Reducing Black Carbon Emissions in South Asia

Low Cost Opportunities

Office of International and Tribal Affairs
U.S. Environmental Protection Agency

Cover photo credits: photo of child with traditional cookstove (Selvan Thandapani – Chennai, India); photos of traditional brick kiln and traffic (The Energy and Resources Institute, New Delhi, India)

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List of Acronyms and Abbreviations

AMC	Ahmedabad Municipal Corporation
C	Celsius
CNG	compressed natural gas
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
DALY	disability-adjusted life year
EPA	U.S. Environmental Protection Agency
ft	feet
g	gram
gal	gallon
GHG	greenhouse gas
IAP	indoor air pollution
I/M	inspection and maintenance
kg	kilogram
km	kilometer
L	liter
lb	pound
LCV	light commercial vehicle
LPG	liquefied petroleum gas
m	meter
MAV	multi-axle vehicle
mg/Nm^3	milligram per normal cubic meter
MJ	megajoule
mm	millimeter
mm WG	millimeter water gauge
MTOE	million tons of oil equivalent
MW	megawatts
μm	micrometer
NGO	nongovernmental organization
NO_x	nitrogen oxide
PCFV	Partnership for Clean Fuels and Vehicles
PCIA	Partnership for Clean Indoor Air
PM	particulate matter
SDS	South Distribution Services
SO_2	sulfur dioxide
SSP	Swayam Shikshan Prayog
TERI	The Energy and Resources Institute
Tg	teragram
UNEP	United Nations Environment Programme
USAID	U.S. Agency for International Development
WHO	World Health Organization

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Reducing Black Carbon Emissions in South Asia, *Low Cost Opportunities*

1. Introduction

Climate change is manifesting itself in varied ways, especially in the world's polar regions and major mountain glacier systems, the latter being critical sources of fresh water and livelihoods for millions, if not billions, of people. It is also becoming clear that climate change is being driven not only by long-lived greenhouse gases such as carbon dioxide (CO2) which are well mixed globally, but also by what are known as short-lived climate forcers or SLCFs (methane, tropospheric ozone, and black carbon), a suite of pollutants that reside in the atmosphere for an extremely short time by contrast, prominent among them being black carbon particles. Despite the short-lived nature of pollutants such as black carbon, they exert a significant influence on the climate system, especially on regional and local scales [1]. By some estimates black carbon might exert fully half or more (27-55%) of the warming attributable to CO2 [1], [2], [3], especially on regional scales.

Because pollutants such as black carbon are significant climate forcers and are at the same time short-lived, mitigating black carbon, as well as other SLCFs, in the near term can contribute to numerous sustainable development goals such as cleaner and healthier air, food and water security, reduced mortality and the mitigation of climate change and its impacts especially in highly sensitive regions such as South Asia[4]. As noted in a 2011 study, *Near-Term Climate Protection and Clean Air Benefits: Actions for Controlling Short-Lived Climate Forcers*, the current state of scientific knowledge is sufficiently robust to justify action on black carbon pollution as well as other SLCFs at national and regional scales [5]. And because there is high confidence that such reductions will bring about significant and immediate health and climate benefits, any measures taken to reduce black carbon and other SLCFs can be viewed with confidence as a 'no-regrets' policy.

Early and sustained action on SLCFs inclusive of black carbon is likely to slow the increase in near-term global warming expected by 2040, by up to 0.4 to 0.5 degrees Celsius. At the same time, by 2030, such actions can prevent an estimated 2.4 million premature deaths annually by reducing black carbon and tropospheric ozone in particular, and improve air quality and health in addition [5]. In its 2012 report, *OECD Environmental Outlook to 2050: The Consequences of Inaction*, OECD notes air pollution is poised to become the world's foremost environmental cause of premature deaths, and Asia is anticipated to be especially hard hit [6].

This report focuses on black carbon and is intended to help achieve near-term climate and other benefits by providing information and examples of a variety of low-cost, high-impact and high feasibility opportunities to reduce black carbon emissions in South Asia. This region is especially vulnerable to the multiplicity of impacts attributable to black carbon.

The Case for Reducing Black Carbon Emissions

Black carbon is an aerosol particle emitted as a by-product of the incomplete combustion of fossil fuels or biomass. Black carbon absorbs solar radiation and releases the energy as heat, which contributes to a strong regional and global atmospheric warming and accelerates the melting of ice and snow not only from atmospheric heating but also from the heat absorbed by black carbon soot deposited on ice and snow surfaces.   And while the indirect effects of the interaction of black carbon and clouds on climate and local weather patterns remains largely unresolved, the direct effects of BC are best quantified and appear to result in significant climate warming globally and regionally, provoking a broad swath of additional impacts as well [7].

There is a growing consensus [3] that black carbon emissions are of concern because of their impacts on climate, health, water and food resources, seasonal weather patterns, and livelihoods. For example, in a recent report, UNEP identified reducing black carbon, as well as other short-lived pollutants, as a real opportunity to slow the rate of near-term climate change, improve public health, and reduce crop-yield losses, with near immediate results, especially in areas of the world such as South Asia where concentrations of black carbon are extremely high. About half of the 0.4°C climate benefit resulting from reductions in SLCFs in 2050 comes from implementing the black carbon reduction measures, mainly in Asia and Africa [5].

Black Carbon in South Asia

Owing to its high concentration of black carbon, its densely populated cities, and its proximity to one of the largest imperiled sources of fresh water in the world, the Himalayan glacier system, South Asia is considered to be especially vulnerable to the impacts of black carbon from the standpoint of climate, health, security, and livelihoods.

Reducing atmospheric concentrations of black carbon in South Asia can result in improved public health and a slowing of the rate of near-term climate change. The health benefits from implementing black carbon mitigation measures would be realized immediately.   Because of the very high particulate matter burden in Asia in general, reductions in black carbon could prevent a greater number of premature deaths in this region than anywhere else.   Regions taking action on black carbon would also benefit significantly from reduced regional warming and reduced disruption of regional weather patterns such as the monsoonal system in South Asia. Such measures would also reduce the volume of black carbon particles being deposited on snow and ice surfaces in the Himalayas, and elsewhere, as black carbon is suspected of contributing to the acceleration of the melting of some mountain glaciers and snowpack in

South Asia. Furthermore, unlike greenhouse gases that remain in the atmosphere for centuries or longer, local and regional reductions in black carbon can bring about significant tangible near-term benefits locally and regionally [5].

Several existing studies explore highly technical and resource-intensive solutions to reducing black carbon emissions (e.g., [8]). This report seeks to fill an important gap in highlighting low-cost yet effective and accessible opportunities and actions for reducing black carbon emissions by illustrating ways policymakers, communities, and nongovernmental organizations (NGOs) can readily engage in South Asia. These mitigation efforts have implications not just for global and regional climate, but also for regional and local health, economic development, trans-boundary air pollution, and related issues. Figure 1 presents a map of the countries in South Asia.

In South Asia, black carbon emissions warrant concern for a variety of reasons:

- *Rising black carbon emissions pose a serious threat to water supplies from Himalayan glaciers and snowmelt*. Black carbon emissions affect water supply in South Asia by contributing to the melting of glaciers and snowpack. When black carbon lands on snow and ice it reduces the reflectivity (albedo); this causes the snow and ice to absorb additional heat from sunlight. Additionally, black carbon contributes to general regional warming, which accelerates snow and ice melting. In South Asia, both of these properties alter seasonal water supply patterns in areas that rely on snow or ice melt from the Himalayas [9, 10, 11].
- *Black carbon emissions alter the monsoon season and harm agriculture*. Black carbon emissions alter rainfall patterns and the annual Asian monsoon by changing atmospheric conditions such as temperature and cloud formation [1]. By altering the hydrologic cycle (including snowmelt and rainfall), black carbon contributes to agricultural stress and failure. Black carbon emissions also affect agricultural production by reducing the amount of sunlight that reaches the Earth's surface, which shields the surface and limits photosynthesis.

Figure 1. Regional map of South Asia.

- *Black carbon emissions contribute to indoor and outdoor air pollution.* Black carbon is a primary component of particulate matter (PM),[1] which can have severe health effects on exposed populations. For instance, exposure to indoor air pollution (IAP) including PM from household solid fuel combustion (e.g., residential cooking) accounts for at least 570,000 deaths annually in India [12]. In addition, across all of Asia, outdoor air pollution is estimated to cause nearly 490,000 deaths per year [14]. These adverse health effects also lead to reductions in worker productivity in South Asia, which can hinder economic development.

The magnitude of black carbon emissions in a region depends on local practices and choice of fuels and technologies used. Although estimates vary, developing nations in the tropics and Asia are generally recognized as dominant source regions of black carbon emissions [13]. All of Asia, including China and India, accounts for approximately 40% of global black carbon emissions [15].

Black carbon emissions in South Asia are primarily derived from four sectors: residential, industrial, transportation, and open biomass burning. The residential sector represents the largest single source of black carbon emissions in South Asia. The transportation and industrial sectors are also significant contributors. Figure 2 displays the sectoral breakdown of black carbon emissions in India, the largest emitter of black carbon in the region. Note that, as shown in Figure 2, brick kilns represent two-thirds of industrial sector emissions and heavy duty trucks represent a little more than half of the transportation sector emissions in India. Appendix A provides additional information on black carbon emissions sources in South Asia.

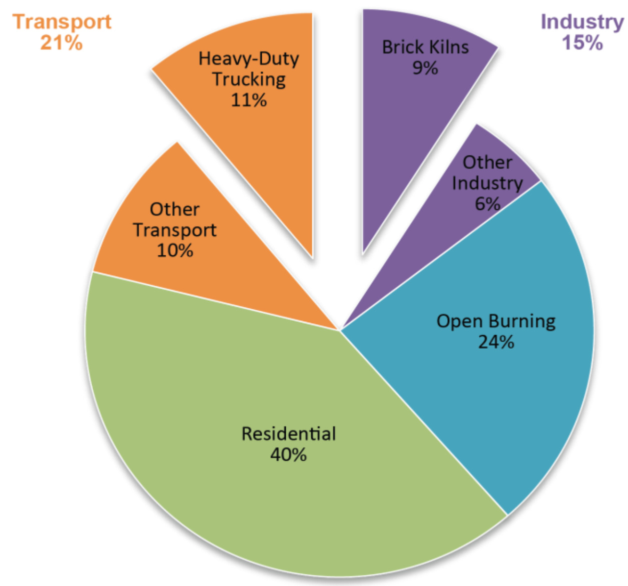

Figure 2. Sectoral black carbon emissions in India.
Sources: [16, 17, 18].

Mitigating Black Carbon in South Asia

Recognizing the acuteness and scale of the black carbon problem in South Asia, as well as the global ramifications if left unaddressed, the U.S. Environmental Protection Agency (EPA) embarked on an

1. Coarse particles that have diameters of less than 10 µm (called PM_{10}) are small enough to be inhaled through the nose and mouth and enter the lungs. However, finer particulates that have diameters of less than 2.5 µm (called $PM_{2.5}$) are harder for the body to protect against and clear once inhaled. Studies have linked PM to respiratory irritation (e.g., coughing), aggravated asthma and bronchitis, irregular heartbeat, nonfatal heart attacks, and premature death in people with heart or lung disease, among other effects [103].

effort to identify and evaluate unique low-cost but high-impact opportunities to reduce black carbon emissions in South Asia. As part of this effort EPA partnered with UNEP to conduct a consultation with regional stakeholders.[2] The consultation held in March 2011 drew together regional government representatives, practitioners, regional NGOs, and international experts to discuss current initiatives and opportunities to reduce regional black carbon emissions in the industrial, transportation, and residential sectors (see Appendix F for list of attendees).

EPA and UNEP recognize that reducing black carbon emissions in South Asia carries the unique potential to achieve global and regional climate benefits while also capitalizing on a number of regional and local co-benefits across South Asia. Appendix B discusses the climate impacts of black carbon and the co-benefits from reducing emissions in South Asia. This report identifies and brings to light a suite of opportunities to reduce black carbon emissions in South Asia within and across sectors. The goal is to assist policymakers, governments, NGOs, and others to take immediate and effective action in South Asia to reduce black carbon emissions. The mitigation options identified here focus on emissions in the industrial, transportation, and residential sectors, three of the four primary sectors that contribute to most of the region's black carbon emissions. The fourth sector, open biomass burning, largely lies outside EPA's technical expertise and mission focus and is therefore not addressed in this report.

Through discussions with regional stakeholders and practitioners, and a review of literature on mitigation strategies in South Asia, EPA identified low-cost, high-impact, and readily accessible emissions reduction opportunities with the greatest potential in the following subsectors of the industrial, transportation, and residential black carbon emissions sectors:

- *Improving the efficiency of brick making.* Brick kilns in the industrial sector represent a largely untapped source of potential emissions reductions, with substantial opportunities for engagement with kiln owners and operators, who remain largely unaware of the financial co-benefits associated with improved firing efficiency.
- *Improving public and private fleet efficiency and management.* Heavy duty trucking represents more than 50% of the emissions from the transportation sector in India. One aspect of addressing emissions reductions from heavy duty trucking includes improving fleet efficiency and management. The United States has considerable expertise in this area, particularly with EPA's SmartWay Transport Partnership, and from experience with recent international community pilot and training programs.
- *Improving the efficiency of cookstoves.* Improving the efficiency of cookstoves in the residential sector is an active area of interest for many U.S. and international agencies,

2. A summary of the consultation is available at http://www.rrcap.unep.org/abc/userfiles/file/BC%20Workshop%20Summary_Final.pdf. The December 2011 UNEP Black Carbon e-Bulletin overviews the consultation (http://www.unep.org/dec/docs/BCBulletinDec11.pdf). A forthcoming issue of the bulletin will include additional information.

but much work remains to be done to communicate the benefits of improved cookstoves.

Table 1 summarizes the mitigation options described in this report for the industrial, transportation, and residential sectors. These options are targeted for agencies and organizations that want to take action in the near future in a meaningful but cost-effective manner. In many cases these activities can result in local economic development through a variety of factors, including reducing fuel expenditures, producing higher-quality and higher-value products, and decreasing worker sick days. Additionally, the activities described in this report build off existing technological and policy-based actions to reduce air pollution (including black carbon emissions) in South Asia; it is advantageous to leverage existing activities by building on them or developing complementary options rather than duplicating them. Finally, the behavior-based mitigation efforts stressed in this report can broaden the scope of co-benefits already achieved by changing public attitudes toward technological interventions and helping mitigation efforts realize their full potential.

Table 1. Black carbon mitigation options in South Asia

Opportunities	Mitigation options
Industrial: Improve the efficiency of brick making	◆ Adopt more efficient low-cost technologies for current combustion practices. (see page 16) ◆ Use cleaner fuels. (see page 18) ◆ Adopt better operating practices in coal firing. (see page 18) ◆ Use alternative building materials. (see page 18) ◆ Develop best practice trainings for kiln operators and firemen. (see page 19)
Transportation: Improve public and private fleet efficiency and management	◆ Demonstrate the benefits of vehicle inspection and maintenance (I&M). (see page 25) ◆ Train drivers and fleet managers on fuel-efficient eco-driving techniques (see page 27) ◆ Improve fleet logistics. (see page 28)
Residential: Improve the efficiency of cookstoves	◆ Increase use of improved cookstoves. (see page 37) ◆ Use alternative fuels. (see page 37)

How to Use this Document

This report is a resource for interested parties seeking information on low-cost and effective opportunities and actions for reducing black carbon emissions that they can readily engage in South Asia. The report and its appendices present a wealth of information and resources on reducing black carbon emissions in South Asia.

The remainder of this report includes four main sections. Sections 2, 3, and 4 describe specific low-cost, high-impact options and opportunities for reducing black carbon emissions in the industrial, transportation, and residential sectors, respectively. Each section begins with a brief overview of the industry and its black carbon emissions. The sections are then structured to present the reader with the co-benefits, including cost savings when possible, of acting to reduce black carbon emissions and then profile actions already occurring and opportunities to mitigate black carbon. Throughout these sections,text boxes highlight innovative projects that are designed to give organizations, including NGOs and governments, a better sense of what can be done at low cost and still result in a meaningful contribution to reducing black carbon emissions. While this document does not provide step-by-step project implementation instructions, it does identify areas ripe for action at a minimal up-front cost. Section 5 summarizes the report's findings and provides a brief conclusion. This is followed by a list of references, which include citations for sources in the main body of the report and the appendices. The appendices include:

- Appendix A – Black Carbon Emissions in South Asia
- Appendix B – Climate Impacts of Black Carbon and Co-benefits of Reducing Black Carbon Emissions in South Asia
- Appendix C – Brick Making in South Asia
- Appendix D – Black Carbon Emissions from On-Road Fleets in South Asia and Current Initiatives to Reduce Emissions
- Appendix E – Improved Cookstove Production Models in South Asia
- Appendix F – List of participants from the Kathmandu Consultation.

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- Use cleaner fuels, page 18
- Use alternative building materials, page 18
- Adopt improved operating practices, page 18
- Train kiln owners and workers, page 19

2. Black Carbon Mitigation in the Industrial Sector

The industrial sector is one of the largest contributors to black carbon emissions in South Asia, accounting for approximately 23% of all black carbon emissions in Asia [8]. In India, the industrial sector accounts for approximately 15% of all black carbon emissions, with approximately two-thirds of those emissions, or 9%, attributable to brick kilns [18]. The most commonly used kiln in South Asia is the Bull's trench kiln (see Figure 3), which uses very simple technologies that are inefficient and highly polluting. Nevertheless, this kiln is commonly used because of its high profit margins combined with low initial investment requirements. To date, the brick industry has been an overlooked sector for black carbon mitigation, leaving room for significant action.

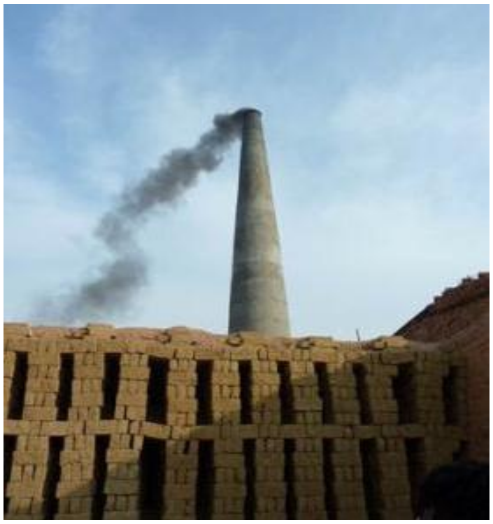

Figure 3. Smoke emissions from a Bull's trench

The brick industry in South Asian countries provides a very important livelihood for large numbers of the rural poor during the dry summer months, when crop production yields little income. In India, between eight and ten million people work in brick kilns, and in Bangladesh brick kilns employ an estimated one million people. The rural poor migrate to work at brick kilns as firemen who control the brick-firing process or clay molders who form the bricks before they are fired (Figure 4 shows laborers fueling a brick kiln). Migrant workers use traditional skills and are typically unaware of improved or new technologies that could increase their skills or improve operational efficiency. Kiln owners usually remain detached from day-to-day kiln operations. They rent land, hire migrant workers through agents, set up kilns, and leave management to local supervisors who carry out little of the actual work themselves. Moreover, brick kiln owners remain largely unaware of new brick-making technologies and operating practices. As a result, brick kilns remain inefficient and are a significant contributor to black carbon emissions.

Figure 4. Workers fueling a brick kiln in India.

An effective and cost-effective means of reducing black carbon emissions from brick kilns is to improve operating practices and increase combustion efficiency by working with both kiln owners and workers – particularly the firemen who control the brick-firing process [19]. Owners are much more likely to adopt better operating practices or make technical modifications to existing kilns when they can see the potential fuel and cost savings that can be achieved by improving combustion efficiency. Firemen, other kiln workers, and local residents would also benefit from improved air quality. Trade associations such as the Federation of Nepal Brick Industries and the All India Brick and Tile Manufacturers Federation can serve as a means to disseminate information to brick-kiln owners and workers on how to improve the efficiency of kiln operations cost-effectively.

The following sections outline the co-benefits of more efficient brick making, identify options to mitigate black carbon emissions, and highlight several examples of innovative South Asian programs already transforming the brick-making industry. While a number of individual projects are aimed at reducing black carbon emissions in the region, there does not appear to be any large-scale coordinated initiatives to reduce brick-kiln emissions across the industrial sector. In this way, brick making in the industrial sector stands in contrast with fleets in the transportation sector and cookstoves in the residential sectors.

Appendix C provides additional information on brick-making practices, kiln technologies, and regulations in key South Asian countries.

A. Benefits of Reducing Black Carbon Emissions from the Brick Industry

Efforts to reduce black carbon emissions from brick kilns to achieve climate benefits can simultaneously result in energy savings and, therefore, cost savings and health co-benefits. The following sections provide information on these benefits.

Energy Savings

Adoption of more efficient operating practices and technologies can result in significant energy and cost savings in the brick-making industry. For example[3]:

- Adopting best operating practices in Bull's trench kilns could result in energy savings of about 1 MTOE per year in India. This is the equivalent of roughly 311 million gal (1.1 billion L) of crude oil – enough crude oil to produce more than 143 million gal (541 million L) of gasoline [20].
- Switching from conventional solid bricks to resource-efficient products such as perforated bricks and hollow bricks could result in energy savings of about 0.6 MTOE per year across India, assuming 30% of Bull's trench kilns in India adopt this technology shift.

3. These estimates are based on the production/fuel consumption figures from a study undertaken by The Energy and Resources Institute (TERI) in 2000, the most recent study on the Indian brick industry. The actual energy savings would therefore be substantially higher than these estimated figures due to growth in the brick-making industry.

- Replacing 10% of solid bricks in India with fly ash bricks could save about 0.3 MTOE per year across the country.

In addition, resource-efficient products such as perforated and hollow bricks have better thermal insulation properties than solid bricks, and so could help reduce heating and cooling loads for buildings, which helps lower energy costs for property owners as well.

Climate Benefits

The economic growth in Asian countries such as India has led to an increase in urban population. This increase has created demand for improved infrastructure, which increases demand for building materials, especially bricks. Brick production has negative climate impacts due to CO_2 and black carbon emissions. One study has shown that emissions from brick making in Asia could be reduced by switching to more efficient kilns, such as the vertical shaft brick kiln, and additional reductions could be achieved by switching to hollow-brick production [21].

Health Benefits

The traditional brick-making technologies that are typically used in South Asian countries are highly polluting. Incorporating pollution control systems such as gravity settling chambers has helped reduce emissions from Bull's trench kilns in India. However, poor operating practices are the norm and continue to result in unhealthy levels of air pollution, especially at kilns where pollution control systems have not been installed. Brick-kiln emissions affect both kiln workers and people residing and working near kilns.

Although there have been few comprehensive studies to assess the impact of emissions from brick kilns on health in general, several studies have evaluated the local health impacts of emissions from specific brick-making industrial areas. For example, one study surveyed the health of residents living in proximity to a brick-making industrial area in the Kathmandu Valley in Nepal and found that 95% of residents in the surveyed area had experienced some type of respiratory disease within the past year, compared with only 51% of the control population [22]. The results of this study are statistically significant and suggest a clear correlation between residents' proximity to brick kilns and adverse impacts on respiratory systems. Improved practices could reduce emissions and resulting health impacts.

B. Opportunities for Reducing Black Carbon Emissions from Brick Kilns

Black carbon emissions from brick making are influenced by a number of factors, including the technology used, the fuel source, and how the brick kiln is operated and maintained.

While mitigation options that attempt to reduce black carbon emissions by introducing new or modified technologies or fuels are typically more costly than traditional kilns or fuels, there are a growing number of illustrative examples of modest up-front investments that pay off quickly. These methods are listed in the text box on this page and described below.

Implementing these emissions reduction methods sometimes requires a change in behavior (e.g., how a kiln is operated or maintained). For example, the market currently demands solid red bricks that produce a good "ring" sound when two bricks are hit together. This ring is considered an important indicator of product quality, and bricks that produce this ring are typically produced by traditional Bull's trench kilns. To encourage the move from Bull's trench kilns to more efficient technologies, it might be necessary to change the perception that the ring sound is a necessary or reliable indicator of quality. Creating communications materials and conducting outreach activities that highlight efficiency and financial gains from new technologies can be an effective means of reducing black carbon emissions from brick kilns. Communications should emphasize that bricks created using alternative technologies, practices, fuels, or design will still result in cost-effective and sturdy building materials. Training sessions and communications and outreach campaigns can focus on best operating practices and associated financial benefits. Such an approach could help overcome behavioral barriers to improving brick-kiln efficiency, such as lack of awareness among kiln owners, workers, and product purchasers regarding alternative technologies and fuels, best operating practices, or improved brick design [23].

Producing Resource-Efficient Bricks

The Bharat Brick Co. started producing and marketing perforated bricks on a small scale in 2005. In 2009, Bharat replaced its fixed chimney kiln with a more energy-efficient, high-draft kiln. With technical support and input from experts, the clay brick molding process was improved through using equipment such as double shaft mixers and conveyor belts. The owner received the National Gold Star Award from the Indian Society for Industry & Intellectual Development for outstanding performance in innovation in the clay processing industry. Based on this success, Bharat is looking to make further upgrades to produce resource-efficient bricks, including hollow blocks, on a large scale.

Source: [24].

The following sections describe several low-cost, high-impact mitigation options to reduce black carbon emissions from brick making in South Asia. Each section includes information on existing activities or initiatives that focus on changing kiln management and operations behavior through knowledge sharing and capacity building.

Adopt More Efficient Technologies

Switching from inefficient to more efficient kilns can reduce emissions and, correspondingly, reduce fuel consumption (see the examples in the text boxes on pages 15 and 17). Reduced fuel costs can increase profits based on the initial level of investment and/or access to appropriate financing. Available cost-effective and efficient technologies include Hoffmann kilns, zig-zag firing kilns, tunnel kilns, and vertical shaft brick kilns (see Appendix C for more information on these technologies). These technologies are profitable, energy efficient, environment friendly, and produce a higher percentage of high-quality bricks (see Figures 5 and 6). For example, it is estimated that vertical shaft brick kilns can reduce emissions by as much as 80% relative to

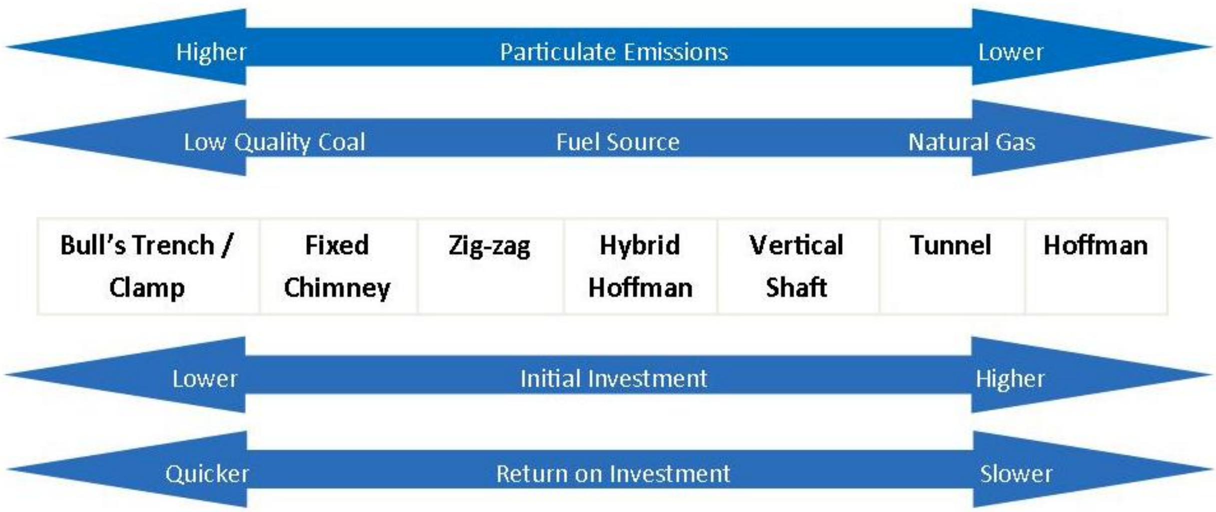

Figure 5. Relative particulate emissions, fuel sources, and investment requirements for various brick kiln technologies assuming good operating practices.* Sources: Compiled from the presentations of Ijaz Hossain and Sameer Maithel [26, 27].

*In most cases, but not all, lower particulate emissions equate to lower black carbon emissions.

traditional combustion technologies [25].

Figure 6. Relative fuel efficiencies for various brick kiln technologies assuming good operating practices.* Source: Compiled from the presentation of D.J. Reeve [28].

*In most cases, but not all, increased kiln efficiency equates to lower black carbon emissions.

Conversion from Bull's Trench Kiln to Natural Draft Zig-zag Firing

Prayag Clay Products of Varanasi, India, switched to a zig-zag kiln, allowing them to more efficiently produce bricks, lower black carbon emissions, and increase profits.

Traditional Bull's trench kilns are used throughout South Asia. These kilns require firemen to feed coal into the kiln at intervals of 10 to 20 minutes, which leads to variations in the internal kiln temperature, inefficient combustion, and high black carbon emissions.

Prayag Clay Products of Varanasi, India, converted from a highly polluting Bull's trench kiln to an efficient zig-zag kiln 10 years ago. The design increases air flow rates and decreases inefficient combustion. Additionally, continuous feeding of fuel ensures consistent internal kiln temperature, more efficient combustion, and lower black carbon emissions.

Several operations practices help ensure that the Prayag kiln is as efficient as possible. These practices include properly stacking the green, unfired, bricks in the kiln; monitoring the kiln firing temperature; and installing a shunt system with a flue gas temperature meter. These practices, along with the kiln design, allow fuel to burn efficiently at a consistent temperature, resulting in more high-quality bricks and less pollution on the ground and in the air.

These reductions in pollution resulted in marked reductions in CO_2 emissions. For example, the CO_2 emissions from the new zig-zag kiln are on average 50% lower than CO_2 emissions from the old Bull's trench kiln.

Greentech Knowledge Solutions, a partner of Prayag Clay Products, estimates that the initial investment to transition from a Bulls trench kiln to a zig-zag kiln was between $10,000 and $15,000. However, switching to a zig-zag kiln increased annual revenue by $20,000 to $30,000. This investment quickly paid for itself in less than one year through lower fuel costs and the ability to produce a higher quality and more valuable product.

Source: [29]. Photos courtesy of O.P. Badlani, Prayag Clay Products.

Use Cleaner Fuels

Using alternate fuels can reduce or eliminate the use of firewood and low-quality coal in brick kilns, fuels that typically lead to substantial black carbon emissions (see Figure 5). Alternative options include natural gas and higher-quality coal. Since natural gas is only available through utility lines, only brick kilns located close to the utility grid, such as several in Bangladesh, can fire their kilns with natural gas. Using higher-quality coal (although more costly than its dirtier low-quality alternative) combined with the adoption of better operating practices will also reduce black carbon emissions and can potentially reduce overall operating costs.

Use Alternative Building Materials

The demand for bricks as a building material is growing due to increasing commercial and housing needs, despite concerns about the availability of resources such as clay and coal, and pressure for the brick industry to reduce pollution. Construction practices in urban areas have also changed over time.

For example, in multi-story buildings the load is now carried by cement columns rather than bricks, and bricks are mainly used as filler material. These changing practices are paving the way for the introduction of alternative resource-efficient products, such as hollow blocks, perforated bricks, and fly ash bricks. Producing and successfully marketing these alternative building products would help reduce the consumption of highly polluting fuel, improve health, and reduce climate impacts. Using these materials would also affect the cooling loads and energy costs of businesses and residents during the summer because they have better insulating properties than traditional bricks. Also, production of hollow and perforated bricks requires that production methods be changed from hand molding to mechanical molding by machines. This will result in a more consistent production of uniform bricks that could command a higher price in the market.

Adopt Improved Operating Practices

Coal is the primary fuel used to make bricks in South Asian countries. A number of better operating practices can be incorporated in coal firing to help control and reduce emissions while conserving fuel (see the example in the text box). Improved operating practices for coal-fired kilns (e.g., the Bull's trench or fixed-chimney kilns in

Results from Implementing Best Operating Practices at Prayag Clay Products

Best practices

- Long firing zone with continuous coal feeding
- Small coal spoon size (200–400 g/spoon versus 1,000–2,000 g/spoon)
- Smaller coal size (0–5 mm versus 0–25 mm)
- High air velocities
- Zigzag firing versus Bull's trench
- Firing temperature measurement
- Flue gas temperature monitoring

Results

- Lower emissions of PM and CO_2
- Coal consumption reduced 15%–25%
- Energy consumption 0.95–1.0 MJ per kg of fired bricks versus 1.2–1.3 MJ per kg
- 85% of the highest quality bricks versus 50%–60%

Source: [29].

India and Nepal and the similar Bull's trench kiln in Bangladesh) aim to increase brick-firing efficiency by maintaining a consistent kiln temperature. A varying kiln temperature causes fuel to burn inefficiently, resulting in additional black carbon emissions. In general, best practices include:

- Using the proper coal size
- Using a good-quality coal with higher energy content
- Using a smaller-capacity spoon for feeding coal
- Charging small quantities of fuel more frequently
- Ensuring a sufficient steady air supply in the combustion zone
- Properly operating side flues to maintain a constant draft
- Using insulated feedhole covers
- Using a wider coal-feeding zone
- Using a minimum temperature of 700°C to start coal feeding.

In addition, kilns that have a higher operating draft (e.g., higher stack heights; less cool air infiltration after the combustion zone; low frictional resistance in the kiln, ducts, and chimney) and use high-quality coal will have lower black carbon concentrations in their emissions.

Conduct Training to Institute Best Practices

Brick firing in kilns is usually performed by untrained firemen who are typically not well versed in the most efficient operating practices. Consequently, there is an enormous opportunity to improve brick-making efficiency by training firemen across South Asia. Training would help firemen implement best operating practices in brick kilns and could help realize energy savings of about 5% [30]. A number of pilot training projects have begun in South Asia, such as at the green vertical shaft brick kiln project in Bangladesh and a project currently being implemented by TERI in India [31]. Given the newness of this effort, few results are available at this time.

An effective training program for employing best practices would likely feature a train-the-trainer approach focused on master firemen, the most well-regarded and experienced firemen in the community, from whom other firemen seek advice and guidance. A trained and certified master fireman could ensure that the firemen under him employ best operating practices, thereby effectively spreading knowledge and expertise to a large number of firemen. The topics covered in this training should include the best operating practices outlined in the previous section. Such a training program would be organized in two phases:

- In the first phase, participatory classroom training sessions could be organized for the master firemen during the "off" season (August–December) when the brick kilns are closed due to monsoon and most of the firemen and master firemen return to their villages. Twenty master firemen could be trained in one class.
- In the second phase, on-site training sessions (with the same participants who attended classroom training sessions) would be organized at the kiln sites during the brick-making season (January–June). During this session, interactive discussions and activities would be carried out with the master firemen, firemen they supervise, and brick-kiln entrepreneurs. On-site sessions ensure the proper implementation of lessons learned in the first-phase classroom sessions, including a means of monitoring and evaluating the impact of the operational training. This on-site follow-up interaction would help fine-tune training programs. It is anticipated that each master fireman could train 10 firemen in his village or locale. Therefore, one training program would effectively reach about 200 firemen.

This two-phase training strategy is expected to maximize the opportunities for the trained master firemen to share their technical knowledge with the firemen – both in the villages and at the kiln sites. The outcome will be wider adoption of best operating practices at the kiln sites, leading to lower operating costs, increased profitability, improved energy efficiency, decreased emissions of black carbon, climate benefits, improved health conditions locally and regionally, and better working conditions for the firemen and other kiln workers. TERI estimates an initial cost of developing course material at $16,000 and $30,000 per training program for one class of 20 master firemen and 20 follow-up training sessions for 200 firemen. See Figure 7 for additional details on the TERI training strategy.

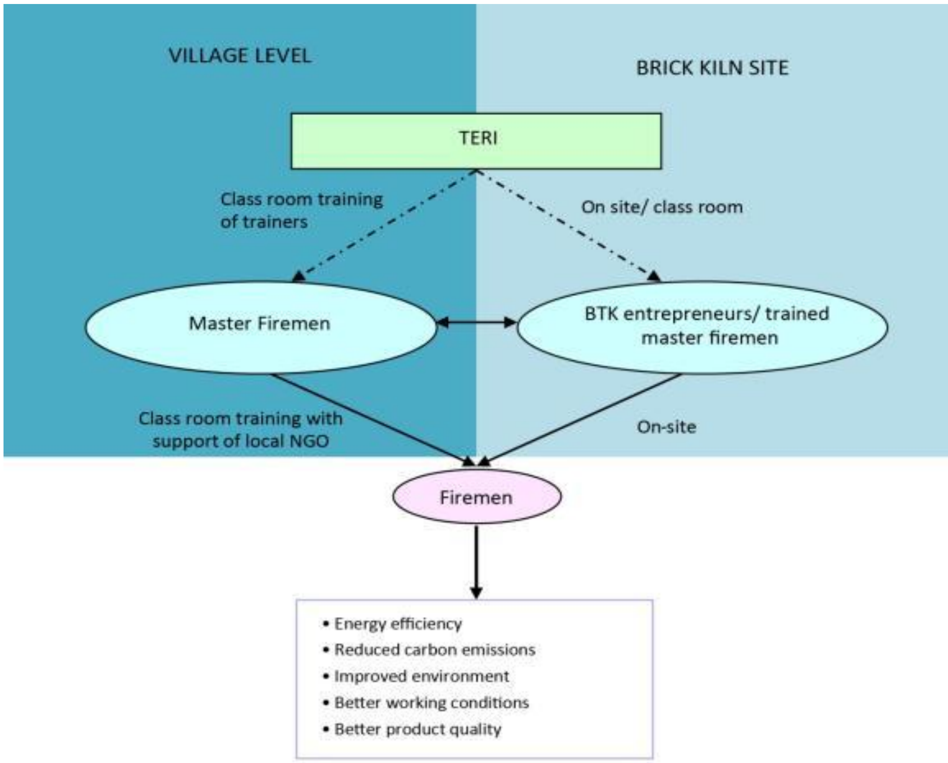

Figure 7. TERI firemen training program structure.

3. Black Carbon Mitigation in the Transportation Sector

Emissions from on-road vehicles (e.g., passenger cars, light duty vehicles, buses, and freight trucks) and off-road vehicles (e.g., boats or barges, planes, construction or agricultural equipment, and trains) contribute greatly to black carbon emissions in South Asia. Overall, the transportation sector is the third largest source of black carbon emissions in Asia and it is expected to become the second largest source by 2030 [8]. In India, the country that contributes the most to South Asian black carbon emissions, transportation accounts for approximately 21% of the country's total black carbon emissions and nearly 60% of black carbon emissions from fossil fuel combustion [16, 17, 18]. These emissions also contribute to considerable impacts on public health. For example, PM is especially prevalent in urban areas, which have high concentrations of both on- and off-road vehicles.

Black carbon emissions from the transportation sector are the result of inefficient combustion of fossil fuels including gasoline and diesel, and improper fleet management (e.g., failing to optimize the amount of cargo carried per trip). The inefficiencies that lead to these emissions also result in increased energy consumption and higher fuel costs. For this reason, improving the efficiency of fossil fuel combustion in the transportation sector can simultaneously save money, improve local air quality, and reduce black carbon emissions to the atmosphere.

Globally, there is a wealth of experience in the development and implementation of activities that improve both fuel efficiency and fleet management in the transportation sector. Traditionally, these activities have focused on reducing the impacts of the transportation sector on air quality and reducing fuel costs, rather than reducing black carbon emissions. This section draws on lessons learned from these activities and explains how they can be effective at reducing black carbon emissions and achieving substantial economic and public health co-benefits.

This section focuses on reducing black carbon emissions from private and public sector fleets (e.g., on-road freight and other goods-carrying vehicles). One reason for concentrating on fleets is that the trucks that make up these fleets have higher emissions factors than nearly all other vehicle types (with the exception of buses) [32]. Overall, heavy-duty trucking (which includes fleet vehicles) accounts for approximately 11% of all black carbon emissions and more than half of all black carbon emissions from the transportation sector in India [16, 17, 18]. In addition, several organizations are implementing successful programs that have reduced black carbon emissions from fleets while achieving sizeable co-benefits, primarily increased fuel savings. Nevertheless, fleets remain a largely untapped, yet achievable front for further action and exploration.

Additional information on black carbon emissions from the transportation sector in South Asia is provided in Appendix D.

A. Benefits of Reducing Black Carbon Emissions from On-Road Fleets

As noted above, activities that reduce black carbon emissions from fleets by both improving fuel efficiency and fleet management can generate substantial co-benefits, primarily reduced public health impacts and mitigated climate impacts. This section describes these co-benefits in greater detail. Additionally, a primary motivation to improve fleet efficiency and management are the often substantial fuel savings realized and thus also cost savings for fleet operators.

Increased Fuel Savings

Fuel economy and fleet management measures can reduce black carbon emissions by reducing the amount of fuel burned thus also decreasing the operational costs to fleets. Many simple behavioral changes can help increase fuel savings. For example, educating drivers about the importance of accelerating gently and maintaining constant speeds can help reduce fuel consumption by more than one-third. Simply tightening gas caps can save as much as 30 gal (114 L) of fuel over the course of one year [33]. Using low-rolling resistance tires on heavy-duty trucks can help reduce PM_{10} emissions and fuel consumption by more than 2,000 L per year per truck [34]. Overall, training programs that address these behavioral changes can improve fuel economy by between 5% and 20% [35, 36]. In addition, improved fleet logistics can reduce fuel use by as much as 7% [37].

Figure 8 illustrates the fuel savings that can be achieved by using various strategies to improve the efficiency of fleet trucks. The figure also illustrates how these strategies can both reduce fuel costs and reduce PM emissions, which include black carbon.

Climate Benefits

Reducing black carbon emissions from the transportation sector in South Asia leads to considerable environmental, health, and economic development benefits. The environmental benefits are generally twofold: black carbon emissions reduction activities reduce emissions of CO_2 (a long-lived climate forcer) and PM (which consists largely of black carbon, a short-lived climate forcer). According to one estimate, trucks and non-passenger light vehicles (i.e., those used for transporting goods) produce 47% of all CO_2 emissions from road transport in India [32]. It is estimated that by 2035, heavy-duty vehicles in Asia will produce more than 2,500 million tons of CO_2 emissions per year, far more than any other type of on-road transportation despite there being relatively fewer heavy-duty vehicles in Asia than other vehicle types [38].

The climate benefits that could be achieved through driver and fleet manager training and outreach are difficult to estimate. However, the SmartWay program suggests that reducing an average U.S. truck's fuel consumption by 5% can lead to an estimated annual reduction in CO_2 emissions of eight tons. Table 2 presents an example of the combined fuel savings and climate benefits associated with installing technology upgrades on all trucks registered in Guandong Province [more information on this project and its predecessor (the Guangzhou Project) is provided in a text box on page 26].

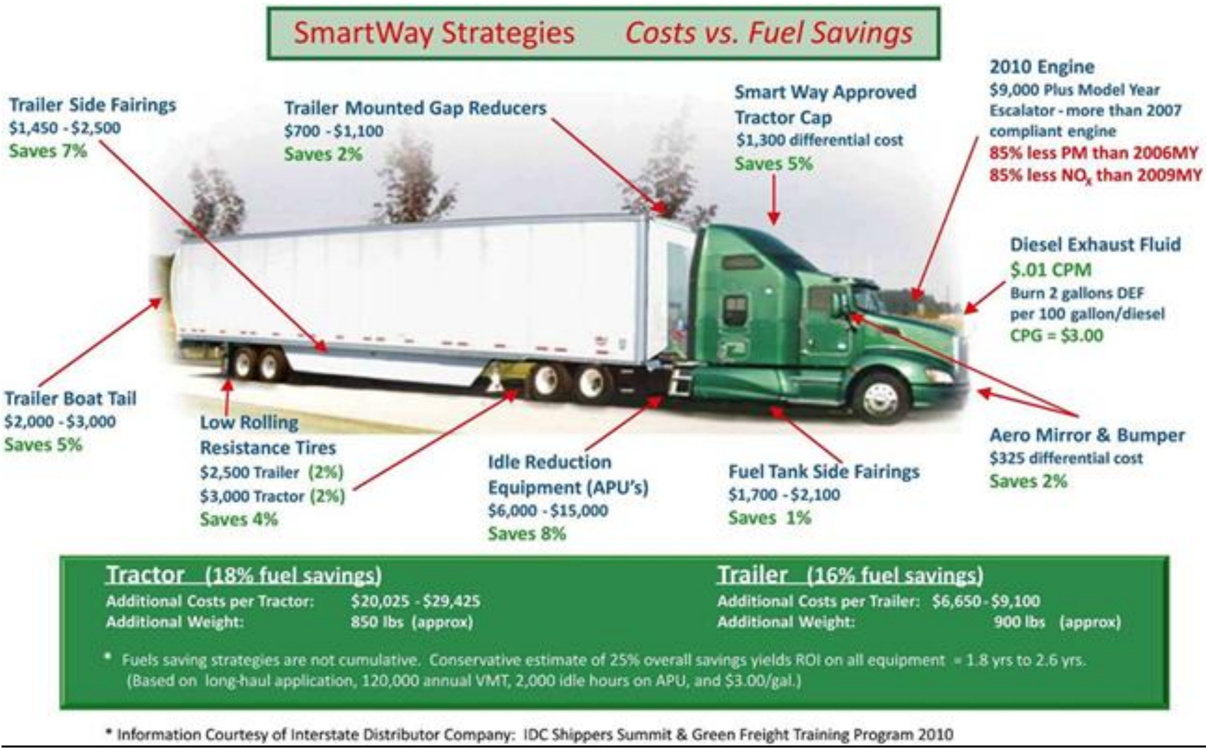

Figure 8. Strategies for saving costs while improving fleet truck fuel efficiency and reducing PM emissions (based on the experience of EPA's SmartWay Program). Source: [39].

Table 2. Benefits from installing technology upgrades on all trucks registered in Guangdong Province

Parameter	Total
Total number of trucks registered in Guangdong Province	1,230,000
Total investment costs (tires and aerodynamics)	$12 billion
Total fuel savings (liters per year)	3.96 billion L/year
Total fuel cost savings	$3.6 billion/year
Total CO_2 savings	10 million tons/year
Total nitrogen oxide (NO_x) savings	37,000 tons/year
Total PM savings	1,584 tons/year
Payback period in years	3.38
Sources: [34, 40].	

Health Benefits

Air pollution in Asia is estimated to contribute to 530,000 premature deaths per year [41]. PM is generally recognized as the air pollutant of greatest concern in Asia [42]. Reducing emissions of PM_{10} could help reduce urban air pollution-related mortality by as much as 15% worldwide [41].

Figure 9 shows the relative contribution of on-road transport to overall emissions of $PM_{2.5}$ in 16 Asian cities.

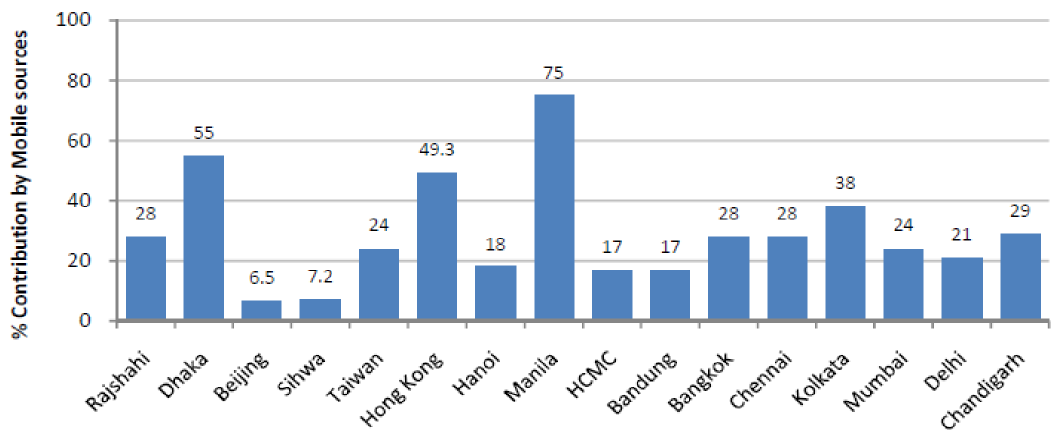

Figure 9. Relative contribution of vehicles to $PM_{2.5}$ in selected Asian cities. Source: [38], adapted from [43].

In addition to reducing impacts on human health by reducing pollutant emissions, emissions reduction programs can help improve the overall safety of roadways in Asia. For example, I/M programs can help reduce the risk of breakdowns and assist with logistical planning to minimize the occurrence of overloading, which has been identified as contributing to road accidents [38]. According to one estimate by the Asian Development Bank, approximately 44% of the world's road deaths occur in Asia and the Pacific, despite the fact that the region only has 16% of the world's vehicles [44].

B. Opportunities for Reducing Black Carbon Emissions from On-Road Fleets

In this section

- Improve I/M practices, page 25
- Implement fuel-efficient eco-driving, page 27
- Improve fleet logistics, page 28

Particulate emissions, including black carbon, from fleets are influenced by the following factors [32]:

- Type of vehicle
- Type of fuel
- Type of combustion engine
- Emissions mitigation technologies
- Maintenance and operation
- Vehicle age.

To reduce emissions from fleets, activities can target one or several of these factors. Traditional, long-term mitigation options include changes to the type of vehicle, fuel, combustion engine, or mitigation technology and might include regulation (e.g., PM emissions standards for new vehicles, engines that use diesel and gasoline). Introducing new emissions control technologies, such as retrofitting vehicles with diesel particulate filters, can reduce PM emissions including black carbon by as much as 95%, but this approach might also require regulation [45]. These efforts are underway in some South Asian areas. For example, in Delhi most commercial vehicles use compressed natural gas (CNG) rather than diesel fuel [32]. Another approach taken by countries is to increase fuel quality to allow the introduction of cleaner vehicle technologies. For example, since 2010 11 Indian cities were providing lower sulfur diesel fuel (50 ppm), which enables the use of cleaner diesel technologies and thus also reduces PM emissions [46]. In some instances, it may be difficult to reach vehicle operators or fleet managers due to the highly fragmented nature of the sector.[4] In addition, fleet managers may not realize that there are incentives for them to change maintenance, driving, or logistics practices (e.g., due to the lack of tax policies and financing mechanisms in South Asia that favor cleaner transportation technologies [40,45, 47]). However, effective training sessions and communications and outreach campaigns can help overcome these obstacles by targeting appropriate audiences and demonstrating the benefits of improved fleet logistics, maintenance, and driving practices in other regions.

The following sections describe several readily achievable, low-cost, and high-impact black carbon emissions reduction activities with the potential to generate considerable economic and public health co-benefits.

Improve Inspection and Maintenance Practices

Improperly functioning vehicles can increase pollutant emissions. According to one estimate by UNEP, approximately one-half of a given fleet’s emissions come from just 10% to 15% of the fleet’s vehicles [48]. For this reason, many governments have developed and implemented vehicle I/M programs to improve fuel efficiency and reduce the amount of pollution generated

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4. It is estimated that at least 80% of India’s trucking enterprises have only one or two trucks and only 10% of companies in the country have more than 15 trucks [38, 40].

by vehicles, including personal vehicles and corporate fleets. Through such programs, governments can require vehicles to be inspected regularly and ensure that they do not produce emissions in excess of a given threshold. If a vehicle is found to produce emissions at levels beyond the established threshold upon inspection, the government can require maintenance in order to reduce emissions.

Even when compliance with I/M programs is not compulsory, fleet managers and owners will benefit from having their vehicles inspected and maintained. Therefore, a key strategy for reducing black carbon emissions and achieving the associated climate and health co-benefits is to promote the fuel-saving benefits of having fleet vehicles regularly inspected and rigorously maintained. This approach can be used both in locations where government I/M programs exist and where I/M is not required by government regulation.

Guangzhou, China "Green Trucks" Pilot Project

The World Bank, with the Clean Air Initiative for Asian Cities and other partners (including EPA), developed a "Green Trucks" pilot project in Guangzhou, China, from 2008 through 2010. The project involved working with three private trucking companies to help them improve the efficiency of their fleet vehicles to reduce fuel costs, air pollution and associated health impacts, and climate impacts.

In addition to a baseline analysis of emissions and fuel consumption and a survey of fleet managers' and drivers' practices, this project involved selected technology upgrades and an eco-driving training course. This course consisted of a one-hour presentation on key topics related to efficient vehicle use and fleet management. Topics included:

- Improved driving practices – progressive shifting to optimize fuel efficiency
- Vehicle I/M – tips for tire maintenance
- Truck loading and equipment – using lighter trucks
- Logistics and planning – planning freight trips to minimize the number of trips with empty trucks

These courses were offered to truck drivers and fleet managers. Based on information collected through the baseline survey and observations, eco-driver training can greatly improve the effectiveness of emissions control technologies (as described below) because in many cases drivers and fleet managers do not know how to properly operate new equipment.

The technology upgrades portion of the project involved installing new tires and aerodynamic equipment on the companies' trucks. The technology upgrades were recommended by EPA's SmartWay program, based on its experiences in the United States. The upgrades achieved a fuel savings of 7% for one company that installed new tires and aerodynamic equipment on two long-haul heavy-duty trucks, and 18% for a second company that installed efficient tires on two garbage trucks [47, 49]. The payback periods for the two companies' upgrades were roughly 5.1 years and 1.5 years, respectively. Based on the findings from the project, the project partners estimated the possible benefits of scaling up the project to include technology upgrades for all trucks in Guangdong Province, which includes Guangzhou (see Table 2).

One of the key findings from this project was that investments in fuel efficiency can have very short payback periods, but that upfront financing is necessary for the investments to be made. The project partners emphasized the need for sources of financing in the region. One solution is to reach out to lenders. For example, in the United States, micro-financing options such as revolving loan funds have been used by a number of small trucking companies to make fleet improvements. These options often involve access to low-interest loans [47].

Looking to the immediate future, the project's success resulted in a $5 million grant from the Global Environment Facility to implement a regional project that spans Guangdong Province (including Guangzhou). The Guangdong Green Freight Project, which will involve retrofitting more than 2,000 trucks with SmartWay technologies, will leverage an additional $17 million in co-financing from multiple sources by incorporating this project into a broader capacity building effort with the Chinese trucking industry [49]. In the long-term, the pilot project (along with the Guangdong Green Freight Project) is being used to test designs for a future Green Freight China program that will be applied at a broader scale.

Source: [34].

Best practices and case studies that provide opportunities for quickly learning the advantages, disadvantages, and unique challenges associated with the design and implementation of these programs in South Asia are available from a number of governmental and nongovernmental sources. For example, I/M programs have been implemented in several localities and larger jurisdictions in South Asia. In 2004, the U.S. Agency for International Development (USAID) produced a comprehensive evaluation of best practices for I/M programs based on international experience [50]. This particular guidance includes case studies from several governments.

Implement Fuel-Efficient Eco-Driving

Vehicle speed and driver behavior can significantly impact emissions and fuel economy. Eco-driving refers to a "driving style characterized by lower speeds, less acceleration and 'thinking ahead' in traffic," that can help improve fuel efficiency [51]. Training courses in eco-driving help the driver reduce fuel consumption while reducing black carbon emissions (see the text box on the Guangzhou project on page 26, the Ahmedabad project on page 29, and the Meralco project on page 30). Over the long run, drivers who have completed eco-driving training courses often achieve 5%–10% fuel efficiency improvements, compared to their fuel efficiencies before the course [51]. In addition, better driving practices can also lead to savings on vehicle maintenance costs (e.g., costs for replacing parts susceptible to wear and tear, such as brakes, clutches, and vehicle suspension systems).

During eco-driving training courses, trainees are taught how to calculate fuel efficiency as well as five basic rules [52]:

1. Anticipate traffic flow
2. Maintain a steady speed at low revolutions per minute
3. Shift up early
4. Check tire pressures frequently at least monthly and before driving at high speeds
5. Remember that any extra energy required costs fuel and money.

The eco-driving training sessions provided in the Guangzhou, China "Green Trucks" pilot project (see the text box on page 26) lasted one hour each and were based on training materials developed by EPA's SmartWay Transport Partnership. Through this pilot project, it was discovered that many drivers lacked knowledge on how to properly operate and maintain their equipment (e.g., operating tire pressure monitoring sensors). The training sessions helped provide the drivers with the information they needed to use the equipment correctly and thus improve their vehicles' efficiency [34].

Table 3 presents a breakdown of fuel savings that can be achieved by implementing different eco-driving practices.

Table 3. Fuel savings from typical eco-driving practices	
Practice	**Fuel savings**
Minimizing load	2% per 100 lbs (45 kg) of load reduced
Avoiding rapid acceleration and sudden braking in city	5%
Maintaining tire pressure	1% for each properly inflated tire
Having regular tune-ups	Up to 20%
Unclogging air filters	One mile per gallon (3.8 L) of fuel consumed
Combining short trips to reduce the number of times the vehicle is started	Every time the engine is started, it uses 20% more fuel than if it were running continuously
Source: [53].	

Improve Fleet Logistics

Poor fleet management can have implications for fuel economy and black carbon emissions. Overloading trucks has been identified as a major cause of pollutant emissions in India; long-distance transport trucks (which weigh approximately nine tons) often carry between 14 and 20 tons of goods on outbound trips, amounts that are beyond their specified loads. In Pakistan, it is estimated that 70% of 2- and 3-axle trucks and 40% of 4- and 6-axle trucks are overloaded [40]. Trucks are overloaded because operational costs can be minimized if the number of truck trips is reduced. However, when these trucks (which run on diesel fuel) are operated at levels outside their specification ranges, their engines are overworked, which results in excess pollution. In addition, overworked engines suffer from increased wear and typically are not serviced regularly. Because truck engines are overworked when the trucks are overloaded, they require additional fuel and are more likely to break down. Fortunately, many fleet managers have found that they can reduce their overall costs by not overloading their trucks [38, 54].

When considering fleet logistics, some trucks carry minimal loads (or no loads at all – called a "deadhead"). In some fleets, deadhead truck trips can account for one-tenth of all fleet miles traveled, and contribute substantially to pollutant emissions and fuel expenditures [38]. In India, it is estimated that between 37% and 46% of all truck trips are deadheads [40]. Figure 10 shows that many fleet vehicle trips are deadhead trips.

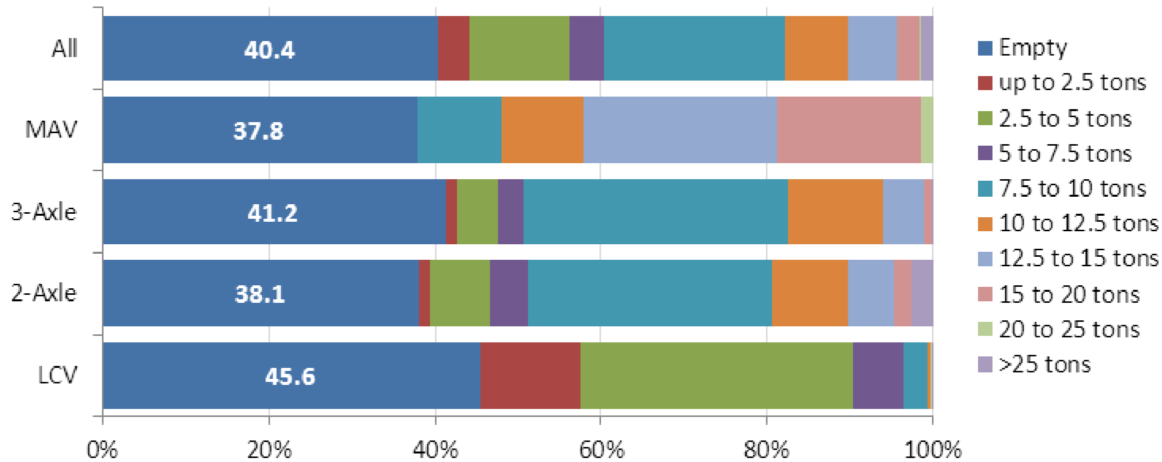

Figure 10. Load distribution of freight vehicles in India. MAV = multi-axle vehicle; LCV = light commercial vehicle. Source: [38].

Ahmedabad, India's Municipal Fleet Program

Ahmedabad is the seventh largest city in India and one of the fastest growing cities in the world. The Ahmedabad Municipal Corporation (AMC) manages the city's various public agencies. It owns a fleet of roughly 1,000 trucks and other vehicles that traditionally operate on diesel fuel. In addition to these vehicles, its contractors own and operate approximately 700 vehicles in the city. Overall, the combined fleet consumes approximately 10,000 L of fuel per day, primarily diesel. AMC estimated that its fleet's annual CO_2 emissions were approximately 13,000 tons and that the fleet was wasting the equivalent of 20 MW of electricity per day due to inefficient fuel use.

In recent years, AMC has endeavored to reduce its fleet's impact on local air pollution while reducing its fuel costs. AMC launched a capacity-building initiative among its fleet drivers and operators, training them on proper usage of fleet vehicles. This training provides participants with information on the benefits of reducing idling and overloading, using the clutch with optimal efficiency, minimizing unwanted accelerating, and limiting excessive speed. Simultaneously, AMC is conducting training that instructs fleet maintenance staff on how to develop proper vehicle I/M regimens, which include routinely verifying that fuel compressors are working effectively and that tire pressure remains at optimum levels.

AMC has also converted its entire diesel-fueled fleet to cleaner-burning alternatives, such as CNG, and has started to replace its older vehicles with ones that are built to comply with more stringent air pollution standards.

Overall, AMC's efforts have reduced their fleet's fuel costs and contribution to air pollution levels in Ahmedabad.

Source: [55].

Meralco South Distribution Services' Green Fleet Program

Meralco South Distribution Services (SDS), part of the Meralco Corporation, is an electricity distributor in the southern portion of Luzon Island in the Philippines. Meralco SDS has a fleet of approximately 300 vehicles, including passenger vehicles and trucks. In 2009, the company adopted a new environment, safety, and health policy that includes a goal of improving fuel efficiency to achieve environmental and health benefits while reducing fuel costs. To reach this goal, the company monitored fuel consumption and kilometers driven in 2008 and used this information to determine average fleet-wide fuel efficiency. Along with this study, the company surveyed its fleet drivers and managers to better understand their awareness of fuel consumption-related factors and practices that might help improve fuel efficiency. This information informed the design of an eco-driving training course for the company's drivers and fleet managers.

In addition to developing fleet-wide fuel efficiency measures, the company developed estimates of their fleet's baseline emissions of CO_2 and other pollutants, such as PM_{10} (which includes black carbon). To develop these estimates, the company used the UNEP-TNT Toolkit for Clean Fleet Strategy Development, which was developed by the PCFV and provides fleet managers with tools to help them understand key health and environmental impacts associated fleet operations. Using this toolkit, the company estimated that its 300 vehicles emitted 1.4 tons of PM_{10} annually.

Based on the results of this analysis and an evaluation of fleet components that contribute most to emissions and fuel consumption, the company identified the following priority areas for improvement: emergency pick-up trucks, utility pick-up trucks, vans, and basket trucks. For each of these areas, the company established a fuel efficiency goal. To meet each goal, the company identified specific activities that it would implement, focusing in particular on the following: eco-driving training for drivers, improved vehicle maintenance, and redesigning its fleet to "right-size" its vehicles (e.g., using smaller vehicles when possible).

The eco-driving component of the Green Fleet Program included several specific activities, including:

- A train-the-trainers program that gave presentations to the company's different fleet sectors and guided drivers' through best-practice based exercises
- A series of driver trainings, run by the trainers who participated in the train-the-trainers program, which involved presentations and driving exercises for the company's 400 drivers
- A rewards program, through which the company recognized drivers for achieving high fuel-efficiency ratings and for having no accidents over the course of a year, among other things
- A communications and outreach campaign that developed eco-driving materials and posted them in all company facilities.

During the eco-driving training sessions, drivers and trainers were given information on specific practices that they can use to improve fuel efficiency. The most attention was paid to practices involving proper acceleration and braking (i.e., not accelerating too quickly and not braking suddenly unless necessary), appropriate gear shifting (i.e., going through lower gears gently and quickly without forcing the engine to reach high levels of rotations per minute), and anticipation of lane changes and obstacles further down the road. After being trained in these practices, drivers were given practical tests to ensure their understanding of the eco-driving principles and to help them visualize the fuel savings. Table 3 presents the approximate fuel savings that can be achieved using such practices. The information in the table is based on a training session that was developed by the managers of the Honda Philippines fleet, which – like Meralco SDS – has adopted the UNEP-TNT Toolkit.

The program's benefits after the first year of implementation were considerable for all fleet operations. Figure 11 presents the fuel-efficiency improvements for three fleet sectors. Overall, from 2008 to 2009, Meralco SDS improved its fleet-wide fuel efficiency by 16% and achieved reductions in its fleet's emissions of CO_2 and PM_{10} by 10% and 4%, respectively. Considering the clear benefits of the program, the company has decided to incorporate eco-driving training into all new driver training modules and to mandate that drivers partake in eco-driving refresher courses every three years. Other branches of the Meralco Corporation are now beginning similar projects on their own.

Source: [56].

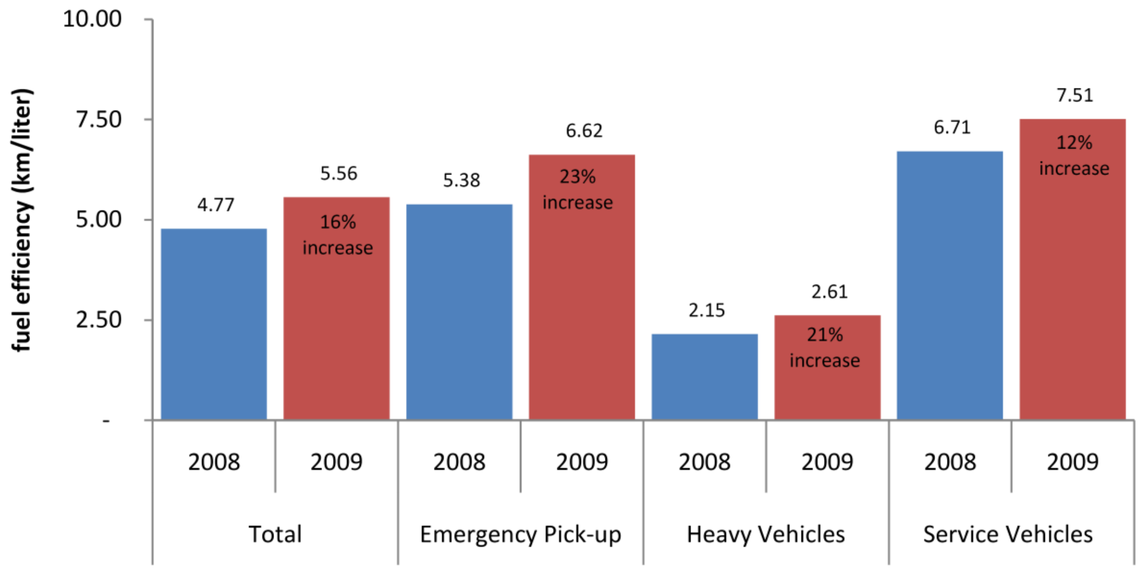

Figure 11. Realized fuel efficiency gains by the Meralco SDS. Source: [56].

C. Examples of Initiatives to Reduce Black Carbon Emissions from On-Road Fleets

Several organizations have developed resources that fleet managers can use to make informed decisions about how their fleets are operated. These resources include the following:

- *Clean Fleet Strategy Development Toolkit* (UNEP, PCFV), developed by the Partnership for Clean Fuels and Vehicles (PCFV). The UNEP-TNT Toolkit for Clean Fleet Strategy Development provides fleet managers with tools to help them understand key health and environmental impacts associated with how their fleets operate. The toolkit contains a number of tools that, when used together, function to prepare both public and private vehicle fleet managers to (1) evaluate the impacts of their fleets on the environment and human health, and (2) then develop a practical strategy for corrective and cost-effective action through a number of options (from eco-driving and improved maintenance to advanced fuels and technologies). The toolkit takes fleet managers and those interested in learning about lowering emissions from road transport through a step-by-step system that is accessible to both the experienced and beginner personnel in the field. UNEP held several training sessions to introduce fleet managers to the toolkit and to explain its application and value. Drivers from one company in the Philippines achieved a 16% improvement in fuel efficiency by using eco-driving practices after completing a UNEP-TNT toolkit training session [40]. The online toolkit can be accessed at http://www.unep.org/tnt-unep/toolkit/.

- *SmartWay Transport Partnership Models and Literature* (EPA). Through the SmartWay Transport Partnership, a partnership between private and public sectors based in the United States, fleet managers can access a series of models that they can use to improve fleet logistics. For example, by entering basic fleet information into the models, fleet managers can generate estimates of the fuel and emissions impacts of their fleets' operations (see Figure 8). The partnership has also developed a large library of information resources on fuel-efficient fleet management, including fact sheets with estimated fuel savings associated with different management practices. The SmartWay Transport Partnership resources can be accessed at http://www.epa.gov/smartwaylogistics/transport/index.htm.

Several international campaigns and partnerships offer forums for fleet managers to gain access to resources, best practices, and information on innovative approaches. Examples of partnerships include:

- *Partnership for Clean Fuels and Vehicles* (UNEP). This partnership was developed by UNEP to work with governments and organizations in developing countries to help them reduce air pollution from the transportation sector. The partnership concentrates on helping regions transition to lead-free, low-sulfur fuels in addition to assisting them in their efforts to reduce transportation-related emissions through technological and behavioral changes. The partnership helps countries reduce PM (and also black carbon) emissions from transport by promoting the cleaner fuels needed for cleaner vehicles as well as cleaner vehicle standards. The partnership offers a wealth of information on the current status of country standards and regulations, as well as best practices and other experience-based resources. More information on the partnership can be found at http://www.unep.org/transport/pcfv/.
- *Sustainable Transport Community of Practice* (Clean Air Initiative for Asian Cities). This initiative administers a community message board for individuals and organizations involved in transport planning and operations. The message board provides an opportunity for community members to share ideas and solicit feedback from colleagues. More information is available at http://www.cleanairinitiative.org/portal/communities/transport_forum.
- *Global Fuel Economy Initiative* (50by50). Several South Asian governments are collaborating with this initiative. For example, the Indian Ministry of Transport is working with the initiative to institute an inspection and certification regime for vehicles, in addition to the establishment of fuel-efficiency labels that are mandatory for all new vehicles in the country beginning in 2011 [57]. More information on the Global Fuel Economy Initiative can be found at http://www.fiafoundation.org/50by50/pages/homepage.aspx.

4. Black Carbon Mitigation in the Residential Sector

Nearly three billion people use biomass fuel in their homes for heating and cooking [58]. Biomass includes wood, dung, or other natural materials such as leaves or agricultural remnants [15]. When these fuels are combusted, they release black carbon and other pollutants into the atmosphere. While residential fuel use, primarily biomass combustion for cooking, comprises 26% of black carbon emissions globally [59], it accounts for approximately 60% in Asia [60]. In India, the most populated nation in South Asia, about 70% of the residents live in rural areas and 90% of them rely on biomass as a cooking fuel [12, 61].

Residential fuel use is also closely tied to health outcomes. The World Health Organization (WHO) estimates that residential fuel use, which contributes to indoor air pollution, is responsible for 2.7% of the global disease burden [62]. In India, where 160 million households use solid fuels and indoor air pollution leads to 570 thousand deaths annually [12].

This section focuses on how using more efficient, improved cookstoves and/or switching to cleaner-burning fuels can help reduce black carbon emissions and contribute substantial public health benefits. It includes detailed information on the co-benefits of and opportunities for reducing black carbon emissions from residential fuel consumption and provides examples of methods that have been used to achieve these co-benefits.

A. Benefits of Reducing Black Carbon Emissions from Cookstoves

Reducing emissions of black carbon from cookstoves can generate numerous co-benefits. This section provides detailed information on several of these co-benefits, including climate benefits, health benefits, and improving conditions for vulnerable populations.

Climate Benefits

Improved cookstoves and cleaner-burning fuels reduce black carbon emissions from the residential sector and offer considerable climate benefits. Improved cookstoves reduce emissions of both black carbon and CO_2, a key GHG. One improved cookstove program estimates that its 80,000 cookstoves would prevent 580,000 tons of CO_2 and 114,000 kg of black carbon from entering the atmosphere [63]. According to one estimate, switching to improved stoves in India could reduce the country's total GHG emissions by 4% [12].

Overall, efforts to reduce black carbon emissions through the increased use of improved cookstoves and cleaner-burning fuels are quite cost-effective. The Copenhagen Consensus on Climate has reported approximate values for the reduction of black carbon. For every dollar spent switching to an improved stove, the benefit is between \$100 and \$880 of carbon dioxide equivalent (CO_2e). In addition, USAID reports that improved stoves have a cost-effectiveness of about \$4 per ton CO_2e [64]. However, there is limited information related to the cost-effectiveness of individual cookstove programs, largely due to the fact that these programs are not collecting data on their black carbon emissions reduction outcomes. To date, just one program, a pilot project called Project Surya, has measured black carbon emissions reductions from its improved cookstove efforts (see the following text box for additional information).

Using Cell Phone Technology to Monitor and Measure Black Carbon Emissions

Project Surya is one of the few improved cookstove programs with black carbon mitigation as its primary objective. It focuses on creating low-cost cookstove technology solutions to mitigate black carbon. Project Surya is exploring solar and biogas cookstove alternatives in addition to typical improved cookstoves. The project emphasizes the importance of centrally manufactured stoves to maintain quality control. During its demonstration phase, Project Surya hopes to reach close to 10,000 Indian homes. In the long term, Project Surya plans to spread these technology solutions across continents.

One particularly innovative idea introduced through the project is community-based monitoring of black carbon emissions using cell phones with support from project partner Nexleaf Analytics. Nexleaf's technology involves placing an air sampler in the homes of cookstove users. A cell phone then captures images of filters that have been exposed to black carbon. The images are sent via cell phone to a computer program that analyses the data. This technology is truly innovative due to its versatility and has been shown to be:

- Inexpensive and portable
- Accurate
- Capable of providing real-time reporting
- Able to work with almost any cellphone camera

In the future, such innovative cell phone technology may be used more broadly for cookstove programs to determine if improved cookstoves are genuinely improved, if they are being used, and whether they are being used appropriately, based on recorded levels of indoor air pollution. Given its worldwide availability and potential for innovation, cell phone technology has the potential to be used in other sectors and for monitoring pollutants other than black carbon. Cell phone technology is likely to transform the way one monitors and evaluates pollution and other important variables such as temperature, thus reducing the need for costly, centrally located, and complex monitoring devices requiring specialized trained and/or highly skilled personnel.

Photo: Nexleaf's black carbon sensor with cell phone attached in an India Kitchen. The sampler sits next to a clean-burning cookstove. Photo courtesy of N. Ramanathan. Sources: Compiled from the reports of [65] and [66].

Health Benefits

Many of the health benefits from improved cookstoves come from reduced indoor air pollution. As stated earlier, residential fuel use in India is linked to 570 thousand deaths annually, primarily due to the inefficiency of traditional cookstoves, which produce large volumes of PM (including black carbon; [12]). Because improved cookstoves can be as much as 50% more efficient than traditional ones, they produce much less indoor air pollution [67, 68]. One study found that improved stoves reduced PM-related illness by 25%–65% [69].

Reduction of illness associated with cookstoves also results in reduced associated medical expenses. Implementation of an improved biomass cookstove program in South Asia would save approximately $18 million per year in health system costs, and these savings would increase if biofuel or liquefied petroleum gas (LPG) programs are included [58]. These health benefits would accrue primarily to women and children because they are more often exposed to high levels of indoor air pollution.

Figure 12. A woman holding an infant near a traditional cookstove. Source: [70].

Benefits to Vulnerable Populations

Transitioning to new fuels or improved stoves could significantly improve the lives of women and children in South Asia (Figure 12). Improved cookstoves increase productivity for women as a result of improved health. For example, for a woman earning minimum wages in South Asia, an untreated mild respiratory infection that lasts about 10 days could lead to lost earnings of roughly 3%–4% of annual income. Cumulatively, South Asia could avoid 84 million sick days with a value of $167 million through the effective implementation of a cookstove program [58].

Stoves that use less fuel or cleaner fuels free women and children to engage in other activities. The time saved on cooking and collecting fuel can be used for activities such as education and microenterprise. WHO estimates that the average household spends about 40 minutes per day collecting firewood in South Asia, and homes in Nepal spend more than twice that time (1.5 hours per day). In South Asia, improved stoves could save 1.7 billion hours of work collecting fuel, with a value of $4.7 billion annually [58]. Additionally, the collection of fuel often compromises the safety of women and children because they are vulnerable when they venture to collect firewood.

The entire improved cookstove supply chain also creates economic opportunities. Local production results in increased job creation. Even in the case of centralized production models, local partners are needed for distribution, sales, and servicing.

B. Opportunities for Reducing Emissions from Cookstoves

A traditional cookstove, shown in Figure 13, contributes to substantial black carbon emissions and indoor air pollution. There are two ways to reduce black carbon emissions from cookstoves: (1) improve the combustion efficiency of the cookstove to require less fuel and reduce emissions, and (2) switch to fuels that produce fewer emissions.

In this section

Most cookstove programs implement both traditional, technology-focused activities and behavioral, intervention-based activities simultaneously. The initial steps of cookstove programs focus on technological change and the introduction of improved cookstoves. This is usually followed by behavior-based activities to both promote the adoption of the technology and dispel reluctance to adoption. The purpose of this approach is to reduce barriers to accepting new cookstove technology that have been chronicled by many cookstove programs. Introducing improved cookstoves does not necessarily translate into adoption (see the text box on page 38). Depending on the program design and stove type, challenges can include affordability, stove performance, design (e.g., multiple dishes cannot be cooked simultaneously, regional foods cannot be cooked long enough or hot enough), and long-term adoption [67, 71, 72]. One researcher noted that you cannot simply ask users if they would use a stove that requires less fuel. The real question is, "If you had a stove that used less fuel, would you be willing to chop your wood into 20-cm lengths, and control, damper, and clean the flue" [73]? Many cookstove designers are now ensuring that stoves have a design that appeals to users, even if the stoves have slightly lower performance levels. Additional information on cookstove production models is provided in Appendix E.

Criteria for Improved Cookstoves

- **User needs**: Solutions must meet the social, resource, income, and behavioral needs of users.
- **Scalability**: Solutions must be scalable through markets or other mechanisms.
- **Performance**: Solutions must substantially improve technology design and performance relative to baseline conditions, and – once industry standards are in place – be able to meet any international standards for performance and safety. The product must also be able to meet the basic needs and expectations of the user, which are likely to vary regionally.
- **Monitoring**: Solutions must stand up to rigorous field monitoring and evaluation to demonstrate actual, in-field impacts.

Source: [74].

The following sections describe efforts to reduce black carbon emissions from cookstoves by using improved cookstoves and cleaner-burning fuels.

Increase Use of Improved Cookstoves

Efforts to improve cookstoves have existed for decades. Characteristics of improved cookstoves include high thermal, fuel, and combustion efficiency; high heat-transfer ratio; low emissions of smoke and other pollutants; and sometimes the use of chimneys to remove stove emissions from kitchens. Only the properties that improve stove efficiency reduce black carbon emissions.

Initial attempts to improve traditional cookstoves (Figure 13) focused on changes to existing stoves, which were predominantly made of mud, clay, stones, and/or bricks. These improvements included the use of additional chambers to improve fuel efficiency (Figure 14) and the use of chimneys (Figure 15) to vent emissions outside the house. Although chimneys reduce indoor air pollution, they contribute to outdoor air pollution. Later improvement efforts introduced the use of metals and ceramics and a complete redesign of the cookstoves (Figure 16). Use of fans to improve air circulation in these stoves led to increased fuel efficiency and lower emissions. In the gasifier stove, another type of improved cookstove, gases and smoke from the fuel are forced into a flame above the fuel where nearly complete combustion is achieved.

The criteria for developing sustainable cookstoves require consideration of not just the performance of the stove but also user preferences, commercial scalability, and monitoring of effectiveness (see the text box above). The importance of including local participation in the design, marketing, and maintenance of cookstoves was repeatedly emphasized in the Kathmandu Consultation (see the text boxes on pages 38, 39, and 40). Improved cookstoves present an interesting problem when costs are considered. First, there are programmatic or implementation costs. Second, there are the costs to the users. Experience from multiple programs shows that the costs of the stove should be passed on to the users so they view the stoves as an investment that requires maintenance and care.

Figure 13. Traditional cookstove.

Figure 14. Cookstove with simple modifications. Source: [75].

Figure 15. Cookstove with chimney. Source: [76].

Figure 16. Cookstove with complete redesign. Photo by Selvan Thandapani.

Switch to a Cleaner Fuel

The second primary method to reduce black carbon emissions from the residential sector is to switch to a cleaner fuel. In many cases this means moving from biomass or coal to kerosene or LPG. In India, the central government and some state governments have launched programs to implement fuel switching among low-income households in urban and rural areas. In rural areas, the central government is planning an initiative to provide a subsidy of roughly $30 to rural households below the poverty line. This subsidy is for LPG cylinders and pressure regulators. Without a subsidy, many users could not afford LPG or other clean fuels. The State of Tamil Nadu has implemented a program to provide free LPG stoves and has subsidized the cost of gas cylinders from a distributor. As a result of this program initiated in 2006, nearly three million stoves are expected to be distributed through 2011.

In urban areas of India there has been an unsubsidized switch to LPG over the past several years; however, government initiatives may substantially increase LPG use in rural areas. There are also efforts to switch from biomass to solar-powered cooking and electricity in rural areas of India, although these efforts are on a smaller scale.

Marketing and Adoption of Improved Cookstoves in India

Gram Vikas is an NGO that has been working since 1979 to bring sustainable improvement to the quality of life of poor, marginalized, indigenous, and tribal rural communities, mostly in Orissa, India. Gram Vikas also works in the field of renewable energy. To date, it has built nearly 60,000 family-size biogas plants (which provide household fuel to families), of which 82% are still working.

Gram Vikas does not focus on black carbon emissions reductions; rather, it helps achieve emissions reductions by improving cookstoves in communities for the benefit of improving women’s health. Gram Vikas’ stove program propagated in-situ, double-pot, energy-efficient, mud stoves with chimneys to reduce smoke in rural areas of Orissa. In the initial phase starting in 1982, Gram Vikas constructed about 50,000 cookstoves. Within one year of establishment most stoves were no longer used. A survey conducted 10 years later revealed that less than 500 of these stoves were working. Gram Vikas realized that although the improved stove technology was simple, there was no one to assist village women with trouble-shooting, and so they reverted to their old stoves. Later, Gram Vikas restarted the stove program by training a few women in several villages. These women constructed stoves and were equipped to solve problems. In a short time, all cookstove users learned how to resolve problems with their new stoves. A total of 35,000 stoves were made in this manner, and at any given time at least 85% of them are working. During this second project phase, Gram Vikas discovered that women want to cook outside during the non-rainy season. The mud stoves are not suitable for outdoor use, so portable steel stoves were introduced, and more than 10,000 families have purchased these stoves.

Source: [77].

Marketing Improved Cookstoves

USAID partnered with Winrock International to promote improved cookstoves in Bangladesh. This program used multiple commercialization and engagement strategies to build support for three stoves that improve indoor air quality and health.

From 2005 to 2007, USAID and Winrock partnered to disseminate new cookstoves that require less fuel and decrease indoor air pollution. Additional partners included Concern Worldwide Bangladesh, the Village Education Resource Center, and the Appropriate Rural Technology Institute. The program promoted three different stove designs and also carried out educational activities on the hazards of indoor air pollution.

This multifaceted program used trained cookstove entrepreneurs to promote the stoves. These entrepreneurs lived in the community and specialized in one or more tasks including manufacturing, installation, and/or retail. The entrepreneurs took part in ongoing training to learn how to fix and repair stoves. They were offered microfinance opportunities to begin their businesses. Ninety-five percent (95%) of the entrepreneurs paid off their microfinance loans on-time and in full. Many of the entrepreneurs, in turn, offered customers payment plans.

The stove and education program used marketing tactics to educate the public and increase demand. Educational tactics included the development of posters, billboards, and song performances. The education program also conducted outreach to targeted audiences including school children and teachers. The cookstove program developed billboards, created product demonstration centers, and distributed pamphlets.

On the right are several examples of marketing materials including posters, billboards, and product demonstrations used by the USAID program and a different program sponsored by the Shell Foundation.

Source: [68].

Photos (top to bottom): Flyer and billboard for the USAID initiative; flyer for the Shell Foundation's Room to Breathe Campaign; and a cookstove product demonstration. Sources (top to bottom): [68, 78, 79].

Woman-Owned Cookstove Venture

Swayam Shikshan Prayog (SSP) in India connects product manufacturers and rural women to promote cleaner and healthier cookstoves and improve the livelihoods of women.

SSP builds networks between established corporations, such as cookstove manufacturers, and female survivors of disasters. These connections enable rural female entrepreneurs to launch retail businesses in renewable home energy products, such as cookstoves. SSP's Business Development Services provide three key benefits:

1. Financial – everyone in the value chain makes a profit.
2. Environmental – all enterprises are rooted in the principles of clean, renewable energy.
3. Social – all businesses fortify the development of village communities.

Female entrepreneurs are involved in both the design and sale of home energy products. First, women assist in designing a product that is accepted by the rural community. Second, women are trained as entrepreneurs to sell stoves door-to-door. These trained entrepreneurs purchase products from the manufacturer, which they pick up at SSP warehouses. The idea behind this approach is that because women are the primary users of these products, they are also the best salespeople. So far, 70,000 cookstoves have been sold.

SSP has worked in disaster-affected areas of three Indian states since 1998, and has launched 8,944 agricultural and non-farm businesses through microfinance. It has also nurtured 1,820 female retail entrepreneurs with a total consumer base of 63,000 families and cumulative earnings of $460,000. On average, entrepreneurs have experienced 33% income growth.

Source: [80].

C. Examples of Initiatives to Promote Improved Cookstoves in South Asia

Initiatives to promote improved cookstoves range from local-level to international efforts and include:

- *National Biomass Cookstove Initiative in India*
  This initiative, a project of India's Ministry of New and Renewable Energy, aims to upgrade 160 million cookstoves in India [12]. The project's goal is to reduce indoor air pollution, including emissions of black carbon, other aerosols, and GHGs. Project coordinators are careful to not assume that there will be an easy adaptation to new clean fuel sources. The goal is to create effective technologies and enable a relatively easy transition by maintaining affordable biomass as the primary fuel source. Additional information can be accessed at http://www.mnre.gov.in/prog-nbci.htm.

Cookstove Program Design Elements

Program design is an important element to ensure that users continue to use, maintain, and replace their stoves after a program has ended. The following elements can increase the sustainability of a cookstove-focused mitigation option:

- Consultation with users regarding stove design
- Worker training
- Quality-control efforts
- Payment plans (versus subsidies)
- Maintenance programs
- Proper and ongoing evaluation

- *Global Alliance for Clean Cookstoves*
  This is a public-private partnership that seeks to create a market for clean cookstoves and fuels worldwide. The goal is to introduce improved cookstoves to 100 million households by 2020. The partners include multiple U.S. government agencies (i.e., Department of State, USAID, EPA, Department of Energy, and Department of Health and Human Services), the United Nations Foundation, other national governments (i.e., Norway, Denmark, Malta, Germany, and Peru), private-sector entities (i.e., Shell, Morgan Stanley, Bosch, and Siemens Home Appliances Group), foundations (i.e., Shell Foundation and Osprey Foundation), and multiple United Nations organizations (i.e., United Nations Development Programme, UNEP, United Nations High Commissioner for Refugees, and United Nations Industrial Development Organization). Among other activities, the initiative is focused on (1) developing strategies for developing and sustaining effective programs and outcomes; (2) increasing the information base on risks and benefits to health and climate; (3) raising awareness of the benefits; (4) evaluating existing programs; (5) developing standards and labels based on testing; and (6) exploring financing mechanisms for deployment. More information on the alliance can be found at http://cleancookstoves.org/.
- *The Partnership for Clean Indoor Air (PCIA)*
  PCIA was launched in 2002 with the goal of reducing indoor air pollution and improving the life of vulnerable populations, primarily women and children. The initiative currently has more than 400 partners who provide technical assistance, build capacity, implement projects, and conduct outreach to promote the use of improved cookstoves and heating systems and reduce indoor air pollution [81]. Additional information on PCIA can be accessed at http://www.pciaonline.org/.
- *Anagi Stove of Sri Lanka*
  An improved cookstove program in Sri Lanka led to the development of the “Anagi” stove. The Anagi is a two-pot, single-piece, clay stove that uses biomass and is more fuel-efficient than traditional cookstoves. Initially, the Anagi stove was not well received. However, after several years and with the right mix of partners, an Urban Stoves Program was created to successfully market the stoves. Using existing tile production and distribution channels, the stoves are sold as an “off-the-shelf” product. Key elements of this program include training potters and quality-control efforts. The success of the stove is apparent with three million Anagi stoves in use and many knock-offs in existence (albeit not built to design specifications; [82, 83]). Additional information on the Anagi stove is available at
  http://www.impactalliance.org/ev_en.php?ID = 49263_201&ID2 = DO_TOPIC.

Table 4 lists local efforts in South Asia where organizations are involved in producing cookstoves, conducting demonstration projects, or conducting outreach to promote the use of improved cookstoves. Stove manufacturers such as Prakti Lab, First Energy, and Envirofit are also involved in marketing improved cookstoves that they manufacture.

Table 4. Examples of local efforts to promote improved cookstoves

Country	Lead organization	Link
India	Appropriate Rural Technologies Institute	http://www.arti-india.org/index.php
India	Gram Vikas	http://www.gramvikas.org/chullah.php
India	SKG Sangha	http://www.skgsangha.org/activ_eco.html
India	Swayam Shikshan Proyog	http://www.sspindia.org/SSP-WhatWeDo2.html
Nepal	Centre for Rural Technology	http://www.crtnepal.org/?option = projects&pjid = 3033333637
Nepal	Child Welfare Scheme	http://www.pciaonline.org/content/breathing-spaces-asha-stoves
Nepal	Practical Action-Nepal	http://www.pciaonline.org/practical-action-nepal
Sri Lanka	Integrated Development Association	http://www.ideasrilanka.org/our%20initiatives.html
Sri Lanka	Practical Action – Sri Lanka	http://practicalaction.org/wherewework_srilanka

5. Conclusion

South Asia contributes a large proportion of global black carbon emissions. Growing populations and increasing demand for fossil fuel consumption in the region will only exacerbate the impacts associated with these emissions over time unless steps are taken now to reduce black carbon emissions. These impacts include exacerbation of regional climate change and increased regional impacts principally on public health, water resources, and economic development. South Asia's populations are uniquely vulnerable to these impacts due in part to the large number of people currently exposed to unhealthy levels of air pollution and the large proportion of people that are dependent on historical seasonal snowmelt, icemelt, and rainfall patterns for drinking water and agriculture. Efforts to reduce black carbon emissions in South Asia can therefore aid in reducing adverse impacts on populations in this region, while also helping to reduce contributions to global climate change.

Recognizing the unique potential for achieving considerable environmental and development co-benefits globally and across South Asia in particular, EPA has undertaken an effort to identify, evaluate, and bring to light unique and possibly overlooked low-cost and high-impact opportunities for reducing black carbon emissions in South Asia. It is EPA's aim, therefore, to make information on these activities and opportunities broadly available, but especially to those organizations interested in taking immediate, low-cost, and effective actions to help reduce black carbon emissions in South Asia.

This report presents information on opportunities in the industrial, transportation, and residential sectors in South Asia. It specifically focuses on low-cost but high-impact opportunities that can have long-term benefits, such as utilizing low-cost technologies, modifying operations, and initiating training and communication and outreach campaigns. These opportunities and actions serve to complement actions that are typically resource intensive such as regional policy and regulatory development, technology transfer (e.g., retrofitting diesel vehicles with filters and switching to low-sulfur fuels), and infrastructure improvements that are traditionally used to achieve environmental and development co-benefits on a different scale. Although not the focus of this report, financing (including microfinancing) of the mitigation opportunities is an important consideration.

Specifically, this report presents information on initiatives that have been developed in response to each of the following opportunities:

- *Improving the Efficiency of Brick Making in the Industrial Sector*
  Brick making in South Asia has changed little over the past millennium. Current practices remain inefficient, which results in high levels of black carbon emissions. Efforts to introduce newer brick-making technologies have not gained traction yet. However, proper operation and maintenance of existing brick kilns can lower fuel costs, reduce

black carbon emissions, and improve worker health. Communications and outreach strategies that promote more-efficient practices to targeted stakeholders – including policymakers, brick-kiln owners and operators, and customers (e.g., architects, builders, and government bodies) – and training sessions targeted at kiln firemen are of critical importance. Such low-cost initiatives can help reduce black carbon emissions by introducing these stakeholders to the considerable environmental, health, and social co-benefits that can be achieved by improving the efficiency of the brick-making process. As a largely overlooked sector, this is a considerable opportunity for action.

Improving the efficiency of brick making represents a unique, relatively low-cost, cost-effective, and under-realized opportunity to bring about immediate and meaningful reductions in black carbon emissions in South Asia. This is because there is currently a deficit of mitigation activities and a general lack of awareness of black carbon emissions reduction-related co-benefits in this sector.

- *Improving Public and Private Fleet Efficiency and Management in the Transportation Sector*
  Black carbon emissions from the transportation sector are increasing in South Asia as populations rise and demand for personal vehicles grows. Immediate low-cost opportunities to mitigate black carbon emissions in this sector include improving driver operations (i.e., eco-driving) and fleet management and logistics, promoting pilot projects, conducting regular vehicle I/M, and improving communication about the benefits associated with these actions. As described in this report, current initiatives in this sector have shown that considerable fuel-cost savings can be achieved while reducing black carbon emissions and other co-benefits.

- *Improving the Efficiency and Adoption of Cookstoves in the Residential Sector*
  Improved cookstoves have been in the spotlight of local, national, and international initiatives for over 30 years. Initial programs aimed at reducing indoor air pollution had mixed success. Many programs failed to meet the basic needs of the users, who quickly reverted to old technologies. More recently, cookstove programs have focused on redesigning stoves that appeal to users and engaging in education and outreach efforts to promote their use. Many large and well-funded initiatives currently dominate this field. Primary low-cost opportunities include leveraging existing initiatives by helping to promote entrepreneurship, increasing the availability of financing, including micro-financing at the local level, and underscoring the health benefits of using improved cookstoves especially for women and children. Perhaps the single most notable opportunity, in an otherwise well-financed global effort principally aimed at manufacturing and marketing improved stoves, is the issue of stove adoption or resistance to adoption. This report underscores the critical importance of involving communities in the original design of cookstoves so that they meet user needs and

preferences, thereby facilitating adoption and retention. As the initiatives described in this report show, these efforts can contribute substantial co-benefits, including improved health and reduced impacts on vulnerable populations (i.e., the poor, women, and children).

In conclusion, this report has identified, evaluated, and brought to light unique and possibly overlooked low-cost and high-impact opportunities for reducing black carbon emissions in South Asia, with a goal of making information on these activities and opportunities broadly available, especially to those organizations interested in taking immediate, low-cost, and effective actions to help reduce black carbon emissions in South Asia.

Appendix A. Black Carbon Emissions in South Asia

This appendix describes the sources (e.g., fossil fuel combustion) and sectors (e.g., residential) that contribute to black carbon emissions in South Asia. Due to the lack of emissions information (including source fuel estimates and emissions factor calculations) for much of the region, many studies rely primarily on information from India as the primary indicator of black carbon emissions for the entire South Asian region (see Figure A.1). India ranks highest in South Asian black carbon emissions at 64%, with other countries contributing substantially less – Pakistan (22%), Bangladesh (8%), Nepal (4%), Sri Lanka (2%), and Bhutan (less than 1%) [60].

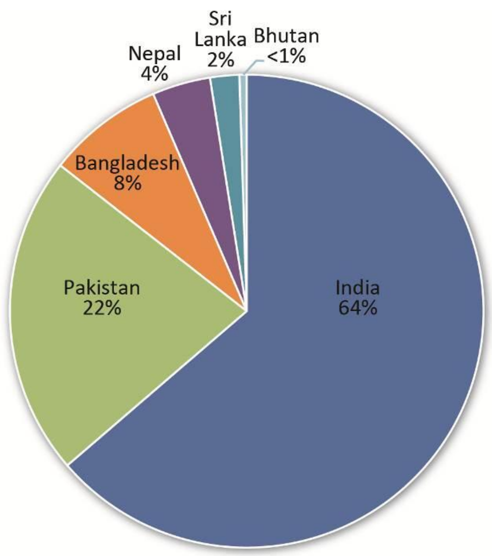

Figure A.1. Percent South Asian black carbon emissions contributions. Source: Adapted from [60].

South Asian Black Carbon Emissions in the Global Context

Black carbon emissions vary considerably by region and sector due to variation in local practices and the types of fuels and technologies used in different regions and sectors. Although region-based inventories of black carbon emissions vary, developing nations in the tropics and Asia are generally recognized as dominant source regions [13]. For the purposes of inventorying black carbon emissions, Asia is generally disaggregated into East/Southeast Asia (consisting primarily of China) and South Asia (consisting primarily of India). Studies on the regional distribution of black carbon emissions consistently identify East/Southeast Asia as the region with the highest total emissions of black carbon (e.g., [15, 60, 84, 85]). However, all of Asia, including China and India, accounts for approximately 40% of global black carbon emissions [15]. A 2009 study estimated that China, India, and Indonesia – the three most prevalent contributors – produced approximately 80% of Asia’s energy-related black carbon emissions in 2006 [60]. In addition, China’s contribution to global black carbon emissions has been increasing rapidly since the 1990s due to its heavy reliance on coal and biofuels [60, 86].

Table A.1 presents regional estimates of global black carbon emissions, showing non-biomass burning anthropogenic sources in South Asia as contributing approximately 7.3% of all black carbon emissions. At this time, there is still considerable uncertainty regarding non-anthropogenic, biomass burning emissions of black carbon in South Asia, which makes it difficult to determine precisely how much of the overall black carbon load is attributable to that region [87, 88].

Table A.1. Regional contributions to global black carbon emissions[a]

Region[b]	Black carbon emissions (in Tg)	Percent of total
Non-biomass burning anthropogenic emissions		
East/Southeast Asia/China[c]	1.5	18.3
North America	0.4	4.9
Europe	0.5	6.1
South Asia	0.6	7.3
Other (South America and Africa)	1.5	18.3
Biomass burning		
South America	1.2	14.6
Africa	1.5	18.3
Other (North America, Europe, South Asia, and Southeast Asia)	1.0	12.2
Total	8.2	100.0

a. The Koch et al. estimates are based on global black carbon emissions estimates from [15].

b. Estimates for major emitting regions are provided for each of two source types: non-biomass burning and biomass burning; minor emitters for each source type are subsumed under the category "other." Koch et al. define six major emitting regions: North America, South America, Africa, Europe, South Asia, and Southeast Asia.

c. Koch et al. define Southeast Asia as being approximately equal to China in geographic area.

Source: [85].

Sources of Black Carbon in South Asia

Globally, approximately 40% of black carbon is from the burning of fossil fuels, 40% is from open biomass burning, and 20% is from the burning of biofuels [13].

However, determining the strength of the three primary source types for South Asia is difficult for several reasons, resulting in disagreement as to the relative contributions from each of the three source types (see, for example, [8, 89, 90, 91]). One reason is that black carbon emissions from the residential sector, which contributes the greatest proportion of black carbon emissions, are derived from both biofuel and fossil fuel combustion, making it difficult to determine the relative contribution from each source to the sectoral total. In addition, open biomass burning (e.g., from forest fires/clearings) contributes a substantial amount of black carbon emissions in South Asia, but the burning is largely seasonal and emissions factors are uncertain and variable across different parts of the region.

In general, it is agreed that biomass burning and fossil fuel and biofuel combustion for residential uses are the largest sources of black carbon emissions in South Asia, while nonresidential fossil fuel combustion (e.g., for transportation and industrial uses) contributes less to overall black carbon emissions in the region. According to one estimate, fossil fuel, open burning, and residential biofuel combustion account for 25%, 33%, and 42% of black carbon emissions in India, respectively [92].

Black carbon in the atmosphere over South Asia does not come exclusively from South Asian sources; it can come from sources outside the region. As noted earlier, aerosol particles are capable of traveling great distances, hence the concern and awareness of transboundary air pollution. For example, one study explains how prevailing wind patterns draw black carbon emissions in considerable quantities from Africa and the Middle East to the region – reaching the Tibetan Plateau – especially during dry months when biomass burning activities in these regions are most prevalent [93]. Although emissions from Africa and the Middle East contribute greatly to total black carbon concentrations above and on the Himalayas and the Tibetan Plateau, India and China remain the primary sources of black carbon in this region [93].

Sector-Specific Emissions of Black Carbon in South Asia

The four sectors that contribute to black carbon emissions include residential, industrial, transportation, and open biomass burning. There are regional and temporal differences in the contribution of these sectors to total emissions of black carbon. These differences are largely dependent on regional development levels. Increasing levels of development lead to a shift from residential and agricultural sources to industrial and transportation sources [59]. Developed countries experience a larger contribution from the transportation and industrial sectors using fossil fuels, while developing countries experience it from biomass burning in the residential sector. This has implications for both the chemical composition of the emissions (i.e., the ratio of organic carbon to black carbon) and the potential effects of the emissions at the local and global levels. Locally, increasing levels of emissions from transportation, for example, can lead to increased levels of ambient black carbon as it is a primary component of emissions from many different types of vehicles (e.g., diesel cars and trucks). At the global level, because black carbon emissions from industry and transportation tend to have higher light absorption tendencies than black carbon emissions from agriculture and other biomass burning sources, development that leads to shifts from rural agricultural emissions to more urban emissions can have implications for overall radiative forcing at the global and regional levels.

Considering the sectoral contributions to total black carbon emissions in South Asia, it is clear that the residential sector contributes the greatest portion of the total amount by far [60, 94]. However, the contributions of the industrial and transportation sectors to black carbon emissions in South Asia have increased in recent years. As shown in Figure A.2, one report estimated the breakdown of the non-biomass burning black carbon emissions from the industrial, residential, and transportation sectors in all of Asia to be 23%, 61%, and 14%, respectively, with an additional 2% of emissions produced by power generation [60].

In India, it is estimated that biofuel use for cooking in the residential sector accounts for 40% of all black carbon emissions (see Figure A.3). Additional emissions from the residential sector include emissions from heating and lighting, but emissions factors for these activities are uncertain [92]. Open biomass burning of agricultural waste and forests accounts for 24% of all black carbon emissions in India, while transportation and industry contribute 21% and 15%, respectively [18]. Within the transportation sector, it is estimated that heavy-duty trucking accounts for approximately 52% of all black carbon emissions [16]. Within the industry sector, brick kilns contribute the largest proportion (approximately 60% of all industrial black carbon emissions; [16]). The high proportion of black carbon emissions from brick kilns in the industrial sector can be attributed to the low-temperature combustion used in the brick-making process relative to other industrial processes, such as cement production and iron and steel manufacturing, which require higher combustion temperatures. These higher combustion temperatures result in more complete burning and thus less black carbon pollution [16].

Black carbon emissions vary according to the season of the year for certain sectors in South Asia. As a result, emissions tend to peak during the dry season months preceding the monsoon in South Asia [93]. In part, this is the result of increased biomass burning and brick-making activities in the region during the dry season [93, 95]. For example, in the Kathmandu Valley of Nepal, brick making at the region's 125 kilns occurs primarily in the dry months of December to April [95].

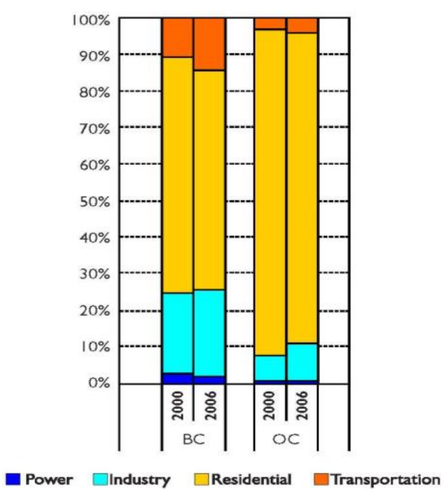

Figure A.2. Black carbon emissions from different sectors in 2000 and 2006 in Asia.

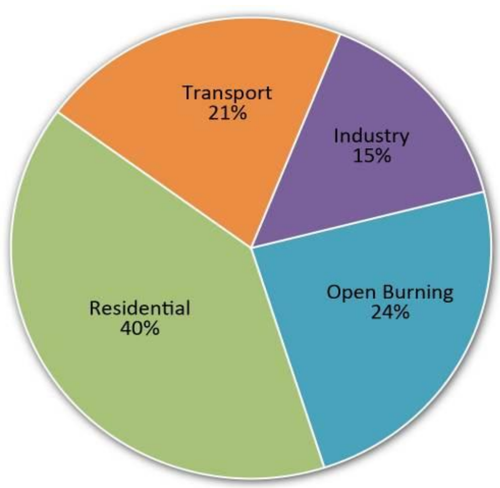

Figure A.3. Sectoral emissions of black carbon in India. Sources: [13, 14, 15].

Appendix B. Climate Impacts of Black Carbon and Co-benefits of Reducing Black Carbon Emissions in South Asia

Black carbon consists of carbonaceous particles that are emitted to the atmosphere as a by-product of the incomplete combustion of biomass, biofuels, and fossil fuels [1]. The chemical composition of black carbon depends on its source and can range from partly charred organic plant residues to fine, nearly pure graphitized carbon particles that result from the combustion of carbon-containing materials, such as coal [96, 97]. Despite this variability, black carbon is generally recognized as the portion of atmospheric carbonaceous particles that absorbs visible radiation [98]. The effects that black carbon can have on climate change and the co-benefits from reducing their emissions in South Asia are discussed below.

Effects of Black Carbon on Climate Change

According to a 2011 UNEP assessment, *Integrated Assessment of Black Carbon and Tropospheric Ozone* [1], black carbon (BC) exists as particles in the atmosphere and is a major component of soot. BC is not a greenhouse gas. Instead it warms the atmosphere by intercepting sunlight and absorbing it. BC and other particles are emitted from many common sources, such as cars and trucks, residential stoves, forest fires and some industrial facilities, resulting from the incomplete combustion of fossil fuels, wood and other biomass. BC particles have a strong warming effect in the atmosphere, darken snow and ice when they are deposited, and influence cloud formation. In addition to having an impact on climate, anthropogenic particles are also known or are suspected of having a negative impact on human health, agriculture, precipitation patterns and the melting of snow and ice in polar regions and snow and ice-covered mountains.

But unlike greenhouse gases such as CO_2, that remain in the atmosphere for decades to millennia, black carbon remains in the atmosphere for only days or weeks. Yet despite its relatively short stay in the atmosphere, black carbon exerts a significant positive radiative forcing and among other things, causes a warming of the atmosphere through a number of different processes. The contribution to climate warming of one gram of black carbon seen over a period of 100 years, for example, has been estimated to be anywhere from 100 to 2000 times higher than that of one gram of CO_2 [1].

According to the UNEP 2011 report, *Near-Term Climate Protection And Clean Air Benefits: Actions for Controlling Short-lived Climate Forcers* [5]," there is a close relationship between emissions of black carbon, a warming agent, and organic carbon, a cooling agent as they are always co-emitted, but in different proportions depending on the source. Similarly, mitigation measures have varying effects on the black carbon/organic carbon mix, and on concentrations of other particles and ozone precursors. Therefore, the effectiveness of mitigation measures applied to different sources must take into account the changes in all emissions that influence warming. Black carbon causes warming of the atmosphere by a number of different processes. These particles absorb visible light due to their dark color. This absorption leads to a disturbance of the planetary radiation balance and eventually to warming. Another impact of black carbon is that when it is deposited on ice and snow it reduces the albedo of these surfaces, increasing both atmospheric warming and the melting rate caused by increased absorption of heat by the darker snow and ice. Black carbon particles also influence cloud formation. The limited level of knowledge of how some of these processes work also leads to a level of uncertainty of the overall effect of black carbon on global warming, that is higher than that, for example, of methane.

Black carbon aerosols have a large impact on regional circulation and rainfall patterns as they cause significant asymmetry in heating patterns over a region [99, 100]. While not fully quantifiable, the impact of black carbon on regional weather patterns and regional warming is more certain than its impact on global warming. This is because, at the global scale, co-emitted species such as organic carbon may offset warming due to black carbon. At the regional scale however, changes are more closely related to atmospheric heating which is dominated by black carbon, and co-emitted species have less of an impact.

Black carbon and organic carbon make up a substantial part of the fine particulate matter in air pollution that is the major environmental cause of ill health and premature deaths, globally [101]. The health-damaging particulate matter is characterized as $PM_{2.5}$, particles with a diameter less than 2.5 micrometers – 'fine' or 'small-sized' particles which affect the respiratory and cardiovascular systems – and its impacts occur due to both outdoor and indoor exposure. The health benefits of reduced emissions from measures that focus on black carbon are mainly achieved by the overall reduction in this fine particulate matter. It should be kept in mind that all reductions of black carbon emissions reduce $PM_{2.5}$ concentrations but all reductions of $PM_{2.5}$ do not necessarily reduce black carbon." [5]

Co-benefits of Reducing Black Carbon Emissions in South Asia

Because of the effects that black carbon particles have both at the ground level locally and in the global and regional atmosphere, a reduction of black carbon emissions can lead to a number of co-benefits in addition to a reduction of adverse impacts on climate change. Examples of the most salient of these co-benefits, each of which has implications for development in South Asia, follow.

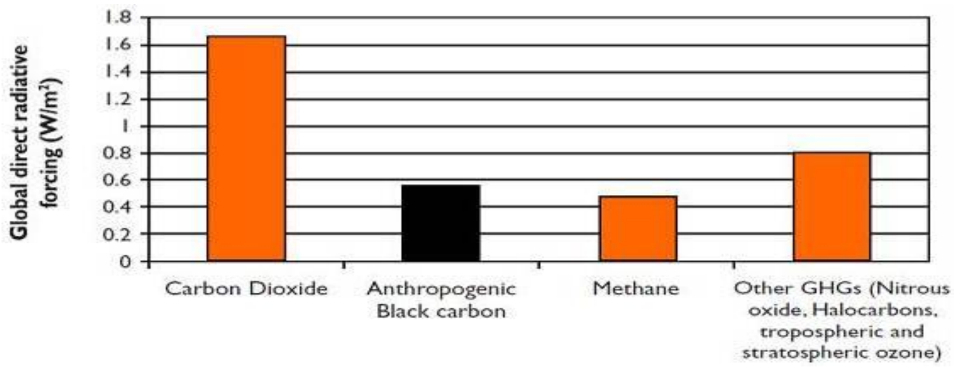

Figure B.1. Contributions of anthropogenic GHG and black carbon emissions to direct radiative forcing at the top of the atmosphere. Source: [2], as adapted by [8].

Reduced Health Impacts

PM, of which black carbon is a primary component, can have severe health effects on exposed populations. Coarse particles that have diameters of less than 10 μm are small enough to be inhaled through the nose and mouth and enter the lungs. However, finer particulates that have diameters of less than 2.5 μm are harder for the body to protect against and clear once inhaled. Studies have linked PM to respiratory irritation (e.g., coughing), aggravated asthma and bronchitis, irregular heartbeat, nonfatal heart attacks, and premature death in people with heart or lung disease, among other effects [103]. The adverse effects on health can be especially severe for populations with pre-existing respiratory conditions, heart disease, and nervous system disorders. Inhalation of PM can occur indoors (e.g., as a result of cooking over an inefficient cookstove) and outdoors (e.g., urban air pollution produced by on-road vehicles).

Black carbon emissions contribute to both indoor and outdoor air pollution. Anenberg et al. [104] estimate that halving global anthropogenic black carbon emissions avoids 157,000 annual premature deaths globally, with India accounting for 31% of the avoided deaths.

The direct health effects are most severe for indoor air pollution. In the 1990s residential fuel use contributed to an estimated 496,000 deaths, more than 448 million illnesses, and over 15.9 million disability-adjusted life years (DALYs) lost annually in India [67].[5] More recent estimates show the number of deaths attributable to IAP growing, with 570,000 Indian deaths attributable to IAP in 2005 [12]. Using efficient cookstoves can help reduce indoor air pollution considerably. According to one study, improved cookstoves reduced indoor PM by 25%–65% [69].

5. "DALYs, or disability-adjusted life years, are a standard metric of the burden of disease. DALYs combine life-years lost due to premature death and fractions of years of healthy life lost as a result of illness and disability" ([67], p. 10).

Outdoor air pollution is also a considerable health threat in much of South Asia. According to one study, more than 80% of the Asian population (close to 3 billion people) is exposed to $PM_{2.5}$ concentrations that exceed the WHO annual mean guideline, in some instances, by more than a factor of four [91].[6] In addition, across all of Asia, one group of researchers estimated that outdoor air pollution in Asia causes nearly 490,000 deaths per year [14]. A 2010 study estimated that anthropogenic $PM_{2.5}$ exposure results in 3.5 ± 0.9 million cardiopulmonary mortalities and 220,000 ± 80,000 lung cancer mortalities annually and Asia accounts for about 75% of the excess mortalities [108]. Reduction of black carbon emissions from the industrial, transportation, and residential sectors can help reduce outdoor air pollution and its adverse health impacts.

Increased Productivity

People who work in industries that produce high levels of black carbon emissions can experience reduced productivity as a result of chronic or acute exposure to black carbon. Because of the health impacts that black carbon emissions can have on humans, reducing black carbon emissions from certain industries can lead to increased worker productivity. For example, a brick-kiln manager might improve the productivity of the company's labor force by increasing the combustion efficiency of the brick kiln, which concurrently reduces black carbon emissions and diminishes adverse health impacts on the kiln operator. In the residential sector, decreasing black carbon emissions and indoor air pollution by using improved cookstoves can lead to decreased sick days and therefore increased household income, and can also reduce the number of hours women and children spend collecting fuel, allowing for additional time spent on microenterprise or schooling.

Reduced Impacts on the Himalayas and Water Resources

Black carbon emissions can impact water resources in South Asia in multiple ways. First, black carbon emissions contribute to general regional warming that leads to increased melting of snow and ice (including glaciers), which alters seasonal water supply patterns in areas that rely on snow or ice melt, including those areas of South Asia dependent on predictable water supplies from the Himalayas [9, 10, 11]. Numerous studies have evaluated the link between South Asian emissions sources and black carbon deposited in the Himalayas and on the Tibetan Plateau. According to one study, snow and ice cover over the Himalayas decreased by almost 1% from 1990 to 2000, with black carbon emissions from India accounting for approximately 30% of this observed change [109]. Combined with emissions from China and Nepal, emissions of black carbon from India account for more than 90% of all black carbon deposited in the Himalayas [93]. India contributes the most substantial portion of black carbon emissions to that

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6. Global models that are used to translate black carbon emissions inventories into estimated surface concentrations (which have implications for public health and radiative forcing) typically underestimate surface concentrations of black carbon by factors ranging from 2 to 10 over India. This is believed to be the result of several factors, including the discrepancies between coarse resolution global models and fine resolution observations in urban areas, underestimation of the emissions' source strength and factors, and improper consideration of aerosol advection and transport properties [105, 106, 107].

region during the months of the pre-monsoonal dry season, when open burning and brick-making activities are most active [93]. In addition to changes in anthropogenic activities that result in increases or decreases in black carbon emissions, natural factors that influence the contribution of South Asian emissions to black carbon deposition on (and loading over) the Himalayas and the Tibetan Plateau include prevailing wind patterns, monsoonal temperature and precipitation trends, and simple proximity [93].

Over the long term, snow and ice melt in the region can have dire consequences for populations dependent on these sources for their water. According to one study, the loss of all Himalayan glaciers would result in reductions of annual water supplies of about one-third in the western Himalayan region [110].

Black carbon emissions can also affect water supplies in the region by reducing the albedo of snow and ice (i.e., reducing its ability to reflect sunlight and thus increasing its propensity to absorb heat). Reduced albedo leads to increased melting of snow and ice in South Asia [111]. Ice core sampling provides evidence that over the past 30 years, and especially since 1990, black carbon concentrations in southern Tibetan glaciers have been increasing, indicating an increase in Asian black carbon sources [112]. A reduction in snow albedo over Tibet has reduced snowpack by 50% in seasonal snow areas due to the snow-albedo feedback and the snow grain size-temperature feedback [113].[7]

Black carbon emissions can also affect water resources by altering rainfall patterns in South Asia because changes in the atmospheric radiation balance caused by black carbon have the potential to influence the Asian monsoon circulation [1]. The emissions of black carbon and other aerosols in Asia give rise to a densely polluted atmosphere over much of the region. This pollution, referred to as the Indo-Asian haze or the Asian Brown Cloud, is most pronounced between December and April, prior to the monsoon rains that flush these pollutants from the atmosphere. However, the density of this polluted layer is significant enough that it may also influence the regional circulation patterns that create the monsoon.

Several studies suggest that black carbon emissions have contributed to changes in the timing and nature of the Indian monsoon. For example, a 2008 study describes that high concentrations of black carbon over South Asia during the dry season because of increased emissions from certain sectors result in increased temperatures in the lower troposphere [115]. Higher temperatures in the troposphere during this season result in increased precipitation (up to a 10% increase during March, April, and May). However, with the onset of the monsoon, the higher temperatures in the troposphere over much of India move northward, resulting in

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7. It is important to note that the notion that increased snow and ice melt in South Asia could result in flooding is incorrect. However, in some instances, flooding could occur as an indirect result of black carbon-induced melting, as in the case of glacial lake outburst floods where water builds up behind the terminal moraine of a melting glacier that ultimately breaks [114].

cooling temperatures over much of the region. This cooling brings reductions in monsoonal precipitation over much of the region [91, 115]. Other studies have found that emissions of aerosols such as black carbon create an “elevated heat pump” effect, whereby a warming of the atmosphere along the southern slopes of the Tibetan Plateau creates a rising air mass, which pulls warm, moist air over India. This circulation reinforces the monsoonal circulation and has the potential to shift the start of the monsoon to earlier in the year [115, 116].

The net effects of black carbon emissions on rainfall are still uncertain and largely dependent on regional specifics. However, it is clear that black carbon has the potential to substantially alter rainfall patterns in South Asia, which could have significant implications for the amount of water available for agricultural and other purposes. Moreover, the implications of reduced water supply for the health of supply-dependent populations should not be overlooked, as changes in water supply can increase vulnerability to nutritional deficiency and disease spread [114, 117]. The implications of these impacts are all the more serious given the fact that large portions of South Asia are projected to be water stressed by 2050 due to other climate change effects not related to black carbon [111].

Reduced Impacts on Agricultural Production

As noted above, black carbon emissions can contribute to changes in water resources by changing snow and ice melt timing and monsoon rainfall patterns. Clearly, these effects have implications for agriculture in many areas of South Asia where agriculture-based populations depend on the predictability of seasonal water supply. Black carbon emissions can also affect agricultural production by reducing the amount of sunlight that reaches the Earth’s surface. Because black carbon in the atmosphere absorbs incoming solar radiation, that radiation is prevented from reaching the surface, a process called “dimming.” According to one estimate, aerosol-induced surface dimming has increased 6% since pre-industrial times in the atmosphere above India and China. This increase in surface dimming has led to reduced photosynthesis productivity [91].

Increased Energy Conservation

As noted above, black carbon emissions are produced as a consequence of incomplete combustion of carbonaceous fuels. Incomplete combustion is an indication that fuel inputs are not producing energy outputs with optimal efficiency. Strategies that improve the efficiency of fuel combustion can therefore achieve black carbon emissions reductions while also reduce the amount of input fuel needed to achieve determined outputs. More-efficient cookstoves, for example, can help reduce the amount of fuel that families need to purchase in order to perform daily cooking tasks. This in turn will reduce the indoor air pollution that is produced by combustion in less-efficient cookstoves. The energy conservation co-benefits can be clearly observed when looking at the transportation sector. For example, it is estimated that improved fleet logistics that reduce black carbon emissions (e.g., reducing vehicle idling) can reduce fleet fuel use by as much as 7% [37]. In the brick-making sector, using best practices to improve the combustion efficiency of a traditional kiln can help save 1 MTOE over the course of one year [30].

Appendix C. Brick Making in South Asia

The following sections provide background information on the brick-making industry in several South Asian countries. Where available, estimates of black carbon emissions from brick making are provided.

India

India comprises approximately 11% of global brick production [118]. Brick-making industry units in India are generally located in clusters. The basic raw material for brick making is clay and the fuel required is coal and biomass. In India, there are more than different 100,000 brick kilns located in peri-urban and rural areas in clusters across the country [119]. It is estimated that these kilns produce about 140 billion bricks every year and that annual demand for bricks in the country will increase to 270 billion bricks by 2020 and 615 billion bricks by 2030 [27]. Brick making is a highly energy-intensive process and consumes about 24 million tons of coal and large quantities of biomass fuels per year [120]. The large-scale brick-making regions in India are shown in Figure C.1.

Several types of brick kilns are being used for firing bricks. The choice of technology depends generally on factors such as scale of production, soil and fuel availability, market conditions, and skills available. The predominant technologies used in India for firing green bricks are Bull's trench kilns and clamp kilns (Figure C.2).

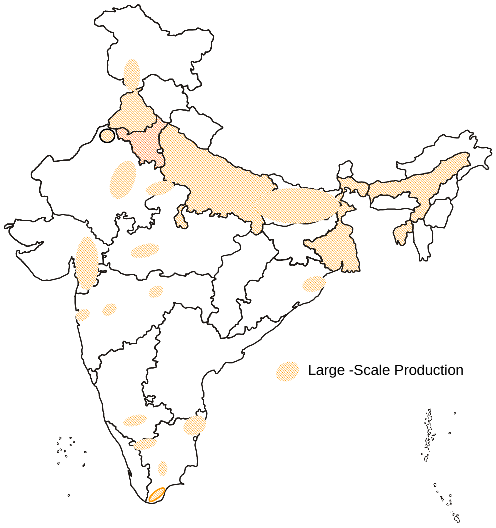

Figure C.1. Prominent brick-making regions in India.

Figure C.2. Clamp kiln.

Existing Emissions Standards for Brick Kilns in India

The Ministry of Environment and Forests issued a notification dated April 3, 1996, on emissions standards for brick kilns. This notification presents standards for maximum allowable suspended PM concentrations in flue gases and minimum stack height for brick kilns (Table C.1).

Table C.1. Emissions standards and stack height regulations for brick kilns

Size	Kiln capacity	Maximum concentration limit of suspended PM (mg/Nm^3)	Stack height
Small	Less than 15,000 bricks per day [less than 15 ft (4.6 m) trench width]	1,000	Minimum stack height 22 m (or) induced draft fan operating with minimum draft 50 mm WG with 12-m stack height
Medium	15,000 to 30, 000 bricks per day [15 to 22 ft (4.6–6.7 m) trench width]	750	Minimum stack height 27 m with gravitational settling chamber or induced draft fan operating with minimum draft 50 mm WG with 15 -m stack height
Large	More than 30,000 bricks per day [more than 22 ft (6.7 m) trench width]	750	Minimum stack height 30 m with gravitational settling chamber (or) induced draft fan operating with minimum draft 50 mm WG with 17-m stack height

Note: The above emissions limits are achievable by installing fixed chimney/high-draft kilns and/or settling chambers.

Source: [121].

Estimates of Black Carbon Emissions from Brick Kilns in India

Overall, it is estimated that brick making in India accounts for approximately 60% of black carbon emissions from the industrial sector in that country and 9% of black carbon emissions from all Indian emissions sources [16, 17, 18].

Emissions from conventional clamp kilns in India can be very high. According to one study, suspended PM from clamp kilns ranged from 117 mg/Nm^3 to nearly 4,000 mg/Nm^3, which is well above the emissions standards [120]. Fortunately, emissions can be reduced using certain control systems. Under a study supported by the Central Pollution Control Board, Government of India, TERI [30] performed a detailed stack emissions monitoring and ambient air monitoring of Bull's trench kilns with gravity settling chambers in different geographical locations in India.

The gravity settling chamber design in India is provided by (1) the Punjab State Council for Science and Technology, (2) the Central Building Research Institute, and (3) the Aligarh Muslim University. The stack emissions levels from all three designs after the pollution control system is installed (i.e., gravity settling chamber) are below the existing emissions standards of 750 mg/Nm^3 for brick kilns having capacities of more than 15,000 bricks per day. The monitored emissions levels are shown in Table C.2.

Table C.2. Stack emissions levels from various gravity settling chamber designs in Bull's trench kilns

	Suspended PM (mg/Nm^3)	
Design	**Minimum**	**Maximum**
Punjab State Council for Science and Technology	113	514
Central Building Research Institute	143	486
Aligarh Muslim University	226	463

Source: [30].

The minimum and maximum emissions levels also indicate that the three pollution control systems are close to the 500-mg/Nm^3 level, which is well below the existing emissions standards for brick kilns (i.e., 750 mg/Nm^3). However, no estimates were made during this study to determine the black carbon emissions associated with the various gravity settling chamber designs in Bull's trench kilns.

Table C.3. Stack emissions of different types of brick kilns

	Stack emissions (mg/m^3)		
Kiln type	**Suspended PM**	**SO_2**	**NO_x**
Bull's trench kiln moving chimney	1,675		
Bull's trench kiln fixed chimney	500–1,040	17	32
Bull's trench kiln fixed chimney with settling chamber	141–187	14	27
High-draft kiln	270–300	26	32
Zig-zag natural draft	296–370	10	23
Vertical shaft brick kiln	78–80	106	1.9

Source: [30].

Using Pollution Control Systems in Brick Kilns

The use of pollution control systems in brick kilns helps control and reduce emissions. In India, the 1996 notification by Ministry of Environment and Forests made it mandatory to use gravity settling chambers in Bull's trench kilns, which has helped reduce emissions (Table C.3).

Bangladesh

Clay-fired bricks are one of the most widely used building materials in Bangladesh. The brick-making industry in Bangladesh employs close to 1 million people and accounts for approximately 1% of the country's gross domestic product [26]. The 2005–2006 annual production of bricks was estimated to be 15 billion bricks from an estimated 5,000 kilns operating in the country [26]. Table C.4 identifies the market share of different brick-firing technologies in Bangladesh. As the table shows, the predominant technology is the fixed-chimney kiln – similar to the Bull's trench kiln in India – which is a highly inefficient firing technology. Table C.4 also shows that energy-efficient vertical shaft brick kilns have not yet been deployed in Bangladesh because of concerns about the quality of the bricks compared to those produced using conventional Bull's trench kiln technology [26].

Table C.4. Share of market for key brick-firing technologies in Bangladesh

Kiln type	Number	Percent of total kilns	Brick production[a] (billions)	Percent of total brick production
Fixed-chimney kiln	3,123	75.4	9.4	75.8
Bull's trench kiln[b]	794	19.2	2.0	16.1
Zig-zag bull's trench kiln	197	4.8	0.7	5.7
Hoffman kiln	26	0.6	0.3	2.4
Total	**4,140**	**100**	**12.4**	**100**

a. Based on an average for each type: Fixed-chimney kiln – 3 million; Bull's trench kiln – 2.5 million; zig-zag Bull's trench kiln – 3.5 million; and Hoffman kiln – 12 million.

b. Bull's trench kilns haven been banned in Bangladesh [26].

Source: [122].

The brick industry in the country has grown by the classic replication principle of copying one brick from the other. As a result, there is practically no variation in kiln design or operation. There is some size variation in the fixed-chimney kiln (same as the Bull's trench kiln in India), but the standard size, which constitutes approximately 80% of the total, produces about 3–4 million bricks per year. In remote areas, some kilns produce fewer than 3 million bricks, while some larger kilns close to large urban centers are capable of producing up to 6.5 million bricks per year.

Presently, there are several initiatives underway in Bangladesh to improve brick-firing technologies in the country. For example, the Bangladesh Department of Environment is undertaking a project to study emissions from different types of brick-firing technologies and evaluating emissions reduction options. In addition, the World Bank is funding a project to review vertical shaft brick kiln technology application in Bangladesh and the Global Environment Facility is funding a project that involves using coal-fired tunnel kilns.

Use of firewood for brick making is banned in Bangladesh. However, a survey conducted under a project funded by the Global Environment Facility found that nearly all kilns use some quantity of firewood, which contributes to deforestation [122]. Use of low-grade coal as a supplementary fuel in brick firing is estimated at about 2.2 million tons. Coal used in the brick industry is imported from India. A few brick kilns located near natural gas grids use natural gas as fuel.

Relevant Environmental Regulations in Bangladesh

The Department of Environment has established regulations for minimum stack height for the fixed chimneys used in brick kilns, which is 38.1 m. The permissible emissions standard for total suspended PM from brick kilns is 1,000 mg/Nm^3. However, there is no regulation for provision of pollution control systems in brick kilns.

The nationwide environment and energy performances of brick kilns have not been monitored in Bangladesh, and this may be the reason for the absence of comprehensive environmental regulations for brick kilns. Samples taken during one particular study revealed that suspended PM concentrations from moving-chimney Bull's trench kilns in Bangladesh can reach up to 2,000 mg/Nm^3, which is double the standard [26]. However, ambient air quality standards are available for Bangladesh, and ambient air quality for industrial areas would be applicable for brick kilns as well. There is also a provision for separate "Environmental Courts" in Bangladesh, which handle cases related to brick kilns.

Nepal

Presently, there are an estimated 500 moving-chimney brick kilns and 200 Bull's trench kilns in Nepal [123]. These kilns produce more than 1.4 billion bricks each year, consuming more than 200,000 tons of coal annually and emitting more than 8,000 tons of particulates annually [23].

Kilns are located mostly in the Kathmandu Valley, with some in the *terai* region, which is a belt of marshy grasslands, savannas, and forests between the Himalayan foothills and the Indo-Gangetic Plain. Major brick clusters in the Kathmandu Valley are Bhaktapur, Lalitpur, and Kathmandu. Brick kilns in Nepal range from small clamp kilns to large-scale Hoffmann kilns.

According to the *Status of Brick Kilns in the Kathmandu Valley* there were nine clamp kilns (Thado Bhatta), 3 Hoffmann kilns (Chinese Bhatta), and 113 Bull's trench kilns (Chimney Bhatta) in the valley [124]. Most of the bricks (87%) are produced from the Bull's trench kilns. All other kilns, except Hoffmann, use sawdust, fuel-wood, and rice husk as fuel. In the Kathmandu Valley, coal consumption is 10–13 tons of coal per 100,000 bricks. The brick industry in the Kathmandu Valley is estimated to consume 50,000 tons of coal per year and is probably the largest consumer of coal in the country.

During 2000, TERI performed detailed energy and environmental monitoring of Bull's trench kilns in Nepal. The stack emissions monitoring results are presented in Table C.5.

Table C.5. Stack emissions monitoring results

#	Type of brick kiln	Suspended PM (mg/Nm^3)	SO_2 (mg/Nm^3)	NO_x (mg/Nm^3)
1	Moving chimney – Bull's trench kiln	570–1,440	160–1,126	44–107
2	Fixed chimney – Bull's trench kiln	99–241	164–657	15–43

Source: [30].

Appendix D. Black Carbon Emissions from On-Road Fleets in South Asia and Current Initiatives to Reduce Emissions

The following sections provide background information on black carbon emissions from the transportation sector in South Asia, focusing on emissions from on-road fleets, as well as information on several current initiatives to help reduce these emissions.

Black Carbon Emissions from the Transportation Sector

Emissions from the transportation sector come from both on-road (e.g., passenger vehicles and freight trucks) and off-road (e.g., shipping, aviation, and rail) sources. Globally, it is estimated that road transportation sources account for approximately 16% of all black carbon emissions, while off-road transportation accounts for 9% [125]. On-road transportation sources typically have higher black carbon emissions factors than non-road sources. According to an inventory of black carbon emissions from a range of combustion sources, diesel-fueled vehicles produce between 1.3 and 3.6 g of black carbon per kilogram of fuel combusted, while rail and shipping sources produce only 0.51 and 0.34 g per kg of diesel fuel combusted, respectively [15].

Black carbon emissions from private and public sector fleets (e.g., on-road freight and other goods-carrying vehicles) are of particular interest because the trucks that make up these fleets generally have higher emissions factors than nearly all other vehicle types (with the exception of buses; [32]). For example, in India the average PM emissions factor for trucks is estimated to be 0.28 g/km, compared to 0.05 g/km, 0.2 g/km, and 0.03 g/km for two-wheelers, light passenger vehicles, and cars/jeeps, respectively [32]. This difference is explained in part by the differences in fuel types. Trucks and non-passenger light vehicles (i.e., those used for transporting goods) typically operate on diesel fuel, while two-wheelers, light passenger vehicles, and cars/jeeps typically use gasoline, which produces less black carbon per kilogram combusted [32]. As shown in Table D.1, diesel fuel accounts for an increasing percentage of overall fuel used in the transportation sector in several key Asian countries. Overall, heavy-duty trucking (which includes most fleet vehicles) accounts for approximately 11% of all black carbon emissions in India and more than half of all black carbon emissions from the transportation sector in that country [16, 17, 18].

In addition, on-road fleets account for the majority of all freight transport in South Asia. With continued increases in consumptive activities in the region, freight transport is expected to continue to increase as well. Figure D.1 shows the percentage of total freight activity accounted for by on-road trucking in several South Asian countries.

Table D.1. Percentage of diesel in the transportation sector fuel mix		
Country	**1980**	**2005**
Bangladesh	73.3%	79.0%
China	13.4%	40.2%
India	55.0%	66.4%
Pakistan	71.4%	84.1%
Philippines	17.6%	54.4%
Thailand	52.2%	68.6%
Vietnam	15.5%	55.6%
Source: [38].		

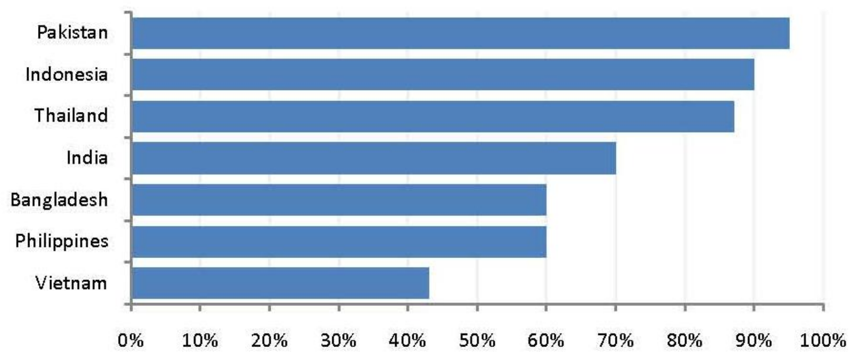

Figure D.1. Percentage share of road transport in total freight activity in selected Asian countries. Source: [38].

Appendix E. Improved Cookstove Production Models in South Asia

There are several models for producing improved cookstoves, including centralized mass production at a few facilities, centralized production in local factories, and artisanal production [74]. The advantages of the centralized mass production model are that it ensures a greater degree of quality control and can enable quick ramp-up of production to meet demand. The disadvantages of this system are that it does not always consider differences among local users, does not increase jobs at the local level, requires substantial capital investment, produces stoves that tend to be higher priced, and incurs increased shipping charges. Centralized production at the local level involves the use of molds and prefabricated parts to assemble stoves locally. The advantages of this method are that it increases local employment, considers local preferences, and produces moderately priced stoves. However, quality control is not as high as with the previous method. The third production model is also referred to as artisanal production where local artisans are trained to build better mud stoves. The advantages of this model are that it improves the local economy and offers the most affordable stove, but quality control is the lowest among the different models.

Many large-scale initiatives emphasize central construction of stoves. Understandably, durability and quality control are important for effective mitigation of black carbon. However, past experience has shown that users often revert to old technologies rather than replace new technologies as time goes on (particularly if the initial program is subsidized). Centrally manufactured stoves that do not receive user input at the local level may not necessarily fit the needs of all users due to variance in local cooking practices or preferences. Additionally, an ongoing concern with centrally manufactured stoves is that they lack the local economic benefits that come from local production. A variety of studies support a local production model [67, 68, 126, 127]. However, differences between the two production models, central and local, can be resolved through quality-control strategies, such as using molds and sourced materials and certifying stoves [67].

Appendix F. List of Participants from the Kathmandu Consultation

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10. Stephanie Borsboom, The World Bank, Nepal
11. Carina Cabrido, Clean Air Network Nepal, Nepal
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35. Joe Madiath, Gram Vikas, India
36. Sameer Maithel, Greentech Knowledge, India
37. Anjila Manandhar, Clean Energy Nepal, Nepal
38. Fan Meng, Chinese Research Academy of Environmental Sciences, China
39. Vijaykumar. H. Mistry, Ahmedabad Municipal Corporation, India
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41. C.P. Muthanna, Environment and Health Foundation, India
42. T. Nakajima, The University of Tokyo, Japan
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48. Upmanyu Patil, Swayam Shikshan Prayog, India
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50. Pratikshya Pradhan, Center for Rural Technology, Nepal
51. Sophie Punte, Clean Air Initiative for Asian Cities (CAI-Asia) Center, Philippines
52. V. Ramanathan, University of California, San Diego, USA
53. Darrell Reeve, Cleaner Production Australia, Australia
54. Ibrahim Hafeez Rehman, The Energy and Resources Institute (TERI), India
55. Heather Adair Rohani, Consultant to World Health Organization, Switzerland
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65. Yuolanda Tibbs, U.S. Environmental Protection Agency, USA

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67. Sushma Upadhyay, Ministry of Environment, Nepal

68. Chandra Venkataraman, Indian Institute of Technology, India

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