# India-California Air Pollution Mitigation Program (ICAMP)

**Initiative for Mitigating Air Pollution from the Transportation Sector**

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

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**Knowledge to Action Plan**
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**Released for Comments**





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

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

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# OVERVIEW

## *ICAMP GOALS*

*Protect the Air*

*Protect Public Health*

*Protect Food Supply*

*Protect Water Supply*

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

**Health:** Ambient particulate matter (PM) from all sources, including the transport sector, lead to about 3.2 million premature deaths every year. Asia is a high-risk region with 2.1 million premature deaths and disability-adjusted life-years of 52 million years

lost. In India, ambient air pollution caused an estimated 627,000 deaths in 2010. The corresponding estimate for the US is 103,000 deaths

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

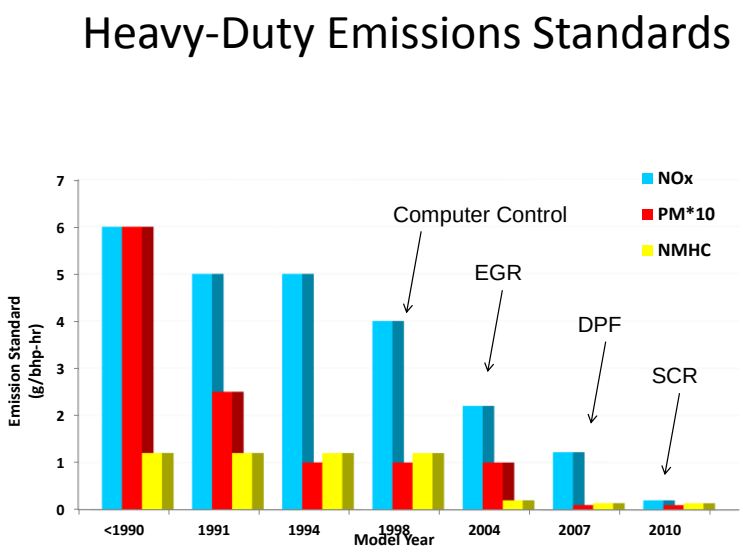
**Water:** Although not widely recognized, air pollution has significant effects on water directly and indirectly through climate change. PM (sulfates, nitrates, organics and dust) reduces sunlight (called as dimming) reaching the ground which reduces evaporation and hence precipitation. Some of the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

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

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

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

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

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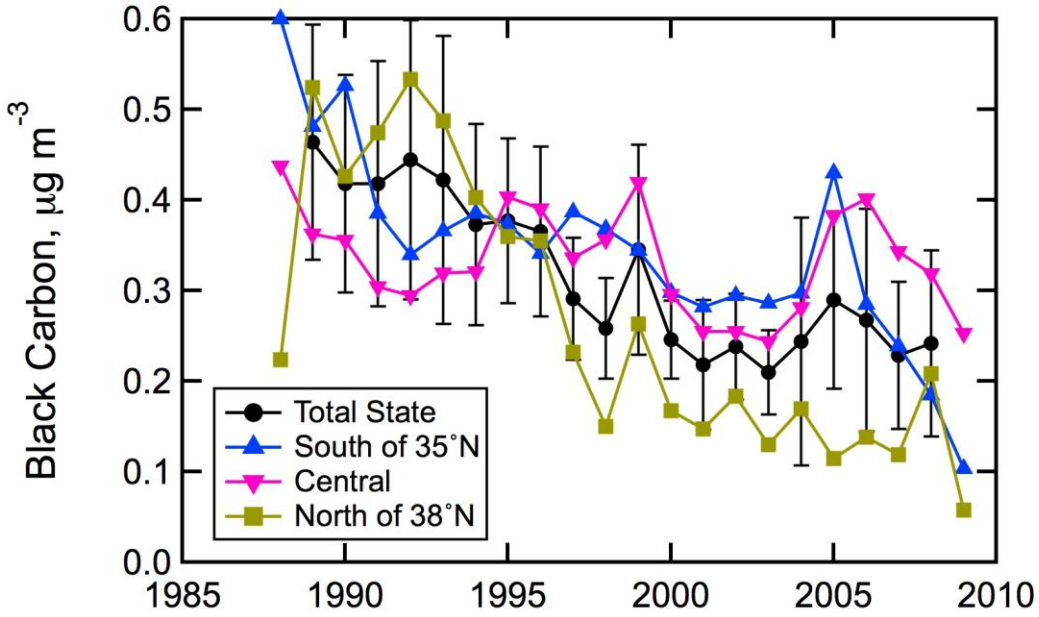
***HISTORY OF ENGINE AND FUEL IMPROVEMENTS IN CALIFORNIA AND IMPACTS ON EMISSIONS OF NOx, PM and volatile organics (NMHC). SOURCE: CROES (CARB, 2013).***

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



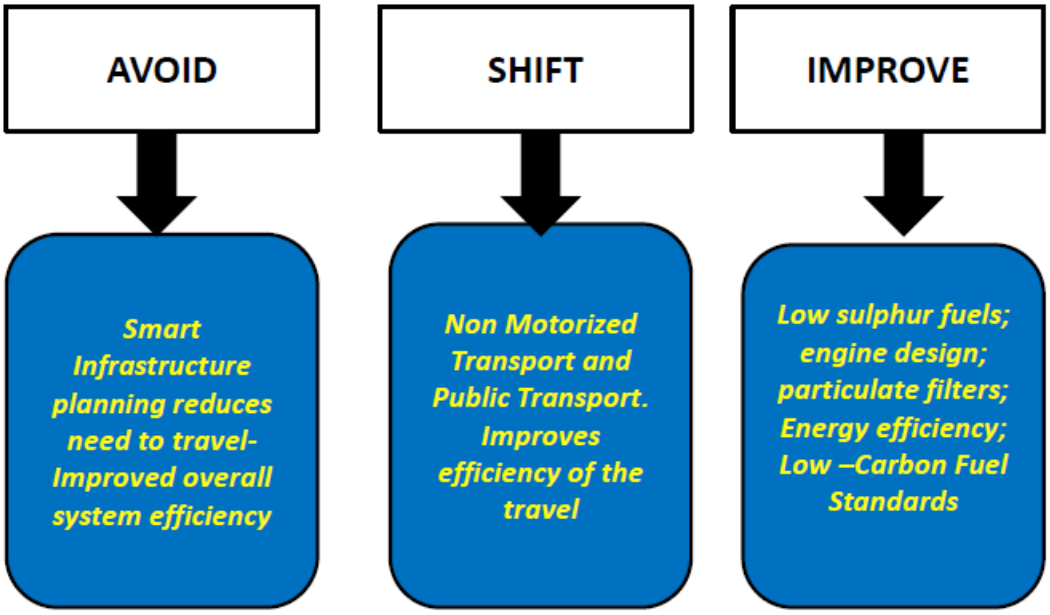

Trends in Black Carbon over south, central and northern California in response to emission reductions from diesel engines (on-road and off-road). Source: Ramanathan et al (2013; Report to CARB).

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

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

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

**The Avoid-Shift-Improve approach to Sustainable Transport Systems**




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

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

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

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

# Executive Summary

# Major Findings and Recommendations

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

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

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

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

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

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

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

- ***We strongly endorse India's National Urban Transport Policy approach of "Avoid (transport use), Shift (from high to lower-emission forms of transport), and Improve (transport technology to reduce emissions). The lessons for India from California are clearest on the means to "Improve," but Avoid and Shift are also part of India's aspirations since India has an important opportunity to build a transport system in which public and non-motorized transport become the first choice for mobility. India should break away from the motor vehicle based path that the developed countries took in their process of growth.***

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

- ***State governments in India have enormous potential as the locus for comprehensive, integrated air quality management, while building state leadership will require national funding to both motivate and enable action, State governments should also be encouraged to invest in effective in Avoid-Shift-Improve interventions to place transport systems in their cities on a sustainable path.***

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

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

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

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

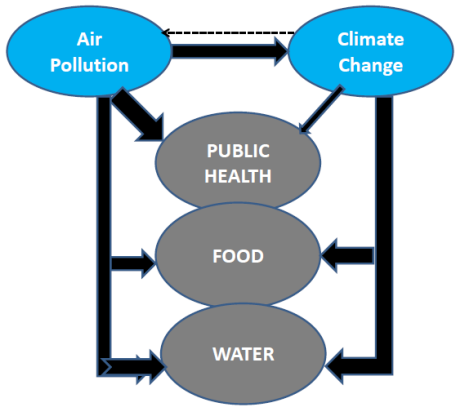
# I. Scientific Basis

## *Major Findings*

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

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

THE AIRPOLLUTION-HEALTH-CLIMATE CHANGE NEXUS



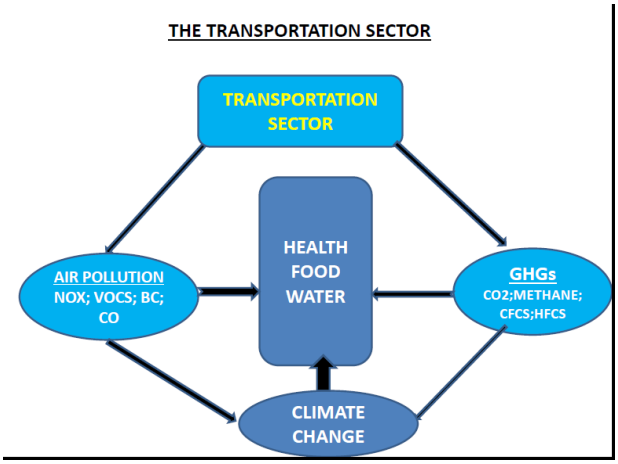

Our concern for these air pollutants is from the following impacts (see inset image):

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

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

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

THE TRANSPORTATION SECTOR



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

- High population densities, mobility demands, and expanding transportation sector have led to accumulation of high quantities of emission loads in cities. This also means that the huge population base is exposed to alarmingly high pollution levels- mainly particulate matter (PM)- presently in Indian cities.

- The main air pollutant of concern is PM2.5 for human health impacts and surface ozone for impacts on food production. 627,000 people die each year from ambient PM. Black Carbon in PM2.5 is emerging as a carcinogen.

- Nearly 40,000 premature deaths each year are caused by vehicle $PM_{2.5}$ emissions in India's cities alone.

- Surface ozone is the major pollutant with respect to crop damages. India produces around 150 million tons of rice (paddy) and 80 million tons of wheat annually, and plays a key role in global food security [FAO, 2013]. Nationally aggregated relative yield loss of wheat and rice due to high ozone exposure totals 5.5 million tons in 2005, which could have fed 94 million people in India. The loss is also about double the amount of wheat exported yearly and about 50% of the rice exported annually. It has been estimated India lost another 4 million tons of wheat due to climate change.

- Nationwide, the residential sector eclipses the contribution of other major sectors towards PM2.5 (particulate matter less than 2 micron) emissions. However, in cities, the transport sector is the major contributor to PM2.5. With respect to ozone, NOx is the major precursor gas and the transportations sector is the major source: 45% nationally and more than of 60% in cities.

- The emissions from transport sector are going to grow about three folds for PM2.5, and five folds for NOx. Black carbon emissions which are the subset of PM2.5 only can also be assumed to grow with similar rates. The dominant sources of PM within the transportation sector are diesel Trucks and Buses (52%) followed by 2-wheelers (25%). Black carbon is the significant part of the emissions form diesel vehicles, which is also the second largest global warming pollutant (next to CO2) and thus reducing diesel PM (black carbon) is a climate-friendly air pollution mitigation action.

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

## *2. Major Recommendations*

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

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

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

# II. Technology Measures

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

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

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

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

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

- For controlling emissions, there are several technology options available, requiring work in combustion research, fuel systems, air-handling systems, controls and after-treatment for providing the most appropriate emission control solution. What is important is to develop the right technology for each application and market served. Different operating conditions and economic factors can and do influence the technology path which is most appropriate

for each market. A second, but no less important part is to involve original equipment manufacturers as early as possible in the development and integration process. This is not a call for research, but rather for close collaboration.

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

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

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

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

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

# III. Governance

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

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

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

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

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

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

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

We also reiterate the following recommendations by the NTDPC report:

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

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

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

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