corporate sector (oil and automobile manufacturing companies) needs to respond to the mandate and upgrade their facilities to meet the advanced fuel quality and vehicular emission norms. Once the supply of fuel is assured, adequate arrangements should be made for controlling adulteration and maintaining the quality of fuels across the country.

Initiatives to Build On and Learn From

There are several initiatives taken across the world on improving fuel quality and reducing vehicular emissions. While in the developed world, US, Europe and Japan have moved to the ULSF, there are plans in place in developing countries like South Africa and China to switch to these standards.

In Japan, the government facilitated the oil companies to produce the low sulphur fuel by giving exemptions (7 per cent) in corporate tax. Depreciation was also allowed on purchased equipment. In Tokyo, the government provided initial incentives to subsidize oil companies that supply ≤ 50-ppm sulphur diesel fuel. This helped in quick discussions between the Government and Industry resulting in defining the road map for bringing ≤ 50 ppm diesel by2004. Federal assistance was also provided in the forms of taxbreaks, depreciation allowances, and research sponsorship on diesel particulate filters.

United Kingdom and Germany introduced tax relaxations on cleaner fuels, which ultimately helped in full switchover all across the country.

In India, the targets as suggested in the earlier road map by MoPNG, 2002 for introducing BS-I to BS-IV quality fuels were successfully achieved. Government mandated the fuel quality norms and the industry responded with upgradation of refineries. By 2010, whole country has switched over to BS-III quality fuel while 13 cities moved to BS-IV fuels.

Timeline

The oil industry has indicated that it would be possible to upgrade the refineries within a span of three years. Also, the Indian automobile industry is exporting Euro-V equivalent vehicles; it has the necessary technology to upgrade the vehicles to advanced emission norms. On this basis, the ICAMP team believes that ideally BS-V fuels could be provided across the country by 2018 and BS-VI emission norms by 2020. However, if this is not possible then the timelines recommended by the AFV 2025 Committee should be notified immediately so that there are nor further delays in introducing the fuels. However, for BS-VI emission norms the Government of India should immediately set up another committee to develop these norms for the automobiles by the year 2017. Thereafter, a time frame of 3-4 years can be given to the automobile industry to prepare for the introduction of BS-VI vehicles in the country by 2020.

3. Tighten Vehicle Emission Standards

Problem

Currently in India with a bifurcated set of emission limits, not many Euro-IV trucks are being purchased (the exception are a few Euro-IV bus fleets that have been put in place in some Indian cities). 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 in areas as BS-III vehicles because of non-availability of BS-IV fuels all across the country. Additionally BS-VI standards would also reduce NOx, HC, and CO emissions, all of which are problematic for air quality in India.

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 lifetime registration of personal vehicles. Two and three wheeled vehicles produce roughly 40 percent of PM2.5, and 35 per cent of PM10, of the emissions inventory for road transport in India. There is a technological shift from 2-stroke to 4-stroke engines, which has resulted in decrease in PM emissions but increase in NOx emissions. Separate, rather than combined standards for NOx and VOCs are recommended. They also produce 40 per cent of carbon monoxide and 70 per cent of volatile organic compounds. The costs of this problem are similar to those laid out to foster new engine management technology and for fuel quality and to upgrade fuel quality.

Action Required

The first step is the adoption of stringent vehicle emission standards. The second step is to ensure uniformity of standards across the country. The third step is to upgrade in-use testing. Finally, the Government of India should issue separate standards for NOx and VOCs for 2/3 wheelers. This will call for notification of BS-IV and BS-VI vehicle emission norms in the country at least by 2017 and 2020, respectively, if these dates cannot be advanced. Considering the fact that BS-VI standards can be introduced with the availability of BS-V fuels latest by 2020, India should immediately set up a committee to discuss and develop BS-VI norms and enforce them by 2020.

Initiatives to Build on and Learn From

The ICAMP participants (and possibly others) serve as nodal point for updating mobile source emission control standards and coordinate with other international efforts such as the ECMA global learning initiative and ICCT's Transportation roadmap Program.

Timeline

ICAMP members recommend that new engine emissions standards be raised but no later than 2018 (to BS-V throughout the country) in 2020 to BS-VI emission standards. There is a need to shift to BS-VI standards in order to take full advantage of the availability of BS-V fuels by 2020 at the latest in India.

4. Upgrade In-Use Testing (Inspection and Enforcement)

Problem

The present air pollution problem in Indian cities is closely associated with the road transportation sector. While, new vehicle standards play an important role, the emission control during their actual use is equally important. Emissions increase during the life cycle of the vehicle if they are not properly maintained. Also vehicles, which comply with standards during the tests, may fail in real world conditions. It is therefore necessary to carry out regular inspection and maintenance of these vehicles to control actual on-road emissions.

Presently, India's regime for enforcing vehicle emissions standards comprises two main components: (a) enforcement of emissions norms in production through Type Approval (TA) and Conformity of Production (COP) verification; and (b) testing of in-use vehicles to ensure that they do not exceed idle test limits prescribed under Central Motor Vehicle Rules (CMVR). The Ministry of Road Transport and Highways (MoRTH) is the nodal agency for implementing TA and COP. States are responsible for establishing "pollution under control" (PUC) centers for testing in-use vehicles for compliance with idle test standards, which are set by MoRTH. Commercial vehicles, which come for re-registration, have to produce PUC certificates at the time of re-registration. Private vehicles, which are registered for 15 years do not come for periodic tests for road-worthiness and therefore do not have to show their PUC certificates unless they are checked on the roads. As a result, not all private vehicles come up for PUC testing. As discussed in the brief, both systems need to be strengthened and necessary changes should be made in the laws.

The infrastructure for TA and COP is in place and the responsible parties (automobile manufacturers) are relatively easy to regulate. CMVR/TAP-115/116 (Type Approval Process) document lays down the procedure for carrying out ageing tests for verifying the durability of anti-pollution devices from 4 wheelers. However, these tests are not carried out on a routine basis and are carried out on requests. During actual use of vehicles, the current I&M system just screens the vehicular fleet to pick out high emitters based on Idle Emission standards. There was also no mechanism to check or recall vehicles, which do not perform in accordance with the COP norms during their whole useful lives. The current in-use Pollution Under Control (PUC) certificate testing is handicapped by two factors: inadequate infrastructure for testing and certifying vehicles in-use, and limited opportunities to verify that vehicle owners have valid PUCs. The equipment employed by PUC centers is not regularly calibrated. Also, operators of PUC centers are not appropriately trained. The points of verification are also limited as private vehicles need to produce the PUC certificates only if they are stopped and checked by transport authorities or police.

Action Required

California has dealt with this problem in the past, which India is dealing with now. Considering the need for testing and control of emissions from in-use vehicles, California initiated a vehicle inspections program in 1970, which in 1984 evolved into the California Smog Check Program administered by the state Bureau of Automotive Repair (BAR). In 2005, CARB adopted a regulation requiring engine manufacturers to install on-board diagnostic systems on vehicles beginning in 2010. This along with tighter standards for fuels and new vehicles has resulted in tremendous improvements in air quality.

In India, similar actions need to be taken for control of emissions from in-use vehicles. There is a need to reconsider the present system of one time registration of private vehicles for 15 years. The Motor Vehicle Rules (1988) and State Rules should be amended to require renewal of registration every 2-3 years for passenger vehicles to ensure that their road-worthiness along with their emission performance is also evaluated regularly. This will help in putting a check on vehicles that do not go for regular PUC checks.

The existing system of PUC is ineffective and needs to be significantly strengthened. For effective I&M, the existing network of PUC testing centers will need to be replaced with a smaller number of modernized and automated centers that can be effectively monitored by the State governments. These centers could be supported by an IT back-end that safeguards data as well as makes it available for analytics to inform enforcement. The testing frequency can be reduced to once a year, which will reduce the overload on the inspection system as well as vehicle owners and ensure that compliance is more realistic. For better compliance, police capacity will need to be augmented to undertake vehicle spot-checks and enable them to issue citations that are actually followed up on. This would include both increasing the manpower available and making the existence of valid PUC more visible such as by placing a prominent sticker on the vehicle. Another way to increase compliance is to link inspection/emissions certification to insurance of the vehicles. This provides an additional incentive for vehicle owners to carry valid PUC certificates.

There is also a need to implement ageing test procedure laid down in the CMVR-TAP document and formulate a recall policy. Alternatively, to ensure compliance of COP norms during the whole life of a vehicle, random samples from in-use vehicles at different stages of their life-cycles should be tested for their compliance with original TA norms after taking into account the respective deterioration factors. Vehicle models found to be emitting greater than their stipulated limits must go in for more comprehensive testing for further investigations. A panel/committee set up by MoRTH could look into the matter and decide on further actions deemed necessary, which may ultimately lead to recall. Now, the new draft of Road Transport and Safety Bill 2014 has a provision to order a recall where a defect is found in a vehicular model that may cause harm to the users or other people or which does not comply with the provisions and standards prescribed under the act. The bill once passed could put additional onus on the manufacturers to improve their processes to supply better quality vehicles.

Gradually, the vehicular fleet should move to include tamper-proof On Board Diagnostic (OBD) system into new vehicles. Such systems reduce the costs and increase accuracy of vehicle emissions diagnostics. There is a need to encourage voluntary industry commitment to pro-actively verify COP, undertake aging tests, and act quickly to implement recalls. Similar initiatives such as the Equator Principles for infrastructure lending have helped resolve coordination problems among companies that see a benefit from avoiding negative publicity for non-compliance but may not be willing to act alone.

As has been pointed out in the Scientific Basis section, an effective I&M [program in India can bring down the PM emissions by a quarter of the values projected for 2030 (refer Table 1.5). TERI, 2014 and AT Kearney, 2013 has estimated a cost of about INR 70-100 million for commissioning an adequate number of desired inspection and maintenance centers in India.

Initiatives to Build On and Learn From

There are number of examples of successful TA and COP testing to learn from regarding staffing levels and resource requirements. Those in key export markets for Indian automobiles (e.g., US, Europe, and the UK) may be the most relevant examples for ensuring a single review for domestic and export markets. Programs such as Brazil's or Singapore's, which rely on private testing agencies to carry out inspections and require vehicles to display a sticker that can be read by traffic cameras may offer relevant lessons for enforcement.

The In-Use Vehicle Compliance Program (IVCP) of the US and illustrated in the California experience is acclaimed as one of the most comprehensive and well-implemented compliance programs in the world. The United States Environmental Protection Agency's (USEPA's) in-use compliance activities doubles up as a feedback mechanism for the vehicle/engine certification process carried out at the manufacturing stage, hence encouraging best possible emission control technology design and durability. This also helps in ensuring engine's optimum performance throughout the vehicle's useful life.

A feature which is quite unique to USEPA's in-use compliance program is that instead of relying entirely on its own testing, USEPA puts the onus on vehicle manufacturers to periodically test and report the results, hence ensuring maximum coverage of the in-use compliance program with minimal government expenditure. Apart from relying on the manufacturers, US EPA also conducts a surveillance testing at its own facility on randomly procured in-use vehicles. Investigations are carried out if non-compliance is witnessed so that adequate corrective measures may be undertaken. Any further failure to pass these tests leads to implementation of remedies in order to rectify the excessive emissions or, in the worst case scenario, recall of the tested vehicle model. This approach of linking the I&M to a stringent recall policy ensures that manufacturers follow highest quality standards.

Timeline

With limited cost and technological requirements, this strategy can be implemented in a short time frame.

5. Foster New Engine Management Technology

Problem

To reduce diesel emissions in the transport sector it is not enough to improve fuel quality and establish lower vehicle emission standards. After-treatment devices are important means to trap additional pollutants and are widely used in the major automobile markets of the US and Europe. In the big cities of India personal four wheeled vehicles largely are equipped with adequate after-treatment. Commercial heavy-duty vehicles largely avoid their use. Also, 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 2 years after registration and subsequently every year. According to the International Council on Clean Transportation (ICCT), (see appendix B: Economic Feasibility) the cost of installing after-treatment devices into diesel passenger cars and light commercial vehicles will be up to Rs. 40,000 ($800) and up to Rs. 1-1.5 lakh ($2,000-$3,000) per heavy commercial vehicle. Out of the 140 million vehicles, there are about 600,000 heavy-duty vehicles on the road. Investing in cleaner technologies has been estimated to cost Rs. 22,600 crore ($4.53 billion) however the net benefit is Rs. 545,000 crore (109 billion). It is to be noted that cost of retrofitment is found to be higher than DPFs installed in the new vehicles in large volumes. It is also expected that the prices in the developing world are likely to be lower than those in developed world.

Action Required

The introduction of fleet-wide emissions control technology (see also Chapter 3) 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. One of the suggestions made by the Expert Committee set up under the chairmanship of Mr S Sundar of TERI and a chair of this report, is to revamp the Motor Vehicles Act. 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 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. Also, the government regulators must play a role in helping manufacturers innovate. Original Equipment manufacturers must especially work with regulators. 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.) The cost for retrofitting heavy-duty vehicles with after-treatment devices largely depend on the year, make and model of the diesel engine, the amount of particulate matter emitted, the desired emission target, the sales volume, and other market factors. Retrofitting a vehicle with an after-treatment device must be done according to OEM specifications to ensure proper operation of the highest quality. As more stringent emission norms are enacted, a combination of after-treatment devices would become necessary.

Initiatives to Build on and Learn From

Climate and Clean Air Coalition's Heavy-duty Diesel Vehicles and Engines Initiative, United Nations Environment Programme's Partnership for Clean Fuels and Vehicles, Clean Fuels and Vehicles Program, California Air Resources Board's example of diesel programs: Healthy Heart and Lung Act (AB 322), On-Road Heavy-duty Vehicle Program, Heavy-duty Vehicle Inspection Program (HDVIP).

Timeline

In July 2014, the AFV 2025 committee set up by the Union Government has recommended to expand the availability of BS-IV fuel to the whole country by 2017, which could allow the use of diesel particulate filters, however at a lower efficiency than what can be achieved with BS-V fuels.There is a need to address and educate the importance of using after-treatment filters through awareness programs and campaigns. (Note that retrofitment is discussed in the Fleet Modernization Action Options). By June 2017, develop and implement a strategic plan to enforce diesel emission control regulation. Due to the majority of the country driving under BS-III norms and only 13 cities requiring BS-IV, many trucks are easily driving in and out of the cities without being properly inspected. With the recommendation of the AFV 2025, there will be availability of uniform quality of fuel from 2017 onwards.

6. Encourage Fleet Modernization

Problem

This Action Option focusses on steps that may be taken to reduce emissions both from Euro-III/Euro-IV trucks and buses through retrofitting where possible, as well as through encouraging fleet modernization as fuel quality improves and emission standards become more stringent. Heavy-duty vehicles are expected to account for a substantial proportion of NOx and particulate matter emissions in the coming years unless policy changes that accelerate fleet modernization are enacted. Figure 4.1 and 4.2 show anticipated emissions trajectories in the absence of policy change.

Action Required

A combination of retrofitting and accelerated turnover is essential for a road transportation fleet such as India's with a high proportion of relatively new, vehicles. Vehicles are typically used for 20 years before being scrapped, and two-thirds of the fleet is less than half that age. Forty percent of the fleet is less than 6 years old (IRADE, 2013). Few of these vehicles, even the newer ones, would be compliant with BS-IV norms since much of India's territory and its fuel supply options only meet BS-III standards.

Fleet modernization must include a portfolio of strategies aimed at the various types of fleet owners. India's freight industry is highly fragmented, and includes both large-scale undertakings such as the Transport Corporation of India and Jaipur Golden as well as an array of smaller, often informal, operators with whom businesses and larger freight companies subcontract through middlemen. More than 80 per cent of the fleet is owned by smaller operators with fewer than five vehicles. (TCI-IIMC, 2012) India's urban bus fleets are largely owned by public sector entities, while utility fleets are increasingly privately owned and operated as solid waste management concessions become more common.

Proposed action items

- National government legislative changes should remove disincentives for fleet consolidation. Many operators avoid owning more than 5 vehicles in one name to avoid being subject to the Motor Transport Workers Act, and taxes and tolls on multi-axle vehicles are higher than those for the smaller, less efficient, two and three-axle trucks that currently dominate the fleet. This shift would also ensure that the fleet becomes more visible and easy to regulate.
- State and National fiscal incentives such as specific purpose grants could be used to motivate State Transport undertakings and city bus operators to modernize their fleets through turnover or retrofitting based on evaluation of cost-effectiveness of both options.
- Outcome-based fleet emissions standards to encourage operators to weigh options of retrofitting and turnover. The relative merit of retrofitting versus turnover will vary across vehicle types and the policy instrument should encourage owner-operators to make this calculation to achieve specified outcomes at the lowest cost.
- National legislative changes to define liability for compliance with emissions norms. Enforcement is a challenge when ownership is fragmented, but there is some evidence of a smaller group of

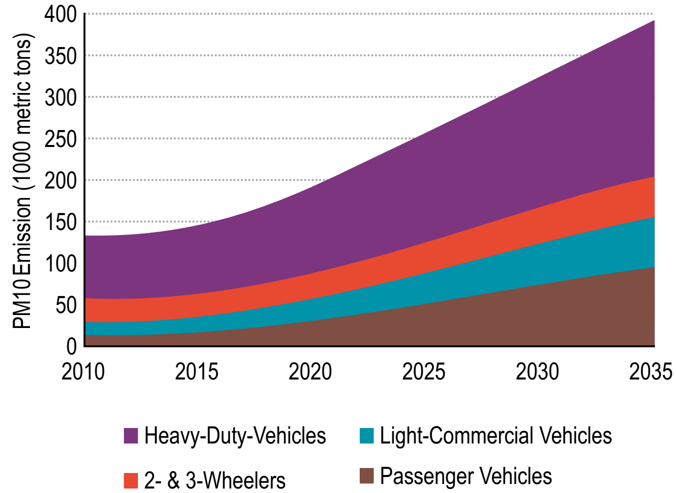

Figure 4.1: Projected total PM10 emissions in the absence of policy change

Source: Bansal and Bandivadekar, 2013

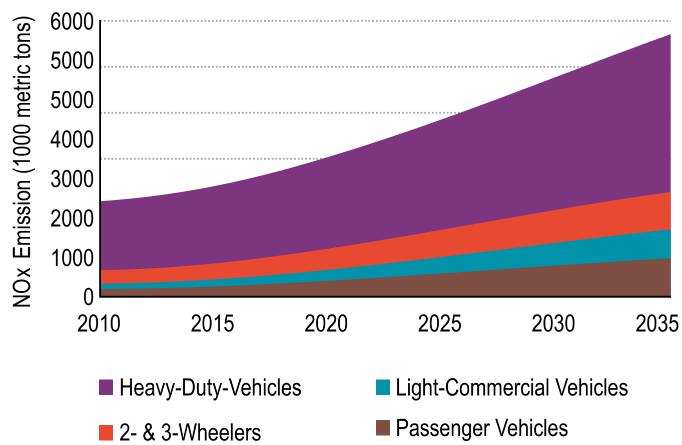

Figure 4.2: Projected NOx emissions in the absence of policy change

Source: Bansal and Bandivadekar, 2013

transport middlemen who could be more easily held accountable for compliance with existing environmental norms.

- Fast track an R&D program for low-cost, robust, easily maintained after-market filters. This could be pursued through established channels for government-funded R&D by technical institutes such as IITs. It could also be launched as a "Grand Challenge" type prize with a financial reward or a market guarantee as incentive for a broader group of inventors to approach.

Initiatives to Build on and Learn From

Lessons could be learned from past international collaboration around bus and truck retrofit programs including those in Beijing (US EPA with Beijing EPB, Chinese SEPA (now MEP), and Southwest Research Institute); Mexico City (WRI/EPA/USAID), and Pune (US EPA, NEERI, Pune Municipal Corporation) to retrofit diesel city buses and gather data on effectiveness of pollution control technology. CARB's Carl Moyer Program offers an alternative model. Green Freight Europe offers lessons on uses of fiscal incentives, and the US Smartway Transport Partnership has an explicit goal of delivering "National Green Freight Programs and urban and transport policies in Europe and Asia that integrate green freight" by 2016.

There are also ongoing discussions of programs to encourage fleet modernization in India. The Society of Indian Auto Manufacturers has advocated a voluntary vehicle requirement scheme that would pay owners to scrap passenger and commercial vehicles more than 15 years old. TERI (2010) proposes a combination of subsidies, access to concessionary finance, and other incentives for funding fleet modernization.

7. Shift Freight Transportation from Higher to Lower-Emitting Modes

Problem

Nearly 70 per cent of India's freight traffic is carried by road. Nearly all of that road freight is carried by vehicles that are significant contributors to emissions: 90 per cent of heavy-duty vehicles meet BS-III emissions standards rather than the more stringent BS-IV or later norms. Rail transport accounts for most of the balance, with the lowest emission per ton-kilometre alternatives (inland waterways and coastal shipping) carrying less than ten percent of freight.

Action Required

India could reduce transport-related emissions by "shifting" freight transport to lower-emission modes such as rail, inland waterways, and coastal shipping. This shift will require changes in both supply and demand side for freight: not only augmenting the supply of efficient, low-emission options but also motivating the freight industry to shift to using these forms of transport.

On the supply side, it is important to augment rail and inland waterway capacity as well as develop supporting infrastructure to link these modes to others for the last mile. Expert reports and investment strategies over the past two decades have nearly called for more investment in track management and capacity expansion on existing routes for rail and terminals, docks and transfer points for shipping. Both are priority areas that recent transport strategy reports including the National Transport Development Policy Committee (NTDPC) have highlighted as a means to become more energy-efficient and reduce energy imports among other goals. More recently, the Minister for Road Transport, Highways and Shipping announced efforts to increase investment in coastal shipping and inland waterways infrastructure and re-emphasized the potential of the Ganga to serve as a major freight corridor.[1]

The stakes are high: McKinsey (2013) estimates economic losses of up to $120 billion/year by 2020 without substantial improvement in rail freight and other investments in India's logistics infrastructure (McKinsey and Company, 2013). KPMG (2013) calls

[1] Press Trust of India (2014). "Government to facilitate investment in inland waterways: Nitin Gadkari," *Economic Times* 11 September 2014. Available at: http://economictimes.indiatimes.com/news/economy/infrastructure/government-to-facilitate-investment-in-inland-waterways-nitin-gadkari/articleshow/42284195.cms

further development of inland waterways and coastal shipping "a game-changing opportunity."[2]

The *Railways Ministry* has an important role to play in both demand and supply side measures. The reform agenda laid out in the NTDPC and echoed in sector policy briefs such as McKinsey (2013) and KPMG (2013) includes: augmenting track-kilometers on congested routes; improving scheduling to maximize flow on existing infrastructure; de-politicizing and rationalizing freight tariffs to be competitive with road transport, and investing in the infrastructure and logistics systems for efficient transfer between modes (e.g., port to rail, rail to smaller local vehicles).

The *Union Ministries of Road Transport and Highways and of Shipping (including the Inland Waterways Authority of India under MoS)* would be primarily responsible for investing in the major interstate inland waterways as well as augmenting facilities for smaller coastal vessels in the major ports. There are three broad requirements: first, maintaining the draft in inland waterways by dredging as well as through cooperation with authorities focused on water use for irrigation and/or hydroelectric power; second, building supportive onshore infrastructure to allow for efficient onloading/offloading as well as transfer points to other modes; and third, regulatory change to allow co-loading of domestic and export goods on coastal ships and encourage ports to cater to the needs of smaller coastal ships as well as international vessels.

State governments have a more significant role to play in developing inland and coastal shipping than rail infrastructure. The "minor ports" that states oversee are a potentially important node of connection between coastal shipping and overland transport, but many do not have adequate draft to accommodate the typical coast vessel draft (7.5-9m, according to NTDPC (2014)). Several state governments (e.g., Maharashtra and Goa) also oversee local waterway systems used for freight shipping.

State and Union government could also offer incentives such as tax concessions or rebates to transport users and service companies to shift freight to waterways, rail, and other lower-emissions options. The EU Marco Polo initiative, for example, provides grant funding for the start-up phases of projects that would shift freight from road to other modes and be economically viable over the long run. Transport users as well as companies that provide transport services and business-to-business support to transport companies are eligible.

Initiatives to Build on and Learn From

The policy initiatives to promote shift from road to rail or inland/coastal shipping freight are discussed above. Current initiatives to invest in freight infrastructure from freight depots to track and track management for rail and dredging/watercourse maintenance for shipping are important to accelerate and support through financial and technical assistance. Broader support for accelerating infrastructure development through technical support for detailed project reports, financing mechanisms, and other general-purpose instruments may also help improve the performance of low-emission freight transport.

Timeline

The action agenda outlined here includes a variety of measures that would require varying time-scales. Some initiatives such as rationalization of tariffs, improving scheduling and providing for better interface between road and rail, can be taken in the short term. A new Committee to examine restructuring the Railway Board and potentially establishing a Rail Tariff Authority has been set up in September 2014. Augmenting rail track-length, on the other hand, is a longer-term goal for public transport investment since it involves land acquisition as well as constructure. Dredging and maintaining waterways themselves can be undertaken in the short term, as can policies to encourage major ports to cater to coastal vessels. Dredging minor ports to enable coastal vessels to enter and developing the onland infrastructure for transferring goods between boat and shore is a medium-run initiative.

[2] KPMG (2013). *Logistics Game Changers*. CII and KPMG. Sector Report, 2013. Available at: https://www.kpmg.com/DE/de/Documents/Logistics_Game_Changers_Transforming_India_logistics_industry_2013.pdf

8. Shift Personal Mobility to Low-Emission Modes: Strengthen Public Transport and Promote Non-Motorized Transport

Problem

More than 90 per cent of passenger traffic takes place by road. Within this, the share of trips by private vehicles (2 and 4 wheelers) vs public transport is increasing. The number of cars per hundred population, in particular, is expected to grow from 13 to 35 in a little over 10 years, more than tripling the vehicles on already congested roadways (Ghate et al., 2013). India's current mix of urban transport passenger-kilometres travelled still includes a substantial proportion of non-motorized transport (NMT -cycling and walking (Hidalgo et al, 2011) but this is often by necessity rather than choice. Most anticipate a shift to motorized transport as incomes rise unless actions are taken to improve safety and convenience of NMT.

Actions Required

India has an important opportunity to build a transport system in which public and non-motorized transport (NMT) becomes the first choice for mobility. NMT is particularly important as a strategy to control air pollution from transport sector since it is the cleanest form (zero emission) of mobility. It is also one of the most marginalized areas in urban transportation policy making as well as city level planning.

However, there are many different pieces that need to come together in order to seize this opportunity: institutional reform that builds capacity for integrated urban transport and land use planning; financing mechanisms that enable plans and encourage innovation; and success in specific policy areas such as upgrading public transport, implementing transit oriented development (TOD), and promoting NMT.

The *institutional challenge* of integrating decision-making among various agencies at three levels of government has been discussed at length in the chapter on policy and governance. Indian states and metropolitan governments must build the capacity to plan across modes to create an integrated network as well as a to link transport investments to land-use changes to create better-connected communities. *Implementing the NTDPC recommendations to a) establish a unified metropolitan transport authority with a legal mandate and permanent technical staff for all cities larger than 1 million*, and b) *Establish state-level Offices of Transport Strategy to pursue integrated transport planning for urban and regional networks* could be an important step toward this goal.

The national government will ultimately have to play a role in *financing* at least some public transportation infrastructure and potential enabling infrastructure for NMT. While cycle paths, footpaths, and protective road future can certainly be developed within capital and maintenance budgets available to urban areas, specific-purpose and/or performance-based funding from national and state goverments could help encourage greater attention to this form of infrastructure. There is no institutional barrier to including NMT infrastructure road designs, city mobility plans and city budgets[3], but incentives must be created by making it a mandatory requirement in urban transport related funding from the Centre.There is an important equity argument for NMTs since the minority of people with motorized vehicles occupy 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).

Similarly, bus-based public transport systems are also within reach of larger cities' budgets as well as state transport funding, but incentives from national programs such as the forthcoming successor to the Jawaharlal Nehru National Urban Renewal Mission could motivate greater attention to buses as an important part of public transport systems. Bus-based systems are particularly well suited for most Indian cities since they are inherently more flexible than rail-based ones and can accommodate unforeseen growth. Routes can be reworked based on changing densities

[3] The Indian Roads Congress (IRC) code for urban roads, UDPFI (Urban Development Plans Formulation and implementation) guidelines and the new Code of Practice for design of Urban Roads prepared by the Ministry of Urban Development (MoUD), all clearly provide for NMT infrastructure as an important cross-sectional element of urban roads but these are not followed.

and development patterns. They can also be deployed quickly and augmented incrementally.

Central and state government financing for lower levels of government could also allow greater expenditure on design including more careful assessment of ridership data and integration with city development and industrial policy plans. National or state-based funding programs could also facilitate sharing of experience and information if reporting requirements are designed well. Rail-based public transport, particularly, metros, has typically been financed in part by the national government as well as state governments.

Specific initiatives to improve public transport and promote TOD and NMT can take place even as the larger financing and institutional changes are being put in place.

State and urban governments are the primary decision makers about TOD, although the Union Ministries of Urban Development and Housing and Urban Poverty Alleviation can influence TOD though financing that encourages particular types of low-income housing, requires integrated plans as a condition of financing (such as the Comprehensive Mobility Plans under the JNNURM). Some of the actions that could be taken within current urban planning processes include: developing mixed-use areas rather than separating commercial and residential sections; allocating density rights according to access to infrastructure carrying capacity (and, on the other hand, investing in infrastructure capacity based on current and anticipated density).

State and urban governments can also adjust urban transport and planning policies to ensure that they encourage vehicle owners to internalize the full social and environmental costs associated with their choices rather than cater to an increasing vehicle fleet. Shifting public investment from road-widening and flyovers into public transport, for example, is one measure. Others include raising parking fees and rationing parking spaces, congestion pricing or limiting access to particularly busy core urban areas. There are a wide variety of vehicle demand management policies around the world to learn from. Singapore's congestion pricing and Budapest's imposition of fees on street parking are two examples that are widely cited in the Indian context.

State and urban governments as well as citizen groups could also contribute to greater use of public transport by improving the passenger experience with public transport with measures such as unified ticketing, clearly communicated route mapping, SMS updates on delays, attention to passenger safety, and other measures. They can also invest in infrastructure that increases the safety and convenience of NMT including pedestrian footpath, cycling tracks, adequate lighting, shelters, toilets that would make walking and cycling more comfortable, and traffic signals specifically for NMT at the intersections.Very few cities in the country have constructed adequate tracks for NMT users. Where footpaths and cycle tracks have been constructed there are problems of bad design, lack of maintenance, encroachment, inadequate lighting, etc.

Both civil society and local governments can support cycle-sharing initiatives as public initiatives, social enterprises, or public-private partnerships. The concept of formal, well-planned, and organized bicycle-sharing system has also not yet been picked up by Indian cities although more and more promising initiatives are emerging across cities from Mumbai to Bangalore. NUTP, 2006 also stresses the need to explore the possibility of a public bicycle program.

Initiatives to Build on and Learn From

As with the shift from road to rail, there is already growing national and state policy momentum for improving urban transport systems as well as expanding pedestrian and cycle areas. The National Urban Transport Policy mandated consolidation of urban transport planning in a unified metropolitan transport agency and the NTDPC reiterated this point. The National Transport Development Policy Committee (NTDPC) in India also recommended the creation of safe Non-Motorized Transport options in all cities as an important Energy and Environment goal as well as a transport goal.

Similarly, present efforts to strengthen urban transport authorities' technical capacity, information base, and financial independence are also important to build on. This can be done at the official level through specific purpose transfers or multilateral policy/finance programs. The World Bank's investment in urban transport governance in Lagos offers one example of fast-tracking for urban transport strategy.

In the shorter run, a number of cities have nascent unified ticketing schemes that could be built on to make public transport easier to use. In October 2011, the Bangalore Metropolitan Transport Corporation (BMTC) and Bangalore Metro Rail Corporation Ltd. (BMRCL) jointly introduced a common day pass, the Metro Bus Transit Day Pass. The pass is available in different denominations, for travel in the Metro, and non-air-conditioned or air-conditioned buses. In addition, the Bangalore Metropolitan Land Transport Authority (BMLTA), an entity set up in accordance with the provisions of the National Urban Transport Policy (NUTP, 2006), is responsible "to initiate steps, where feasible, for common ticketing system." Unified ticketing is also under consideration by the Mumbai Metropolitan Regional Development Authority (MMRDA) and Chennai Metropolitan Development Authority.

Civil society groups can also play an important role in building transport planning capacity. Chennai and Bangalore chapters of City Connect, an informal association of corporate, civil society, and government, have contributed to policy strategy including some measures that have been implemented. The Institute for Transportation and Development Policy, an international NGO, has also contributed to urban transport in cities around India including Chennai and Ahmedabad.

Outside of government, corporate initiatives to transport employees by bus, now common as a kind of employee perk among companies in congested urban areas or in far-flung outlying areas, could also be expanded. Civil society initiatives such as "busroutes.in" or Transport for Mumbai (transportformumbai.com) to improve user experience with public transport by providing information about actual schedule, route, and other information could also be scaled up.

There are many examples to learn from in promoting NMT. The Wuhan and Hangzhou Public Bicycle bike-share programmes in China are the largest in the world, with around 90,000 and 60,000 bicycles respectively. The next largest, the Vélib' in Paris comprises of about 20,000 bicycles and 1,450 bicycle stations.

UNEP along with the FIA foundation has developed an initiative called Share the Road with the goal to catalyze systematic investments in walking and cycling road infrastructure. Present, focus of the initiative is on countries in Africa. Under the program, in 2011, Kenya adopted a policy to integrate NMT facilities in all new urban road projects.

Under EU, the Netherlands has promoted cycling and tried to reduce motor vehicle use. They used methods of infrastructure planning by taking into account 'traffic calming' measures to encourage cycling (by specific infrastructure, low vehicle speeds, and low motor vehicle volumes). They design public space to integrate landscaping with walking and cycling facilities. Plying restrictions are enforced for motorists while cycling is encouraged at the city centers

Tokyo enacted the national Bicycle Law in 1980 and encouraged provision of bicycle lanes, paths, and parking facilities near railway stations to promote cycling as a feeder mode. The shared use of sidewalks and footpaths with pedestrians was another important step taken in Japan to promote NMTs.

Timeline

Building India's urban transport planning capacity is a long-term institutional project, particularly given the fragmented context of urban governance and infrastructure finance. India's cities cannot yet count on well-funded, politically empowered, governments that are structurally accountable to urban residents. Integrating infrastructure decision-making across several agencies and levels of government is technically challenging, and linking it to land-use decisions that are themselves at times divided between competing authorities, particularly in larger cities adds another layer of complexity. Urban infrastructure finance is generally controlled by state or national government, and expertise across the country in planning and transport planning is thin.

Still, several steps could be taken in the short run to improve public transport, promote non-motorized transport, and accelerate TOD in order to reduce emissions per passenger-kilometre.

The hierarchy of public and NM transport over road development could be embedded in terms of central and state funding for urban transport. The concentration of the sources of finance actually creates an opportunity to establish incentives to focus on public and non-motorized transport should the relevant Union Ministries decide to promote these alternatives. These could include: preferential terms (e.g., a lower state share) for capital investment in public and NM transport; financial support for design and maintenance of public and NM transport; financial support for city development plans to be revised along TOD principles, among other motivation.

At the city level, improving the passenger interface for public transport through unified ticketing, clearer route mapping, and schedule notifications, can be undertaken quickly by local governments or even local civic groups based on information provided by the transport operators. Augmentation of bus fleet and implementation of demand management measures like congestion charges could take time. Building urban transport planning capacity is perhaps the longest-run endeavour, though several states have set up transport planning agencies that do bring together relevant stakeholders across levels of government and agencies, even if these do not have the financial and technical capacity that may be desired.

9. Increase Distribution of Electric and Hybrid Vehicles

Problem

The vehicular sector has grown at a rapid pace and has contributed significantly to the deteriorating quality of air in Indian cities. Despite improvements made in the quality of fuels and technologies of vehicles, immense growth in the sector has resulted in further increase of emission loads. Other than a significant source of air pollution, vehicular sector has a major share in petroleum product consumption in the country. With growing mobility demands for passenger and freight transport, the consumption of petroleum products have increased substantially in the road transportation sector. Transport sector presently accounts for about 17 per cent (72 million tons of oil equivalent) of the total energy consumed in the country making it the second largest consumer of commercial energy after the industry sector. 70 per cent of diesel and 95 per cent of petrol consumed in the country can be attributed to transport sector. Moreover, the sector is expected to grow at a steady rate at least for the next few decades. With this, the oil import dependency is expected to increase from 76 per cent of 164 million tons in 2012 to 93 per cent of 493 million tons by 2032. This raises important concerns about the energy security in India.

As the IIASA Global Energy Assessment Toward a Sustainable Future recently pointed out, hybrid electric vehicles (HEV's) can improve fuel economy by 7-50 per cent over comparable conventional gasoline vehicles, depending on the precise technology used and on driving conditions (although comparable modern diesel engines can be equally fuel efficient). IIASA also wrote that all electric battery vehicles (BEV's) can achieve a very high efficiency (more than 90 per cent, four times the efficiency of an internal combustion engine vehicle, but excluding the generation transmission of the electricity), but they have a short driving range and battery life.

As a result, electric mobility in India is still at a nascent stage. Electric vehicles (EVs) have a very small share in the overall sales of automobiles in the country. Electric cars and two wheelers had a meagre share of just 0.027 per cent (January, 2011), and 0.69 per cent (2010) in the total sales of cars and two-wheelers, respectively. There is presently a clear preference for internal combustion engine (ICE) mainly due to factors like technology reliability, upfront initial costs, and support infrastructure. Government subsidies in past have proven to be useful in increasing demand for EVs in India.

Despite a number of policy directives (Auto Policy 2002, and the Automotive Mission Plan 2006-16, the National Electric Mobility Mission Plan (NEMMP), National Action plan for Climate Change in India (NAPCC), National Urban Transport Policy (NUTP)) which support the promotion of electric vehicles in India, the penetration of electric vehicle have not yet picked up. There is a lot to be done for effective implementation of objectives and recommendations mentioned under these plans and policies.

Action Required

The major actions that are required to be taken to improve electric vehicle penetration in India will include efforts in the direction of a) demand creation, b) research and development, c) designing financial incentives, and d) development of support infrastructure.

Demand creation measures are to be taken by the State governments that will include assured procurement of EVs for government use and certain public facilities. Demands may also be generated by declaration of certain areas as LEZ (low emission zones) where only electric mobility is permitted. A certain share of electric buses should also be mandated in city/State bus fleets. Fiscal incentives need to be provided for increase in demand from private sector.

There is a need for increased R&D initiatives in electric mobility sector. Currently, Indian manufacturers have limited R&D capabilities, with no patents as yet. The situation demands for R&D in the fields of battery cell technologies, EV Powertrain system integration, electric motors, and power electronics. The R&D has to focus on developing technologies that suit Indian conditions. The Twelfth Five Year Plan proposed to set aside an amount of about INR 7.4 billion (88.8 million Euros) for research and development related to electric vehicles and hybrids.

The EV sectoral growth is presently hindered on the issue of high upfront cost. There is a need to devise a model to provide financial incentives for promotion of EVs in India. A demand incentive strategy could be used to provide incentives based on vehicle parameters like battery size, technology and minimum performance criteria. There were subsidies announced in the past which have resulted in growth of the sector. The EV sales surged due to the subsidy (overall INR 950 million, incentives up to 20 per cent on ex-factory prices of EVs) provided by MNRE during the 11th five year plan period which came to an end in March 2012 and resulted in a 65 per cent decline in the sales. Currently, no subsides are provided on purchase of electric vehicles. Twelfth Five Year Plan (2012-17) proposed to continue the lower excise duty for manufacture of vehicle types that are a national priority for the country. Budgetary announcements have also granted concessions to hybrid and electric vehicles and battery packs for such vehicles from basic customs duty and also special CVD being extended to certain items imported for their manufacture. In addition, State level incentives in the form of exemption of VAT, road tax, and additional subsides were also tried out in past to popularize electric vehicles. An initiative to disincentivise the petroleum product based vehicles, could also help in boosting the demand for EVs.

Another important factor limiting the sales of EVs is the absence of support infrastructure for charging and maintenance of EVs. There is a need to ensure availability of city-wide, quality support infrastructure to ensure usability by the existing users and also to attract potential users. This would call for promotion of PPP models for commission and O&M of the charging stations. Corporate should encourage developing this infrastructure with a minimum guarantee scheme.

Above all, there is a need to launch major awareness programs to make electric mobility popular. Communities need to be made aware of the energy and emission benefits of the technology and lower life cycle costs.

The Ministry of Heavy Industries and Public Enterprises, has the prime responsibility of implementing the recommendations of the National Electric Mobility Mission Plan (NEMMP) 2020, to assure the growth of EV industry in India. The Ministry of New and Renewable Energy (MNRE), and the Ministry of Science and Technology will have the key responsibility of promoting R&D efforts to develop and improve the technologies. MNRE also needs to devise a financial model for providing incentives for promotion of EVs. Assured power supply is pre-requisite for promotion of EVs and the Ministry of Power (MoP) need to accordingly plan for it. MoUD, and city governments in consultations with local pollution control authorities, research institutes, and NGOs should identify LEZ (low emission zones) and mandate the use of electric vehicles in these areas. State government should mandate the use of electric vehicles in city/State bus fleets.

The provisions of NEMMP are expected to incur investments up to INR 233 billion (2.79 billion Euros) by 2020. This will include investments for financial subsidies and support infrastructure by the government and expenditure over R&D efforts by both government and the industry.

Initiatives to Build on and Learn From

California would be an excellent partner for India in the expansion of electric vehicle use. In 2014, California added $116 million in support for clean vehicle programs. Plug in vehicles qualify for a per vehicle incentive of $2,500. This followed a number of new bills to encourage electric vehicle use, which were signed into law by Governor Brown in 2013. Those new laws provide access to carpooling lanes; require new housing developments to install charging stations; made charging stations easier to locate and use; provide $48 million to encourage electric vehicle purchase and fleet modernization; and creates programs to support EV technology development. Governor Jerry Brown signed an Executive Order that sets a target for California of 1.5 million EV by 2025. California has already 35 percent of the EV in the United States. Currently, 50,000 electric vehicles ply California highways. In addition to consumption and use of EV, California manufactures the premier electric vehicle in the world known as the Tesla. From its Palo Alto HQ, the company is known for its innovative process and design. Tesla vehicles have a range of over 260 miles and accelerate to 60 miles an hour in 4.2 seconds.

There are also successful models of building the necessary infrastructural support for EVs. Singapore, in June 2010, initiated a project to invest 20 million dollars in setting up a comprehensive network of recharging points, and to provide subsidies for the purchase of electric vehicles. Spain proposed a set of measures for enhancing charging facilities. The offered public support to owners of EVs for installation of private charging points and also to promote installation of charging points in new buildings. They also offered subsidies of about 30 per cent of the investment (up to 600,000 euros) to promote private sector participation.

In India, Delhi and Bangalore have moved ahead and installed charging ports for EVs in some of their sub-stations and parking spaces in malls and office. The overall progress is slow mainly due to limited interest shown by the infrastructure developers due to minimal population of EVs on the roads.

Timeline

Enhancing the share of electric vehicles in India is a long term agenda. The current target of 5-7 million vehicles by 2020 should be the first target, which could be built upon further.

10. Use Microgrid with Electric and Hybrid Vehicles

Problem

The storage of power from intermittent sources like solar and wind energy has long been a problem for electric grid operators. The technology of a smart grid with electric and hybrid vehicles. supports benefits such as the attainment of large renewable energy levels as proposed by the new Government of Prime Minister Modi in India. India can leverage this technology being demonstrated on the UC San Diego campus (see inset next page) today to help India reduce Black Carbon and NOx emissions from both its transportation and power generation sectors while reducing oil imports and increasing energy security. The benefit to cost ratio is positive. In the case of the University of California, San Diego microgrid, a 42 megawatt system allows the University to save $ 10 million per year over purchasing power from the local utility. If a similar system were installed at an appropriate level in Ahmedabad, similar savings could be expected in India. Co-benefits of the project are the reduction of black carbon, oxides of nitrogen, and greenhouse gases.

The indispensable ingredient for 'firming' renewables in high penetrations is energy storage. When the policy is decarbonizing both the electric system and transportation, combining personal electric vehicles (PEVs) with an intelligent 'grid friendly' charging control system presents significant cross-cutting benefits by leveraging the vehicle batteries for both transportation and grid support/stability applications. PEVs are typically inactive or stationary for long stretches during a given day. When connected to an ecosystem of intelligent charging stations, they can effectively be unified into a 'non-generator resource' (NGR) that can respond to oversupply and undersupply conditions in the grid.

With large penetration rates of PEVs, electric system operators can reach higher renewable energy (RE) portfolio goals which would otherwise require larger investments in stationary energy storage devices. Those added investments would contribute nothing to decarbonizing transportation.

Further, when a microgrid is located in a remote region and is unable to tie into other electric systems for back-up, storage becomes that much more critical to developing a robust and reliable service for community development. This is especially true if it relies on intermittent renewables like wind and solar.

Action Required

The governance of the system would require the Government of India to accept the mature standard that allows electric cars to interact and the mature technology incorporating electric vehicles into the grid. All these rules of the road need to be incorporated into regulation. Also it helps if one has a unified vision of energy use in the future. California has an integrated energy policy that encourages crossover of technology in pursuit of reductions of carbon dioxide, particulate matter and oxides of nitrogen. India appears to be developing one over time as it moves toward decisions on electric vehicle subsidies and price increases for petrol and diesel to support fuel quality increases.

Timeline

By July 2015, the Ministry of Roads and Motor Vehicles should initiate a dialogue with electric utilities and electric vehicle manufacturers to determine the outlook for dispatchable electric loads. By December 2015, business (Auto Industry) to forecast timing of major energy storage through PEV.

Initiatives to Build on and Learn From

One might assume that this action area would require a major resource stream. The box below details how an initiative could be done at appropriate scale. The ICAMP authors, through WB funding, can design a pilot project similar to UCSD's for a city like Ahmedabad.

11. Avoid Transport: Improve Integrated Land-Use Planning Industrial Policy, Planning, and More

Problem

Travel demand is expected to increase over the coming decades. There are no reliable models of projecting overall transport demand in India, but planners and policymakers expect passenger and freight transport requirements to grow faster than

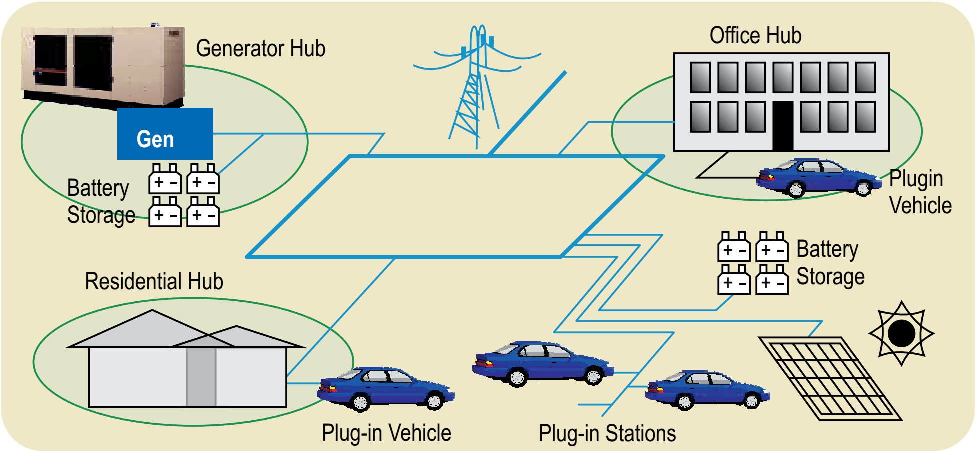

Figure 4.3: Microgrid with electric vehicle diagram
Source: Harrop P, Electric Vehicles Research

the economy. The Ministry of Road Transport and Highway estimates an income elasticity (the change in transport requirements associated with a change in income) of freight transport (billion ton kilometers - TKM) per unit of growth of 1.2, or about 10 per cent increase in transport demand for 8 per cent annual growth. Similarly, road passenger transport (billions of passenger-kilometers) grew at an average of 8.8 annually from 1980-2011 even as growth averaged 4.9 per cent per year. Rail passenger and freight demand has not increased as fast as GDP (an elasticity of 0.79 over 2005-2009) as more freight and passenger trips have shifted to road transport (discussed elsewhere) but the Railway Ministry has targeted an elasticity of 1.25. International evidence suggests that transport elasticity will increase over time before declining, though patterns vary widely across countries based on demography, geography, land use patterns, sources of growth (e.g., manufacturing versus services) and other factors.

"Avoiding" transport is rarely stated as a policy goal in India — most reports and strategies focus on increasing both capacity and access to the transport network in order to lower costs of freight transport, increase household access to national employment markets, and integrate markets. The following suggests some potential ways to achieve these and other development benefits with less physical movement of goods and people.

Action Required

Move information, not people: Union, State, and urban governments in India could provide incentives for telecommuting. About 17 per cent of workers worldwide and 56 per cent of online workers surveyed in India telecommuted frequently, according to a 2012 Ipsos-Reuters poll. The aggregate impact of telecommuting on emissions may be limited given the relatively small number of online employees in the workforce, but a variety of studies have argued that it is effective as a local air quality measure. It may also be appealing as a traffic-reduction measure in IT hubs.

Evaluate all options: Coal movement, for example, accounts for nearly half of Indian Railways' freight volume. The need for transport could be reduced by reallocating coal blocks to power and steel plants closer to the mines, relocating planned new power plants closer to coal sources, or shifting to other sources of power. Further analysis along the lines of Bergerson and Lave (2005) would be required for each project,

Table 4.1

Empirical results of the relationship between urban form and transport energy demand as well as car use.

Source: Li, 2011

Study	Subject area and data	Relationship between urban form and transport
Kenworthy and Laube (1999)	44 cities around the world over the 1960-1990 period	Negative correlation between automobile dependency and urban density
Kenworthy (2003)	84 cities in the world	Idem
Mindali et al. (2004)	Data in Newman and Kenworthy (1989), 32 major cities in four continents	No direct impact of urban density on transport energy demand
Glaeser and Kahn (2004)	131 major MSAs in the US; 70 international cities	Positive correlation between low-density cities (what we call sprawl) and car ownership
Bento et al. (2005)	114 urban areas in the US	City shape, road density and population centrality have significant effect on annual household VMTs
Shim et al. (2006)	Small-and medium-sized cities in Korea	High density and population concentration decrease transport energy consumption
Vance and Hedel (2007)	Panel data of daily travel in Germany 1996-2003	Causative impact of urban form on car use (urban form is a statistically significant determinant of automobile use)
Grazi et al. (2008)	Dutch Housing Survey 1998; 458 municipalities in the Netherlands	Significant impact of urban density on private car ownership and driving distance
Karathodorou et al. (2010)	Millennium cities database for sustainable transport (1999); 84 cities from 42 different countries	Urban density affects fuel consumption, mostly through variations in the car stock and in the distances travelled

given variation infrastructure, population density, and other factors that weigh in the cost-benefit analysis, but it is possible that investing in transmission could be superior to shipping coal and this question should be considered.

Finally, India could take steps to *integrate land use and transport planning* to support more mixed-use development in which people can avoid long commutes by working and shopping locally. Increasing density, for example, tends to reduce transport use around the world [Table, from Li (2011)].

Changing land use regulation to encourage mixed-use development could also reduce commuting. High land prices are already leading to rapid expansion of built-up areas in India's suburbs; some of these new areas could be developed as coherent hubs in and of themselves rather than as satellites of the core business district.

Linking air quality targets to urban planning is a third instrument for integration. The National Urban Transport Policy has already called for integration of ambient air quality goals into the urban planning process to ensure that the emissions costs of land use choices is factored into decision-making among other goals.

Initiatives to Build On and Learn From

California's Sustainable Communities and Climate Protection Act of 2008 offers an 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 travelled, thus reducing fuel consumption and saving money.

Microgrid and Electric Vehicles in Small Communities

The University of California at San Diego (UCSD) provides the power for its own community of roughly 50,000 people. This is not an experiment but an economic reality. UCSD now saves more than $850,000 per month from its microgrid compared to the cost of importing from the utility grid. The UCSD miracle is produced without the resources of a country or state but that of a smallish town. For the ICAMP report, this means that a microgrid with electric vehicle chargers can be built to appropriate scale in an Indian state like Gujarat. UCSD could bring together its partners with Indian partners like Mahindra, which is already manufacturing electric vehicles. The relevant UCSD partners for such a program would be Daimler-Benz, the California Electric Commission and RWE (Germany's second largest electric utility).

UCSD has a 42 Megawatt (MW) microgrid with a master controller and optimization system that self generates 92 per cent of its annual electricity load and 95 per cent of its heating and cooling load. UCSD will possess the largest most diversified portfolio of energy storage systems by any university in the world. The generation side of the system includes a molten carbonate 2.8 MW fuel cell using biogas from wastewater treatment, 1.5 MW of photovoltaics (PV), 2 concentrating PV systems and a 30 kW/30 kWh PV integrated storage system. The system operates in conjunction with a 27 MW combined cooling heat and power plant and a 4 million gallon thermal storage system. Despite an ambitious capital building program, energy growth has been offset by an extensive $22 million/year energy efficiency program on the legacy occupable building space.

Mercedes-Benz smart cars already use twenty-five Level 2 Electric Vehicle (EV) charging stations on campus. UCSD has received California Energy Commission funding for an additional twenty-six RWE (Germany's second largest utility) Level 2 and 3 DC fast chargers. The RWE equipment will be the first US demonstration of ISO 15118 standard adopted by the US and European manufacturers for implementation in 2017. UCSD is launching a concurrent campaign to have EV manufacturers provide the students, faculty, staff, and campus fleet with promotional rates to fully utilize the EV charging infrastructure on campus that will form the basis for a significant long term consumer behaviour study. When completed, UCSD will possess the largest most diversified portfolio of EV chargers by any University in the world.

Timeline

Telecommuting incentives could be implemented quickly. The other measures are longer-term initiatives, but important to consider, as new urban areas and power infrastructure are being developed.

12. Increase Cooperation Between the California Air Resources Board (CARB) and The State and Central Government Of India (GOI)

Problem

Many Indian cities consistently fail to meet the Indian National Ambient Air Quality Standards (NAAQS), with ambient pollutant concentrations exceeding standards by factors of 5 to 10 in major cities. With their growing population, India faces a situation very similar to that of California in the 1940s to 1960s. Over the years, CARB has successfully implemented a variety of emissions control measures that are more stringent than the US standards, including exhaust and evaporative standards for light-, medium-, and heavy-duty vehicles, in-use fleet regulations, and fuel standards, in addition to a significant incentive program instituted to clean up diesel vehicles. Together, these programs have resulted in a very comprehensive strategy for mitigating transportation emissions that have led to significantly declining emissions even as the overall fleet size has increased. A similar strategy could be pursued by India with technical assistance by CARB scientists and engineers who have done the work before. The cost of this additional tool to reduce air pollution would be negligible.

Action Required

California's Government both CARB and the Governor's Office have been in touch with officials of the State Governments of Gujarat and Uttarakhand and have received statements of interest from them. The California officials offer valuable lessons for other regulators and policymakers about policy design and implementation. India's transportation emissions could be reduced significantly by policies and investments that promote an integrated urban transport strategy, and a systemic shift of passengers and freight to more efficient, lower-emissions forms of transport, as well as by more direct regulatory and policy approaches aimed at encouraging more efficient, lower-emitting vehicles, similar to the California model. Specifically, CARB could conduct training for the GOI staff and NGOs for comprehensive regulatory development, inventory development and verification, program implementation and evaluation. It could assist in capacity building for developing an integrated urban transport strategy, and program development for potential local and region projects identified by GOI for policy action (fleet upgrade/modernization, retrofit, etc.) It could advise on building robust regional monitoring networks and dissemination of information. Technical assistance could be offered from CARB on identifying and prioritizing potential projects for mitigation. Finally, through their work together, professional networks could be established to continue dialogue on specific issues on air pollution mitigation programs. Following the successful cooperation with states, CARB might work with the India Union Government (Ministry of Heavy Industry) to engage with the Auto Industry to encourage coordination and to accelerate innovation in emission control technologies.

Initiatives to Build on and Learn From

A Memoranda of Understanding on air pollution has ben signed between the State of California and the national governments of China and Mexico.

Timeline

July 2014 begin exchange of ideas to agree on an MOU for knowledge transfer. January 2015 training and seminars begin. July 2015 CARB asists in capacity building and program development. July 2015 the Government of India engages with stakeholders to determine changes that need to be made to the program.

The Way Forward

Sharma S, Sundar S, Ramanathan V

Evaluation Projects

The ICAMP report seeks to identify from among the interventions that were made in California to improve air quality, those that are most relevant to India. Chapter I contains the scientific basis for air quality monitoring and management. Chapter II lists the technologies that are available to improve air quality. Chapter III details the policy issues that need to be addressed to improve air quality in India. These chapters have drawn from the discussions that were held in California in October 2013, and in New Delhi in February 2014. Chapter IV draws from all the earlier chapters and suggests environmental goals options for action in India. While some of the actions can only be taken by the National government, there are others which can be taken by the States. The interventions that need to be taken at the National level are being discussed with the National government. Separately, the ICAMP partners propose to develop and implement pilot projects in select cities to demonstrate the impact of interventions that States could take on air quality in select cities. The pilots would emerge from workshops, with state and city officials. At these workshops, ICAMP partners would identify together with the state officials the options that would be most appropriate for the state. Based on this, the detailed project reports could be prepared. Some examples of interventions are discussed below.

5.1 Possible Interventions for India

Based on the Californian experience, the following interventions have been identified which can be introduced across the country at a National scale in India. These would have substantial impact over both urban and rural regions of India.

a) Upgradation of diesel fuel quality (Action option priority 2)

Improved fuel quality (sulphur content less than 10 ppm) greatly enables introduction of advanced tailpipe treatment devices and advancement of vehicle emission standards to Euro-VI equivalent levels. It is a tested model in California, wherein it resulted in decrease in air pollutant concentrations in a significant manner. It is now essential in India to supply fuel with sulphur content less than 10 ppm all over the country at the earliest date feasible.

b) Tightening of engine emission standards and foster development of new engine management technologies (Action option priority 3

In India, while some cities have moved to BS-IV (Euro-IV equivalent) standards, the rest of the country is still dependant on BS-III norms. Uniformity of the standards and further advancement to Euro-V and Euro-VI equivalent levels together with advanced tailpipe treatment devices should reap considerable emission reductions and air quality benefits, as happened in the case of California. This could also lead to innovation and production of low cost after-treatment devices to cater to the growing Indian market.

c) Upgradation of in-use vehicle testing (inspection and enforcement) (Action option priority 4)

While the previous two interventions are important to ensure lower emissions from newer vehicles, their real world performance depends on their maintenance. Currently, the inspection and maintenance system for in-use vehicles in India is weak and inadequate. There is a lot that India can learn from California with respect to strict enforcement measures, I&M practices, heavy penalties for defaulters, recall policies, etc. Some of these are interventions could be taken up by State governments. We should also be moving away from the existing network of PUC centers to more advanced, better equipped, and automated centers.

On the other hand, it is to be noted that Californian interventions were mainly focussed on improving the emission quality from the tailpipes. However, the discussion of the two meeting also revealed that other than the 'Improve' measures, the 'Avoid', and 'Shift' measures could also help in reducing emissions from the sector. Moreover, these strategies also result in reducing congestion, fuel consumption, and time required for mobility. These strategies are region specific depending on the existing travel demands, transport modal share, vehicular vintages, and transport infrastructure. The efficacy of these strategies needs to be evaluated specifically for the selected cities. The overall list of interventions can then be classified into Avoid, Shift and Improve, wherein efforts need to be put in to reduce the travel demand (Avoid), shift from energy intensive modes of transport to energy efficient modes (Shift), and improve the technologies and fuel quality to reduce tailpipe emissions.

5.2 Testing Efficacy of Interventions Suitably Modified for India in Select Cities as Pilot Projects

The strategies identified for Indian context can reduce vehicular emissions in all Indian cities. In the second phase of the project, we aim to measure the impacts of these strategies at the city scale. The second phase is proposed to measure and demonstrate the effect of interventions on prevailing air quality in some cities. However, very little data is available in public domain on the transport systems in different Indian cities and their impacts on air quality. Drawing up a pilot project for a city would call for a detailed understanding of the city characteristics, transport systems and emission levels and air quality status. This understanding is necessary in order to recommend and identify interventions that are city-specific and will have maximum impact.

This phase of the project would also involve modelling exercises to gauge the emission reduction and air quality improvement potential of different strategies. Based on this detailed study (as well as analysis of economic, financial,social and implementation impacts), the State governments with the assistance of the ICAMP team make appropriate requests to the World Bank for technical and financial assistance to implement the agreed recommendations. They will also setup monitoring stations as required to continuously and effectively monitor air quality improvements flowing from these interventions.

5.3 Cities Chosen for Pilot Projects

After discussions with the State Governments and other important stakeholders in October 2013, February and mid-November 2014, we expect that four cities namely Ahmedabad, Dehradun, Bangalore, and Chennai will initiate demonstration projects. All four cities are the capital cities of their respective states (except Ahmedabad is a twin town of Gandhinagar which is the capital of Gujarat) and are rapidly growing cities. Figure 5.1 shows the population in the four cities as per the latest Census 2011.

The cities are also quite different from one another geographically and also in terms of their characteristics. While Ahmedabad is a city in western part of India, Dehradun represents a town in the foothills of the Himalayan mountain ranges. Bangalore is now popularly known as the silicon valley and has shown tremendous increase in activity levels and mobility demands in the last decade. Chennai quite differently from other towns, belongs to the category of coastal cities wherein the sea breeze effect dilutes the air

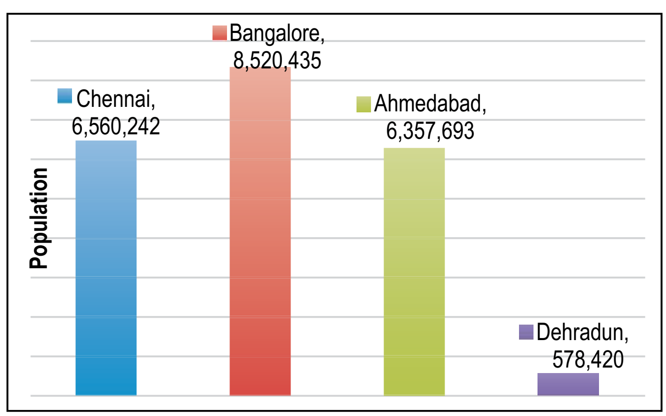

Figure 5.1: Population in the four cities
Source: Census 2011

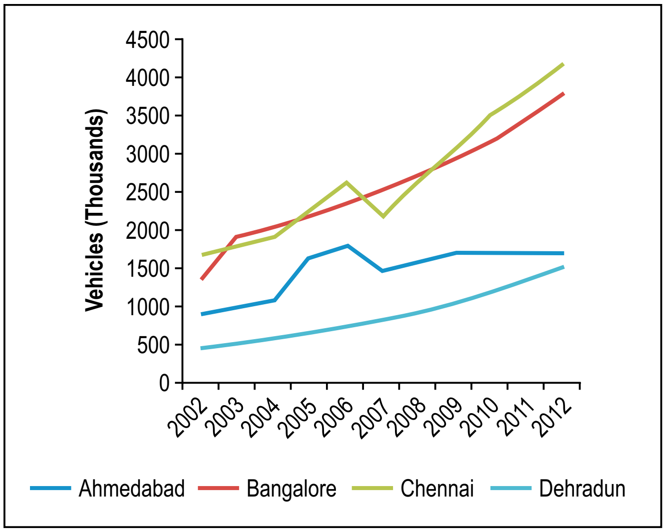

Figure 5.2: Shows the multi-fold growth of vehicles in the four cities during 2002-12.
Source: MoRTH, 2012

pollutant concentrations to some extent. Hence, despite higher number of vehicles, Chennai still has somewhat better air quality than the other cities (Figure 5.3). However, the air quality in all four cities is not acceptable and has violated the standards consistently. Some cities have shown improvements due to measures taken in past, however growing activity levels have kept air pollutant concentrations still above the permissible limits.

The proposed cities not only geographically represent different part of the country, but are also

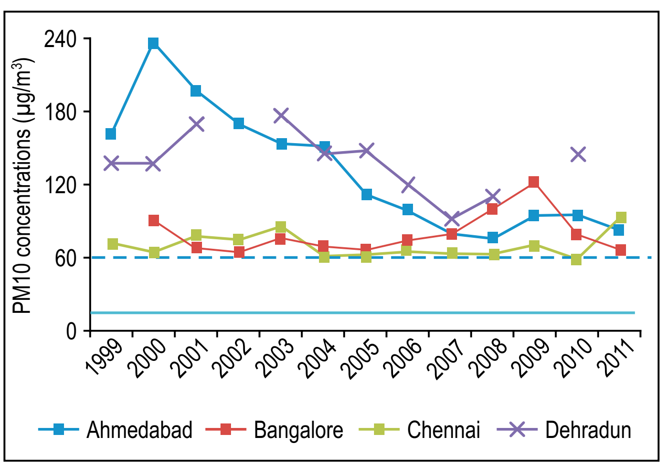

Figure 5.3: Trends of annual average PM10 concentrations in the four cities during 1999-2011
Source: CPCB, NAMP

significantly different which would allow testing the efficacy of interventions in diverse environments.

5.4 Pilot Projects

The proposed evaluation projects in the four cities will primarily consist of the following major activities.

5.4.1 Pre-feasibility study

5.4.1.1 A 1-day workshop in respective States

A one day workshop will be carried out in consultation with the State Governments to kick start the projects. The project objectives and activities will be discussed and data needs will be stated to the local authorities. The workshop will also be able to highlight city specific issues related to vehicular pollution.

5.4.1.2 Study of transport systems in the chosen cities

Based on the discussion and data collected after the previous activity, the city will be analysed for its travel demand, vehicular fleet mix, modal shares, Inspection and maintenance systems, etc. Travel demand estimates need to be collected from city mobility plans, city development plans or any other source to adjudge the mobility requirements. Thereafter, the modal shares need to be analysed to classify the travel demand into different modal categories (bus/private vehicles/para transit/non-motorized). The vintage of vehicles, fuel-wise and technological distributions are the other extremely important parameters to understand the tailpipe emissions of different pollutants from the vehicles.

5.4.1.3 Establish a baseline

After the analysis of the existing transport system in the city, an emission inventory needs to be prepared for all contributing sectors to simulate air quality in the cities. This will involve collection of activity level data from industrial, transport, domestic, and other sources. The reliable government/published data sources will be used for data collection process. The broad approach to be followed for emission inventorization is depicted in equation 1.

$$Ek = \Sigma_1 \Sigma_m \Sigma_n A_{k,1,m}.ef_{k,l,m}.(1 - \eta_{1,m,n}.\alpha_{k,l,m,m}).x_{k,l,m,n} \quad ...(1)$$

where **k**,**l**,**m**,**n** are region, sector, fuel or activity type, abatement technology; **E,** denotes emissions; **A,** the activity rate; ef, the unabated emission factor; η, the removal efficiency; α, the maximum application rate; and **X,** the actual application rate of control technology **n**.

This approach will require careful selection of emission factors applicable to the relevant sources in the cities. This will also require identification of control technologies that are already in existance in the cities for control of pollution in different sectors. Eventually, a macro level emission inventory (2x2 km resolution) will be prepared to assess the spatial distribution of emissions in the city limits. The emission inventory will be prepared for the current year (for model validation) and future (2030) for evaluating air quality scenarios under different emission control scenarios. Existing city developmental, industrial and mobility plans and existing government policies will be assessed to generate emission inventory for future under the BAU (business as usual) scenario.

5.4.1.4 Identification of interventions to be tested

A list of interventions that are most relevant for the city wiil be prepared and need to be tested for its effects on the air quality and corresponding alternate emission scenarios will then be generated.

5.4.1.5 Basic simulations to assess impacts of different strategies

The emissions under the BAU and alternate scenarios will be fed into the air quality model to simulate air pollutant concentrations. The differences in air quality under different alternate scenarios with respect to the BAU will gauge the impact of the interventions.

5.4.2 Implementation of pilot projects and evaluation

Based on the results of the pre-feasibility study, the selected high-impact interventions will be implemented in the four cities. A state of the art air quality monitoring system will be established to assess the pre and post air quality parameters to gauge the real air quality improvements attributable to the interventions.

5.5 Time Frame and Financing Requirements

The second phase project timeframe is presented below.

Activity in months	0-6	6-12	12-18	18-24	24-30	30-36
Pre-Feasibility						
Pre AQ measurements						
Implementation						
Post AQ measurements						
Synthesis						

Financial requirements of the second phase of the project can be estimated in three major heads:

a) Feasibility study
b) Implementation of intervention
c) Pre and post air quality monitoring systems

The costs involved in implementation of interventions can only be assessed after the completion of feasibility study which will ascertain the interventions that will be most relevant for a particular city. The cost of monitoring systems will also depend on initial analysis on number of stations that will be required in a particular city. It is then suggested that a feasibility study should be initiated to plan and prepare proposals for the implementation projects. Finally, before implementation, a detailed project report (DPR) will have to be developed for pilot projects in the cities.

Bharat and Euro Emission and Fuel Standards

Bharat Stage (BS) Vehicular Emission and Fuel Quality Norms In India

The Auto Fuel Policy in India, 2002 suggested a road map for advancement of vehicular emission and fuel quality norms in India (Table AA.1). They introduced the Bharat stage emission and fuel quality standards, which were primarily based on European regulations to regulate the output of air pollutants from automobiles.

A BS norm for a vehicle denotes the maximum it is allowed to emit per unit of vehicular activity. For fuel, it denotes the quality of fuel in terms of different parameters such as sulphur, benzene, PAH, etc. To control emission from the transportation sector, a combination of fuel quality and vehicular controls are required. For example, a DPF can only function to the best of its efficiency in the presence of fuel having sulphur less than 10 ppm.

Based on these, all new vehicles manufactured after the implementation of the norms need to comply with the regulations. Different vehicle manufacturers have used different technologies to meet the desired norms for various vehicle categories. The norms and the technologies used to achieve them are shown in subsequent sections.

1) Heavy-duty vehicles - Diesel

Table AA.1

Emission Standards for Diesel Truck and Bus Engines, (g/kWh)

Source: Indian Auto Fuel Policy, MoPNG 2002

Norm			Year	Test cycle		CO	HC	NOX	PM	PN
India	Stage	I	2000			4.5	1.1	8	0.36	
Bharat	Stage	II	2001[a]			4	1.1	7	0.15	
Bharat	Stage	III	2005[b]	ESC	Test	2.1	0.66	5	0.10/0.13[x]	
Bharat	Stage	III	2005[b]	ETC	Test	5.45	0.78	5	0.16	
Bharat	Stage	IV	2010[c]	ESC	Test	1.5	0.46	3.5	0.02	
Bharat	Stage	IV	2010[c]	ETC	Test	4	0.55	3.5	0.03	
	Euro	V				1.5	0.46	2.0	0.02	
	Euro	VI				1.5	0.13	0.40	0.01	8.0×1011

*ESC: European Stationary Cycle; ETC: European Transient Cycle

[x] for engines with swept volume <0.75 litre per cylinder and rated power speed >3000 rpm

[a] From October 24, 2001, in Delhi; October 31, 2001, in Mumbai, Kolkata and Chennai; April 1, 2003, in Bangalore, Hyderabad; Ahmedabad, Pune, Surat, Kanpur, and Agra; April 1, 2005, in the rest of the country.

[b] From April 1, 2005, in Delhi, Mumbai, Kolkata, Chennai, Bangalore, Hyderabad, Ahmedabad, Pune, Surat, Kanpur, and Agra; April 1, 2010, in the rest of the country.

[c] From April 1, 2005, in Delhi, Mumbai, Kolkata, Chennai, Bangalore, Hyderabad, Ahmedabad, Pune, Surat, Kanpur, and Agra.

[y] for gasoline CO: 1.1 HC: 1.05 NMHC: 1.2 CH_4: 1.2 NOx: 1.05

2) Light-duty vehicles

Table AA.2

Emission Standards for Light-Duty Diesel Vehicles, g/km

Source: Indian Auto Fuel Policy, MoPNG 2002

Norm			Year	CO	HC	HC+NOx	NOx	PM	PN
India	Stage	I*	2000	2.72–6.90	-	0.97–1.70	-	0.14–0.25	
Bharat	Stage	IIa	2001a	1.00–1.50	-	0.70–1.20	-	0.08–0.17	
Bharat	Stage	IIIb	2005b	0.64–0.95	-	0.56–0.86	0.50–0.78	0.05–0.10	
Bharat	Stage	IVc	2010c	0.50–0.74	-	0.30–0.46	0.25–0.39	0.025–0.06	
	Euro	Va		0.50	-	0.23	0.18	0.005	
	Euro	Vb		0.50	-	0.23	0.18	0.005	
	Euro	VI		0.50	-	0.17	0.08	0.005	6.0×10^{11}

Table AA.3

Emission Standards for Gasoline light-duty Vehicles (g/km)

Source: Indian Auto Fuel Policy, MoPNG 2002

Norm			Year	CO	HC	HC+NOx	NOx	PM	PN
India	Stage	I*	2000	2.72	-	0.97	-	-	
Bharat	Stage	IIa	2001a	2.20–5.00	-	0.50–0.70	-	-	
Bharat	Stage	IIIb	2005b	2.30–5.22	0.20–0.29	-	0.15–0.21	-	
Bharat	Stage	IVc	2010c	1.00–2.27	0.10–0.16	-	0.08–0.11	-	
	Euro	V		1.0	0.10	-	0.060	0.005 ef	
	Euro	VI		1.0	0.10	-	0.060	0.005 ef	6.0×10^{11}

* Exact standard dependent on seat number and weight of vehicle

a. From April 1, 2000, in Delhi; January 1, 2001, in Mumbai; July 1, 2001, in Kolkata and Chennai; April 1, 2003, in Bangalore, Hyderabad, Ahmedabad, Pune, Surat, Kanpur, and Agra; April 1, 2005, in the rest of the country.

b. From April 1, 2005, in Delhi, Mumbai, Kolkata, Chennai, Bangalore, Hyderabad, Ahmedabad, Pune, Surat, Kanpur, and Agra; April 1, 2010, in the rest of the country.

c. From April 1, 2010, in Delhi, Mumbai, Kolkata, Chennai, Bangalore, Hyderabad, Ahmedabad, Pune, Surat, Kanpur, and Agra.

Table AA.4

Technological options for LDVs to achieve vehicular emission norms

Source: ICCT

Regulation	Gasoline Technology	Diesel Technology
No control	Carburetor–no control	IDI–no control
1991	Adjustments in carburetor operation	IDI–improvement in mechanical fueling methods
1996	Adjustment in carburetor and EGR	IDI–improvement in mechanical fueling methods
2000–Euto I	Electronic fuel control (TBI)	IDI–improvement in electronic fueling methods
	Catalytic converter (TWC)	EGR
	EGR	
Bharat II	Electronic fuel control (TBI and MPFI)	Direct injection
	Catalytic converter (TWC) with one oxygen sensor	EGR with cooling systems
	EGR	

Bharat III	Electronic fuel system requires MPFI	Common rail fuel injection at 900–1,300 bar
	Oxygen sensor is upgraded with heating capabilities for cold-start operation	EGR with cooling systems
	EGR	
Bharat IV	Similar to BSIII	Increased fuel injection pressure 1,300-1,600 bar
	TWC system includes a close-coupled catalyst and a under-floor	Turbocharger and intercooler
		Cooled EGR
		Oxidation catalyst
Bharat V*	Improvements in combustion and catalytic converter performance	Same technology as BS-IV
		Improvements in fuel atomization with injection pressure 1,600-1,900 bar
		Diesel particulate filter for PM control and lean NOx trap for NOx control
Bharat VI*	Improvements in combustion and catalytic converter performance	Same technology as Bharat-V
		Improvements in fuel atomization with injection pressure 1,600-2,100 bar
		Diesel particulate filter for PM control and lean NOx trap for NOx control
Bharat VII*	Improvements in combustion and catalytic converter performance	System improvements over Bharat VI technology

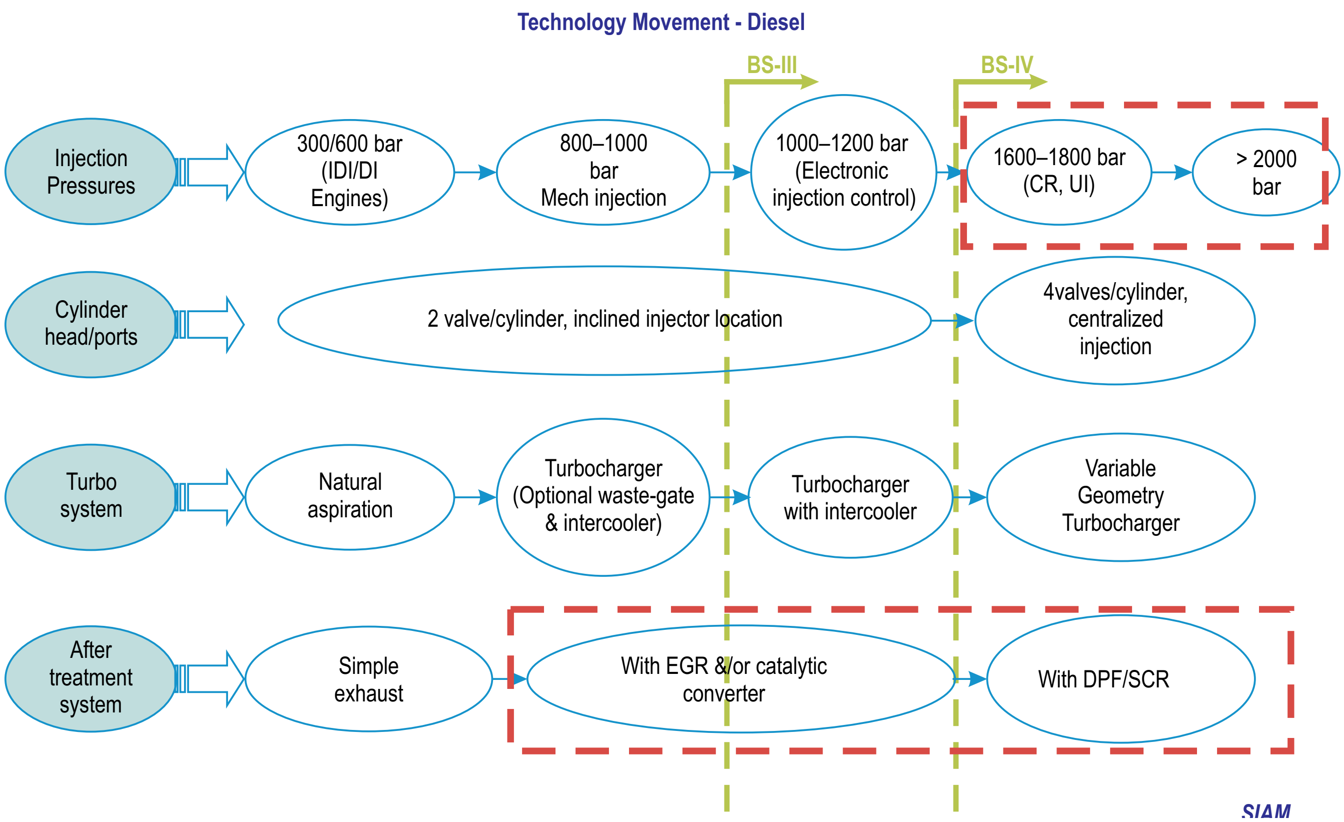

Figure AA.1a: Technology Movement – Diesel
Source: SIAM

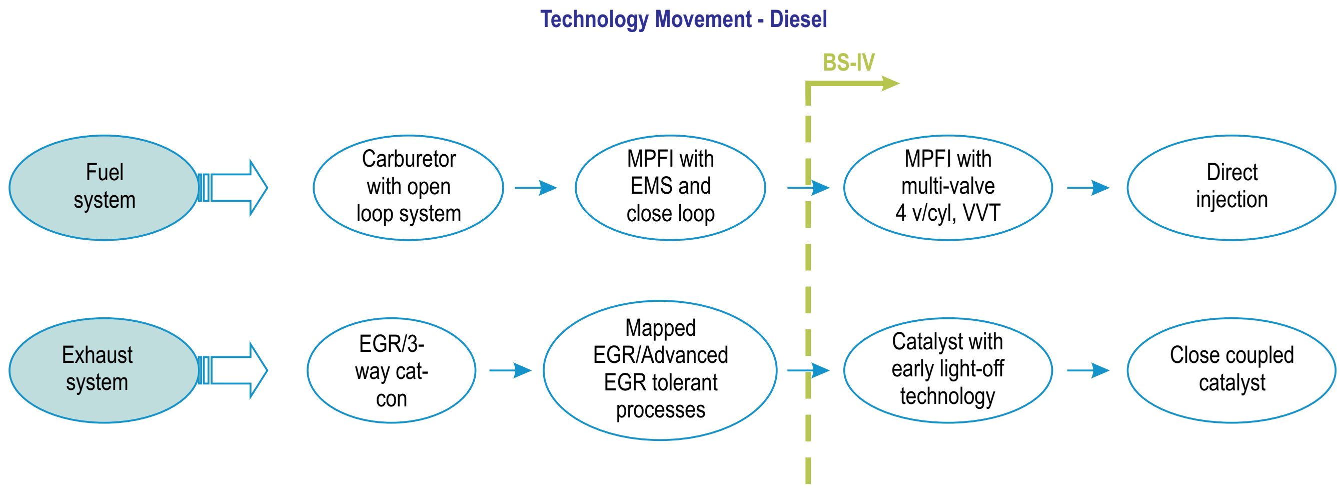

Figure AA.1b: Technology Movement – Gasoline

Source: SIAM

3) Two and Three Wheelers

Table AA.5

Emission Standards for 2/3-Wheel gasoline vehicles, g/km

(2-Wheel Gasoline)			
Year	CO	HC	HC+NOx
1991	12-30	8-12	-
1996	5.50	-	3.60
2000	2.00	-	2.00
2005 (BS-II)	1.5	-	1.5
2010.04 (BS-III)	1.0	-	1.0

(2-Wheel Gasoline)			
Year	CO	HC	HC+NOx
1991	12-30	8-12	-
1996	5.50	-	3.60
2000	2.00	-	2.00
2005 (BS-II)	1.5	-	1.5
2010.04 (BS-III)	1.0	-	1.0

2/3-Wheel (Diesel)			
Year	CO	HC+NOx	PM
2005.04	1.00	0.85	0.10
2010.04	0.50	0.50	0.05

Table AA.6

Technological options for 2/3 wheel options to achieve vehicular emission norms

Source: ICCT

Regulation	2W Gasoline Technology	3W Technology
No control	2-stroke	2-stroke
1991	2-stroke	2-stroke
	Carburetor improvements and engine lubrication improvements	Carburetor improvements and engine lubrication improvements
1996	2-stroke	2-stroke
	Carburetor improvements and engine lubrication improvements	Carburetor improvements and engine lubrication improvements

2000	2-stroke	2-stroke
	Carburetor improvements and engine lubrication improvements	Carburetor improvements and engine lubrication improvements
Bharat II	4-stroke	2-stroke
	Carburetor improvements	Carburetor improvements and engine lubrication improvements
Bharat III	4-stroke	Gasoline 4-stroke or shift to CNG 4-stroke
	Carburetor improvements and oxidation catalyst	
Bharat IV	4-stroke	Gasoline 4-stroke or shift to CNG 4-stroke
	Carburetor and improved oxidation catalyst	
Bharat V	4-stroke	Gasoline or CNG 4-stroke
	Fuel injection improvements and oxidation catalyst	with oxidation catalyst
Bharat VI*	4-stroke	Gasoline or CNG 4-stroke
	Fuel injection improvements and three-way catalyst	With port fuel injection oxidation catalyst
	Oxygen sensor and closed-loop air-fuel control	
Bharat VII*	4-stroke	Gasoline or CNG 4-stroke
	Fuel injection improvements and three-way catalyst	With port fuel injection oxidation catalyst and oxygen sensor
	Oxygen sensor and closed-loop air-fuel control	

Table AA.7

Indian gasoline specifications

Source: MoPNG, 2002

Serial No.	Characteristics	Unit	Bharat Stage II	Bharat Stage III	Bharat Stage IV
1	Density 15 °C	Kg/m^3	710-770	720-775	720-775
2	Distillation				
3	a) Recovery up to 70 °C(E70) b) Recovery up to 100 °C (E100) c) Recovery up to 180 °C (E180) d) Recovery up to 150 °C (E150) e) Final Boiling Point (FBP), Max f) Residue Max	%Volume %Volume %Volume %Volume ^{0}C %Volume	10-45 40-70 90 - 210 2	10-45 40-70 - 75min 210 2	10-45 40-70 - 75min 210 2
4	Research Octane Number (RON), Min		88	91	91
5	Anti Knock Index (AKI)/ MON, Min		84 (AKI)	81 (MON)	81 (MON)
6	Sulphur, Total, Max	ppm	500	150	50
7	Lead Content(as Pb), Max	g/l	0.013	0.005	0.005
8	Reid Vapour Pressure (RVP), Max	Kpa	35-60	60	60
9	Benzene, Content, Max a) For Metros b) For the rest	%Volume	- 3 5	1	1
10	Olefin content, Max	%Volume	-	21	21
11	Aromatic Content, Max	%Volume	-	42	35

Table AA.8

Indian diesel specifications

Source: MoPNG, 2002

S. No	Characteristic	BS-II	BS-III	B-IV
1	Density Kg/m^3 15°C	820-800	820-845	820-845
2	Sulphur Content mg/kg max	500	350	50
3(a) 3(b)	Cetane Number minimum and/or Cetane Index	48 or 46	51 and 46	51 and 46
4	Polycyclic Aromatic Hydrocarbon	-	11	11
5 (a) (b) (c)	Distillation Reco. Min. At 350°C Reco. Min. At 370°C 95%Vol Reco at 0°C max	 85 95 -	 - - 360	 - - 360

Economic Feasibility

Overview

The clean up costs of air pollution in the transport sector of India are not astronomical and are estimated to be tens of US billion dollars. They are much less than the damages to human well-being (health and food security) and managed (agriculture) and natural ecosystems which a are estimated to be in the hundreds of US billion dollars.

The direct costs of refinery investment to meet ultra low sulphur standards are estimated by the International Council on Clean Transportation at $4.2 billion (Hart Energy 2012). Some Indian refining companies have put the costs at up to three times this amount (MoPNG, 2011). A comparison with California cost figures for refinery upgrades, where the capacity is in the range of 50 per cent of the Indian refining industry, also suggest lower figures than the India industry estimate.

A second cost category of an air pollution mitigation program is the cost of purchasing and installing after-treatment devices to meet Bharat Stage-VI, the increasingly strict motor vehicle emission standards. The cost of diesel particulate filters to meet standards for particulate matter and selective catalytic reduction for NOx has been estimated at $800 per light-duty vehicle. The cost of meeting the same standards for heavy-duty vehicles has been estimated at $3,000 (Bansal et al, 2012). Later in this annex we roughly estimate a cost of $3.4 billion to change the entire current fleet of heavy-duty vehicles. In addition the EPA has shown how a few simple measures (Inspection and Maintenance, using fuel efficient eco driving and improving fleet logistics) can yield benefits on black carbon emission reduction (EPA, BC in South Asia).

On the benefit side, the savings in health and productivity of labour (mortality and morbidity) have been estimated by The World Bank. The World Bank states that environmental degradation is costing India $80 billion annually and accounts for 23 per cent of nation's child mortality rate. The bank estimated that reducing particulate emissions by 30 per cent by 2030 would save India $105 billion in health-related costs (World Bank, Diagnostic Assessment, 2013).

The Organization of Economic Co-operation and Development recently estimated that the annual health impact of outdoor air pollution in India was $500 billion (OECD, 2014). In OECD countries, road transport accounts for about 50 per cent of the cost of health impact of outdoor air pollution. So even if India were only at an OECD level of road transport air pollution as a share of overall outdoor air pollution, the burden would still be quite significant. The OECD study also documented the growth in health costs from outdoor air pollution. From 2005 to 2010, India had a 12 per cent increase in deaths and a 3 per cent increase of years of lost life.

Air pollution has been known to have grave consequences. 620,000 mortalities have been estimated to occur annually in India that is attributable to ambient air pollution. Not only are respiratory problems linked to deteriorated air quality, the cardio-vascular impacts are also evident. The World Bank (TERI, 2014) has estimated the total cost of damage caused by outdoor air pollution in India to be around Rs 1.1 lakh crore annually. This is about 1.7 per cent of the total GDP and clearly shows a dent in the economy caused by deteriorated air quality. Significant economic damage has also been caused due to decrease in crop-yields by the ground level Ozone formed through the reactions of air pollutants. Nationally, the aggregated relative yield loss of wheat and rice due to high ozone exposure amounts to 5.5 million tons in 2005, which could have fed 94 million beneficiaries under the National Food Security Act for a year. The question is whether India can sustain its economic growth with a population base severely affected by respiratory and cardiovascular disorders and crop-yields affected by pollution. There are serious steps to be taken to make a clear move towards achieving the air quality standards in a shorter term. Source apportionment studies at urban and regional scales are required to be carried out to ascertain the share of different contributing sources to draft sector-specific strategies for control. Improvement in fuel quality and advancement of vehicular emissions norms is the key to reduce vehicular emissions. According to the World Bank (2013), the emission reduction that can be accrued through introduction of BS-VI fuel quality and vehicular norms in the country can result in the reduction of 127,000 mortalities by 2030 and economic benefits ranging between Rs 3.9-6.7 lakh crore cumulatively till the year 2030. In US dollars the savings would be 65.9 billion to 113 billion. Benefits of implementation of these norms will soon outweigh the costs incurred on initial capital investments.

The second primary benefit of reducing air pollution from transport is the foregone loss of crops like rice and wheat. The crops that would be saved could feed 94 million beneficiaries for one year under the terms of the National Food Security Act. Such an economic loss is roughly $1.2 billion (2005) in crop damage. Another researcher, Jennifer Burney, in a presentation at the ICAMP Oakland workshop, shared preliminary results of her research. The impacts of climate change and air pollution on Indian agriculture were 14 million tons of wheat and 15 million tons of rice when India must import 6 million tons of grain per year.

In addition to the direct benefits, mitigating air pollution yields many co-benefits. Costs and benefit estimates for black carbon have been made (Carver, 2011). A recent study done for the World Bank concludes that health benefits alone were enough to justify on a benefit cost basis the retrofitting of heavy-duty vehicles in Istanbul and Sao Paulo. Adding the benefits of reduced climate change from reductions in Black Carbon enhanced the ratio of benefit to cost in the case of Istanbul (Minjares, 2014). Finally, an unquantified benefit not directly tied to air pollution is that less NOx means less reactive nitrogen clogging up the rivers, coastal lands, mangroves etc.

A Note of Caution

We want to emphasize the uncertainty and tenuous assumptions involved in dealing with programs of this scale and impacts of this magnitude - the multipliers, say from yield loss to dollar value, or DALYs missed to dollars matter a lot. And they are far from precisely known. The Copenhagen Consensus Center compares the health and climate benefits of various interventions to lower black carbon emissions. However, by taking a purposely broad approach they cannot incorporate India-specific behavioural elements where the high governance cost of pursuing "super emitters" in India might exceed the cost of regulations that force original equipment manufacturers to meet high vehicle emission standards. The Copenhagen Consensus Center further notes that, "BC evaluation should ideally include a comprehensive assessment of social and environmental costs and benefits, and not be limited to climate and health alone (Kandlikar M, Reynolds C O, Grieshop A, Copenhagen Consensus). Same on the cost side - we really don't know how much it costs in normal circumstances, steady state markets, to put a new truck with the latest DPF on the road or improve para-transit or establish some number of new testing stations.

We have gone to the limit of responsible use of existing studies already, and do not want to push the data further than they should be pushed to get to false certainty. The pilot projects themselves would help us get more empirically grounded sense of costs and benefits so that we can make a stronger case for national scale-up. We can explicitly build in data collection so that we get this empirical base.

Refining Costs India

The refinery investments needed to transition to ULSFs in India could be less than 2 per cent of the present fuel price. Cost drivers at the upstream or refinery end of the diesel fuel production chain include reduction of sulphur content, limitation of aromatic content, lubricity additives and recoupment of capital and operating costs.

Hart Energy and MathPro (2012) found the refinery investments needed to transition to ULSFs in India to be around $4.2 billion. Summing investments and increased operational costs, and normalizing them to a per litre basis, Indian refineries would pay an extra

0.70-0.88¢ per litre of fuel produced. Thus, ultra low sulphur fuels would cost only about 50 paisa per litre. Even after including tax impacts, the net increase in fuel price due to ULSFs will be less than 2 per cent 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 sulphur reduction technologies, and investment seen by the oil industry as providing no economic benefit to them.

Recently, the government agreed to increase the price of diesel to reduce the subsidy to a particular point. This is a tremendous step forward for India's oil industry, and could be used to free up capital for investments in ultra low-sulphur fuel production technologies. One extra month of on-going monthly Rs 0.50 per litre diesel price increase will ensure that investments made by oil sector in producing ultra low sulphur fuels could be recouped.

Significant capital costs may be required for refiners to produce low-sulphur 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.

California Costs Support Lower Estimates

When CARB adopted the 15 ppm diesel sulphur limit in 2003, eight of the 12 large refineries in California reported that capital expenditures to produce low-sulphur diesel fuel would be minimal. Three refineries reported significant costs involving the installation of new hydro-desulphurization 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, CARB staff estimated that refiners would incur capital expenditures of approximately $170 to $250 million to comply with the low-sulphur diesel requirements.

Along with the initial capital investment, annual operating and maintenance (O&M) costs were considered. Most of the survey responses included annual O&M costs. Usually, these are costs associated with labour, material (such as catalysts, etc.), sulphur 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, CARB staff estimated that the cost-per-gallon impact of the lower diesel fuel sulphur requirements were about 2.5 cents per gallon.

The total cost impact of lower-sulphur diesel fuel may be much higher if refiners need to make significant capital expenditures for hydro-sulphurization equipment. Furthermore, additional hydrogen production capacity may need to be installed to support that hydro-desulphurization. When diesel fuel sulphur levels are lowered through hydro-desulphurization, some of the naturally occurring compounds in diesel that help with lubricity are also removed, so lubricity additives are usually required.

Significant capital costs may be required for refiners to produce low-sulphur 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.

The cost of control In California was about 0.5 per cent of GDP and brought in $10 to $30 of health benefits for each $1 spent in control and added 30,000 jobs in the air pollution control industry and 123,000 jobs in the clean energy industry.

Cost of After-treatment Devices

According to the International Council on Clean Transportation (ICCT), the cost of installing after-treatment devices into diesel passenger cars and light commercial vehicles will be up to Rs 40,000 ($800)

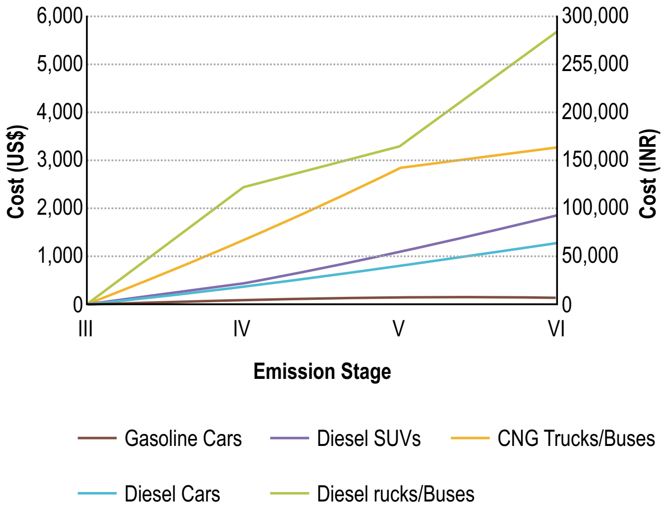

Figure AB.1: Per vehicle technology cost of going from Bharat III to Bharat IV for four-wheeled vehicles in India

Source: Bansal, Bandivadekar, ICCT, 2013

and up to Rs 1-1.5 lakh ($2,000-$3,000) per heavy commercial vehicle (Bansal, Bandivadekar, ICCT, 2013). The cost for transitioning from BS-III to BS-IV is Rs 65,000 ($1,300) per diesel passenger car or utility vehicle, Rs 2.87 lakh ($5,700) per commercial diesel vehicle (Figure AB.1). However this is a significantly lower cost compared to the California Air Resources Board (CARB) estimate, which reports the cost for an active or passive diesel particulate filter (DPF) estimated to be between $8,000 and $50,000 in California. Investing in cleaner technologies has been estimated to cost Rs 22,600 crore ($4.53 billion) however the net benefit is Rs 545,000 crore (109 billion) (Bansal, Bandivadekar, ICCT 2013).

The cost for retrofitting heavy-duty vehicles with after-treatment devices largely depend on the year, make and model of the diesel engine, the amount of particulate matter emitted, the desired emission target, the sales volume, and other market factors (MECA, 2009). Retrofitting a vehicle with an after-treatment device must be done according to OEM specifications to ensure proper operation of the highest quality. Off the showroom heavy-duty vehicles are sold BS-III compliant. After-treatment devices are not required to be installed when meeting BS-III standards. Some

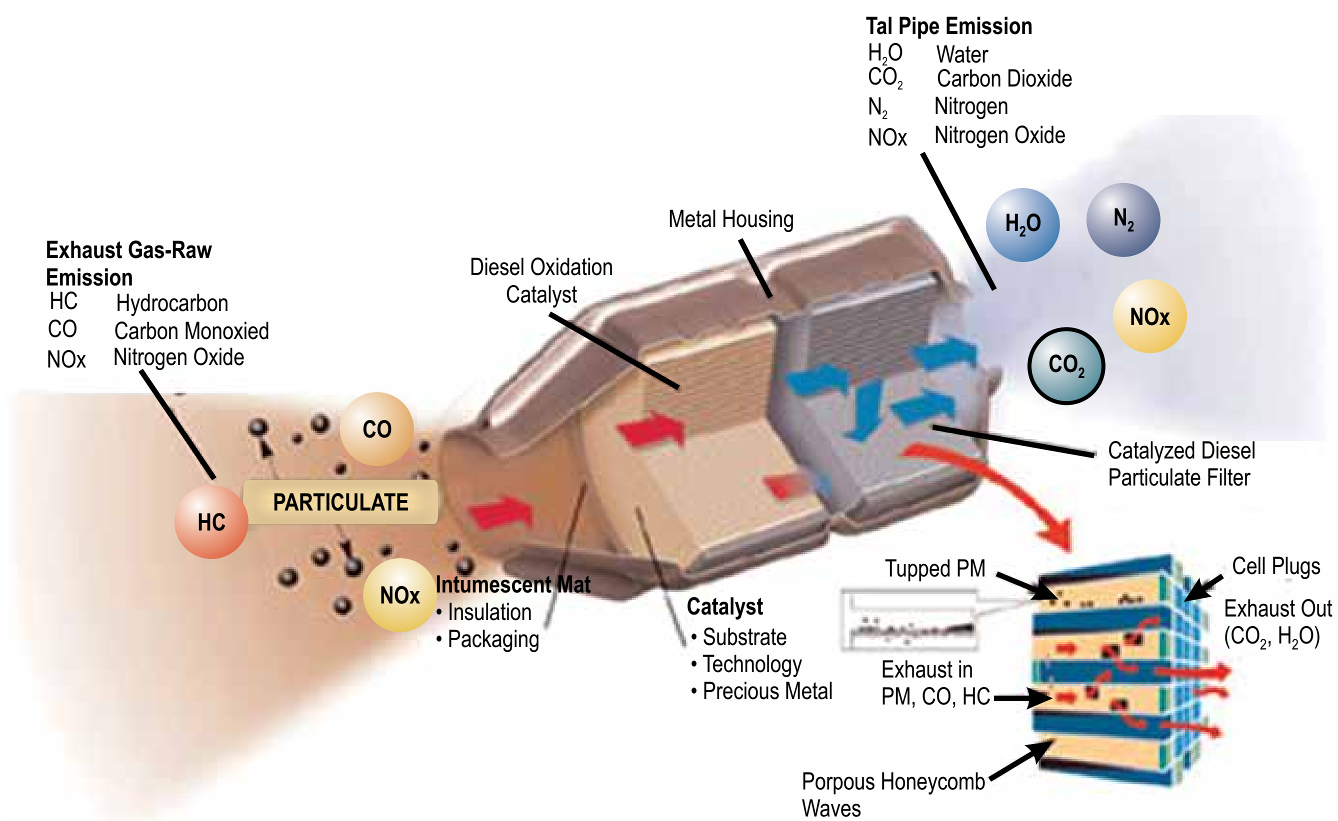

Figure AB.2: Diesel Particulate Filter

Source: Umicore Autocat, USA Inc. as cited from the Emissions Control Technology Association (ECTA) models have an option to be either bought as either BS-III or BS-IV. However, heavy-duty vehicles must comply with BS-IV norms when entering into one of the thirteen BS-IV mandated cities. The significant drop of sulphur content from 350 ppm in BS-III to 50 ppm in BS-IV, allows for the retrofitting of DPFs since they require a low sulphur fuel content. Of course the air quality only increases if the sulphur content is reduced to 10-15 ppm at BS-V and BS-VI. DPF's can be installed with engines built between 1960 and 2006 (MECA, 2006). As more stringent emission norms are enacted, a combination of after-treatment devices would be become necessary.

Out of the 140 million vehicles, there are about 600,000 heavy-duty vehicles on the road (Parikh J, 2011). Using ICCT's numbers, a rough estimate in transitioning after-treatment devices from BS-III to BS-IV for diesel commercial vehicles would be $3.4 billion.

Health Benefits from Air Pollution Mitigation

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 PM2.5 emissions in India's cities alone. In her survey of the literature on black carbon reduction strategies, Liz Carver noted that the health benefits of reducing mobile source particulate matter emissions may exceed diesel retrofit costs by a factor of ten. She notes also "When the economic benefits of avoided health impacts are included, many projects to control black carbon or carbon monoxide may have higher benefits than costs even without including reduced warming" (Carver L. Ibid).

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. 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, which is 2/3rd 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 per cent of DALYs in 2000 compared with 3.1 per cent in GBD 2010. The self-proclaimed limitation of this report though, is that it does not address 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.

Various estimates suggest that at the Indian National scale the transport sector has contributed 7-34 per cent in overall BC emissions across different years. However, the contributions may increase when we move to urban centers, e.g. in Bangalore, the contributions are as high as 56 per cent 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."

Increased Crop Yields with Air Pollution Mitigation

The four largest crops in the world – rice, wheat, maize, and soyabeans – provide 75 per cent of all calories consumed by humans on the planet. Of these, rice and wheat are the most important for India. 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 beneficiaries for one year in India under the terms of the National Food Security Act. The loss is also about double the amount of wheat exported yearly and about 50 per cent of the rice exported annually. It has been estimated that India lost another 4 million tons of wheat due to climate change (Ghude, Sachin D, 2014).

Short-lived Climate Pollutants, 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 sulphates (mostly formed from sulphur dioxide (SO_2) emissions) and organic carbon (OC) – impact analysis necessitates discussion of broader aerosol impacts (BC + OC + SO_2/sulphates) and joint analysis of and O_3 and its precursors NOx, NMVOCs (non-methane VOCs), and CO.

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.

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, soyabean, rice and wheat due to ozone exposure.

Climate change has important ramifications for agricultural production and food security. 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 per cent 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.

Cost-Benefit Analysis of Various Options to Reduce PM Emissions from Road Transport Sector in India

A cost benefit analysis was carried out to compare the costs of various interventions to reduce vehicular emissions with economic benefits accrued from reduction in health impacts. TERI, 2014 has carried out a similar assessment and the same methodology has now been followed in the current study as is depicted in Figure 1. Integrated energy-emission-air quality modelling approach was followed. Using the TERI-MARKAL model, energy consumption estimates were prepared for different categories of vehicles for the baseline (2010) and future years (2030). The energy estimates have been used to compute the air pollutant emissions using the GAINS-Asia model in the second step. In the third step these emissions have been translated into ambient concentration using a combination of meteorological and air quality model (WRF-CMAQ). The ambient concentrations have finally been used to compute the associated health risks both for the base year as well as for the projected year. The relative risks functions used for computation of health impacts due to air pollutant concentrations are adopted from WHO, 1999.

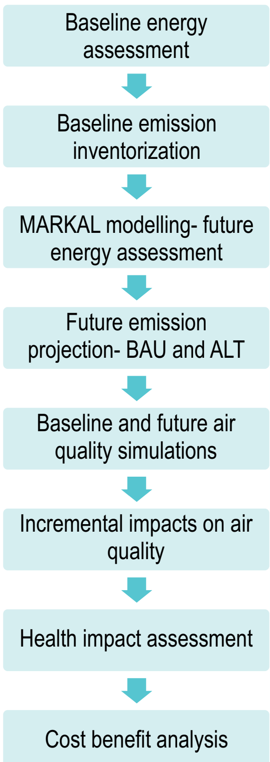

Figure 1: Broad methodology followed in the current study

The entire country has been chosen as the study region for the current work in order to assess the impact of advancement of vehicular emissions and fuel quality norms. The study region is divided into grids of 36 x 36 km^2 to account for the finer representation of vehicular populations at the district levels in India. Number of different categories of on-road vehicles has been estimated using the data on yearly registration of vehicles for the year 1995–2010 and also accounting for their respective useful lives. Daily average distances travelled by different categories of vehicles are broadly adopted from CPCB (2000) and adjusted according to the actual total fuel consumption in the sector taken from MoPNG, 2012. Energy and emission assessments were made under the Business As Usual (BAU) and different alternative scenarios for the year 2030 (Table 1).

The economic benefits associated with the resulting reduction in health impacts due to air pollution are compared with the costs of different interventions. The costs of different interventions are estimated and adopted from multiple sources. The benefits of cleaner fuels and vehicles were computed in the form of reduction in health impacts of improved air quality in terms of PM10. Estimated avoided mortality was valued using the concept of Value of Statistical Life (VSL), a measure of the value to society of reducing the risk of

Table 1

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	Laying CNG pipeline and enhance share of CNG vehicles (70% buses, cars, and 3-wheelers)
In-use vehicle management	RETRO	Retro-Fitment of 50% of existing BS-III/IV truck/lmv/bus with DPF with 90% efficiency
	FM	Fleet modernisation of 50% existing trucks and buses to BS-VI vehicles
	I&M	Implementation of effective I&M system

mortality (Ref). The World Bank 2013 reviews a number of VSL studies for India and finds the average value at about Rs 17.8 million per life for 2010 (Ref). This value was further projected for 2030 using a VSL-income elasticity factor and was also the projected value of real per capita income for India in 2030. The international literature suggests that the VSL-elasticity factor ranges from 0.5 to more than 1.0, being linked inversely to the stage of development of a country. In this analysis, an elasticity range of 0.5 to 1.0 was used leading to lower and upper estimates of the economic value of health benefits.

The costs are annualized accounting for the life of infrastructure and cumulative costs and health benefits are computed for the period 2015-2030. The health benefits are still an underestimate for several reasons. First, only the health impacts associated with PM10 were considered. Reduction in the level of pollutants such as NO_X, SO_2, VOCs, CO, and O_3 due to vehicular emissions may result in additional health benefits. Second, the analysis does not consider the morbidity impacts of improved air quality in terms of lower incidence of respiratory ailments amongst children and adults which results in significant costs in the form of both treatment expenses as well as opportunity cost of time lost. Third, the climate benefits of PM reduction have not been accounted.

Results and Discussions

Table 2 shows the costs benefit analysis of various options to reduce PM emissions from the road transport sector in India.

It may be noted that all the interventions show satisfactory benefit-cost ratio in terms of monetary health benefit and expenditure incurred on implementation of proposed interventions. Fleet modernization which does not show satisfactory benefit to cost ratio needs to be employed selectively for some categories of vehicles in selected zones. Health benefits are found to be highest for ALT-VI, although, with higher costs and considering the state of air quality in Indian cities and high share of transport sector, it makes total sense to move to stringent standards of fuel quality and vehicular emissions. Retrofitment of vehicles show a good benefit to cost ratio, however technical feasibility in Indian context needs to be further investigated. Effective I&M programs turn to be the most cost effective way to reduce health impacts, although the overall potential to reduce PM is limited. Provision of CNG can also significantly reduce PM emissions and health impacts, but its reach is going to remain limited and hence there is need to provide cleaner liquid automotive fuels for widespread betterment of air quality.

ICCT, 2014 shows similar benefit-cost analysis for intervention to improve fuel quality and reduce Black carbon (BC) emissions form vehicles. The study shows a benefit to cost ratio of 0.82 which is slightly less than what has been estimated for India in the current study. It is mainly because of the fact that fuel quality improvements and vehicular technologies reduce other constituents of PM also along with BC which cause considerable health impacts. Hence, the benefits

Table 2

Cost benefit analysis of various options

Area	Scenario	Description	PM10 reduction (Tons) wrt BAU	Avoided mortalities	Health Benefit (Million INR) (Value of Statistical Life approach)#		Cost of program (Million INR)*	Total Cost (million INR)/ton of PM red.	Benefit to cost ratio		Remarks
			2010-2030		Low est.	Higher est.			Low est.	High est.	
Fuel and vehicle technology	ALT-I	Introduction of BS-IV across the country by 2015	936	103151	3135399	5332632	1264710	1351	2.5	4.2	Cost of Fuel and vehicle upgradation
	ALT-II	Introduction of BS-IV across the country by 2020	484	53339	1709876	3039167	790354	1633	2.2	3.8	Cost of Fuel and vehicle upgradation
	ALT-III	Introduction of BS-IV across the country by 2015 and BS-V in 2020	1035	114061	3485146	5954280	3469688	3352	1.0	1.7	Cost of Fuel and vehicle upgradation
	ALT-IV	Introduction of BS-IV all across the country by 2015 and BS-VI in 2020	1156	127396	3912615	6714072	3912038	3384	1.0	1.7	Cost of Fuel and vehicle upgradation
Alternate fuel	CNG	Converting 70% buses, cars, and 3-wheelers to CNG	300	51509	1565671	2662866	1472712	4914	1.1	1.8	Cost of CNG pipeline @ Rs 65 million / km pipeline
In-use vehicle management	RETRO	Retrofitment of 50% of existing BS-III/IV truck/ bus with DPF @ 80% efficiency	789	105435	3204823	5450708	2622128	3322	1.2	2.1	Cost of Fuel and vehicle retrofitment
	FM	Fleet modernization of 50% existing truck/bus to BS-VI vehicles	970	125350	3810179	6480286	6948251	7162	0.5	0.9	Cost of Fuel and fleet modernization @ cost of new bus 1.2 million, and truck for 1.5 million
	I&M	Implementation of effective I&M system	403	62836	1909986	3248472	157680	392	12.1	20.6	Cost of I&M Infrastructure

* includes capital (annualized based on life of infrastructure) and O&M costs for the period 2015-2030

BAU: Based on the current plans and policies. BS-III all across India and BS-IV in 13 cities

Low and high end values of health benefits are based on VSL-elasticity factor of 0.5 and 1 with income growth, respectively

of overall PM reduction are expected to higher than just BC.

ICCT, 2013 also conducted a cost benefit analysis for a combination of interventions like improving fuel and vehicular technology, alternative fuels, and inuse vehicle management. The benefit-cost ratio varies in between 1.5 to 3.8 for the analysis years 2025 and 2035. The present results are in line with findings in other studies.

The analysis was carried out till the year 2030, however, benefits are expected to go even higherin future (as shown by ICCT, 2013) due to avoided health impacts with more and more penetration of interventions. These estimates indicate that there are multiple options with varying potential and cost-effectiveness to reduce vehicular emissions and air pollution in India.

Other Benefits

Strategies to reduce emissions and improve air quality may also result into considerable co-benefits. These may include creation of jobs, improvement in agricultural productivity, energy savings, and boost to the economy (World Bank, 2014). Reduction in PM emissions results in reduced mortalities and morbidities. Mitigating NOx not only helps in reducing health impacts but also reduce the Ozone forming potential. Reduced Ozone concentrations can lead to enhanced agricultural yields of many crops like wheat, rice, and soyabean.

A modal shift towards public transportation systems not just reduce emissions but also help reducing congestion in cities. Significant energy savings can be claimed out of a successful public transport system. Additionally, considerable fuel savings can be made on account of reduced congestion due to lesser vehicular density. Similar benefits can be accrued through shift from road to rail and inland waterways based transport systems. As seen in California, these interventions lead to lot of job creation and hence a boost to the economy.

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List of Acronyms

2S – two stroke engine
2w – two-wheeler
3w – three-wheeler
4S – four stroke engine
4w – four-wheeler
AAQS – Ambient Air Quality Standards
AFV – Auto Fuel Vision
AKI – anti knock index
ALRI – acute lower respiratory infections
ALT – alternative
APCD – Air Pollution Control District
APPCD – Andhra Pradesh Pollution Control Board
ARAI – Automotive Research Association of India
ARI – acute respiratory illness
ASI – Avoid, Shift, and Improve
ATCM – airborne toxic control measures
BaP – benzo(a)pyrene
BAR – Bureau of Automotive Repair
BAU – business as usual
BC – black carbon
bhp – brake horsepower
BS – Bharat Stage
CA – California
CARB – California Air Resources Board
CCAC – Climate and Clean Air Coalition
CFCs – chlorofluorocarbons
CH_4 – methane
CMPs – Comprehensive Mobility Plans
CMAQ – Community Multi-scale Air Quality model
CMVR – Central Motor Vehicle Rules (India)
CNG – compressed natural gas
CO – carbon monoxide
CO_2 – carbon dioxide
COP – Conformity of Production
COPD – chronic obstructive pulmonary disease
CPCB – Central Pollution Control Board (India)
CR – common rail
CRP – C-reactive protein
CV – cardiovascular
CVD – cardiovascular diseases
DALYs – daily-adjusted life-years
DG – diesel generator
DI – direct injection
DNA – Deoxyribonucleic acid
DOC – Diesel Oxidation Catalyst
DPF – diesel particulate filter
ECMA – Emission Controls Manufacturers Association
EGR – exhaust gas recirculation
EMS – engine management system
EPA – Environmental Protection Agency
EPB – Environmental Protection Bureau (Beijing)
ESC – European Stationary Cycle
ESMAP – Energy Sector Management Assistance Program
ETC – European Transient Cycle
EU – European Union
EV – electric vehicle
FAO – Food and Agricultural Organization
FBP – final boiling point
FM – fleet modernization
g – grams
GBD – Global Burden of Disease
GDP – gross domestic product
GHG – greenhouse gases
GOI – Government of India
GWPs – global warming potentials
HC – hydrocarbon
HDDT – heavy-duty diesel truck
HDT – heavy-duty truck
HDV – heavy-duty vehicle
HDVIP – Heavy-duty Vehicle Inspection Program
HFCs – hydrofluorocarbons
hp – horsepower
hr – hour
I&M – Inspection and Maintenance
ICAMP – India-California Air Pollution Mitigation Program
ICCT – International Council on Clean Transportation
IDI – Indirect Injection
IEC – International Electrotechnical Commission
IIASA – International Institute for Applied Systems Analysis
IIHS – Indian Institute for Human Settlements
IIMC – Indian Institute of Management Calcutta
IIT – Indian Institute of Technology
INDOEX – The Indian Ocean Experiment
IOCL – Indian Oil Corporation Ltd
IRADE – Integrated Research and Action for Development
ISO – International Organization for Standardization
IT – information technology
IUC – In-use conformity testing
KAA – Knowledge Action Options
km – kilometer
kpa – kilopascal
kt – kiloton
kwh – kilowatt hour
LCV – light commercial vehicle

LDT – light-duty truck
LMV – light motor vehicle
LPG – liquid petroleum gas
m – metre
MARKAL – market allocation
MECA – Manufacturers of Emission Controls Association
MEP – Ministry of Environmental Protection
MMT – million metric tons
MoEF – Ministry of Environment and Forests (India)
MoPNG – Ministry of Petroleum and Natural Gas (India)
MoRTH – Ministry of Road Transport and Highways (India)
MOU – memorandum of understanding
MPFI – multipoint fuel injection
MUTAs – Metropolitan Urban Transport Authorities
NAAQS – National Ambient Air Quality Standards
NAC – NOx Adsorber Catalyst
NAMP – National Air Quality Monitoring Program
NAPFA – National Automobile Pollution and Fuel Authority
NCEF – National Clean Energy Fund
NCR – (Delhi) National Capital region
NEERI – National Environmental Engineering Research Institute
NEMMP – National Electric Mobility Mission Plan (India)
NGO – non-governmental organization
NGV – natural gas vehicles
NH – national highway
NMHC – non-methane hydrocarbons
NMT – non-motorized transport
NMVOC – non-methane volatile organic compounds
NO – nitric oxide/nitrogen monoxide
NOx – nitrogen oxide
NREL – National Renewable Energy Laboratory (USA)
NTDPC – National Transport Development Policy Committee (India)
NUTP – National Urban Transport Policy (India)
O&M – operation and maintenance
O_3 – ozone
OBD – onboard diagnostic
OC – organic carbon
OECD – Organization for Economic Cooperation and Development
OEM – original equipment manufacturer
PAH – polycyclic aromatic hydrocarbons
Pb – lead
PCI – pulse count injection
PEVs – plug-in electric vehicles
PJ – peta joules
PKM – passenger kilometre
PM – particulate matter
PM10 – particulate matter less than 10 micrometers/microns
PM2.5 – particulate matter less than 2.5 micrometers/microns
POA – primary organic aerosols
ppb – parts per billion
ppm – parts per million
ppmw – parts per million by weight
PSNS – parasympathetic nervous system
PTS – public transportation system
PUC – Pollution Under Control
PV – photovoltaic
R&D – research and development
RF – radiative forcing
RIL-SEZ – Reliance Industries Limited-Special Economic Zone
RMD – reduced mobility demand
RON – research octane number
Rs – Indian rupees
RSPM – respirable suspended particulate matter
RTOs – Regional Transport Offices
RTV – rugged terrain vehicle
RVP – Reid vapor pressure
SAFAR – System of Air quality Forecasting and Research
SCAQMD – South Coast Air Quality Management District
SCR – selective catalytic reduction
SEPA – State Environmental Protection Administration (China; now MEP)
SEZ – Special Economic Zone (See RIL-SEZ)
SIAM – Society of Indian Manufacturers
SLCPs – short-lived climate pollutants
SLoCAT – Partnership on Sustainable Low Carbon Transport
SMS –short message service
SNS – sympathetic nervous system
SO_2 – sulphur dioxide
SOA – secondary organic aerosol
SPM – suspended particulate matter
SUV – sport utility vehicle
TA – type approval
TAP – type approval process
TBI – throttle body injection
TCI – Transport Corporation of India
TERI – The Energy and Resources Institute
Tg – teragram
TWC – three way catalyst
UCSD – University of California, San Diego
UFPs – ultrafine particles
UI – unit injector
ULSD – ultra low sulphur diesel
ULSF – ultra low sulphur fuel
UNECE – United Nations Economic Commission for Europe
USAID – United States Agency for International Development
USD – United States dollars
VG – variable geometry
VOCs – volatile organic compounds
VPP – virtual power plant
VVT – variable valve timing
WB – World Bank
WBCs – white blood cells
WRI – World Resources Institute
YLDs – years lived with disability
YLLs – years of life lost
µg – microgram
µm – micrometer

ICAMP Meeting Participants

A policy conclave took place February 4 and 5, 2014 in Delhi, India to consider the Action Options that should follow from the India California Air Pollution Mitigation Program (ICAMP). Present were representatives from the India Union and State Governments, representatives from the U.S. and California Governments, academia and non-profit organizations. A number of the Delhi participants attended the preparatory meeting in Oakland, California, U.S.A. October 21-23, 2013.

- Aggarwal A, Cummins India Ltd.
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