

RAISING AWARENESS AND MOBILIZING ACTION



BLACK CARBON FINANCE STUDY GROUP REPORT 2015

A work led by



WORLD BANK GROUP



**CLIMATE &
CLEAN AIR
COALITION**
TO REDUCE SHORT-LIVED
CLIMATE POLLUTANTS

About

At its high-level assembly in September 2013, the Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants (CCAC) commissioned the Black Carbon Finance Study Group (BCFSG) “to review potential strategies for supporting financial flows toward projects that can significantly reduce black carbon emissions.” Consultations with CCAC Partners further specified the BCFSG’s mandate as being to develop financing mechanisms that can deliver results in the near term to demonstrate and build momentum for scalable approaches to black carbon finance. As a co-leader of the CCAC Finance Initiative, the World Bank was designated to lead and facilitate the BCFSG. This activity was co-led by Eduardo Ferreira and Megan Meyer.

The BCFSG convened between July 2014 and April 2015, bringing together 43 international experts with scientific, policy, and finance backgrounds to design approaches to catalyzing investment in black carbon abatement. Through this process, the BCFSG identified both overarching and specific opportunities for action and formulated strategies for achieving results in the near term.

This report of the BCFSG was drafted on behalf of the study group by Emilie Cassou with input from Gary Kleiman, Eduardo Ferreira, Megan Meyer, Sameer Akbar, and Scott Cantor. It conveys the general sentiment of the study group, and the drafters have made every effort to reflect the range of views expressed by expert group members (listed in the appendix) though it does not necessarily reflect the views of individual members. Moreover, experts participated in the study group in a personal capacity and this report does not intend to represent the views of the organizations with which they are affiliated.

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About the CCAC

The Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants (CCAC) is a voluntary global partnership of governments, intergovernmental organizations, businesses, scientific institutions, and civil society committed to catalyzing concrete, substantial action to reduce SLCPs including methane, black carbon, and many hydrofluorocarbons. The coalition works through collaborative initiatives to raise awareness, mobilize resources, and lead transformative actions in key emitting sectors.

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Acronyms and Abbreviations

ABC	Atmospheric brown cloud
ACCESS	Africa Clean Cooking Energy Solutions
ADALY	Averted disability-adjusted life year
AMC	Advance market commitment
BC	Black carbon
BCFSG	Black Carbon Finance Study Group
BIX Fund	Base of the Pyramid Exchange Fund
C2P2	Climate Credit Pilot Project
CACCI	Central America Clean Cooking Initiative
CCAC	Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants
CDM	Clean Development Mechanism
CER	Certified emission reduction
Ci-Dev	Carbon Initiative for Development
CO₂	Carbon dioxide
CO₂-e	Carbon dioxide-equivalent
DALY	Disability-adjusted life year
DPF	Diesel particulate filter
EAP CSI	East Asia and Pacific Clean Stove Initiative
EnDev	Energising Development
EPA	Environmental Protection Agency
ESMAP	Energy Sector Management Assistance Program
EU	European Union
FCPF	Forest Carbon Partnership Facility
GACC	Global Alliance for Clean Cookstoves
GDP	Gross domestic product
GEF	Global Environment Facility
Gg	Gigagram (1,000 metric tons)
GGFR	Global Gas Flaring Reduction Partnership
GHG	Greenhouse gas
HAPIT	Household Air Pollution Intervention Tool
HDDI	CCAC Heavy Duty Diesel Initiative
HHK	Hybrid Hoffman kiln
ICCI	International Cryosphere Climate Initiative
ICIMOD	International Centre for Integrated Mountain Development
IFC	International Finance Corporation
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standards
LPG	Liquid petroleum gas

NO_x	Nitrogen oxides
PAF	Pilot Auction Facility
PAH	Polycyclic aromatic hydrocarbon
PCFV	Partnership for Clean Fuels and Vehicles
PM	Particulate matter
PM_{2.5}	Particulate matter of 2.5 micrometers in diameter or less
RBF	Results-based finance
REDD	Reducing Emissions From Deforestation and Forest Degradation
SCAR	Social cost of atmospheric release
SIDA	Swedish International Development Agency
SLCP	Short-lived climate pollutant
SNAP	Scenario National Action Planning
STAP	Scientific and Technical Advisory Panel
STIF	Short-term integrated forcing
ULSD	Ultra-low sulfur diesel
UN	United Nations
UNEP	United Nations Environment Programme
USAID	United States Agency for International Development
EPA	Environmental Protection Agency
VER	Verified emission reduction
VOC	Volatile organic carbon
VSBK	Vertical-shaft brick kiln
WHO	World Health Organization
WMO	World Meteorological Organization

Executive Summary

Black carbon abatement can play an instrumental role in curbing climate change and improving public health outcomes—and that role is unique in its capacity to deliver multiple benefits and near-term results. Because black carbon is short-lived in the atmosphere, the rapid implementation of abatement measures in the agriculture, residential, transportation, industry, and energy sectors will lead to a range of near-term health, climate, and other benefits.

Yet despite these benefits, an array of black carbon abatement measures that are technically within reach have not been financed and deployed to their full potential. Possible interventions include reducing emissions from the burning of flared gas, forests, crop residues, and various fuels that power residential activities, transportation, and industrial processes.

Efforts to curb climate change to date—including those driving climate science, finance, policy, and diplomacy—have largely focused on greenhouse gas emissions, and rightly so. Presently, however, complementary efforts are urgently needed to reduce emissions of black carbon and other short-lived climate pollutants on a wide scale. Recognizing the need to accelerate and scale up black carbon abatement, the Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants (CCAC) established an expert group facilitated by the World Bank—the Black Carbon Finance Study Group (BCFSG)—to identify approaches that will catalyze investment for this purpose, while maximizing near-term climate and health benefits.

Finance for black carbon abatement needs to be customized for specific interventions within key sectors. The nature of black carbon precludes the exact replication of approaches that have been developed to finance the abatement of greenhouse gas emissions across sectors. One important distinction is that tons of averted black carbon emissions cannot universally be used to assess and compare health or climate impacts across interventions. This is because one ton of black carbon emitted in one sector and in one location may have very different climate and health consequences than one ton of black carbon emitted in another sector or in another location.

Encouragingly, a number of existing funds—both funds with sector-specific mandates such as clean energy and green cities, and others with broader climate- and health-related mandates—are already in a position to finance businesses, activities, technologies, and policies that will contribute to cutting black carbon emissions. Several black carbon-rich sectors identified in this report are sufficiently mature to absorb finance, and the availability of funds and financial instruments are not necessarily limiting factors when it comes to directing finance to black carbon abatement activities within these sectors.

Moreover, performance measurement tools are sufficiently advanced in certain sectors to direct finance on their basis. However, existing funds often lack an explicit mandate, and in some cases the performance measurement tools, to privilege, prioritize, or even track investments based on their contributions to black carbon abatement.

A central message of this report is that public and private financiers can and need to adopt black carbon performance measurement to direct new and existing financial flows to cleaner (i.e., lower-black carbon) technology. This shift can start today in sectors where investment is already occurring and where black carbon performance measurement tools are nearly or already in place (as in the municipal transportation and clean cooking spaces). Meanwhile, continued efforts are needed to strengthen the performance measurement tools and enabling environment that will make it possible to channel finance for black carbon abatement on a wider scale.

This report presents two sets of strategies to mobilize finance for high-impact black carbon abatement activities. Those in Part 1 of the report are sector-specific and aim to accelerate investment in the near term. These primarily highlight opportunities to accelerate investment in the residential cooking and diesel sectors, although Part 1 also touches upon brick kilns, kerosene lighting, agricultural burning, and oil and gas flaring.¹ The strategies in Part 2 cut across sectors and aim to unlock finance for black carbon abatement on a larger scale over time.

Sector-specific Strategies to Accelerate Investment in the Near Term

In the residential cooking sector, continue to develop black carbon performance standards; and adopt these as a basis to invest in and build the private sector's capacity to commercially supply cleaner (i.e., lower-black carbon) technology. This can build on existing efforts, notably those surrounding the development of ISO performance standards and guidelines. Hundreds of millions of dollars are already flowing into the residential cooking sector to usher in cleaner fuels and more modern technologies, but very few of these investments are occurring with specific consideration for their impact on black carbon. As a result, those dollars are bypassing cooking solutions with the potential to deliver both near-term health and climate benefits (e.g., the use of liquefied petroleum gas or LPG, ethanol, biogas, electricity, solar energy, and advanced combustion of solid biomass). The use of performance standards in screening potential investments will allow funds to deliberately target or prioritize activities that lead to black carbon abatement—and, more specifically, to related health, climate, and other benefits. Instruments such as concessional loans, grants, and potentially patient equity can support supply chain investments ranging from manufacturing capacity to business administration, marketing, design and testing, and distribution capacity. In addition, loan guarantees and advance market commitments can help reduce investment risk to bring more commercially oriented lenders to the table.

Implement innovative results-based payment programs to widen the distribution of lower-black carbon cooking fuels and equipment. Results-based payments can provide revenues beyond those the market will support, bridging the gap between the price at which suppliers can sell and households can buy cleaner technology. By making financing contingent on results, this approach shifts risk from donors to project developers and technology distributors, ultimately attracting private risk-capital to the sector. This concept has proven successful in the past, notably in the context of carbon markets. Using it to encourage black carbon abatement calls for the development of innovative approaches in which payments are made against measurable climate or health outcomes (e.g., changes in global temperature, near-term climate forcing, premature deaths, or a dollar indicator of multiple impacts) or outputs (e.g., number of stoves distributed, or emissions reduced).

¹ The study group took as its starting point five emitting sectors defined in broad alignment with the CCAC's Sectoral Initiatives: agriculture-related open burning, residential energy, transportation, industry (especially brick kilns), and oil and gas flaring. It then identified leading abatement opportunities in each of these, and further narrowed these down using two broad lenses: the impact on climate and health, and the opportunity to catalyze finance in the near term.

In the transportation sector, competitively offer economic incentives that factor in black carbon performance to accelerate the early adoption of soot-free diesel technology in countries or cities where technology transition is under way. Development finance institutions can deploy concessional loans and grants—possibly a loan- or grant-backed revolving loan fund—to economically incentivize diesel vehicle owners to transition to lower-soot or soot-free engines. Results-based finance instruments can be used in a complementary fashion to incentivize the adoption and continued maintenance of diesel abatement technology. To determine the efficient level of incentive, funding can be allocated on a competitive basis, such as via reverse auction. In practice, funds can flow through designated national authorities to municipalities, private fleet owners, and other beneficiaries.

Fund policy development and institutional strengthening efforts to support regulatory change. To complement the financial incentives described above, concessional loans or grants can be deployed to support the development and implementation of policies that require, incentivize, and enable the transition to cleaner technology. In the diesel sector, investment in black carbon abatement technology is unlikely to scale up in the absence of public sector intervention to compel technology transition (e.g., in the name of social and economic development, public health, or climate change mitigation).

Tailor black carbon financing strategies to other priority sectors of intervention. As relates to brick kilns, accompany market-led sector modernization by supporting access to finance, supply chain development, market linkages, and regulatory incentives, while supporting regulatory change. **As concerns kerosene lanterns,** support the development of a commercial market for kerosene- and kerosene lantern-substitutes, and in some contexts, energy policy reform. **To increase investment in alternatives to the burning of agricultural residues,** including conservation agriculture practices, support access to finance to purchase or lease needed farm equipment; raise awareness of applicable techniques and their benefits; and incentivize behavior change. In certain contexts, support the regulation of open burning and compliance. **And to spur investments that reduce emissions from oil and gas flaring,** support policy and regulatory change and, where applicable, demonstrate how climate finance can nudge industry to invest in potentially lucrative yet overlooked abatement opportunities.

In developing further strategies, build on those identified in this report. In summary, where commercial forces are already being harnessed to carry clean technology² forward, as in the residential cooking sector, finance based on black carbon performance standards and innovative results-based payment programs can stimulate markets to better focus these efforts on solutions that are cleaner with respect to black carbon specifically. And in sectors where a lower-black carbon future depends more heavily on regulatory requirements, as in the diesel sector, concessional and results-based finance can speed up the transition to soot-free technology in places where regulatory action is already under way. In parallel, readiness grants and policy loans can support and strengthen national institutions to bring about the regulatory change needed for large-scale abatement to occur.

² Clean technology is used in a broad sense here to include incrementally cleaner fuels as well as more efficient processes or devices even if they are not necessarily cleaner with respect to black carbon.

Practical steps that can be taken immediately to implement these strategies include the following

In the context of residential cooking and diesel transportation:

- Continue to fund and support the development and use of black carbon performance standards (such as the emerging ISO standards for cookstoves, and PM_{2.5} for diesel) to direct capital—within existing or new funds—toward cleaner cooking and vehicle technology. Investors need black carbon performance standards to screen investments so as to ensure that these will reduce black carbon emissions and achieve the sought after benefits (e.g., climate or health).
- Demonstrate innovative approaches to results-based finance that can widen the distribution of cleaner (i.e., lower-black carbon) technology. While results-based finance has proven successful in increasing the distribution of efficient technology (e.g., cookstoves that are more thermally-efficient though not necessarily cleaner from a black carbon perspective), its potential to drive black carbon abatement associated with measurable health and climate benefits still needs to be demonstrated to investors.
- Design and pilot the use of a reverse auction mechanism that competitively allocates incentives for diesel-fueled municipal buses, service vehicles, and machinery to undertake upgrades that lead to black carbon abatement (those incentives can cover capital and other associated costs).

More broadly across all black carbon-rich sectors:

- Analyze the landscape of relevant sources of climate, health, and other development finance that can be channeled to abatement interventions using the identified financing strategies; and define the financial structures and institutional arrangements capable of channeling these funds. Such mapping will help to identify potential resources for concessional and results-based finance that can be directed on the basis of black carbon performance (namely using emerging performance standards).
- Identify, for sector-specific abatement interventions, a pipeline of abatement projects that can be implemented in the near term, along with associated funding and technical assistance needs.
- Assess opportunities and constraints for financing reductions in black carbon emissions from brick kilns, kerosene lanterns, the burning of agricultural residues, and oil and gas flaring. Adapt and tailor strategies to accelerate finance in these sectors, building on those identified in this report.

Cross-cutting Strategies to Scale Up Black Carbon Finance over Time

Streamline and unify black carbon performance measurement. The ability to make targeted investments in black carbon abatement rests on the availability of solid and accepted performance measurement tools to define, estimate, and assess all forms of return on investment. Performance measurement tools are necessary, for example, to determine eligibility for concessional loans and grants, to trigger result-based payments in the context of results-based finance, and to analyze the implications of different investment options using social cost analysis. The BCFSG sees a specific need for the adoption of universal impact indicators; for continuous work on intervention-specific estimation models; and for the elaboration of a framework to guide the development of accounting methodologies.

Mainstream black carbon into development finance, systematically incorporating it into investment decision making. This has the potential to harness the vast sums invested in black carbon-emitting sectors to bring about wide-scale change over the long term. Development finance institutions have several options to do this. One option is for development finance institutions to offer sovereign borrowers more concessional loan terms for choosing to follow a low-black carbon pathway. Another is to offer them development policy loans and grants to finance the elaboration and implementation of policies that contribute to transforming a particular sector. Yet another option is for development finance institutions to make use of social cost analysis, thus factoring into their investment decisions the multiple costs and benefits of black carbon and its abatement (alongside those of its co-pollutants).

Practical steps that can be taken immediately to implement these strategies include the following

- Convene a group of 10–15 black carbon science and finance experts to reach consensus on and recommend the indicator (or indicators) on the basis of which black carbon performance shall be measured and financed across sectors.
- Task the group with developing a standardized approach for determining and communicating estimation uncertainty to financiers (using risk ratings or other approaches), as well as other guidance on the development of black carbon accounting methodologies.
- Initiate a dialogue on mainstreaming black carbon among development finance institutions, to determine and coordinate appropriate approaches.

The Time to Act Is Now

It bears repeating—black carbon abatement has an instrumental role to play in slowing the rate of climate change and reducing the burden of disease in the near term. This report identifies opportunities to take action now to save lives, to slow global and regional climate change, to promote sustainable development, and to build the capacity to finance black carbon abatement on a broader scale. It is the BCFSG's expectation that donors and financiers will deploy coordinated and complementary efforts to pursue these opportunities in a way that aligns with their respective business models, priorities, and resources.

CONTEXT

I. Why Black Carbon Finance?

Black carbon (BC) is a short-lived climate pollutant (SLCP) and its emissions are a major contributor to near-term climate change, with notable effects on monsoon patterns as well as snow- and ice-melt. Black carbon affects the climate by absorbing solar radiation, changing surface albedo, and affecting cloud brightness, emissivity, and lifetimes. It is one of the most important human emissions in the present-day atmosphere in terms of its climate forcing (Bond et al 2013). Black carbon is also a component of fine particulate matter, or PM_{2.5}, which is among the most significant contributors to local and regional air pollution. Exposure to fine particle pollution causes illness and death from heart and lung disease in adults and children; and while there is still uncertainty regarding the health impacts of specific components of particulate matter, recent research indicates that black carbon plays a role in these adverse health effects.

Black carbon abatement has an instrumental role to play in curbing climate change and improving public health outcomes—and that role is unique in its capacity to deliver near-term results. Because black carbon is short-lived in the atmosphere, the rapid implementation of abatement measures offers a range of near-term health and climate benefits. Where population exposure is high, actions taken to reduce exposure to air pollution mixtures containing black carbon may directly reduce the burden of disease (van Erp et al. 2012). Cutting black carbon emissions can also slow the rate of climate change, reducing sea-level rise, preserving snow- and ice-covered regions of the planet, mitigating the regional disruption of rainfall patterns, and reducing the risk of crossing thresholds that may activate climate feedbacks in the coming decades (e.g., from greenhouse gas emissions associated with melting permafrost).³ Maintaining these climate benefits, however, will require concerted action to reduce emissions of carbon dioxide (CO₂) and other greenhouse gases (GHGs). Other benefits of black carbon interventions include improved agricultural yields, economic growth, and employment. Annex 1 provides a primer on the science of black carbon; Annex 2 provides an overview of black carbon emissions by sector, source, and region.

³ Slowing the rate of climate change will lessen its impacts on disease vectors, agriculture, and biodiversity, provide greater time for adaptation to climate change, and lengthen and improve quality of life.

BOX 1. Black Carbon Abatement Can Deliver Multiple Near-term Benefits While Complementing Ongoing Climate Change Mitigation Efforts

More than 7.5 million metric tons of black carbon are emitted each year, more than 45 percent from the use of residential biofuels and diesel engines (Bond et al. 2013). Prior studies (Ramanathan and Xu 2010; UNEP 2011) have shown that there is significant benefit to eliminating black carbon emissions to the maximum extent possible. The rapid reduction of black carbon emissions along with co-emitted components of particulate matter could avert approximately 0.18–0.19°C of warming by 2050 (Rogelj et al. 2014, Shindell et al. 2012). Reducing SLCPs with 16 measures targeting methane and black carbon can prevent more than two million deaths annually from outdoor air pollution and hundreds of thousands more from indoor air pollution by 2030 (UNEP and WMO 2011). Moreover, efforts to abate these pollutants can, in many cases, lead to complementary reductions in greenhouse gas emissions (Rogelj et al. 2014). An optimal approach to climate change mitigation, recent analysis suggests, may involve a hybrid approach that abates emissions of greenhouse gases and SLCPs simultaneously (Shoemaker et al. 2013).

Despite these multiple benefits, an array of black carbon abatement measures that are technically within reach across several sectors have not been financed and deployed to their full potential. Some of these measures suffer from a lack of private investment given unattractive risk-return profiles or the public good nature of their returns. They also suffer from a lack of public sector intervention. Moreover, the slow diffusion of even those abatement measures that are financially attractive highlights a host of other barriers, including hidden transaction costs, low liquidity, limited access to finance, a lack of knowledge of or ability to measure the economic and other benefits of mitigation, insufficient

local technical and institutional capacity, and challenging legal and regulatory environments.

Achieving black carbon abatement on a scale that will yield significant climate, health, and other benefits will require tailored policy interventions and financing mechanisms that directly target black-carbon-rich emission sources. Black carbon abatement is today largely financed indirectly, in pursuit of other objectives; as a result, it is not being achieved on a wide scale in many parts of the world. It is, for instance, a co-benefit of certain efforts to reduce urban air pollution (such as PM_{2.5}) and even, in some cases, greenhouse gases.⁴ Yet these mitigation measures often do not systematically or comprehensively reduce black carbon emissions.

II. Vision for Catalyzing Black Carbon Finance

Driving the BCFSG's mandate is the perspective of stimulating investment in replicable black carbon abatement projects to achieve impact in the near term. Of equal importance is the desire to build the foundations for investment to scale up over time: approaches to financing black carbon abatement that are more streamlined and applicable across sectors, geographies, and contexts. This report identifies opportunities both to take action now to save lives and slow global and regional climate change, and to build the capacity to tackle black carbon pollution more comprehensively going forward.

Vision for Near-term Impact

The guiding vision of the BCFSG is to stimulate near-term investment in specific intervention areas that offer important near-term health and climate benefits at the global level. Indeed, the multiple benefits of black carbon abatement are sufficiently understood today to not only justify immediate investment in a range of abatement measures but also to underpin dedicated funding streams targeting specific abatement interventions.⁵ For example, the expected health and climate benefits of instituting diesel emission controls are both strong and well established, and some can be readily measured by existing performance measurement tools that have already been adopted by programs targeting diesel engines around the world.⁶

⁴ For example, efforts to curb greenhouse gas emissions from forest burning, traditional forms of cooking and heating, and oil and gas flaring can, in some instances, reduce black carbon emissions.

⁵ This is the case, for instance, where performance measurement tools are already in place or at an advanced stage of development.

⁶ See Bond, T. C., et al. 2013. "Bounding the Role of Black Carbon in the Climate System: A Scientific Assessment." *Journal of Geophysical Research: Atmospheres*, 10.1002/jgrd.50171. This is subsequently referred to as the "bounding black carbon study." Also see Janssen, N., et al. 2012. "Health Effects of Black Carbon." World Health Organization.

Vision for Scaling Up

The vision for scaling up black carbon finance over time—enabling finance to flow to a wider number and range of abatement interventions—is to bring focus to black carbon finance as a whole and, in the process, make investment in black carbon abatement more straightforward, familiar, reliable, and attractive to financiers of all kinds. This vision follows the need to develop financing approaches that are congruous with what sets black carbon apart from greenhouse gases. That precludes the exact replication of approaches that have been developed to finance the abatement of greenhouse gases across sectors.

One important distinction of black carbon is that tons of averted emissions cannot universally be used to assess and compare health or climate impacts across interventions (though tons of emissions can be used to estimate impacts within certain sectors). This is because one ton of black carbon emitted in one sector and in one location may have very different climate and health impacts than one ton of black carbon emitted in another sector or in another location.⁷ Finance for black carbon abatement will thus need to take into account this pollutant's intricacies, and to some degree be customized for specific abatement interventions. There is, however, scope for developing cross-cutting approaches that create a coherent basis for financing black carbon abatement across emission sources, and time and space.

III. A Bottom-up Approach

In order to identify pathways toward the above vision for black carbon finance, the study group adopted a bottom-up approach that involved exploring strategies to catalyze finance on a sector-by-sector basis. Early consultations emphasized the need to accelerate near-term investment and maximize impact, and guided the study group to focus primarily on identifying opportunities for action at the sector level.

Grappling with sector-level challenges, meanwhile, led the BCFSG to uncover a number of more broadly relevant insights. While much of this report is devoted to presenting strategies to directly increase investment in near-term, sector-level abatement interventions, it also presents a number of cross-cutting strategies to increase investment over time.

⁷ The impacts of black carbon—in contrast to those of GHGs, which can be expressed in terms of CO₂-equivalence—are not proportional to the quantity emitted; rather, they vary according to context. Indeed, the overall effects of black carbon abatement are significantly influenced not only by co-emitted species but also by the timing and location of emissions. (See Annex 1 on the science of black carbon.)

A Two-sector Focus

To make best use of resources, the study group identified and focused on several sector-level abatement priorities, honing in on two black carbon sources in particular: residential cooking and diesel engines. The study group took as its starting point five emitting sectors defined in broad alignment with the CCAC's Sectoral Initiatives: agriculture-related open burning, residential energy, transportation, industry (especially brick kilns), and oil and gas flaring. It then identified leading abatement opportunities in each of these (see Annex 3), and further narrowed these down using two broad lenses: the impact on climate and health, and the potential to catalyze finance in the near term. With respect to impact, the study group considered several criteria, including the effects of abatement on temperature (and its potential to cause unintended short-term warming), the monsoon, the cryosphere, and premature mortality. To grapple with different options' readiness for finance solutions, the study group discussed barriers to realization, potential revenue models and financing tools, and signs of momentum and appetite for investment.

Presentation of the BCFSG's Recommendations

This report presents what the BCFSG sees as both overarching and specific opportunities to substantially increase investment in activities that will result in beneficial black carbon abatement. While this report focuses primarily on broad opportunities and specific strategies to catalyze investment related to residential cooking and diesel engines, all major black carbon-emitting sectors were discussed, and the report also offers recommendations for next steps in other priority areas. Each section lays out a set of strategies that can be pursued in the near term, as well as practical next steps that can be taken to implement these. It is the BCFSG's expectation that donors and financiers will deploy coordinated and complementary efforts to pursue these in a way that aligns with their respective philosophies, priorities, and resources.



PART 1

Direct Financial Flows to Sectors Where Impact and Momentum Are High to Accelerate Their Shift to Lower-Black Carbon Technology

The BCFSG recommends that finance be directed to black carbon abatement in sectors where (a) expected impacts on climate and health are significant; and (b) momentum for change is high and already mobilizing significant resources—through the use of concessional and results-based finance based on black carbon performance.

This opportunity to mobilize finance for black carbon abatement at the sector level reflects the specific strategies the study group identified in considering the financing challenges that beset clean cooking, diesel, and other priority interventions. The BCFSG identified three sets of sector-level strategies to catalyze black carbon finance in the near term. They are to:

- Build the capacity of commercial markets to diffuse cleaner cooking technology with finance based on black carbon performance, including concessional finance and results-based payment programs.
- Accelerate technology transition in the diesel sector through concessional and results-based finance, while supporting regulatory change.
- Tailor black carbon finance strategies to other priority sectors.

This section describes these strategies and how they can be implemented. Although the first two are tailored to the specific circumstances and challenges of the residential cooking and diesel sectors, several of the proposed instruments and approaches could be adapted and applied to other sectors. The section ends by offering some practical steps for moving forward.



Strategy 1: Build the Capacity of Commercial Supply Chains to Diffuse Cleaner Cooking Technology with Finance Based on Black Carbon Performance

The Opportunity

Residential cooking and heating are among the largest sources of global black carbon emissions—second only to open burning.⁸ Clean cooking and related residential energy solutions offer vast potential for reducing black carbon and other emissions known to increase mortality and morbidity—disproportionately among women and

⁸ Bond et al. 2013, the “bounding black carbon study.”

children⁹—and to contribute to global warming, regional monsoon disruption, and snow- and ice-melt (see Box 2).

There is considerable institutional momentum in this sector to address critical design, behavioral, operational, and financial barriers associated with the broad diffusion of cleaner cooking fuels and technologies, albeit seldom ones that specifically cut black

⁹ In absolute terms, a larger number of men die from stove smoke exposure than women—but smoke exposure is a relatively higher risk factor for women.

BOX 2. Health and Climate Impacts of Black Carbon and Particulate Emissions from Residential Cooking

The residential sector is the second largest source of black carbon emissions. Global residential black carbon emissions were estimated at between 1,720 Gg and 2,480 Gg in 2000 (based on Bond et al. 2013). Sector emissions of black carbon are primarily linked with the residential burning of biomass, but also other solid fuels, for cooking and heating. Some three billion people in the developing world—representing nearly half the world’s population—burn solid fuels such as wood, dung, coal, charcoal, and crop residues in traditional stoves and open fires for these purposes (U.S. EPA report to Congress 2012). Asia is the dominant source region for residential emissions, although the use of wick lanterns and solid biomass fuels is also prevalent in Africa.

The World Health Organization (WHO) estimates that exposure to household smoke from cooking constitutes the fourth leading risk factor for disease in developing countries, and causes 4.3 million premature deaths per year—more deaths than those attributable to malaria or tuberculosis (WHO 2014). Tens of millions more suffer from related, preventable diseases, including pneumonia (which affects children), lung cancer, cardiovascular disease, stroke, and chronic obstructive pulmonary disease, which includes emphysema and bronchitis (WHO 2014). In Asia and Africa in particular, household air pollution is the second biggest health risk factor for women and girls (Institute for Health Metrics and Evaluation 2010).

Residential cooking also contributes significantly to ambient outdoor air pollution. In 2010, household cooking with solid fuels accounted for 12 percent of ambient PM_{2.5} globally, varying from zero percent in five high-income regions to 37 percent¹ in

¹ 2.8 µg/m³ of 6.9 µg/m³ total

southern sub-Saharan Africa. This caused the loss of 370,000 lives and 9.9 million disability-adjusted life years globally in 2010 (Chafe et al. 2014). The global adoption of leading cookstove measures² could avert 1.2–1.6 million premature deaths annually by 2030 due to reduced ambient air pollution alone, according to one study (World Bank/ICCI 2013).³

On a global average basis, the impact of residential biomass combustion on the climate is uncertain given the variation in the impacts of black carbon and co-emitted pollutants in different geographical regions. However, climate impacts on the cryosphere (snow and ice regions of the planet) from this source category are quite clear. Some of the largest source regions are close to the Hindu Kush-Himalayan-Tibetan and East African highland regions where significant deposition on snow and ice occurs. Moreover, the replacement of traditional cooking technology with clean-burning alternatives could yield among the most significant reductions in global black carbon emissions. For both of these reasons, a recent study that modeled the impact of nine different abatement interventions on the climate in the cryosphere found residential cooking interventions to offer the greatest potential for slowing near-term warming in each of the five largest snow and ice regions, relative to the other modeled interventions (WB/ICCI 2013).⁴

² The measures are fan-assisted cookstoves, pellet woodstoves, and coal briquettes in coal stoves.

³ This does not factor in accidental fire-related deaths. An estimated 195,000 burn deaths occur annually (GACC).

⁴ A replacement of all current biomass cookstoves (all traditional wood or dung stoves globally) by clean-burning stoves using biogas (50 percent) or LPG (50 percent) would reduce radiative forcing by an estimated average of 1.39 W/m² across the five cryosphere regions (World Bank/ICCI 2013). Further research is needed, however, to better understand the role of various black carbon-rich sources near the Andean Range.

carbon emissions. In addition, various performance measurement tools that are tailored to this sector are at an advanced stage of development and testing (see examples in Boxes 4, 6, 7 and 15). Importantly, the focus and direction of many of these efforts highlight the growing understanding that cleaner cooking solutions can, to a large extent, be delivered through commercial channels. Through the 1990s, efforts supporting the diffusion of clean cookstoves were mainly subsidy-based. Today, there is a consensus that commercially sustainable approaches are preferable. Donors and international development agencies can support these by investing resources in awareness-raising, marketing, promotion, and other activities that generally stimulate the development of clean cooking markets (GIZ 2014).

The Challenge

Despite the substantial opportunity for mitigation and existing momentum to bring about wide-scale change in this sector, many previous efforts to modify cooking practices have faced significant barriers on both the supply and demand sides. Common challenges have included a broad and dispersed customer base (i.e., households, community organizations); limited awareness of the serious health risks associated with current practices; poorly adapted technologies that do not conform to consumers' needs or preferences or that lend themselves to improper usage; limited infrastructure to support fuel-switching; limited access to finance on the consumer and

producer sides¹⁰; weak supply chains; and a lack of scale to achieve sustainable commercialization. Ongoing efforts to catalyze cleaner cooking solutions have also generally been driven by the pursuit of health, energy, GHG, and other benefits without an explicit black carbon focus, and technology that has been deployed in pursuit of these benefits has not often achieved substantial reductions in black carbon emissions. Meanwhile, few funders are willing to take risks on innovations for which there is no ready-made market.

The Applicability of this Strategy

The study group discussed these wide-ranging challenges and identified two strategies that will help deploy health and climate finance synergistically to build commercial markets for cleaner cooking solutions, and to specifically accelerate the sector's move toward technology that reduces black carbon. These strategies could potentially apply, fully or selectively, to other abatement opportunities in the residential energy sector (e.g., heating, kerosene lighting) and other sectors of intervention that face similar financing challenges (e.g., brick kilns, agricultural residue burning). Considering that the businesses which offer clean cooking solutions often also cater to broader household energy needs, including lighting and heating, the strategies and specific financial instruments discussed below could be designed in ways that also stimulate the commercial production and distribution of other technology that contributes to reducing residential black carbon emissions.

¹⁰ When it comes to consumer finance, a key constraint is the small size of transactions. These are often below the threshold at which microfinance becomes available.

STRATEGY 1A: Enable Supply Chains to Deliver Low-Black Carbon Cooking Technology by Enhancing Access to Capital on the Basis of Performance Standards

The proposed strategy involves deploying a suite of concessional finance instruments (see Box 3) to support the development of commercial supply chains for cleaner cooking technology. The need for concessional funds to support supply-side actors is based on their general lack of access to finance on commercial terms (due to a lack of collateral, track record, and financial sophistication, and financiers' limited understanding of the sector's risk/return profile). This is particularly true when it comes to supplying solutions that are effective at reducing black carbon emissions (e.g., forced convection stoves or liquefied petroleum gas), as these do not necessarily sell at a sufficient premium to make up for the higher costs of supplying them compared to technologies that economize fuel but do little to reduce black carbon emissions. The expectation is that, in the long run, financial support will accelerate the development of a

commercially viable market for clean cooking solutions—at which point the need for donor intervention will cease.

The Financial Instruments

The following are examples of concessional finance instruments that could be deployed to support commercial supply chains supplying cleaner cooking solutions with respect to black carbon.

Concessional loans and grants, and potentially patient equity, could support supply chain investments ranging from manufacturing capacity to business administration, marketing, design and testing, and distribution capacity. By reducing investment risk, loan guarantees and advance market commitments could help bring more commercially-oriented lenders to the table; this will expand the pool of available funds in an investment environment where

BOX 3. Concessional Finance Instruments

Concessional finance refers to finance extended on terms that are substantially more generous than those generally available from commercial financiers, in pursuit of goals that go beyond the realization of private financial returns. A variety of financial instruments (e.g., debt, securities, trade credits, deposits) can be offered on concessional terms. The following are examples of concessional finance instruments.

- **Concessional debt** designates lending that involves lower interest rates, or longer grace periods, than are available commercially (for a given level of risk).
- **Patient equity** refers to a form of investment in which the provider of capital expects to realize a given level of return over a longer period of time than it could expect in financial markets or from a commercial investment. Patient investors are usually willing to forego maximum financial returns in recognition of social or environmental returns.
- A **loan guarantee** is a promise, usually by a third party to a credit transaction, to assume a borrower's debt obligation (in full or in part) in the event of default. The purpose of guarantees is to stimulate lenders and borrowers to engage in credit transactions when either or both parties' risk perceptions would otherwise prevent them from doing so.
- An **advance market commitment (AMC)** is a binding contract used to guarantee a viable market for a product yet to be developed or commercialized. AMCs have primarily been used to incite the development of vaccines and drugs for neglected diseases or less affluent markets. In the context of clean cooking, they can enable suppliers to quickly scale up production, helping to both stimulate and respond to demand for new technology—and to build a commercial market. An AMC seeking to bring lower-black carbon cookstoves to a specific market could, for example, guarantee businesses willing to manufacture and commercialize stoves meeting minimum specifications (i.e., that ensure a given level of performance in terms of black carbon emissions, or in terms of health or climate impact) the ability to recoup part of their investment and/or service a related business loan (e.g., a loan used to build out manufacturing capacity). An AMC contract could also establish that, over a set period of time, suppliers that fail to meet pre-established sales targets despite bona fide efforts to do so will be paid the difference between the market price and a guaranteed price (e.g., prices prevailing in similar markets), or a fixed per-unit payment, on up to a maximum number of units (e.g., unsold units or units sold at a discount).

lending is otherwise stymied by risk perceptions as much as by actual risk, and by a lack of familiarity on the part of lenders with the sector and its stakeholders. Early-stage grant funding could be deployed strategically to help accelerate the identification of a broader pipeline of eligible projects for funds to target. It can also be used to help support proposal development.

Eligibility for funding or investment through any of these instruments would hinge, at a minimum, on meeting pre-established, technology-agnostic performance standards that specify, among other things, target emission rates for black carbon—and potentially for other pollutants as well (e.g., PM_{2.5} more broadly, organic carbon, carbon monoxide, methane, and other pollutant precursors). The use of performance standards in screening potential investments would allow funds to deliberately target or prioritize activities that lead to black carbon abatement—and, more specifically, to related health, climate, or other benefits.

Establishing performance standards for this purpose calls for empirical evidence linking emission rates to results. In the case of cookstoves, performance standards need to be calibrated or used in such a way as to account for significant differences in the performance of different cooking technologies depending on whether

they are tested in a laboratory setting or used in people's homes. Box 4 describes recent and ongoing efforts to develop cookstove performance standards.

Funds with an explicit or implicit mandate to mitigate climate change or preventable disease could benefit in several ways from systematically incorporating black carbon performance standards into investment screening. First, the use of performance standards can reduce transaction costs involved in screening investments by simplifying due diligence tests relating to an investment's climate or health impacts—these impacts being particularly complex to determine in the case of black carbon. Second, the use of performance standards that have been widely vetted by the scientific community can increase a fund's transparency, vis-à-vis its investors, with regard to the impact of its investments. Third, screening investments on the basis of performance standards can decrease fiduciary and reputational risk. It can provide fund executives with stronger assurances that their investments are in alignment with the fund's mandate—whether or not that mandate explicitly refers to upholding given performance standards—and that they have taken bona fide precautions to prevent investments from resulting in unintended harm.

BOX 4. Cookstove Performance Standards Under Development

Performance standards for cookstoves are in a phase of rapid development as multi-stakeholder efforts are progressing to establish standards that are broadly accepted and accessible. A central effort in this regard is that driving the development of ISO¹ standards for cookstoves.

Partners of the Global Alliance for Clean Cookstoves, together with the International Organization for Standards (ISO), in 2012 developed a framework for rating the performance of cookstoves. The ISO International Workshop Agreement *Guidelines for Evaluating Cookstove Performance*² rates cookstoves as belonging to one of five tiers (0–4) in four domains of performance. One of these is indoor emissions (made up of PM_{2.5} and CO), a dimension of direct relevance to health outcomes. The other domains of performance are fuel use, total emissions, and safety. The thresholds used to

define tiers of performance for indoor emissions were derived by linking emission rates to levels of exposure, taking into consideration the World Health Organization's 2005 indoor air quality guidelines.³

Forthcoming ISO standards for cookstoves will encompass more areas of performance and include emission rate thresholds for a broader set of pollutants including black carbon and organic carbon. At the time of writing, an ISO technical committee on clean cookstoves and cooking solutions was overseeing the development of both laboratory and field testing methodologies to establish thresholds that are consistent with a specified level of health and climate performance.

¹ The International Organization for Standards (ISO) is an independent, nongovernmental membership organization and leading developer of voluntary international standards.

² The ISO International Workshop Agreement, IWA 11:2012, *Guidelines for Evaluating Cookstove Performance*, was a product of broad stakeholder consultation orchestrated by the Partnership for Clean Indoor Air, the Global Alliance for Clean Cookstoves, and the American National Standards Institute.

³ In 2014, the World Health Organization updated its household (indoor) air quality guidelines. In addition to addressing indoor concentrations of pollutants, these now include emission rate targets for PM_{2.5} and CO. Like the ISO thresholds, these targets are based on observed impacts of indoor concentrations on health. It is important to note that many cleaner cooking technologies do not achieve the WHO's interim targets and may not reduce pollution to the point of significantly reducing the health risks associated with indoor exposure. Such interventions may nonetheless have substantial health benefits that are worthy of finance due to their effect on ambient outdoor air pollution when implemented on a large scale.

Capitalization

A number of existing funds are already in a position to target businesses, activities, and technologies that contribute to black carbon abatement going forward. These include several funds and facilities that have been established to support investments in clean cooking supply chains using one or a combination of the financial instruments described above. Examples include the Global Alliance for Clean Cookstoves Spark Fund, the Global Alliance-Deutsche Bank Working Capital Fund, the BIX Fund, USAID's Development Credit Authority, and the Swedish International Development Agency, which are using grants, loans, pre-finance, and loan guarantees to support investments in residential energy and clean cooking supply chains. Box 8 describes their activities in further detail.

A number of funds with broader mandates related to climate or health may also be in a position to finance supply chain actors whose investments will result in black carbon mitigation. These funds do not at this time, however, explicitly privilege, prioritize, or even track projects that contribute to black carbon abatement. In order to direct more funds to black carbon abatement projects—and attract additional capital for this purpose—existing fund managers may consider (1) adopting the use of black carbon performance standards in their investment screening process; and (2) creating

and administering a dedicated black carbon window within an existing fund already under their management.

As an alternative or complement to the above approach, a new, black carbon fund could be created to raise capital expressly for those clean cooking projects which lead to black carbon abatement. The fund could (1) directly invest in the clean cooking supply chain; or (2) invest in existing funds (as described above). This may be an attractive option if concessional investors are keen to create momentum for black carbon abatement through a new vehicle; if investor backing of black carbon-abating projects exceeds existing funds' absorption capacity; or if existing investment funds are precluded by their investors or bylaws from focusing on black carbon.

Support for such funds would primarily involve sovereign donors, foundations, and impact investors. Commercial financiers, including private equity investors, could play a role once viable business models have been identified and investor returns sufficiently documented. Commercial financiers will favor high-growth market opportunities with potential for significant upside in order to be compensated for the risk exposure that comes with such investments.

Prerequisites

For this strategy to succeed, black carbon performance standards need to be finalized with input from financiers, scientists, and policy makers—and supply chain actors need to have the desire and

capacity to absorb and make productive use of funds. In addition, the demand side of the market needs to be sufficiently stimulated or supported to justify increased supply side capacity; this is what Strategy 1b addresses.

STRATEGY 1B: Stimulate the Diffusion and Use of Low-Black Carbon Technology through Results-based Payment Programs Targeting Clean Stove or Fuel Distributors

The proposed strategy involves offering distributors results-based payments that provide them revenues beyond those the market will support to get cleaner technology into use. Many households employing traditional methods of cooking are unable or unwilling to pay a commercially viable price for cleaner cooking devices and fuels—particularly those that are effective at reducing black carbon emissions. The reasons include the high cost, competing household priorities, low exposure to and appreciation of cleaner technology, limited awareness of the health benefits, cookstove designs that do not match user needs, and entrenched cooking habits.

The lack of households' willingness or ability to pay for the full cost of devices and fuels that reduce black carbon emissions leads to limited distribution; this in turn limits opportunities for distributors and other entities within the supply chain to realize economies of scale and bring down costs. It also prevents households from potentially discovering the value of cleaner technology through direct experience with its use. By helping to bridge the gap between the prices at which suppliers can sell and households

can buy cleaner cooking technology, results-based payments are intended to help the market emerge from this impasse. By making financing contingent on results, moreover, this strategy shifts risk from donors to project stakeholders to more readily attract risk-capital. (See Box 5 on how results-based payment programs have supported clean cooking supply chains in the past.)

The Financial Instruments

As the words “results-based payments” suggest, distributors receive payments against results, the nature and measurement of which are defined at program onset. In principle, results are defined by funders' objectives and by what can reasonably be measured by the recipient of funds. Provided results are measurable, payments could be made against climate or health *outcomes* (e.g., changes in global temperature, near-term climate forcing, or premature deaths) or against measurable *outputs* (e.g., number of stoves distributed, or

BOX 5. Building the Supply Chain Using Results-based Payments: Lessons from Carbon Finance

Carbon finance is a form of results-based finance meant to incentivize greenhouse gas emission reductions by attaching a price to them. (Carbon in this context refers to greenhouse gases and not to black carbon.) Although not its primary purpose, carbon pricing played a pivotal role in strengthening clean cooking supply chains in the late 2000s, prior to prices plummeting due to a fall in demand for tradable emission reductions (specifically compliance-grade ones).

In 2012, at least four million clean cookstoves were distributed annually with the financial support of voluntary carbon markets.¹ This outcome suggests that results-based finance

mechanisms, including payments for black carbon abatement benefits, may have a continued role to play in stimulating market expansion going forward.

The potential for results-based payments to aid the development of commercial clean cooking markets presupposes a degree of willingness to pay for results—however these are defined—on the part of public or private sector stakeholders. Looking forward, a few actors are forging ahead on the premise that the multiple benefits of black carbon abatement are in demand and that robust measurement protocols will serve to attract more funds and more buyers.

Boxes 6 and 7 illustrate how results-based payment programs are being piloted to stimulate the commercial distribution of clean cooking technology.

¹ Ecosystem Marketplace for the Global Alliance for Clean Cookstoves. “2012 Results Report: Sharing Progress on the Path to Adoption of Clean Cooking Solutions”; and Ecosystem Marketplace and Bloomberg New Energy Finance. “Maneuvering the Mosaic: State of the Voluntary Carbon Markets 2013.”

BOX 6. Paying for Health Impacts Based on ADALYs.

In the Lao People's Democratic Republic, the World Bank is working with several partners¹ to assess the feasibility of a mechanism that monetizes health benefits resulting from the adoption of cleaner cooking technology—specifically technology associated with lower PM_{2.5} and black carbon emissions. Payments will be made based on averted disability-adjusted life years (ADALYs) for women and children, estimated based on third-party verified reductions in household particulate matter and carbon monoxide pollution, and computed using the

¹ These include C-Quest Capital, the University of California (Berkeley), Berkeley Air, SNV, the Lao Institute for Renewable Energy, and the Lao PDR government.

Household Air Pollution Intervention Tool (HAPIT). HAPIT calculates and compares health benefits attributable to stove or fuel programs that reduce exposure to household air pollutants resulting from solid fuel use in traditional stoves in developing countries. Its outputs include ADALYs attributable to an intervention by diseases category. The project is exploring the possibility of linking payments for ADALYs with payments for carbon credits using the CDM cookstove methodology (i.e., for reductions in CO₂-e) but without the need for CDM project registration. The project has already conducted surveys on the social acceptability of the improved cooking technology on a small scale.

BOX 7. Paying for Climate Impacts based on the Global Warming Potential of SLCPs

Project Surya's Climate Credit Pilot Project (C2P2)¹ in India has created a fund to reward customers who purchase and use improved biomass cookstoves based on direct monitoring of improved stove use via cellular sensing technology. Stove users receive payments on the basis that the switch to improved cooking technology mitigates climate change by reducing emissions of both CO₂-e and SLCPs, including black carbon. To become eligible, households must adopt stoves that meet a

¹ C2P2 is funded by Mac and Leslie McQuown, the UK Department for International Development (DFID), and the Qualcomm Wireless Reach Program. Project Surya has been supported by the National Science Foundation, DFID, and the Vetlesen Foundation. Partners include but are not limited to the Scripps Institution of Oceanography at the University of California at San Diego, the Energy Resources Institute, and Nexleaf Analytics.

number of criteria related to thermal efficiency and emissions performance that imply a ceiling on black carbon emissions. Monthly payments to households are then made on the basis of the climate benefits, expressed in tons of CO₂-e, that are estimated to result from the actual, monitored use of these stoves. The calculation of benefits factors in data on hours of usage and fuel consumption (monitored and transmitted via cell phones equipped with temperature sensors), energy efficiency, and reductions in multiple pollutants (including black carbon and cooling agents like organic carbon). The calculation also incorporates India-specific climatological data on daylight hours, cloud fractions, vertical profiles of black carbon, and other factors.

emissions reduced). One possible approach to results measurement that combines outcomes and outputs would involve initially verifying that a set of technologies, as tested in the field, performs to a given standard for a specific health or climate indicator (e.g., reduces black carbon emissions beyond an established threshold)—and then paying against the estimated uptake and continued use of these vetted technologies using established methodologies. This would likely involve vetting technologies and measurement tools for use in a given geographic and social context (see Boxes 6 and 7). The challenges of results measurement, and possible ways forward, are discussed further in Part 2.

A key feature of results-based payments is that they do not dictate how their beneficiaries—in this case, distributors—are to use the additional cash. The payments instead intend for market

players to freely determine, for instance, how to price and mark-up stoves, whether to invest in consumer finance schemes, and how much to invest in marketing and distribution. That said, since results-based payments do not meet the need for up-front financing (given that they are only paid after sales have been completed), they can be combined with concessional debt or grants—or commercial finance—from other sources. Signed, long-term contracts for results-based payments can help recipients (e.g., distributors) secure up-front financing as illustrated in Box 8.¹¹

¹¹ The newly created BIX Fund will, for example, offer debt-financing to value chain actors that anticipate revenues from a range of donor-funded, results-based payment programs.

Capitalization

While existing results-based finance funds or facilities such as the World Bank's Carbon Initiative for Development (Ci-Dev) and Pilot Auction Facility (PAF), described in Box 8, may be able to channel results-based cash payments to distributors that achieve black carbon abatement, establishing a specialized window within an existing fund—or a new fund—may help ensure that funding flows to projects that reduce black carbon emissions. Grants could also be used to support upstream technical work to develop or calibrate metrics, to develop methodologies, and even to originate projects.¹²

¹² The CCAC is currently developing and calibrating standardized protocols for measuring emissions and co-benefits in the brick sector. This effort is expected to have significant impact in terms of mobilizing finance for abatement projects in the sector.

These instruments or funds could be capitalized by a variety of sources, including donors (using funds earmarked for climate or health), host country governments (in the name of reducing public health costs), private companies (with environmental, social, and corporate governance objectives), foundations, and impact investors.

Prerequisites

For this strategy to succeed, distributors must be in a position to address the constraints that hold back demand and, if necessary, to secure up-front financing. In addition, supply chains must have the capacity to meet increased demand, something that is addressed by Strategy 1a. This strategy also requires that performance measurement tools be developed and accepted for use in results measurement.

BOX 8. Examples of Existing Clean Cooking Funds or Facilities that Could Potentially Target Black Carbon Abatement

Example Involving Grants: The Spark Fund

The Global Alliance for Clean Cookstoves Spark Fund provides investment-like growth capital and capacity development support to help enterprises reach commercial viability, scale, and ultimately unlock additional investments for future growth. The Spark Fund has already successfully awarded two rounds of venture grants (in 2012 and 2013) totaling \$4 million.

The Spark Fund targets the specific capital and capacity development needs of social enterprises that have passed proof-of-concept, are at the venture or growth stage, and are focused on the commercial scaling of their operations. As such, enterprises supported by Spark are:

- Market-based, commercially viable enterprises.
- Venture- or growth-stage enterprises that are generating income but are not yet mature enough to access growth capital from traditional investment sources.
- Scalable enterprises with the potential to make a significant contribution to the Alliance's goal of enabling 100 million households to adopt clean and efficient cooking technologies and fuels by 2020.

Each year, the Spark Fund awards a total of \$2 million in grants and capacity development services to at least six qualifying enterprises via two distinct application categories: Spark Venture and Spark Growth. Spark Venture provides selected earlier stage enterprises with grants of up to \$300,000 each. Spark Growth provides selected later, growth-stage enterprises with grants of up to \$500,000 each. Funding is disbursed in

at least three tranches over the course of 12 months and upon successful completion of performance milestones.

Example Involving Loans: The Working Capital Loan Fund

Deutsche Bank's global social finance team has long been active in defining opportunities for private capital to help drive meaningful and scaled solutions to global challenges. Through its partnership with the Global Alliance for Clean Cookstoves (GACC), Deutsche Bank came to appreciate the need for a loan facility that could serve the working capital needs of a variety of enterprises serving the clean cookstove sector. The Clean Cooking Working Capital Fund was created in tandem with the GACC to invest in earlier-stage companies that design, manufacture, distribute, and finance clean cookstoves and fuels that have reached the point at which they are ready for debt financing. This is a high-risk fund that was designed as a pilot to prove the potential of these social enterprises to build traction in their local markets, and that this can lead toward sustained profitability. The GACC has laid the foundation for the fund's success by supporting the development and growth of clean cooking enterprises that have the potential to be scaled up.

The Clean Cooking Working Capital Fund is a \$4 million not-for-profit loan fund (\$2 million initial capitalization via grants and investments followed by a subsequent \$2 million in fund replenishments). The fund will deploy working capital loans and loan guarantees to enterprises that are not able to access more traditional forms of debt financing. This fund will make available 3–5 year flexible financing of \$100,000–400,000 with interest rates of less than 10 percent. The aim is to operate

the facility for 7–10 years, and to grow and adjust it over time based on the needs of the sector as it continues to mature.

Example Involving Pre-finance: The BIX Fund

The Base of the Pyramid Exchange Fund, or BIX Fund, catalyzes the use of impact certification mechanisms (such as the voluntary carbon credit market) to improve the availability and affordability of essential energy products for low-income households in emerging markets. Among other things, it provides upfront finance to social enterprises looking to deliver and monetize social and environmental impact. The finance is repaid as these impacts are monetized. Pre-finance must be used to improve the availability and affordability of the product that is responsible for impact (such as clean cookstoves or solar lights). This can be achieved by enabling producers to lower prices to stimulate demand and achieve economies of scale; enhance value chain margins and credit terms for distributors and retailers to open new sales channels; or stimulate product innovation through research and development, and monitoring and evaluation.

Examples Involving Loan Guarantees: USAID's Development Credit Authority and SIDA's

The U.S. Agency for International Development's (USAID) Development Credit Authority uses partial credit guarantees backed by the U.S. Treasury Department to mobilize local financing in developing countries. Credit guarantees, backed by the United States and others, encourage private lenders to extend financing to under-served borrowers in new sectors and regions. In November 2014, USAID and the Swedish International Development Agency (SIDA) launched a facility that will guarantee up to \$100 million in private financing to support the deployment of household technology products—including cookstoves, solar lanterns, and water filters—to households around the world that lack access to basic services. This transaction involves private-sector partners AlphaMundi, the Calvert Foundation, and Signina Capital. USAID estimates that \$25 million of this facility will go toward financing clean cookstoves and cooking fuels.

USAID is also structuring a second guarantee facility to mobilize an additional \$100 million in private financing exclusively targeting manufacturers and distributors of clean cookstoves and cooking fuels. This new financing package, co-guaranteed by SIDA, will support new lending from anchor

financial partners Deutsche Bank and the Bank of America, as well as from other institutional investors. Paired with technical assistance from the Global Alliance for Clean Cookstoves and its partners, this facility has the potential to significantly increase availability of commercial capital for the growth of enterprises operating along the clean cookstove and cooking fuel value chains.

Examples Involving Results-Based Finance: The World Bank's Ci-Dev and Pilot Auction Facility

The Carbon Initiative for Development (Ci-Dev) is a \$125 million fund that seeks to increase low-carbon energy access in the world's poorest countries by offering carbon-linked, results-based finance (RBF) utilizing the Clean Development Mechanism (CDM). Ci-Dev was, at the time of writing, reviewing projects that would contribute to clean cooking, including ones involving cookstove and household biogas digesters. Most of these programs will be implemented by private companies planning to invest hundreds of millions of dollars in underlying activities. Furthermore, these programs, are expected to deliver millions of tons of greenhouse gas emission reductions and broad social, environmental, and health co-benefits.

The Pilot Auction Facility (PAF) is an innovative climate finance model developed by the World Bank Group to stimulate investment in projects that reduce greenhouse gas emissions while maximizing the impact of public funds and leveraging private sector financing. Its results-based payment mechanism will set a floor price for future carbon credits in the form of a tradable put option that will be competitively allocated via auction. The PAF will disburse its resources only against independently verified emission reductions, using existing carbon auditing standards such as the CDM or voluntary standards such as the Verified Carbon Standard or Climate Action Reserve. This pay-for-performance feature can be attractive to governments facing funding pressure and scrutiny with respect to their achievements. The combination of an auction process and payments based on performance maximizes value for public money. The PAF is backed by Germany, Sweden, Switzerland, and the United States. The facility has a capitalization target of \$100 million. In its first phase, it will support projects that cut methane emissions at landfill, animal waste, and wastewater sites facing low carbon prices. The facility has the potential to be scaled-up and used to finance other climate pollutants besides methane.

Strategy 2: Accelerate Technology Transition in the Diesel Sector with Concessional and Results-based Finance while Supporting Regulatory Change

The Opportunity

Broad abatement potential exists in the diesel sector, primarily via the adoption of diesel particulate filters (DPFs) in conjunction with cleaner engines and low-sulfur fuel, but also through diesel substitution and the switch to alternative fuels.¹³ Reducing black carbon emissions in this sector can yield some of the most certain, significant, and measurable¹⁴ impacts on climate and health—the latter being particularly concentrated in urban settings where

¹³ For the purposes of identifying focused investment opportunities, the upgrading of refining capacity to produce low-sulfur diesel, demand management, mode switching, and other approaches to black carbon abatement were not the focus of the BCFSG.

¹⁴ The relatively small fraction of co-emitted organic carbon and sulfur dioxide that have potential to cool the planet make diesel sector abatement interventions among those most suited to using emissions as a proxy for impact measurement. Thus, PM_{2.5} emissions from diesel engines have a high percentage of black carbon (approximately 77 percent), with attendant health and climate impacts that are easier to determine based on PM_{2.5} measurements alone.

population exposure is high (see Box 9).¹⁵ While black carbon abatement costs are generally high in the diesel sector compared to others, so too are the socioeconomic returns once health, climate, agriculture, and other benefits are considered. These social returns usually exceed the private costs many times.

Sector momentum is generally high as many countries, particularly in Latin American, Africa, and Asia, are investing heavily in modernizing transportation infrastructure and services. Many countries are also adopting more stringent standards for fuels, vehicle emissions, and air quality. Both of these developments have a bearing on diesel fleet operations (especially public bus fleets) and opportunities for black carbon abatement. The expansion of access to low-sulfur fuels in developing countries for example, is expanding the window of opportunity—at least from a technical

¹⁵ Reducing emissions near snow and ice can also specifically contribute to curbing climate change in the cryosphere.

BOX 9. Health and Climate Impacts of Black Carbon and Particulate Emissions from Diesel Vehicles

The transportation sector is the third largest source of black carbon emissions behind the agriculture and residential sectors. Global black carbon emissions from transportation were estimated at between 1,271 Gg and 1,550 Gg in 2000 (based on Bond et al. 2013). Sector emissions are primarily linked to the combustion of diesel fuel by heavy duty on-road vehicles and, secondarily, by non-road diesel vehicles (including locomotives, tractors, construction machinery and ships). Asia is the largest source of emissions, followed by North America and Europe.

A comprehensive review of the health effects of traffic-related emissions was published by the Health Effects Institute in 2010; it concluded that the existing evidence base is suggestive of causal associations between traffic exposure and all-cause mortality, asthma onset and exacerbation in children, respiratory symptoms in adults, decreased lung function, and cardiovascular mortality and morbidity (HEI 2010). Other work (Chambliss et al. 2014) has shown a direct link between transportation PM emissions—90 percent of which are attributable to diesel vehicles (ICCT 2013)—and health impacts. A recent World Bank Study (2014) found that black carbon controls on diesel engines would produce clear health benefits, mainly as

a result of the gas-phase co-pollutant reductions that lead to reduced ozone formation. The World Bank and International Cryosphere Climate Initiative (ICCI) estimate that the global adoption of Euro VI standards could potentially avoid from 300,000–700,000 premature deaths in 2030, by reducing particulates as well as co-pollutants emitted by on-road and non-road vehicles (World Bank/ICCI 2013).

Transportation emission reductions may offer among the most certain climate benefits of all sectors due to the fact that particulate emissions from diesel engines have a very high ratio of black carbon to organic carbon. Although there are other climate-co-pollutant interactions,¹ there is very little potential for unintended climate consequences from reducing diesel emissions.²

¹ For example, fuel-sulfur reductions that may be required for large diesel retrofit programs or new vehicle performance standards could—as with organic carbon—offset some of the benefit of black carbon abatement.

² The left end of the error range for estimated climate forcing associated with diesel engines in the “bounding black carbon study” (Bond et al. 2013) is -0.01 W/m^2 , the least negative value of all sectors considered (see Figure A1).

BOX 10. Examples of Economic Incentives and Instruments Used to Accelerate the Adoption of Diesel Emission Controls in the U.S. and EU

Air Quality Grants to Local Authorities. The state provides grants to local authorities for retrofitting vehicles that they own or that are operated on their behalf. Scotland has used this approach to help local authorities meet their statutory local air quality targets.

Cash Grants or Subsidies to Vehicle Owners. The state subsidizes filter retrofits and upgrades on privately owned and independently operated vehicles. Italy's Lombardy region (Milan) has complemented the establishment of limited traffic areas with cash subsidies. In California, the Carl Moyer Program provides grants to cover, among other things, the incremental cost of filter retrofits—which are required by regulation—and the cost of retiring non-equipped vehicles before the end of their useful life. As funds are issued in advance of the filter being adopted, recipients are subject to extensive prequalification screening and sign contracts agreeing to the key terms, including penalties for failure to comply with the

terms. Program implementers have developed methods to anticipate retrofit costs in advance.

Tax and Fee Reductions for Vehicle Owners. The government exonerates eligible, filter-equipped vehicles from paying specific taxes (or refunds them). In Switzerland (where public transportation buses were already eligible for a refund on fuel taxes), the government introduced a differentiated refund in 2008, whereby only buses equipped with particulate filters became eligible to reclaim a particular oil tax. A separate program adopted in 2012 offers heavy goods vehicles a 10-percent discount on the heavy-duty vehicle fee for the verified adoption of diesel particulate filters. Germany incorporated individual vehicle emission levels into the determination of road tolls from 2007 to 2013, providing an incentive for frequent users such as truck owners to upgrade or retrofit their vehicles to reduce toll costs.

perspective—to control diesel emissions using DPFs (see Box 13).¹⁶ This highly effective technology can eliminate 85–95 percent of particulate emissions mass (World Bank/ICCT 2014).¹⁷

The Challenge

The obstacles to reducing black carbon emissions from diesel engines are significant, highlighting the need for a financing program to accelerate the transition to clean engines. As noted above, abatement costs are high and in many cases offer diesel owners limited private returns (aside from direct health benefits, which are not often considered). Investment in black carbon abatement is likely to remain limited in this sector without the combined push of regulation and policies, and the pull of financial and other incentives. While some countries have successfully implemented regulation and incentivized reductions in diesel air pollution (see Box 10), many other countries lack the regulatory and financial means to trigger investment on their own.

¹⁶ As shown in Box 13, low-sulfur fuel is now available—sometimes in pockets—in a number of developing countries that have yet to adopt vehicle emission standards that would require the adoption of DPFs on diesel engines (i.e., standards equivalent to Euro VI). This includes parts of China, India, Brazil, South Africa, and the Russian Federation. Several more countries are expected to follow suit.

¹⁷ Wall-flow DPFs redirect and channel exhaust gases through porous walls as they escape to the filter exit. Black carbon particles are then combusted within the filter during a subsequent regeneration process, effectively eliminating 85–95 percent of particulate emissions mass.

The Applicability of this Strategy

The strategies outlined below were specifically identified with a view to accelerating the diffusion of low-soot technology (e.g., DPFs or advanced alternative fuel engines)—whether or not they are taken up as part of a package that includes such concomitant upgrades as engine repowers or rebuilds, engine or vehicle replacements, and fuel efficiency retrofits. Because regulatory, institutional, and infrastructure-related obstacles to abatement are critical in this sector, the concept of accelerating technology transition in the diesel sector applies primarily in geographies where political motivation to act is strong.

Looking beyond the diesel sector, the strategies described below could potentially apply, in full or in part, to other abatement opportunities involving similar constraints (e.g., fuel-switching, a ban on oil and gas flaring, or a ban on agricultural burning). The first strategy (to economically incentivize the adoption of emission controls or cleaner technology) could apply where needed regulatory requirements or mandates are scheduled, expected, or being contemplated—or even where regulatory requirements are in place but unlikely to take effect without financial support to reduce the costs and risks of compliance. The second strategy (to support regulatory change) could apply where needed regulatory action of relevance to black carbon is lagging.

STRATEGY 2A: Incentivize the Early Adoption of Low-soot Technology with Concessional and Results-based Finance

The proposed strategy generally involves buying down the cost of transitioning to lower-soot technology (e.g., DPF-equipped vehicles or their equivalent in terms of black carbon emissions). Its intent is to accelerate the transition to soot-free engines and fuels as part of ongoing sector transformation efforts in places where the political will exists or a regulatory schedule is already in place to move in this direction.

This strategy recognizes that the transformation of the diesel sector, even in countries where transformation is underway, could take several decades due to the durability of diesel technology. The long time horizon for structural change toward soot-free engines highlights the opportunity for interim interventions to accelerate the adoption of diesel particulate filters and other low-emissions technology. This would bring forward the substantial positive impacts of associated black carbon mitigation on health, the climate, and broader welfare. Concessional finance would be phased out as policy and market conditions align for broader sector transformation.

The instruments highlighted below are intended to target diesels operating in urban contexts where the potential benefits for public health are highest—and where there is the political and technical capacity to create the enabling conditions for success. By 2015, roughly one quarter of transportation-related black carbon emissions are expected to come from buses running in urban areas, where population exposure tends to be high (Chambliss et al. 2013). While fuel quality is an obstacle in many developing countries, a substantial and growing number of cities offer—or are expected to mandate—the low-sulfur fuel (50 ppm or lower) needed to render DPFs effective. Where low-sulfur fuel is available on a limited basis rather than on a national scale, supplying it to a captive fleet within a city (e.g., municipal bus fleets that are centrally fueled and managed, or large or mid-sized commercial fleets) could be logistically more feasible than seeking to supply it more widely.

The Financial Instruments

Concessional loans and grants—possibly a loan-or grant-backed revolving loan fund—could be used to incentivize the move to lower-soot engines. Box 10 provides examples of economic incentives and instruments that have been used in the U.S. and EU. At a minimum, loans or grants would finance the incremental cost of filters or other technologies that represent the key to black carbon abatement. They could, however, also finance broader upgrade packages that offer both public and private returns, such as fuel efficiency retrofits (e.g., low-rolling resistance tires, aerodynamic improvements, anti-idling technologies, and driver training) and vehicle or engine replacements. Private returns could result from fuel savings in the case of a new engine or fuel efficiency retrofits,

or from improved vehicle life and performance in the case of full vehicle replacement or a new or repowered engine.¹⁸

Where barriers to direct borrowing and funding exist, funds could flow through a designated national authority to municipalities, private fleet owners, and other borrowers. At the national level, funding could be allocated on a competitive basis (e.g., a reverse auction or blind tender—see Box 11) or on a first-come-first-serve basis. Applications could be compared on the basis of multiple criteria, including cost, black carbon emission reductions, health impact, programmatic aspects (such as how vehicle retirement is handled), fuel availability, cost-effectiveness, and potentially the policy framework in place to support the project.

Results-based finance could be offered to induce the adoption, proper use, and regular maintenance of equipment over time. To encourage compliance with regulatory mandates to adopt filters—or voluntary early adoption of these where mandates are scheduled or anticipated—diesel owners could be paid or rewarded for verified compliance. Similarly, paying or rewarding vehicle owners or operators to maintain filter maintenance—without which filters cease to be effective—could be one means of ensuring this practice is upheld. Such a program could be complemented by grant funding for training on regeneration and maintenance needs.

Rewards for adoption and maintenance can take a number of forms, ranging from cash payments to fiscal incentives (e.g., tax exoneration as in the Swiss model described in Box 10), full or partial debt forgiveness, preferential access to express lanes or restricted-entry city zones, and other context-relevant sources of value. These types of instruments can be used as a complement to debt and grant financing of capital costs, and also involve the competitive allocation of funds (e.g., via reverse auction, a mechanism being used by the Pilot Auction Facility described in Box 8). Box 12 describes a practical illustration of how the above instruments could hypothetically work together to accelerate technology transition.

Capitalization

A number of existing climate- and development-focused funds or facilities, including the World Bank's previously mentioned Pilot Auction Facility (PAF, see Box 8), may have the capacity to target black carbon abatement in the diesel sector. The PAF, in particular, could potentially be in a position to pilot the auction mechanism described above. The need for significant investment however, could justify the creation of a dedicated fund, or window within

¹⁸ There is a large global market for used vehicles, and opportunities exist to source high quality used trucks and buses from advanced markets.

BOX 11. Reverse Auctioning Financial Incentives to Accelerate Emission Reductions by Privately-owned Diesel Fleets

Particulate emission controls such as diesel particulate filters (DPFs) do not offer private financial benefits in the form of fuel savings or improved vehicle performance, and most of the health benefits of adopting them are broadly shared by society rather than enjoyed by the vehicle owner exclusively. As a result, covering the incremental cost of control technologies can fall short of incentivizing their adoption by private vehicle owners. In many cases, the adoption of emission controls will require financial incentives for a broader package of equipment upgrades or replacements—ones that offer benefits that a vehicle owner will have a private interest in pursuing. The optimal level and use of financial incentives is bound to vary by constituency and context, and to be a challenge for funders to discover. Reverse auctions offer a means for funders to overcome this challenge and set financial incentives at levels that maximize the impact of incentive dollars.

In a reverse auction, rather than compete for a good or service by offering increasingly higher prices at which they would be willing to buy, participants compete to provide a good or service by undercutting each other's bids. Beyond that, there

are multiple ways of designing and conducting reverse auctions. They can involve open or closed bids, single or multiple rounds, real-time or deferred bidding, different bundling options, and different rules about who wins and what winners pay (e.g., the lowest price, or the next to lowest price, the price they bid, and so forth). Reverse auctions are commonly used by the public and private sectors to procure goods and services at lowest cost.

To take a simple example in the diesel context, a funder wishing to financially incentivize the adoption of cleaner city buses that meet a specified standard (e.g., Euro VI) could use a reverse auction to allocate funds budgeted for this purpose. The funder could call upon cities to bid for financial support by indicating how much funding they need for a given number of buses that meet the specified standard. Bids would then be ranked on the basis of the average amount of money requested per bus. Some cities may need more than the marginal cost of a (Euro VI) bus and others may need less. The funder could then allocate funds at the level requested by cities, starting with the lowest bid and moving up to higher ones until the allocated funds are exhausted.

an existing fund, for this purpose. Funding to cover the capital costs associated with filters or fuel-switching could flow through national-level borrowers or grantees (such as a national finance authority) to municipal or local authorities, or to other designated entities (such as private fleet owner-operators charged with project implementation).

The instruments could be capitalized by resources earmarked for health or climate. They could rely on public sector co-financing and regulatory intervention to maximize reach and impact. They could also seek to leverage private sector capital by offering financing not strictly for filters but also for vehicle- or engine-upgrade packages that offer private benefits—or financial returns that filter

adoption alone does not. Involving the private sector in such a financing scheme would likely require significant outreach efforts.

Prerequisites

For this strategy to succeed, policy reform needs to be under way or on the horizon in targeted countries (see Box 13). In addition, the governments of these countries must be in a position to at least minimally co-finance the activities supported by the above instruments on the basis of both health and broader economic benefits. This strategy also requires that multiple technical requirements for program success be in place (again, see Box 13).

STRATEGY 2B: Support Regulatory Change

The proposed strategy aims to strengthen the regulations as well as the institutions that, together, will make low-sulfur diesel, cleaner engines, particulate filters, and other emission control technologies and alternative vehicles and fuels the norm. Given that emission controls are unlikely to be diffused through commercial channels in the absence of regulatory intervention, support for policy development and institutions operating at the national and sub-national levels is needed to bring systemic change to the diesel sector and establish large-scale demand for filters as well as for cleaner fuels

and engines. At the same time, ongoing momentum around broader sector transformation represents an opportunity to incentivize cleaner development with respect to black carbon. This future could involve policy changes in a wide variety of areas, including fuel pricing, fuel subsidies, fuel import restrictions, fiscal incentives, public spending on infrastructure (e.g., refinery upgrades or fuel infrastructure), the enabling environment for investment, fuel quality management and standards, and vehicle emission standards.

The Financial Instruments

The instruments highlighted below are intended to work in concert with those laid out under the preceding strategy (to accelerate technology transformation).

Readiness grants could support counterparts (e.g., national or sub-national agencies) to design black carbon project components and an enabling environment for implementation. They could, for example, pay for the upstream technical work needed

to put in place a revolving loan or results-based finance program, measures enabling the supply of low-sulfur diesel fuel, training on filter maintenance, or the customized design of emission control technologies and programs. Although not specific to any particular country or municipality, the CCAC Heavy Duty Diesel Initiative's recently launched municipal bus activity (see Box 14) generally illustrates how a grant can support readiness in the urban context.

Development policy loans targeting national or sub-national governments could more broadly finance the development and

BOX 12. Concessional and Results-based Finance to Accelerate Technology Transition: A Hypothetical Cascade Scheme for Cleaner Mexican Trucks

Regulatory change is underway in Mexico, and heavy-duty diesel vehicles are headed toward more stringent emission standards that will require new diesels to be equipped with diesel particulate filters (i.e., the standards will change from the equivalent of Euro IV to Euro VI). The schedule for these new standards to take effect will be coordinated with the roll-out of ultra-low-sulfur diesel, which is anticipated to happen by late 2017 under separate regulatory action.

The adoption of these higher standards has the potential over time, through fleet replacement, to drastically change the emissions profile of Mexico's average truck (which has been on the road for 25 years) and vastly reduce black carbon pollution. There may also be an opportunity to accelerate this process through a cascade scheme that specifically targets, as its entry point, Mexico's larger and relatively newer and cleaner fleets—fleets of 100+ trucks, of an average age of 5–10 years. These fleets are a minority, however, as the Mexican trucking landscape is dominated by owner-operators running 1–5 vehicles that have on average been on the road for 28 years.

There is some evidence that Mexico's larger fleet owners may be willing candidates to participate in a voluntary program that would allow them to access concessional loans to upgrade their aging pre-Euro IV fleets before the end of their useful life and ahead of the regulatory schedule. A revolving fund could provide these fleet owners concessional credit to purchase newer, more efficient, and lower-emission vehicles (i.e., vehicles that are DPF-equipped or running on diesel alternatives). In exchange, fleet owners would cede their trucks to smaller companies operating much older and dirtier vehicles for free or a small fee (hence the cascade metaphor). The transferred trucks could potentially be retrofitted with DPFs, depending on the program's endowment and if the cost-benefit analysis were favorable. Program beneficiaries would enjoy fuel savings, as well as the extended life, comfort, safety, and health benefits

of newer vehicles acquired at below-market costs. At the same time, the beneficiaries of hand-me-downs would be required to scrap their old vehicles. (This aspect of the program would require a robust monitoring system to be in place.)

Because the effectiveness of DPFs requires their proper use and maintenance, something that costs fleet operators time and money, the program could include a results-based finance component to incentivize good practices. This could involve rewarding truckers for adhering to a pre-established maintenance regimen with cash payments, loan alleviation or forgiveness, tax exonerations, preferential access to express lanes or city zones, or other incentives. Program design could seek to enhance compliance by incorporating behavioral design features (e.g., rewarding fleet owners for complying with multiple actions rather than a single one, using variable rewards and lotteries, or providing truckers benefits that are withdrawn in the case of non-adherence).

To quantify ongoing environmental benefits from the program, participants could be encouraged or required to have the vehicles checked annually through the end of the expected vehicle lifetime. This could include checking the odometer, which along with a projected emissions reduction factor based on the paired model year emission rates, could provide a reliable estimate of black carbon and NO_x benefits as well as fuel savings.

A program of this nature could potentially be brought under an existing government program, such as Transporte Limpio, which is a voluntary national program that works with freight companies to reduce fuel use, greenhouse gas emissions, and costs and to put inspection and maintenance programs in place at the state level. A designated national authority could play a role in coordinating supply for program participants ahead of the national provision of ultra-low sulfur diesel fuel.

BOX 13. Promising Markets for DPF Adoption

The U.S., EU and Japan have regulations in place that require the use of diesel particulate filter (DPF) technology or equivalent in new diesel vehicles (Euro VI, for example). Supporting the diffusion of DPFs globally will require identifying locations in developing countries where multiple policy and technical conditions can be met.

The key technical conditions for the development of successful DPF programs include:

- Low-sulfur fuel (ultra-low sulfur fuel, <15 ppm optimally, 50 ppm max)
- Fleets with existing vehicles emitting below 0.1 g PM/bhp-hr (roughly corresponding to <20% opacity, similar to Euro II engines or newer)

Other important enabling conditions include:

- Government implementation of supporting policies or regulations
- Manufacturer involvement in the installation design
- System of technology verification and performance monitoring
- Capacity, equipment, and training for DPF maintenance

With the caveat that the availability of low-sulfur diesel fuel is a necessary but insufficient condition, on its own, for the diffusion of DPFs, the following table is meant to provide an indication of where the potential for DPF diffusion may be the highest. It identifies countries that have yet to adopt DPFs, but where a key condition for the diffusion of this technology—the availability of low-sulfur fuel—is already a reality or on the horizon.

Group 1—Countries with low sulfur fuel without Euro VI standards	Group 2—Countries intending to adopt low sulfur fuels in the near future
Africa: Burundi, Kenya, Mauritius, Rwanda, South Africa,* Tanzania, and Uganda.	Africa: Benin, Burkina Faso, Chad, Congo, Cote d'Ivoire, Democratic Republic of Congo, Ghana, Liberia, Mali, Niger, Nigeria, Sierra Leone, and Togo.
East Asia and Pacific: China,*+ Marshall Islands, Singapore, and Thailand.	East Asia and Pacific: Indonesia and Malaysia.
Europe and Central Asia: Albania, Armenia, Belarus, the Former Yugoslav Republic of Macedonia, Georgia, Kazakhstan, Montenegro, Russian Federation,* Serbia, and Turkey.	Europe and Central Asia: Moldova and Ukraine.
Latin America and Caribbean: Argentina*, Barbados, Brazil*, Chile, Colombia, Costa Rica, Jamaica,* Paraguay,* Peru,* and Uruguay.	Latin America: Ecuador
Middle East and North Africa: Algeria,* Morocco, Qatar, Saudi Arabia,* and Tunisia.	Middle East and North Africa: Bahrain, Kuwait, and United Arab Emirates.
South Asia: Bangladesh* and India.*	

* Low sulfur fuel is available in select regions/cities. + Includes Hong Kong SAR, Macau SAR, and Taiwan, China.

Note: Mexico is in the process of adopting emission standards for new trucks that will be equivalent to Euro VI in stringency, thus virtually eliminating their black carbon and fine particle emissions. Low sulfur fuel is anticipated by late 2017 under separate regulatory action.

Source: The ICCT

implementation of policies that contribute to transforming the diesel sector—ushering in cleaner and filter-equipped engines and low-sulfur diesel fuel. Funding could be used for stakeholder consultation, economic analysis, outreach, building institutional capacity for implementation (institutional strengthening), peer-to-peer and city-to-city learning, and so forth. Development policy lending supports policy development with concessional finance, yet implies substantial financial participation on the part of sovereign borrowers.

Incentives for policy change and public sector investment are discussed in Part 2 as part of the strategy to mainstream black carbon in development finance. Various instruments are available to systematically encourage the adoption of black carbon emission controls or diesel alternatives as a matter of policy in the context of financing transportation projects.

Capitalization

Several existing financing vehicles, such as the Global Environment Facility and Climate Investment Funds, are already in a position to fund readiness grants to support policy and institutional strengthening efforts. Development policy loans and other incentives for policy change and public sector investment can be financed by development finance institutions, including multilateral development banks and bilateral lenders.

Prerequisites

For this strategy to succeed, national, regional, and local authorities will need to demonstrate strong political will to bring about the reforms that will enable the sector to develop along a cleaner pathway. This political will, in turn, may be a function of stakeholders' ability to present needed reforms as an integral and integrated part of a broader sector transformation package, with the multiple social, environmental, economic, and political benefits that they would be expected to bring.

Strategy 3: Tailor Black Carbon Finance Instruments to Other Priority Sectors

The BCFSG sees the strategies it has identified to increase investment in the clean cooking and diesel sectors as having the potential for broader applicability. To build on the strategies identified in this report to tackle other black carbon abatement opportunities, the study group recommends that further analysis be undertaken to adapt applicable approaches to stimulate investment in other black carbon-emitting sectors.

The BCFSG has identified four additional black carbon abatement opportunities as the starting point for a potential next round of analysis: enhancing brick kiln efficiency and adopting alternative materials; replacing kerosene lanterns; adopting alternative uses of agricultural residues that avert burning; and reducing emissions from oil and gas flaring. The study group views these abatement opportunities as offering strong potential for impact and action in the near- to medium term. There are, of course, other sectors or sub-sectors with significant potential for abatement with strong benefits. See Annex 3 for more information on the full range of abatement opportunities considered by the BCFSG.

Although the BCFSG did not extensively analyze the other priority areas of intervention it recognized, it did identify opportunities and financing constraints. Based on these, the study group offers the following high-level strategies for increasing investment in these areas of intervention:

- **Brick kiln efficiency and the adoption of alternative materials:** Accompany market-led sector modernization by supporting access to finance, supply chain development, market linkages, and regulatory incentives. Several abatement options are well-understood and some offer adopters positive financial returns. The supply of cleaner technology, moreover, is spreading globally, reflecting sector momentum. However, investment in brick kiln modernization is likely to remain inadequate without both regulation and new approaches to finance. There is an opportunity to explore opportunities for extending financing mechanisms recommended for the residential cooking and diesel sectors to this industry (for market stimulus and regulatory change respectively).
- **Kerosene lantern replacement:** Support the development of a commercial market for kerosene- and kerosene lantern-substitutes. In some contexts, also support reforms in related energy policies (e.g., policies governing fuel pricing). There may be opportunities to extend the financing mechanisms recommended for the residential cooking sector to this industry.
- **Alternative uses of agricultural residues that avert burning:** Support access to finance to purchase or lease needed farm equipment to adopt and manage the inconveniences of

alternatives to burning. In tandem, raise awareness of applicable techniques and their benefits, and incentivize behavior change. Favor solutions—that is, alternatives to burning—such as those rooted in conservation agriculture, which can offer multiple co-benefits related for example to soil fertility, water conservation, crop yields, risk management, and the mitigation of greenhouse gas emissions. In certain contexts, support the regulation of agricultural burning along with regulatory compliance.

- **Reductions in emissions from oil and gas flaring:** Support policy and regulatory change. Where applicable, demonstrate how climate finance can nudge industry to invest in potentially lucrative yet overlooked abatement opportunities.

The BCFSG recommends that focused work be carried out to elaborate specific strategies that can be implemented in the near term to catalyze investment in black carbon abatement in these sectors. Given the foundation that has already been established, analysis of additional sectors has the potential to be streamlined and to build on the lessons learned from the study group's work.

BOX 14. City Readiness: An Example of How a CCAC Grant Will Prepare Cities to Usher in Soot-free City Buses

The CCAC Heavy Duty Diesel Initiative (HDDI) is working to accelerate the shift to soot-free urban bus fleets around the world. Part of the grant will go to inform, motivate, and secure a public commitment from city officials to shift to soot-free urban bus fleets. The grant will also support implementation efforts in committed cities that request assistance to execute an agreed-upon work plan.

The HDDI will also establish an industry partnership with a private sector coalition of soot-free bus manufacturers and suppliers to serve as an ongoing technical resource to cities—and as a point of contact for clean bus procurement. The partnership will also assess current and future market demand for clean buses and estimate the total financial assistance needed for their deployment in developing countries. Finally, the partnership intends to conduct a baseline assessment of urban bus fleets to identify barriers to clean bus deployment and guide future research and activities at the international level.

Practical Next Steps

- Continue to fund and support efforts to develop performance standards across priority, black carbon-rich sectors. ISO standards for cookstoves define tiers of performance in relation to their emissions of $PM_{2.5}$, and efforts are under way to develop performance thresholds incorporating emission rates for black carbon and other pollutants. Continued efforts and funding are needed to develop and test these, as well as similar standards for other technologies and sectors. These investments will be central to the public and private sectors' ability to integrate black carbon performance into investment decision making.
- Establish, within a new or existing fund, the use of performance standards to direct capital to cleaner (i.e., lower-black carbon) cooking technology. The fund can make use of various, well-established financial instruments, including loans and loan guarantees, grants, equity, and advance market commitments, to develop supply chains' capacity to supply technology that cuts black carbon emissions. The fund could also accelerate finance for other black carbon abatement technology, including kerosene lantern replacements and modern brick kiln technology.
- Demonstrate innovative approaches to results-based finance to widen the distribution of cleaner (i.e., lower-black carbon) cooking technology. A fund could experiment with making payments against measurable climate and health outcomes or outputs. The fund can make use of and offer a testing ground for performance measurement tools that are already available or under development. Other sectors could benefit as well.
- Design and pilot the use of a reverse auction mechanism that competitively allocates grants for diesel-fueled municipal buses, service vehicles, and machinery to undertake upgrades that lead to black carbon abatement (the grants could cover capital and other associated costs). In the diesel sector, tons of averted black carbon or $PM_{2.5}$ are a potential proxy for health and climate impact; thus, the program can use these to develop funding criteria in the near term if not longer. In addition to offering price discovery, such a program can help to identify institutional entry points and structures suited to channeling finance for diesel sector abatement (though arrangements will vary by country).
- The program—which could be housed in a multilateral or bilateral development finance institution—can initially target countries, regions, or cities where authorities have already taken steps to regulate vehicle emissions or enable the supply of cleaner fuels (see Box 13). As its first order of business, the program can conduct a detailed analysis of the countries, cities, institutions, and fleets that it could target to identify a specific project pipeline and estimate funding needs.
- Pilot the use of results-based incentives to encourage the adoption and maintenance of diesel emission control technology adopted through the municipal fleets activity described above. This program can experiment with different types of rewards and award structures. Rewards could range from cash payments to fiscal incentives, full or partial debt forgiveness, preferential access to express lanes or restricted-entry city zones, and other context-relevant sources of value. These can complement funding for the capital costs of upgrades.
- Design and create financial structures and institutional arrangements capable of channeling funds to diesel vehicle owners using the instruments discussed above. In the longer run, this readiness arm of the program could also support policy development and institutional strengthening by offering grants, concessional loans, technical assistance, and reimbursable advisory services.
- Analyze the opportunities and constraints as they relate to financing reductions in black carbon emissions from brick kilns, kerosene lanterns, the burning of agricultural residues, and oil and gas flaring. On this basis, adapt and tailor strategies to accelerate finance in these sectors. Picking up where the BCFSG left off, this next stage of work on black carbon finance can involve a mixture of analytic work by a focused group of sector experts and action research. This next stage could involve the following two steps.
- Analyze the landscape of relevant sources of climate, health, or other development finance that can be channeled to abatement interventions using the identified financing strategies. The Global Alliance for Clean Cookstoves has already undertaken this analysis for potential cookstove projects and the CCAC's Heavy-Duty Diesel Initiative is conducting such a study for municipal bus fleets; other categories of diesel engines still need to be assessed, as do interventions in other priority sectors.

- Identify, for sector-specific abatement interventions, a pipeline of abatement projects that can be implemented in the near term, along with associated funding and technical assistance needs. For example, in the diesel sector: quantify the magnitude of funding needed to support clean diesel projects (e.g., soot-free buses); quantify the potential benefits that could be achieved per vehicle and in the aggregate; identify the types of institutions that would be potential loan or grant recipients; calculate the potential

of this seed funding to catalyze change in purchases of heavy-duty diesel vehicles around the world.

Some of these last activities could be undertaken by the CCAC's Finance Innovation Facility, which is being established to systematically engage private sector actors in mobilizing private finance. It will specifically assist lenders and investors to develop and market commercial financial products for black carbon abatement.



PART 2

Unlock Black Carbon Finance on a Broader Scale

To enable the replication and scale-up of successful strategies across multiple sectors, the BCFSG recommends (a) building the foundations for black carbon finance with a focus on performance measurement; and (b) harnessing the capital already flowing through existing development and climate finance institutions.

Part 2 presents opportunities for action that are not sector-specific but relevant across sectors and contexts, and that can be pursued today to scale up investment in black carbon finance over time. The BCFSG sees these opportunities as the key to attracting capital on a larger scale as well as to enabling that capital to flow to a broader array of abatement interventions across more sectors and geographies. They came to light in the process of exploring opportunities for impactful, near-term action to abate black carbon at the sector level (consistent with the BCFSG's bottom-up approach described earlier in this report).

The BCFSG identified two cross-cutting strategies to unlock black carbon finance on a broader and large scale. They are to:

- Streamline and unify black carbon performance measurement.
- Mainstream black carbon in development finance.

This section describes these strategies, highlighting key conditions for success. Finally, this section offers some practical steps for moving forward.



Strategy 1: Streamline and Unify Black Carbon Performance Measurement

The Opportunity

The availability of performance measurement tools to define, estimate, and assess the benefits of black carbon abatement is fundamental to the ability to finance it. Performance measurement tools include (1) impact indicators that define the outcome of interest; (2) estimation models for quantifying indicator magnitudes; and (3) accounting methodologies that make use of impact indicators and estimation models to inform investment decisions.

Performance measurement tools are necessary, for example, to determine eligibility for concessional loans and grants, to trigger result-based payments in the context of results-based finance, and to analyze the implications of different investment options using social cost analysis. In this respect, the prospects for the expansion of black carbon finance are positive in that a variety of performance measurement tools are already in wide use and available to underpin black carbon finance across a number of sectors and types of

interventions. Several of these performance measurement tools are illustrated in Box 15.

The Challenge

Notwithstanding the breadth of existing tools and the broad opportunities they offer to finance black carbon abatement across sectors, there has been an uneven embrace and use across sectors and impact areas of specific indicators, estimation models, and accounting methodologies. As a result, existing measurement tools do not currently form a consistent or unified basis for scaling up black carbon finance within or across sectors. This is partly a reflection of the highly source-specific and context-specific ways in which black carbon and its co-pollutants impact health and the climate as well as the resulting need for specific-use tools to account for their effects (even if these are ultimately expressed in more universal terms).

BOX 15. Performance Measurement Tools for Defining, Estimating, and Accounting for the Impacts of Black Carbon and its Co-pollutants

Various indicators are already widely used to characterize health and climate impacts, and a number of them have universal applicability across sectors and contexts. For example, changes in radiative forcing, temperature, and tons of CO₂-e have all been used to express climate impact; health impacts, meanwhile, are commonly expressed in terms of changes in specific disease risks, premature deaths, and disability-adjusted life years (DALYs, a subtler measure that takes into account quality of life). Emissions of black carbon or PM_{2.5}, of which black carbon is a critical subset, are also sometimes used as a proxy for health and climate impacts, although emissions are not reliable as a cross-cutting impact indicator.

When it comes to estimating or quantifying indicator values, a number of estimation models—some of them sector-specific or requiring intervention-specific calibration—are available to quantify the impacts of a range of abatement activities on climate and health indicators. Models such as HAPIT and BenMAP, for instance, compute health impacts in terms of premature deaths or DALYs—of indoor and outdoor air pollution respectively (including concentrations of PM_{2.5}). These models need to be calibrated for use in specific circumstances.

Several air quality (chemical transport) models, including GEOS-Chem, TM5, and ECHAM models, are used to

estimate the dispersion, deposition, and climate implications of different emission scenarios (that include black carbon) in terms of changes in radiative forcing and temperature. Benefits estimation tools such as the EU Joint Research Centre's FASST and the CCAC's Scenario National Action Planning (SNAP) toolkit make use of several of these models to quantify the health, climate, and other benefits of specific abatement interventions. FASST is based on the TM5 model, for instance, and the SNAP toolkit uses GEOS-Chem, LEAP, health impact functions, and other models to estimate abatement impacts in terms of crop yields, radiative forcing, premature deaths, and—soon—DALYs.

In addition, different accounting methodologies are being developed to incorporate these quantitative estimates of various indicators into decision making. ISO's tiers-of-performance system for cookstoves, discussed in Part 1, is one such example based on an emission rate indicator. Meanwhile, the Gold Standard Foundation has developed a methodology to account for the climate impacts of abating emissions of black carbon and other SLCPs. Parallel efforts are under way to develop an accounting methodology revolving around averted disability-adjusted life years.

Selecting indicators on which to base financing decisions, moreover, implies a number of tradeoffs. Indeed, different indicators are associated with different types and levels of uncertainty depending on where they sit in the causal chain (i.e., for health the causal chain includes combustion → emission → exposure → health impact, whereas for climate it includes combustion → emission → dispersion → climate interaction → temperature impact). For example, financing a project on the basis of emission reductions, as opposed to health benefits such as avoided premature deaths or ADALYs, may offer financiers greater certainty and ease with

respect to measurement and verification but less certainty with respect to health benefits. However, a calculated measure of health or climate benefits embeds estimation uncertainty in its methodology but does not eliminate it (in converting emission reductions into a health impact). Thus, while it may be more straightforward and transparent to direct finance on the basis of emission reductions—whether the intention is to finance climate, health, or other benefits—doing so may not guarantee the health or climate benefits envisioned further down the causal chain.

STRATEGY 1A: Determine and Coalesce Around Impact Indicators on which Finance for Black Carbon Abatement Can Universally Be Based

The proposed strategy involves determining and coalescing around impact indicators on which mitigation finance can universally be based. While measurement tools are in some cases available to catalyze action in the near term, unlocking large-scale investment in black carbon abatement across sources, geographies, and contexts to reap its multiple benefits will be aided by expanding consensus around impact indicators that soundly capture the major impacts of abatement across a multitude of abatement interventions and circumstances. The BCFSG urges those involved in selecting impact indicators to:

- **Consider only indicators that reliably characterize impact across sources, geographies, and contexts.** Examples of health indicators include a change in avoided premature deaths or avoided disability adjusted life years (ADALYs). On the climate side, potential indicators¹⁹ include change in global average surface temperature by 2050, change in global average surface temperature 10 or 20 years post-intervention,²⁰ and change in radiative forcing integrated over 2–3 decades (short-term integrated forcing). Additionally, indicators of regional climate impact could also be considered—for example, changes in radiative forcing or temperature integrated across a continent or national boundaries.²¹ An alternative to all of the above would be an indicator that allows for the comparison of the relative scale, in dollar terms, of the multiple impacts across multiple time-scales of multiple pollutants, including black carbon, such as the social cost of atmospheric release (SCAR) metric (Shindell 2015).

A measure of black carbon emissions on its own is a poor cross-cutting proxy for either climate or health impacts. Both are determined in large part by post-emission factors such as the dispersion and deposition of black carbon particulates and their interaction with the climate system and populations along the way. Impact is also influenced by other pollutants that are co-emitted with black carbon. In some contexts, such as the diesel sector, changes in emissions of either PM_{2.5} or black carbon are generally considered reliable predictors of both health and climate impacts. By contrast, in the context of the burning of biomass, the significant presence of co-emitted organic carbon makes this indicator less appropriate as a proxy for climate or health benefits. This difference underscores the need for cross-cutting indicators to be selected that are further along the causal chain (i.e., the causal chain that leads from fuel combustion to its ultimate effect on the climate and human health).

- **Specify the appropriate time scale for assessing impacts, along with the range of pollutants (besides black carbon, if any) for which impacts are to be taken into consideration.** Consider, for instance, if it is necessary to assess and measure potential short-term cooling impacts of co-pollutants or, alternatively, whether these potential cooling effects can be considered negligible in the time scale relevant for black carbon mitigation.
- **Avoid indicators that attempt comparability to greenhouse gas abatement impacts or CO₂-e.** Although there are advantages to comparability, including markets' familiarity with greenhouse gases and CO₂-e and the ease of comparing investment results, disadvantages include the risk of facilitating the substitution of one form of abatement for another when both are urgently needed and serve different purposes.

¹⁹ Note that each of these climate indicators requires consideration of pollutants other than black carbon.

²⁰ Either in comparison to CO₂ as global temperature potential (GTP) or not.

²¹ The impacts of black carbon tend to be primarily regional in nature, and become dissipated and potentially irrelevant on global scales. By the same token, black carbon emissions can be particularly harmful when they occur near snow- and ice-covered regions (the cryosphere).

STRATEGY 1B: Continue to Develop, Refine, and Adapt Impact Estimation Models to Expand Black Carbon Finance to Additional Sector-specific Sources, Geographies, and Contexts

Continued efforts to develop, refine, and demonstrate existing measurement tools are needed both to improve the basis for black carbon finance for sector- or intervention-specific uses in the near term and to expand the basis for finance in new sectors

over the longer-term.²² The evolving nature of scientific discovery supports the continuous improvement of measurement tools that are already in place and in wide use.

²² This can include the calibration of broadly applicable models to specific interventions, geographies, and contexts. For example, the BenMAP model can be applied to estimate the health impacts of outdoor air pollution in any context, but requires calibration for a given set of pollutants, local conditions, and population risks.

STRATEGY 1C: Develop and Coalesce around a Framework to Guide the Development of Methodologies that Account for Abatement Impacts

The development and broad adoption of a unified framework for black carbon performance measurement could play a transformative role in drawing in, gaining the confidence of, and facilitating the role of investors in this relatively new area of climate finance. This framework could, at a minimum, set standards for accounting methodologies used in measuring and monitoring abatement impacts. Ideally, the framework will build on the impact indicators that have been discussed and the impact estimation models that have been illustrated earlier in this section. By way of guidance, the BCFSG urges those involved in developing such a framework to:

- **Meet the needs of financiers in offering transparency, consistency, accuracy, and simplicity.**²³ The framework should have a high level of scientific integrity and precision underpinned by testing and evaluation data to ensure credibility. At the same time, the framework should maximize simplicity and ease of understanding with consideration for time-to-implementation, transaction costs, and uptake.
- **Ensure that methodologies, including the models used to calculate indicator values, are evaluated and updated in tandem with scientific progress.**²⁴ This could be achieved by establishing a process for reassessing and improving methodologies as understanding improves over time, enabling progress to be made while maintaining near-term action.

- **Establish a standardized way for methodologies to communicate to financiers the level of scientific and estimation uncertainty associated with impact measurements.** Indeed, the error range around impact estimates varies depending on what is being measured and how it is measured. Thus, a system is needed to clearly and simply convey the relative risk of various investment opportunities, and to do so with consistency. One approach would be to establish target levels of uncertainty for given indicators and guide each sector to develop methodologies for attaining that specified level of accuracy. An alternative approach would be to lay out a system for clearly and simply conveying to the finance community different ranges of uncertainty—a rating system—that can readily be used to evaluate risk-return tradeoffs. For example, specific estimations of climate or health benefits (measured using any given indicator discussed above) from the on-road transportation sector may be identified as being associated with low uncertainty, while those for open burning may have a different uncertainty rating. Different levels of uncertainty could result in benefits being valued differently by financiers. Either approach would enable financiers to properly value interventions, taking into account that the benefits of abatement can be assessed with different levels of certainty reflecting variation in co-emitted pollutants, the choice of indicator (e.g., emission rate rather than assessed health benefits), or the location of emissions (e.g., in the tropics versus near snow and ice).

The BCFSG further recommends that the various actors working on impact monitoring, measurement, and accounting, including the CCAC's Scientific Advisory Panel, carefully coordinate their work to avoid duplication.

²³ Based on the Greenhouse Gas Protocol, developed by the World Resources Institute and World Business Council on Sustainable Development.

²⁴ The understanding of black carbon impacts continues to evolve. Recent scientific studies, for instance, have found that a substantial amount of organic carbon emissions are actually so-called brown carbon and may absorb rather than reflect light. If so, there may be less potential than previously thought that some forms of black carbon abatement could result in unintended climate warming. Sources: Feng, Y., V. Ramanathan, and V. R. Kotamarthi. 2013. "Brown Carbon: A Significant Atmospheric Absorber of Solar Radiation?" *Atmos. Chem. Phys.*, 13, 8607–8621, doi:10.5194/acp-13-8607-2013. Chung, Chul, V. Ramanathan, and Damien Decremer. 2012. "Observationally Constrained Estimates of Carbonaceous Aerosol Radiative Forcing." *PNAS Early Edition*, approved May 30, 2012.

Strategy 2: Mainstream Black Carbon Abatement in Development Finance

The Opportunity

The vast flows of finance that support the development of black carbon-emitting sectors, including agriculture, transportation, industry, and energy, represent a pool of resources that can be invested in cleaner technology, infrastructure, and practices. While development finance—inclusive of multilateral, bilateral, and private sources—offers broad potential for low-black carbon growth, climate and health finance have a particularly important role to play.

The Challenge

Development finance currently overlooks many opportunities to displace black carbon emissions, including opportunities that would result in net benefits for development. At this broad level, the lack of investment in black carbon abatement reflects multiple factors, including a lack of awareness or prioritization of black carbon abatement on the part of decision makers and, in some cases, the perceived cost of abatement when the multiple external benefits of abatement are not fully factored in.

The Strategy

The proposed strategy aims to harness the large sums invested in the development of various black carbon-emitting sectors to bring about systemic transformation and cleaner growth. It involves multilateral, bilateral, or private development finance institutions encouraging, as a matter of policy, the adoption of black carbon

emission controls and supportive regulation in the context of financing projects in black carbon-emitting sectors (e.g., residential energy, transportation, agriculture, infrastructure, or others). So-called mainstreaming can be approached in various ways. The Global Environment Facility is one example of a development finance institution exploring approaches to mainstreaming black carbon (see Box 16).

Access to more concessional terms for sector-level loans can be made available to clients that opt for a low-black carbon pathway in developing a given sector. This approach would require developing a means of comparing the abatement impacts of alternative investments.

Development policy loans and grants can be used to finance the development and implementation of policies that contribute to transforming a particular sector. Funding could be used, for example, for stakeholder consultation, outreach, coalition building, economic analysis, institutional capacity building, or for peer-to-peer learning.²⁵

Social cost analysis—also referred to as cost-benefit analysis—involves systematically analyzing black carbon impacts (along with other climate and health externalities) of investments in

²⁵ By the World Bank's account, development policy loans are meant to support structural reforms, including policy and institutional changes, in an economic sector or in an economy as a whole. Originally designed to provide support for macroeconomic policy reforms and adjustment to economic crises, DPLs have evolved to focus on longer-term structural, financial sector, and social policy reforms. Loans seek to address complex institutional issues, improve a country's investment climate, and address weaknesses in governance, public expenditure management, and public financial accountability.

BOX 16. Mainstreaming Black Carbon and Co-pollutants into the Global Environmental Facility

The Global Environment Facility (GEF) is a partnership involving 183 countries working together with international institutions, civil society, and the private sector to address global environmental issues, including climate change. The most recent GEF Climate Change Mitigation Strategy (GEF-6 CCM, 2014–2018) supports integrated approaches that combine policies, technologies, and management practices with significant climate change mitigation potential—including reductions in the emissions and concentrations of black carbon and other short-lived climate pollutants. However, while the current (GEF-6) strategy supports actions to reduce black carbon emissions, the GEF does not presently account for these.

The *New Guidelines for Greenhouse Gas Emissions Accounting and Reporting* for GEF projects (to be submitted for approval

by 48th GEF Council in June 2015) therefore recommend that the GEF encourage project proponents to undertake assessments of black carbon emissions and to report reductions in these as project co-benefits. The GEF's Scientific and Technical Advisory Panel (STAP), at the time of writing, was developing a guidance document for the GEF that outlines how black carbon abatement measures might be integrated into new projects and programs (Sims et al. forthcoming 2015). The document provides GEF partners information about black carbon mitigation options in the transportation, residential, industrial, and agriculture sectors. It also outlines current methods used to monitor and measure reductions in black carbon pollution from sources such as vehicles, brick kilns, cookstoves, and the open burning of biomass.

BOX 17. Social Cost Analysis: Incorporating Black Carbon Alongside Other Climate and Health Externalities into Cost-Benefit Analysis or Macroeconomic Modeling

Translating the multiple benefits that result from black carbon abatement policies and projects into economic terms can provide a compelling case for action. Two possible approaches for doing this are highlighted below.

The first is cost-benefit analysis. This approach typically involves factoring in discrete environmental externalities by quantifying the benefits associated with a particular course of action, and then adding these to the benefits side of the ledger in monetary terms. Cost-benefit analysis is widely used to make the case for environmental and green growth investments. There are, however, limitations to this approach. A recent report by the World Bank and the ClimateWorks Foundation (2014) highlights these limitations as well as the opportunity for more holistic economic analysis that not only factors in the multiple pollutants and benefits at stake in certain climate-smart policies and investments but also accounts for their broader economic repercussions.

The alternative approach calls for analyzing the impacts of green investments and policies through macroeconomic

modeling that accounts—in economic terms such as employment or GDP—for their multiple impacts as they flow through an economy. The proposed framework rests on comprehensively identifying all benefits categories, selecting sector-specific benefits assessment tools, developing transmission channels describing how these sector-specific benefits feed into the macro-economy, and estimating all benefits in terms relevant both to specific sectors and to the broader economy. This approach is meant to capture benefits that are not routinely captured in cost-benefit approaches. To illustrate this, the World Bank and ClimateWorks (2014) estimate that if China spent \$400 million to deploy more than 70 million clean cookstoves, it could avoid more than one million premature deaths over 20 years. Other economic benefits—excluding the monetized public health benefits—would approach \$11 billion, and 22,000 new jobs would be created as a result of the switch to the new cookstoves.

sector-specific operations. It could, for example, involve modeling black carbon-related climate and health externalities in project cost-benefit analysis or in macroeconomic analysis (see Box 17). This could, in turn, lead to the consideration and adoption of technological pathways that would be rejected on a pure cost-effectiveness basis.

Prerequisites

For the mainstreaming of black carbon abatement to succeed, widely accepted performance measurement tools must be available.

In addition, countries must be willing to borrow or take action once black carbon is factored into development finance institutions' policies and loan negotiation and preparation processes. Another key prerequisite for success in many countries will be the adequacy of institutional capacity to adopt and implement enabling policies and conditions. The BCFSG urges development finance institutions to set aside grant funds to strengthen local capacity in support of program objectives—whether for regulatory development and dissemination, to build enforcement and compliance systems, for performance measurement, or to support other aspects of the enabling environment.

Practical Next Steps

- Convene a group of 10–15 black carbon science and finance experts to reach consensus on and recommend the indicator (or indicators) on the basis of which black carbon performance shall be measured and financed. The indicator(s) in question will ideally offer a universal basis for black carbon finance that can be used to direct resources to abatement activities regardless of the sector or geography in which they occur or the technology upon which they rely.
- Task the group with developing a standardized approach for determining and communicating estimation uncertainty to financiers (using risk ratings or similar approaches), as well as other guidance on the development of black carbon accounting methodologies. This guidance can build on that offered in this section of the report (Part 2, Strategy 1c). As discussed above, black carbon accounting methodologies need to offer financiers the ability to incorporate estimation risk into their financial valuation of black carbon abatement investments. Standardized information on estimation uncertainty would allow financiers to more accurately evaluate risk-return tradeoffs without having to delve into the intricacies of a given indicator or estimate. Different levels of uncertainty could result in benefits being valued differently by financiers.
- Initiate a dialogue among development finance institutions on black carbon finance to determine appropriate approaches to mainstreaming and to coordinate efforts to adopt these. Such a dialogue can facilitate the exchange of information on how to more systematically incorporate information on black carbon emissions and impacts into investment decision making, and potentially lead to the harmonization of approaches.



APPENDIX

Black Carbon Finance Study Group Background and Participants

BCFSG Context and Process

The Institutional Context

The Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants (CCAC) was formed in 2012 to tackle short-lived climate pollutants (SLCPs) at the global level. As of early 2015, the CCAC counted 100 partners, including states, multilateral institutions, and private organizations. The Black Carbon Finance Study Group (BCFSG) is part of the CCAC's Financing of SLCP Mitigation Initiative (the Finance Initiative), one of several cross-cutting and sector-focused initiatives of the CCAC addressing SLCPs.²⁶

The purpose of the CCAC Financing Initiative—under the joint leadership of the World Bank and UNEP Finance Initiative (UNEP FI)—is to mobilize investment in near- and medium-term SLCP mitigation efforts. This work has two components. Component 1 is supporting the design and implementation of tailored finance strategies for the CCAC Sectoral Initiatives, with a particular focus on mobilizing private finance. It is addressing SLCP mitigation broadly. Component 2 is focusing on specific research and knowledge-generation activities that inform the design and implementation of interventions to mobilize finance. The first key activity under Component 2 was the BCFSG, which focused on black carbon mitigation and not on other SLCPs. The BCFSG was led by the World Bank's Climate Change Group, with support from the UNEP FI.

²⁶ The most relevant CCAC Sectoral Initiatives from a black carbon perspective are Reducing Black Carbon Emissions from Heavy-Duty Diesel Vehicles and Engines (Canada, United States, International Council on Clean Transportation); Mitigating SLCPs and Other Pollutants from Brick Production (Colombia, Mexico, Switzerland, Center for Human Rights and Environment, Institute for Governance and Sustainable Development); Accelerating Methane and Black Carbon Reductions from Oil and Natural Gas Production (Nigeria, United States); Reducing SLCPs from Household Cooking and Domestic Heating (Nigeria, Global Alliance for Clean Cookstoves); and Addressing SLCPs from Agriculture (Bangladesh, Canada, Ghana, United States, European Commission, World Bank, International Cryosphere Climate Initiative). See the following link for more information: <http://www.unep.org/ccac/Initiatives/tabid/130287/Default.aspx>.

BCFSG Origins and Objectives

The proposal to create the BCFSG emerged from the CCAC's High Level Assembly in September 2013, a few months after the Methane Finance Study Group delivered its final recommendations.²⁷ Loosely modeled on its methane counterpart, the BCFSG's mandate is "to review potential strategies for supporting financing flows toward projects that can significantly reduce black carbon emissions." It was expected to:

- i. Identify opportunities to catalyze investment in abatement activities in the short- to medium-term.
- ii. Identify financial mechanisms to leverage investment in such projects.
- iii. Advance the issue of developing metrics for measuring the health and climate benefits of abatement.
- iv. Recommend how to scale up mitigation finance in the medium-to-long-term.

Early consultations with a number of CCAC partners specifically directed the BCFSG to prioritize making recommendations for near-term action that (a) focus on one or two sectors that already have an ongoing CCAC sector initiative; (b) can attract financing without the need to develop cross-cutting, universally applicable metrics for estimating the climate, health, or other impacts of black carbon abatement; and (c) maximize climate and health benefits.

²⁷ Commissioned by the G8, the Methane Finance Study Group convened ad hoc, outside the CCAC framework. One of the opportunities it identified was to create a pay-for-performance mechanism, and work is underway to create a facility within the World Bank that operates along this principle. The final report of the Methane Finance Study Group can be found at <http://go.worldbank.org/MD7GRQRDT0>.

BCFSG Process and Expected Outcomes

Between July 2014 and April 2015, the BCFSG came together to design strategies to catalyze investment in one to two black carbon-emitting sectors. Its work was structured around a series of consultative meetings (three in-person, and one virtual) bringing together 43 global experts with backgrounds in science, policy, project development, and finance.

The BCFSG's first order of business, at its July 18, 2014, meeting in Paris, was to narrow its scope. At its second meeting, September 24–25, 2014, in Washington, DC, the study group discussed how to address specific challenges within two focus sectors and identified opportunities and strategies to increase financial flows to these. On November 25, 2014, experts held a teleconference to discuss draft recommendations to catalyze black carbon finance in these sectors as well as more broadly. The study group used its third in-person meeting, on March 3, 2015, to finesse its messages.

The study group process generally followed the roadmap outlined below:

- **SPECIFY focus sectors and abatement opportunities.** At its first of three in-person meetings, the study group identified promising abatement opportunities across sectors and selected two of these to focus the remainder of its efforts on. The study group selected the clean cooking and diesel sectors as its focus.
- **IDENTIFY opportunities and strategies.** At its second in-person meeting, the study group discussed constraints to investment in black carbon abatement in the diesel and clean cooking sectors and ways to overcome these constraints. The group converged on a set of opportunities and strategies which it continued to notionally test, validate, and refine through stakeholder and expert consultations. During this phase, the study group communicated in writing and via teleconference.
- **ARTICULATE proposed action.** At its third and final in-person meeting, the study group formulated its final recommendations based on the most actionable, replicable, and scalable ideas it uncovered in the design process.

Study Group Participants

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ANNEX 1

Primer on the Science of Black Carbon

Introduction

This annex provides scientific context for issues related to the reduction of atmospheric black carbon (BC), a short-lived climate pollutant (SLCP). It provides an overview of technical issues that may be relevant to the charge of the Black Carbon Finance Study Group (BCFSG) of the Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants (CCAC), including issues related to black carbon emissions, climate and health interactions, and the fate and transport of black carbon.

Broadly speaking, sources with emissions that are rich in black carbon can be grouped into a small number of categories, including open burning, diesel engines, industry, and residential solid fuel and other energy-related combustion. Depending on the source, several co-emitted species may accompany black carbon emissions. Black carbon—and, importantly, co-emitted species—can have a strong effect on climate systems. Black carbon is one component of particulate matter, a form of air pollution and a major risk factor for adverse public health outcomes. Given its relatively short lifetime in the atmosphere (several days to weeks) it has climate and health consequences that can be important locally as well as globally. Each of these issues—black carbon emission sources and co-pollutants, black carbon climate and health effects, and black carbon’s spatial and temporal scale of influence—is discussed in the following sections.

Sources and Co-pollutants

Black carbon consists of extremely small particles that result from the incomplete combustion of fossil fuels and biomass. Commonly known as soot, it is one of the many types of particulate matter (PM, also called aerosols) that influence the climate; the others include sulfates and volcanic ash (World Bank 2011). Over the past decade, black carbon has come to be recognized as one of the principal agents of global warming despite its relatively short

atmospheric lifetime. Climate scientists now view black carbon as one of the largest warming agents after carbon dioxide (CO₂).²⁸

As mentioned above, source categories with black carbon-rich emissions include diesel engines, industry, residential solid fuel, and open burning. The largest global sources are open burning of forests and savannas. Dominant emitters of black carbon from other types of combustion depend on the location. Residential solid fuels (i.e., coal and biomass) contribute 60–80 percent of Asian and African emissions, while on-road and non-road diesel engines contribute about 70 percent of emissions in Europe, North America, and Latin America. Residential coal is a significant source in China, the former Soviet Union, and a few Eastern European countries. These categories represent about 90 percent of black carbon emissions in terms of mass. Other miscellaneous sources, including emissions from aviation, shipping, and flaring, account for another nine percent, with the remaining one percent attributable to sources with very low-black carbon emissions.²⁹

In order to determine the net climatic impact of changing a black carbon-emitting activity, all of the co-emissions of gases and PM from the activity need to be considered (see Table A1). Black carbon is often emitted with organic carbon particles, which tend to condense into gray or white PM (that is, smoke) that can reflect sunlight back into space, thus exerting a cooling influence on the climate. While black smoke has a high proportion of black carbon and exerts a strong warming influence, white smoke contains mostly organic carbon and so exerts a cooling influence. For example, open burning of biomass creates near-white smoke and thereby exerts a large net cooling influence. The combustion of biomass for cooking generates varieties of gray smoke that may have either a net warming or net cooling influence. In contrast, diesel engines and coal combustion create almost pure black smoke, with a strongly warming influence. Because particulate matter consists largely of black carbon, cutting PM from diesel and coal is highly likely to mitigate global warming—although some high-sulfur coal combustion results in sulfate emissions, another light-colored aerosol that can offset warming.

²⁸ Bond et al. 2013, the “bounding black carbon study.”

²⁹ Ibid.

TABLE A1. Co-pollutants Associated with Black Carbon Emissions, by Source Category

BC Source Category	Other Short-lived Co-pollutant Species				
	NO _x	SO ₄	POA	VOC	CO
Agricultural/Open Burning			X		X
Industry		X			
Residential			X	X	X
Transport	X				
Oil and Gas Flaring	X			X	X

NO_x – Nitrogen oxides include NO and NO₂, and are combustion products resulting from the thermal dissociation of N₂ in the presence of oxygen. NO_x contributes to the formation of tropospheric ozone, or smog.

SO₄ – Sulfate is a secondary pollutant and a principal component of particulate matter (PM_{2.5}) formed through atmospheric processes from the emission of gas phase sulfur dioxide (SO₂). It is generally reflective (except near snow and ice) and—when co-emitted—offsets some of the warming influence of BC.

POA – Primary organic aerosol is the component of atmospheric organic carbon (OC) that is emitted directly in the solid phase. POA combined with semi-volatile (gas phase) organic species that condense after emission constitutes OC, which is also generally reflective (except near snow and ice) and acts to offset a portion of the warming influence of BC.

VOC – Volatile organic carbon consists of a variety of carbon-based but gas phase species that result from combustion of fossil fuels or biofuels. VOCs contribute to tropospheric ozone (smog) and semi-volatile species can condense to form particulate OC.

CO – Carbon monoxide contributes to formation of CO₂ and tropospheric ozone.

Source: Adapted from Bond et al. (2013).

The “bounding black carbon study” (Bond et al. 2013) attempted to account for the nuance in Figure A1 (excerpted from that study). It shows that some black carbon-rich source categories may offer good opportunity for intervention from the standpoint of global average climate impacts. It does not, however, provide enough information to guide the selection of region-specific interventions that make the most sense. For example, while biofuel-cooking interventions—if done well—would provide an undeniable health benefit, this figure suggests very large uncertainties as to whether it would yield a global benefit for the climate system. Despite this finding, one could see—even based on the information in this chart—that in a cloud-free environment very near to snow and ice regions, reductions of biofuel-cooking emissions would be much more likely to benefit the climate (i.e., the highly certain benefit of reducing black carbon that affects atmospheric warming and snow and ice reflectivity would outweigh the highly uncertain impacts of organic carbon/primary organic aerosols on liquid and other clouds). Still, identifying which regions are cloudless enough and near enough to snow and ice to shift this balance remains challenging.

Similar comparisons are important when considering the net health benefits of a specific emission reduction activity. While reducing emissions of all components of PM (including black carbon) offers some degree of health benefit, the magnitude of the overall health benefit will depend not only on the exposure to PM (proximity of emissions to people) but also on the role of other co-pollutants in the formation and distribution of PM. Similarly, many co-emitted pollutants of black carbon reduction interventions, such as volatile organic carbon (VOC) or nitrogen oxides (NO_x), play a role in the formation of ground-level ozone, another important air pollutant with strong health consequences; thus, the

net effect of all emissions on PM and ozone concentrations will determine the net health benefit.

Influence on Climate, Health, and Agriculture

Black Carbon Climate Interactions

Black carbon interacts with the climate system in three principal ways: (1) it directly absorbs light and heat from the sun as it is transported in the atmosphere; (2) it interacts with cloud processes affecting the amount of solar radiation that clouds reflect back to space; and (3) when deposited or rained out onto reflective surfaces (e.g., snow or ice), it affects the amount of solar radiation reflected back from the surface of the earth.

Direct Atmospheric Warming: Black carbon is similar to CO₂ and other long-lived greenhouse gases (GHGs) in terms of light-absorbing properties that allow it to convert light energy to heat and warm the air around it. However, black carbon acts much more intensely than CO₂ for a much shorter time.³⁰ Black carbon particles absorb light and re-radiate it as heat into the atmosphere, as do other black objects such as pavement. When black carbon

³⁰ While CO₂-based metrics do not offer a perfect comparison due to the mismatch of timescales over which they act, the 100-year global warming potential (GWP) for BC is approximately 900 (120 to 1800 range) (Bond et al. 2013). Over 20 years, the GWP for BC is closer to 3,000 (ClimateWorks 2011). A better metric to assess the influence of SLCPs may be short-term integrated forcing (STIF) (Bond and Chen 2013), which can be source-specific and region-specific.

particles are suspended in the air, light that would otherwise be absorbed or reflected at ground level may be redistributed higher in the atmosphere. Black carbon may reduce the amount of light reflected back into space, depending on the reflectivity of the underlying surface and how black carbon is mixed with other particulate matter and the particle size.

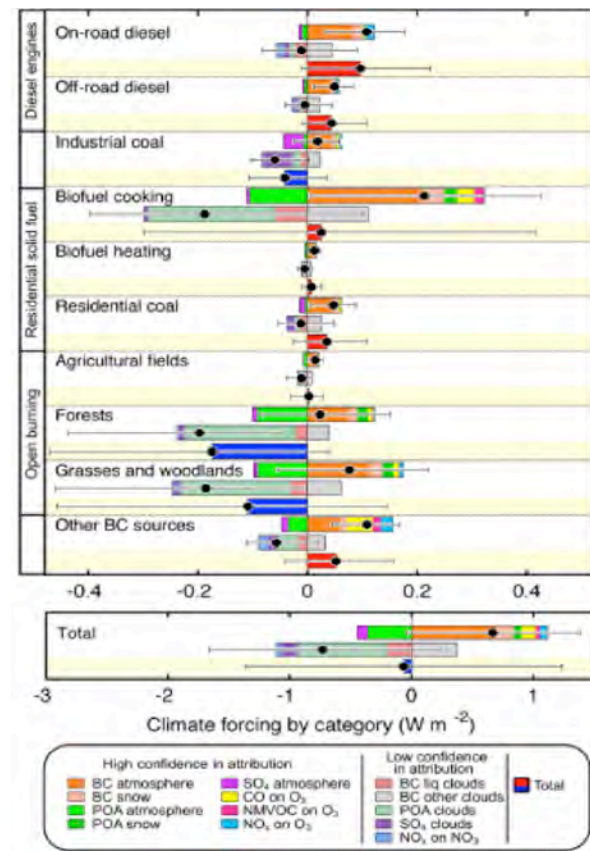
Cloud Interactions: Black carbon can significantly influence cloud formation and cloud properties. Black carbon particles can seed new clouds in the right circumstances by acting as additional condensation nuclei. Where black carbon particles are incorporated into existing clouds, they can act to increase the number of condensation nuclei in a given location. This in turn can influence clouds' radiative, rainfall, and other properties by spreading the same moisture across a greater number of cloud droplets. For example, clouds with a high fraction of black carbon may be less reflective than normal clouds, rise to different atmospheric levels, and alter rain cycle frequency and location. Black carbon particles contribute to the formation of atmospheric brown clouds (ABCs) with large regional climate impacts, including shifting rainfall patterns and temperature gradients (Ramanathan et al. 2008). ABCs have been implicated in the changes in the South Asian monsoon and rainfall patterns over eastern China (Ramanathan and Carmichael 2008). The way black carbon interacts with clouds is among the most uncertain modes of climate forcing and remains an active area of research.

Snow and Ice Feedbacks: Fundamentally different from long-lived GHGs, black carbon remains in the atmosphere for a few days to a few weeks before it is rained out or settles out of the air. Black carbon particles' light-absorbing properties may darken the surface when settling on snow or ice. This increases snow and glacial melt, enabling strong feedback with land and ocean surfaces that may otherwise reflect sunlight. Many arctic regions are now able to absorb significant quantities of heat for whole seasons because of early season melting of snow cover (World Bank 2011). The regional specificity of impacts suggests that black carbon emission reductions near the Arctic, the Himalayas, and other snow- and ice-covered regions will be more beneficial than reductions elsewhere (U.S. EPA 2012; World Bank/ICCI 2013).

Health Impacts

Black carbon is a ubiquitous component of particulate air pollution from a variety of combustion sources. Emissions from older diesel engines still in wide use in low- and middle-income countries—and now being phased out in developed countries—contain a high proportion of black, or elemental, carbon to which other pollutants (e.g., carcinogenic PAHs) are adsorbed, together with organic carbon and other gaseous co-pollutants. PM emissions from cookstoves

FIGURE A1. Climate Forcing by Black Carbon-rich Source Categories in 2005

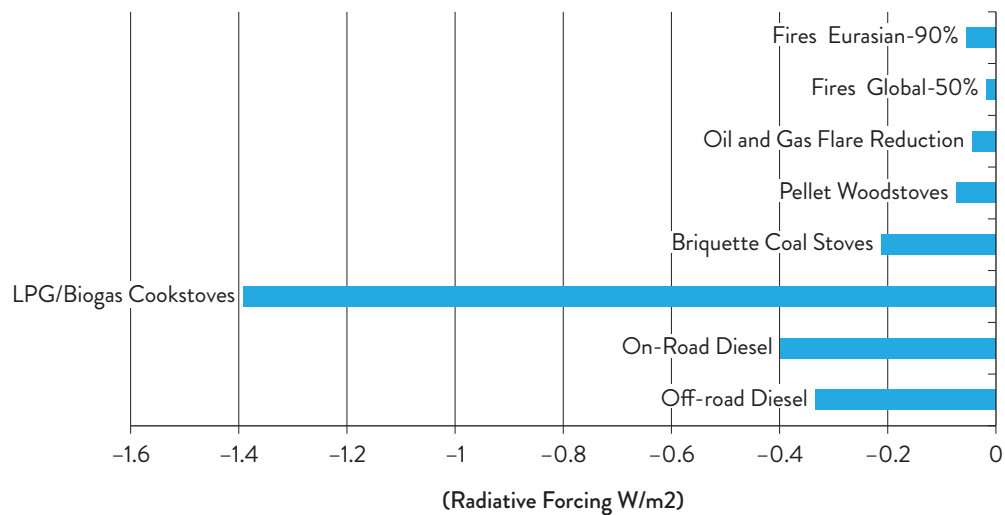


Source: Bond et al. (2013), Fig. 37.

Notes: Total climate forcing for BC-rich source categories continuously emitting at year-2000 rates scaled to match observations in 2005. Three sets of climate forcings are shown for each source as bars with a best estimate (black circle) and uncertainty range. The top bar contains the components for which attribution to particular species is straightforward: direct forcing by aerosol and most gases, and cryosphere forcing by aerosol (including climate feedback). The second bar shows the components for which there is less confidence in apportionment to individual species and, therefore, to sources. These components include all cloud indirect effects and forcing by nitrate from NO_x . Effects of BC on liquid clouds include the cloud albedo and semi-direct effects. Other BC-cloud forcings represent the effects of cloud absorption, mixed-phase clouds, and ice clouds. The bottom bar in each group shows estimated net climate forcing by each emission source, combining all forcings and their uncertainties.

or agricultural burning are also a complex mixture of black carbon, organic carbon, and other co-pollutants as described earlier. Fine particles—particles that are under 2.5 microns in diameter ($\text{PM}_{2.5}$)—such as those emitted by older diesel engines and cookstoves, can penetrate deeply into the lungs where they react in ways that affect not just the lung but also the cardiovascular system (U.S. EPA 2001). Epidemiologic studies indicate that exposure to fine particle pollution causes illness and death from ischemic heart disease (heart attacks), stroke, chronic lung disease and lung cancer, and lower respiratory infections. Toxicological studies provide

FIGURE A2. Reduction in Radiative Forcing Near Snow and Ice from Mitigation Measures: Average of Modeling Results for Five Cryosphere Regions in 2030



Source: Authors, based on World Bank / ICCI 2013 data.

considerable experimental evidence to support these conclusions. A number of different PM constituents, including black carbon and sulfate particles, have been implicated in the effects of PM_{2.5}, though their relative toxicity is uncertain. Nonetheless, exposure to black carbon particles in the home and the ambient environment is associated with serious adverse health effects, including increased daily mortality and admission to hospital for heart and lung diseases (Stanek et al. 2011; WHO 2012).

Agriculture Impacts

Through its various co-pollutants and the impact of its deposition on glacial melt (and therefore groundwater and water availability/scarcity), black carbon has a significant impact on agriculture and sustainability. Most prominently, water availability downstream of glaciers is already changing with increased glacial melt; this portends dire consequences in regions where glaciers may melt completely, leaving downstream populations without any source of fresh water at some time in the future. Changes in production capacity, distribution costs, and consumption patterns are just some of the ways in which these changes will affect the lifestyle of people living downstream of major glacier areas such as the Himalayas and the Andes. Beyond the direct impact on the scarcity of drinking water, the economic costs for agriculture and power generation (many areas are highly dependent on hydropower from glacially-fed river systems) could increase the risk of conflict, reduce food security, and change rural-urban migration patterns at local and national levels.

Black carbon measures that also result in a decrease in ozone precursors (e.g., diesel emission controls) can provide a local benefit in terms of increased crop yields and other ecosystem services. Regions with large potential for reducing diesel emissions could see staple crop production increase by 7–9 million metric tons annually, primarily as a result of reductions in associated nitrogen oxide emissions. Controls on emissions from cookstoves could improve crop production by approximately 1.5–2 million tons annually, primarily as a result of reductions in carbon monoxide (World Bank/ICCI 2013).

Spatial and Temporal Scale of Impact

The mechanisms that lead to climate and health impacts from black carbon emissions operate over a range of scales. Within the planetary boundary layer of the atmosphere (the lowest part of the atmosphere), black carbon has the greatest impacts on health and the climate close to where it is emitted (and to where it deposits on the earth's surface in the case of climate³¹)—holding other factors, such as population concentration and density, constant. In South and East Asia, for instance, the widespread use of solid biomass fuels for residential cooking leads to high levels of household air pollution with widespread public health effects. The

³¹ BC's lifetime of a few days to a few weeks is associated with transport of continental to hemispheric distances.

deposition of black carbon from regional sources on snow and ice has been shown to be a significant factor in the observed increase in melting rates of some glaciers and snowpack in parts of the Hindu Kush–Himalayan–Tibetan region (aka, the “third pole”). Emissions of black carbon and organic carbon in South Asia have been linked to atmospheric brown clouds, which have resulted in changes in the timing and intensity of regional monsoon behavior (Ramanathan et al. 2008). In the Arctic, studies have found that gas and oil flares contribute to nearly half of surface concentrations of black carbon in that region (Stohl et al. 2013); however, initiatives of the CCAC and the World Bank’s Global Gas Flaring Reduction (GGFR) program offer the prospect of significant near-term progress in reducing flare emissions. An evaluation of the global impact of interventions for key black carbon-rich source sectors on the major snow and ice regions of the planet is shown in Figure A2.

As black carbon from the boundary layer mixes into the free troposphere, it becomes more widely dispersed around the globe (though mostly the Northern Hemisphere) where its direct absorption of solar radiation warms various layers of the atmosphere and affects cloud formation and cloud properties. These more globally dispersed phenomena have climate impacts that resemble those of GHGs, including increased frequency of extreme weather, flooding and drought, sea-level rise, and others described in the latest Intergovernmental Panel on Climate Change assessment report (IPCC 2014).

The atmospheric lifetime of black carbon is short and, therefore, black carbon’s effects on climate depend largely on the emission rate, or flow, of black carbon into the atmosphere. Hence, reduction in black carbon emissions will lead to relatively immediate climate benefits (Shoemaker et al. 2013). In contrast, long-lived GHGs may persist in the atmosphere for centuries. Reductions in greenhouse gas emissions will take longer to influence atmospheric concentrations and will have less impact on the climate on a short timescale. However, since GHGs are the largest contributor to current and future climate change, and because GHGs accumulate in the atmosphere, deep reductions in these pollutants are necessary for limiting climate change over the long term (U.S. EPA 2013).

Mitigating black carbon can also make a difference for climate in the short term, at least in sensitive regions. Benefits in sensitive regions like the Arctic, or in regions of high emissions such as Asia, may include reductions in warming and melting (ice, snow, glaciers) and associated sea-level rise (Hu et al. 2013), and reversal of changes in precipitation patterns. Black carbon reductions could help reduce the rate of warming soon after they are implemented. A hybrid climate strategy that will lead to the greatest long-term

reduction in global average temperature and simultaneously minimize near-term impacts of climate change depends on significant reduction of both SLCPs and GHGs in the next several decades (Shoemaker et al. 2013).

Key Takeaway Messages

Black carbon has been shown to have a strong influence on climate—much stronger than that of GHGs, but for a shorter duration—and one that is fundamentally different from that of CO₂ and other long-lived GHGs. Cutting black carbon emissions can have immediate benefits for the climate system and help to reduce snow and ice melt and sea-level rise, to avoid extreme weather, flooding, and drought, and to lessen the burden of disease.

Assessing the climate influence of black carbon emission reductions is complicated by several factors; however, there are also many contexts in which fewer complications exist and climate benefits are assured. Unlike CO₂, the effect of black carbon emissions on the global climate system is context-specific. Due to its far stronger warming potential, gram-for-gram, compared to CO₂, and much shorter atmospheric lifetime compared to that of most GHGs, black carbon can influence climate on a local and regional scale, especially when deposited onto otherwise reflective surfaces such as snow and ice. The added climate effects of co-emitted pollutants and the variety of mechanisms by which black carbon acts (i.e., direct absorption of heat, cloud interactions, deposition on snow and ice) mean that there are some situations in which the net response of the global climate system to a specific black carbon emission reduction activity is non-intuitive and climate modeling may be required to determine the magnitude and even the sign (plus or minus) of climate impacts (i.e., whether it causes warming or cooling).

Black carbon has unambiguously negative local and regional health consequences. Fine particulate matter is a major health risk anywhere it is emitted and expected to lead to human exposure. All reductions of any component of PM_{2.5} will potentially benefit human health. In situations where the climate response to a specific emission reduction activity is uncertain, the health benefits may still justify action.

Selecting optimal black carbon mitigation measures requires taking into account the full suite of impacts of black carbon and co-pollutants and attempting to maximize multiple benefits and minimize unintended consequences across all objectives (health, climate, and environment).

ANNEX 2

Black Carbon Emissions by Sector, Source, and Region

Summary of Black Carbon Emissions by Source and Region

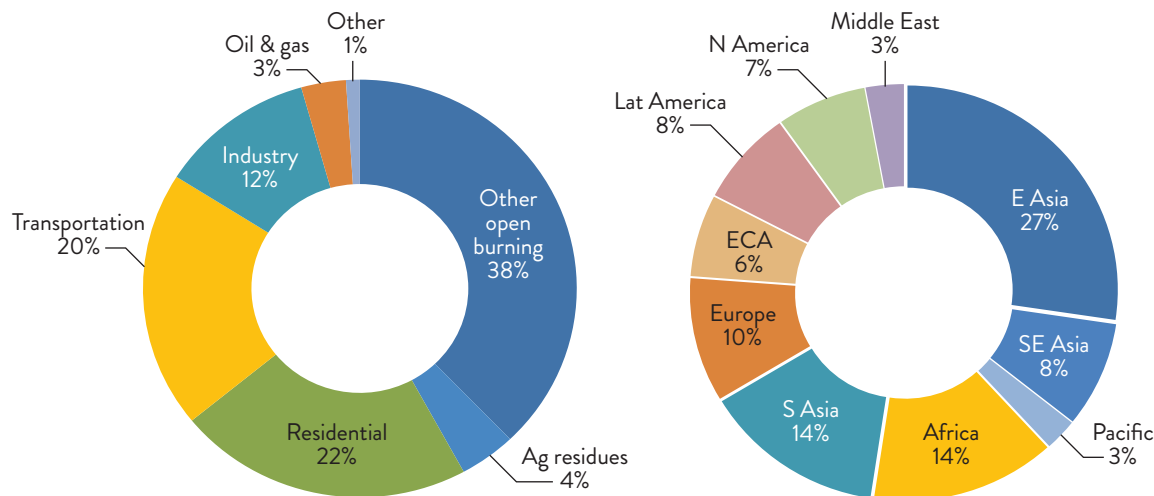
Total emissions of black carbon were estimated at approximately 7,500 Gg per year in 2000 (in the range of 2,000 Gg to 29,000 Gg per year) (Bond et al. 2013), and at 8,500 Gg to 9,200 Gg per year in 2005 (UNEP/WMO 2011). Of these, around 63 percent

were energy-related and 37 percent were from open burning of biomass (proportions of year 2000 estimates, Bond et al. 2013). Table A2 shows a break-down of black carbon emissions by source. Figure A1 breaks emissions down by sector and region.

TABLE A2: Black Carbon Emissions by Source (in Gg per year, 2000)

Source	GFED	RETRO	GAINS	SPEW	Best estimate	Average
1) Open burning of biomass	1,730	2,370		3,280*	2,760	
a) Grassland and open savanna	820	310		1,710*		
b) Woodland	330	1,220				
c) Deforestation and degradation	230	830		1,240*		
d) Forest (excl. deforestation and degradation)	300					
e) Peat	2					
f) Agricultural waste burning	50	Not est.	290	330*		223
2) Energy-related combustion			4,690	4,510	4,770	4,600
a) Residential			2,480	1,720		2,100
i) Cooking and heating			2,310	1,620		1,965
(1) Wood, cooking regions			1,580	1,000		1,290
(2) Other biofuel, cooking regions			310	290		300
(3) Coal, cooking and heating			420	330		375
ii) Residential, other including diesel generation			170	100		135
b) Transportation			1,271	1,550		1,411
i) Diesel engines			1,150	1,320		1,235
(1) On-road diesel			780	840		810
(2) Off-road diesel			370	480		425
ii) Gasoline engines, on-road			80	110		95
iii) Aviation			1	20		11
iv) Shipping			40	100		70
c) Industry (excluding oil and gas)			370	910		640
i) Coal			340	740		540
ii) Non-coal, including biofuel			30	170		100
d) Oil and gas (flaring)			260	Not est.		260
e) Power plants			20	20		20
f) Other low-BC sources (besides power plants)			60	Not est.		60
Grand Total					7,530	

Sources: Based on Bond et al. 2013, Tables 6, 7, and 8. Notes: GFED, RETRO, and GAINS are models used to estimate emissions. *SPEW estimates for open biomass burning are for a climatological average rather than a specific year (in this case 2000). Residential, transportation, industry, and oil and gas categories added by authors. Data are based on year-2000 energy data and technology. Cooking regions are those where solid fuel is primarily used for cooking, even if some heating occurs. In transportation, estimates only include landing and takeoff, no cruise emissions. Totals do not match exactly due to rounding. Average column is calculated by authors.

FIGURE A3. Black Carbon Emissions by Sector and Region

Source: Based on data in Bond et al. (2013). Notes: For sector emissions, uses “current” bottom-up annual black carbon emissions by region in Gg per year. For regional emissions, based on SPEW estimates, and GAINS where SPEW estimates not available.

Black Carbon Emissions by Sector

Agriculture-related Open Burning of Biomass

No study appears to provide a complete estimate of black carbon emissions from agriculture-related open burning of biomass. Several studies estimate emissions from all open burning—which is larger than the category of interest since not all open burning is driven by agriculture—while other studies estimate emissions from the burning of agricultural residues, a subset of the category of interest. Actual emissions from agriculture-related open burning are bound to lie between the emissions of these two inventory categories.

Total global open burning of biomass (including forest, savannah, and agriculture residue burning) accounted for nearly 37 percent of global black carbon emissions in 2000, with emissions estimated at 2,760 Gg per year (Bond et al. 2013). Although the figure of 2,760 Gg per year is an overestimate for agriculture, the sector would be the largest emitter of black carbon even if only approximately 60 percent of these emissions were related to agricultural activities. Viewing agricultural emissions as limited to the burning of agricultural residues would place this sector in fourth place (with emissions estimated between 50 and 330 Gg in 2000, based on Bond et al. 2013).

Taking into account all open burning of biomass, the largest emitting regions are Africa, Asia, and South America, followed by the Russian Federation/Central Asia and North America (U.S. EPA 2012). Emissions are projected to increase over time as a result of population and economic growth, which in turn will lead to

changes in lifestyles and increase demand for agricultural products (namely creating pressure to increase yearly crop cycles), especially in Asia and Africa.

Residential

The residential sector is the second largest source of black carbon emissions. Global residential black carbon emissions were estimated at between 1,720 Gg and 2,480 Gg in 2000 (based on Bond et al. 2013). Sector emissions of black carbon are primarily linked with the residential burning of biomass, but also other solid fuels, for cooking and heating. Some three billion people in the developing world burn solid fuels such as wood, dung, coal, charcoal, and crop residues in traditional stoves and open fires for these purposes (U.S. EPA Report to Congress 2012). In addition to the residential burning of solid fuels, the combustion of kerosene in traditional wick lanterns contributes to black carbon emissions.³² Asia is the dominant source region for residential emissions, although wick lanterns and solid biofuels are also prevalent in Africa.

Residential emissions are projected to remain fairly constant through 2030, although their distribution across source regions

³² Emissions are estimated at 270 Gg per year—or in the range of 110 Gg to 590 Gg per year (Lam et al. 2012). About 250 million households comprising 1.3 billion people lacked reliable access to electricity to meet basic lighting needs in 2010 (IEA 2012). Note that this source is not singled out by Bond et al. (2013) and may be underestimated in the total sector emissions reported above.

is assumed to shift.³³ Africa's contribution to sector emissions, in particular, is expected to rise substantially (UNEP/WMO 2011). Asia is expected to remain the largest emitter in this sector despite its emissions being projected to decrease (U.S. EPA 2012).

Transportation

The transportation sector is the third largest source of black carbon emissions behind the agriculture and residential sectors. Global black carbon emissions from transportation were estimated at between 1,271 Gg and 1,550 Gg in 2000 (based on Bond et al. 2013). Sector emissions are primarily linked to the combustion of diesel fuel by heavy duty on-road vehicles and secondarily by non-road diesel vehicles (including locomotives, tractors, construction machinery, and ships). Asia is the largest source of emissions, followed by North America and Europe.

Total emissions from transportation are projected to decline slightly by 2030, but emissions are expected to grow in Asia. Substantial decreases in emissions are anticipated in North America, Europe, Japan, and other locations as a result of the broad adoption of diesel particulate filters and the prerequisite adoption of low-sulfur fuel. Emissions are anticipated to increase in other regions as a result of dramatic increases in traffic volumes. Black carbon emissions from non-diesel fuels used in road transportation (e.g., gasoline) are projected to increase substantially in China (UNEP/WMO 2011).

Industry (including bricks)

While the CCAC sector initiative for industry focuses on brick production, the present discussion of industrial emissions and abatement opportunities is broader since it includes coke production as well (coke is a key input used in the production of iron and steel).³⁴ Industry is the fourth source of global black carbon emissions after the residential and transportation sectors. Global black carbon emissions from industrial coal were estimated at between 370 Gg and 910 Gg in 2000 (based on Bond et al. 2013). However, it is worth noting that emission estimates are based on a limited set of measurements and remain quite uncertain in this sector.

Sector emissions of black carbon are primarily linked to traditional, small-scale coke and brick production. Emissions from brick production result from the use of low-quality fuels (coal, firewood, and waste fuels such as tires) and energy-inefficient kilns. In the coking process, coal is heated to very high temperatures in an airless furnace, giving off volatile carbonaceous gases if these are not captured (U.S. EPA 2012). Industrial sources of black carbon emissions are overwhelmingly concentrated in Asia (coke production emissions are largely from China), where traditional and inefficient production technology is in high use. While much smaller from a global perspective, significant local pollution problems are associated with brick manufacturing clusters in parts of Latin America (e.g., Mexico) and Africa.

While sector emissions almost doubled from 1990 to 2005, they are projected to stabilize by 2030, with Asia's contribution increasing and those from other regions stabilizing or decreasing (UNEP/WMO 2011). This stabilization assumes the partial replacement of the most inefficient technology currently in use. Emissions growth in Asia at least partly reflects industrialization and urbanization. However, these projections may not adequately reflect recent efforts in China to reform the coking industry (see Huo et al. 2012). In other words, Asian emissions may be on a less steep growth path than projected.

Oil and Gas

The oil and gas sector is the fifth and smallest source of black carbon emissions among those discussed in this report. Global sector emissions in 2000 were estimated at approximately 260 Gg (Bond et al. 2013) but remain highly uncertain owing to a wide range and limited number of emission factor measurements. Sector emissions of black carbon from the oil and gas sector are primarily linked with the practice of flaring natural gas when it is treated as a waste gas byproduct of the oil extraction process. Flaring is concentrated in a few regions, particularly within and near the Arctic. Ongoing measurement efforts supported by the World Bank Global Gas Flaring Reduction (GGFR) partnership (through CCAC) are in progress to improve the quantification of the magnitude of this source category, as current estimates remain very preliminary.

³³ The projected stability in emissions in this sector is largely due to the assumptions that global fuel use will remain about constant, and that limited adoption of cleaner technology (in particular cleaner cookstoves) will occur. However, emissions from biofuel are expected to increase while those from coal are expected to decrease, namely due to changes in China.

³⁴ This definition excludes the power sector.

ANNEX 3

Sector-level Abatement Opportunities

Summary of Leading Black Carbon Abatement Opportunities by Sector

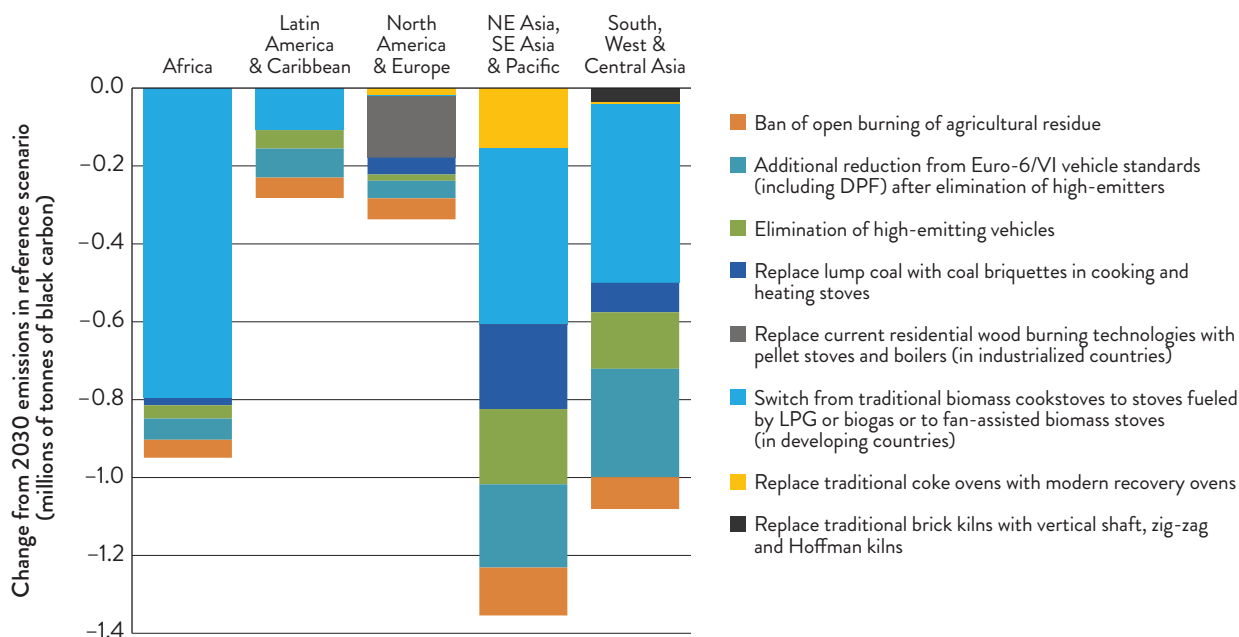
Table A3 presents leading black carbon abatement options by sector, and Figure A4 represents abatement potential by region.

TABLE A3. Leading Black Carbon Abatement Options by Sector, and Associated Costs

Sector	Abatement Option	Technical Abatement Potential, 2030 (Gg BC)	Private Cost (\$/t CO ₂ -e)	Social Cost (\$/t BC)
Agriculture (open burning)	No field burning of agricultural waste	400 Gg	Negative-Low (Not est.)	Negative-Low (Not est.)
	Wildfire reduction	Not est.	Not est.	Not est.
	Management of prescribed burning	Not est.	Not est.	Not est.
Residential	Coal briquettes in lieu of lump coal in cooking and heating stoves	400 Gg	Low (~0)	Low (~0)
	Biomass pellet or briquette stoves and boilers in lieu of wood-burning technologies	200 Gg	High (440 to 880)	High (200,000 to 400,000)
	Stoves using clean-burning fuels (LPG or biogas) in lieu of biomass	1,800 Gg	Low (6 to 14)	Negative (-240 to -200)
	Fan-assisted biomass stoves, boilers, and stokers		Negative (-7 to -3)	Negative (-12,000 to -5,000)
	Controls on diesel generators	Not est.	Not est.	Not est.
	Solar lanterns in lieu of kerosene wick lanterns	Not est.	Negative-Low (Not est.)	Negative-Low (Not est.)
Transportation	Vehicle emission controls, including diesel particulate filters on road and non-road vehicles	700 Gg	High (80 to 2,000)	High (36,000 to 815,000)
	Retirement of high-emission vehicles	400 Gg	Not est.	Not est.
	Fuel efficiency retrofits on existing vehicles	Not est.	Not est.	Not est.
	Fuel-switching in shipping	Not est.	Not est.	Not est.
Industry (excluding oil and gas)	Modern brick production: switch from traditional to vertical shaft kilns	40 Gg	Negative (-8 to -5)	Negative (-5,600 to -4,400)
	Coke oven emission controls: switch to modern recovery ovens	200 Gg	Moderate (0.3 to 1.1)	Moderate (140 to 500)
Oil and Gas	Recovery and utilization of natural gas in lieu of flaring	Not est.	Not est.	Negative (-6,400 to -143)
	Removal and utilization of light hydrocarbon liquids present in flare streams	Not est.	Negative (Not est.)	Not est. (Not est.)
Total		> 4,140 Gg*		

Sources: Authors, based mainly on UNEP (2011) abatement potential and social costs; social cost for flaring reduction based on ClimateWorks (2011). Notes: * Potential exceeds 4,140 Gg since abatement potential is not estimated for certain options included in the table. Converted into Gt CO₂-e: 3.6 Gt CO₂-e (-0.2 to 5.9), GWP₁₀₀; 13 Gt CO₂-e (0.2 to 20), GWP₂₀. These estimates take into account radiative forcing of black carbon and its co-emitted substances. The effect of NO_x on methane over 20–100 years and the removal of the cooling aerosols (such as organic carbon or sulfur compounds) explain the negative values in the range.

FIGURE A4. Regional Black Carbon Abatement Potential from Listed Mitigation Options in 2030
(in millions of metric tons of black carbon)



Note: This chart is based on a global assessment and regional analysis is needed to identify the most relevant regional actions. In addition, this chart reflects data available at the time of publication (2011). The CCAC is currently funding efforts to better assess certain opportunities in Asia, and in Latin and America and the Caribbean.

Source: UNEP (2011).

Leading Black Carbon Abatement Opportunities by Sector

Table A4 lists leading abatement opportunities by sector. These draw both on analysis carried out by the United National Environment Programme (UNEP) as well as BCFSG experts' discussion of these.

TABLE A4. Abatement Opportunities by Sector

Agriculture-related Open Burning	<ul style="list-style-type: none"> No field burning of agricultural waste Wildfire reduction Management of prescribed burning
Residential Energy	<ul style="list-style-type: none"> Coal briquettes in lieu of lump coal in cooking and heating stoves Renewable biomass pellet or briquette stoves and boilers in lieu of wood-burning technologies Stoves using clean-burning fuels (LPG or biogas) in lieu of biomass Fan-assisted biomass stoves, boilers, and stockers Replacement of kerosene wick lanterns
Transportation	<ul style="list-style-type: none"> Vehicle emission controls, including diesel particulate filters on road and non-road engines Retirement of high-emission vehicles Fuel efficiency retrofits on existing vehicles Fuel-switching in shipping
Industry	<ul style="list-style-type: none"> Modern brick production: switch from traditional to low-emission brick kilns and production practices Coke oven emission controls: switch to modern recovery ovens
Oil and Gas	<ul style="list-style-type: none"> Recovery and use of natural gas in lieu of flaring Removal and use of light hydrocarbon liquids present in flare streams

Source: Based on UNEP (2011) and Black Carbon Finance Study Group expert discussion.

Agriculture-related Open Burning of Biomass

Leading Abatement Options and Associated Potential

There are two broad technical options for reducing emissions from agricultural burning: reducing the amount of burning and increasing combustion efficiency (U.S. EPA 2012). Burning of agricultural residues can be reduced by instead incorporating residues into soil (as in conservation tillage) or removing residues to processing sites. The development of alternatives to slash-and-burn agriculture is another avenue for abatement. Various methods exist to increase combustion efficiency, including the use of baling and stacking, the use of propane flammers as an alternative to open field burning, and the use of flaming combustion (“backburning”) as an alternative to smoldering combustion.

A fully implemented ban on open burning of agricultural residues could reduce annual black carbon emissions by 400 Gg BC by 2030 (UNEP 2011). As more work is done in this field to better understand sources and causes of emissions, improved estimates for abatement potential for other forms of open burning (including forests, savannah, and so forth) will likely demonstrate an even larger abatement potential for this sector.³⁵

Abatement Costs/Savings

The costs of mitigating emissions from agricultural burning were not estimated in the studies referenced for other sectors. However, interviews with experts indicate that certain abatement options in the agriculture sector may have negative or low cost profiles. For example, the technologies required to adopt alternatives to burning often involve small investments (e.g., improved ploughs, basic machinery for incorporating biomass into fields, herbicides and pesticides for managing unwanted species). In addition, there are likely to be private economic benefits (either additional revenues or avoided costs) associated with the adoption of alternatives to burning (e.g., improved soil structure, fertility, and yields over time as well as fuel savings if biomass is converted to pellets for energy use).

Practical Obstacles

Many countries have opted to curtail the practice of agricultural residue burning by means of regulatory restrictions and bans. The regulatory approach has generated several success stories; in other cases, however, similar restrictions have encountered challenges related to monitoring and enforcement capacity, low awareness of impacts and the benefits of alternatives, and access to finance and equipment. Attempts to control other forms of open burning,

such as slash-and-burn agriculture, can be fraught with additional challenges given the often informal and unmonitored nature of the sector.

Sector Momentum and Opportunities

Despite ongoing activity, interviews with experts indicate broad consensus that more research is needed to understand the sources and underlying causes of black carbon emissions in the agriculture sector. This work was underway at the time of writing and should provide a strong foundation to identify promising abatement actions that can be pursued in the medium term. Efforts to curb deforestation through the REDD+ framework—which are relevant to the extent that deforestation is agriculture-driven and involves the combustion of biomass—have also gained momentum in recent years.

Ongoing Activities/Key Players

The CCAC Agriculture Initiative, led by Bangladesh, Canada, Ghana, the U.S., the European Commission, the World Bank, and the International Cryosphere Climate Initiative (ICCI), is pursuing three parallel work streams focused on open burning, livestock enteric fermentation, and paddy rice production respectively. The open burning stream is the most relevant one for black carbon mitigation. It aims to develop concrete options for reducing emissions from agriculture-related open burning, targeting at least two staple crops or technologies in each of two target regions—both near glaciated regions so that the climate as well as crop yield benefits are clear. It will design at least two pilot projects in each region aimed at demonstrating options for scaling up alternatives to open burning in both target regions and globally.

The CCAC Agriculture Initiative recently launched its work on open burning, and is looking to identify mitigation options in the Eastern Himalayas and Andes regions in 2015. The work is being led by the ICCL together with the International Centre for Integrated Mountain Development (ICIMOD) and the Molina Center. It (1) has used satellite surveys over 12 years to determine the nature of open burning in the target regions (who burns what, when, where and why); (2) has convened one conference in each region; and (3) going forward, will develop shovel-ready and replicable mitigation pilots involving targeted activities for each region and crop.

The Arctic Black Carbon Initiative, coordinated by the U.S. State Department, has dedicated \$5 million to funding a number of activities, including a project by the U.S. Department of Agriculture to address biomass burning emissions in Eurasia (U.S. EPA 2012).

REDD+. Although efforts to reduce emissions from deforestation and forest degradation (REDD+) are focused on controlling CO₂ emissions (not black carbon emissions), REDD+ is relevant to the

³⁵ There is limited literature examining the effectiveness of practices for reducing black carbon emissions from open burning (U.S. EPA 2012).

extent that a certain amount of deforestation (1) involves biomass combustion, and (2) is agriculture driven.³⁶ REDD+ work has considerable traction at the international level, and work is moving forward to develop results-based and other financing options as well as to develop approaches to safeguards and to monitoring, reporting, and verification. Some of the leading initiatives include the World Bank's Forest Carbon Partnership Facility (FCPF) and the UN REDD initiative.

Residential

Leading Abatement Options and Associated Potential

Traditional stoves used for residential cooking and heating in developing country contexts offer the largest opportunity for abatement within the sector. A large number of technologies have the capacity to reduce black carbon emissions from cooking and heating to varying degrees.³⁷ In urban settings where households predominately rely on charcoal, the key opportunity is generally fuel-switching, along with efficiency improvements. Depending on fuel/electricity availability and household income, possible substitutes for charcoal include cooking with electricity, renewable biomass pellets or briquettes, ethanol, and liquefied petroleum gas (LPG). In rural settings where households rely on various types of biomass (e.g., wood, cow dung, and so forth), the key opportunities lie in improving stove combustion and thermal efficiency.³⁸ Based on the abatement measures identified by the UNEP (2011), the residential sector presents an annual abatement potential of 2,400 Gg BC by 2030.³⁹

Significant abatement potential is also thought to exist in connection with changes in lighting technology, and specifically from replacing kerosene wick lanterns with electric lighting and solar lanterns. The size of this opportunity has yet to be quantified, but Lam et al. (2012) suggest that associated black carbon emissions are on the order of 270 Gg per year globally.

³⁶ Agricultural activities in the developing world are estimated to contribute indirectly to some 3.93 Gt CO₂-e per year through forest clearing and degradation (Scholes et al. 2014).

³⁷ The EPA's Report to Congress on black carbon proposes the following hierarchy of improved cooking solutions: (1) electricity; (2) clean fuels, such as LPG and ethanol; (3) advanced biomass stoves (e.g., forced air fan or gasifier stoves); (4) rocket stoves; and (5) other improved stoves. The switch from using cookstoves to cooking with grid-supplied electricity or gas represents a large opportunity for abatement, though one which generally involves large infrastructure investments (although off-grid renewables may be feasible in some situations).

³⁸ Improvements in one form of efficiency while holding the other constant will reduce black carbon emissions. Good design typically aims to improve both types of efficiency. Focusing on thermal efficiency to the detriment of combustion efficiency, however, could fail to reduce black carbon emissions overall.

³⁹ Open burning may offer more abatement potential, but estimates are not put forth in cross-sector studies.

Abatement Costs/Savings

Various studies estimate that residential measures offer abundant, negative cost abatement potential. Though some abatement technologies are high cost (e.g., biomass pellet stoves), most abatement potential is achievable at negative to low cost (e.g., LPG, biogas, or fan-assisted biomass stoves) ranging from -\$12,000 to -\$100 per metric ton of BC from the social planner's perspective, and from -\$7 to \$14 per ton of CO₂-e from the private investor's perspective (UNEP 2011). These estimated savings place the residential sector in first place under this sub-criterion. If the biomass saved from using modern stoves is assigned a monetary value—a value that derives largely from the time saved gathering wood (mostly by women in many contexts)—cleaner cookstoves generate even larger savings over their lifetime.

The cost of abating lighting-related emissions is not estimated, but could be a negative or low cost option. Up to 25 billion liters of kerosene are used annually to fuel the world's kerosene lamps, costing end-users up to an estimated \$23 billion each year—and more if fuel subsidies are considered.⁴⁰

Practical Obstacles

Significant resources have been mobilized to change cooking practices in the developing world—many of them through market-based solutions—but many efforts have faced significant barriers on both the supply and demand sides. Common challenges include an atomized customer base (e.g., households, community organizations), limited awareness of the serious health risks associated with current practices, poorly adapted technologies that do not conform to consumers' needs or preferences or that lend themselves to improper usage, limited access to finance on the consumer and producer sides, weak supply chains, lack of scale to achieve sustainable commercialization, and limited infrastructure to support fuel-switching.

Sector Momentum and Opportunities

A great deal of momentum exists around efforts to usher in new cooking and lighting technology in the developing world. Although mission-driven organizations (e.g., public sector, multilateral, and philanthropic organizations) have been leading the charge, their focus has largely been on developing private sector-led markets for cleaner cooking and lighting technology. These markets remain incipient, and business models implemented thus far have not achieved the scale to be sustainable (with encouraging exceptions);

⁴⁰ UNEP 2013 article: <http://www.unep.org/Documents.Multilingual/Default.asp?DocumentID=2704&ArticleID=9407&l=en>. Note that annual kerosene use for lighting is estimated at between 4–25 billion liters (Brookings 2013).

increasing private sector involvement, however, holds promise for product and service model innovations to come.

Some of the most promising opportunities discussed with experts include improved combustion and thermal efficiency in off-grid cooking and heating and the replacement of kerosene lanterns with solar lanterns where electricity access is limited. Experts highlight the importance, in these cases, of design and marketing, education, outreach, and capacity-building efforts to enhance demand for cleaner technology. Other opportunities for the study group to consider are fuel-switching in off-grid cooking and heating, and on- or off-grid electrification, namely using renewables.

Ongoing Activities/Key Players

The CCAC Residential Initiative, *Reducing SLCPs from Household Cooking and Domestic Heating*, led by Nigeria and the Global Alliance for Clean Cookstoves, aims to speed up reductions in SLCP emissions through high-level advocacy and support for new financing mechanisms, new research, and the development of standards and testing protocols to provide clear criteria for evaluating emission reductions for improved cookstoves, heatstoves, and fuels. At the time of writing, the initiative had received approval to launch its first phase of work and developed a work plan revolving around three main activities: (1) a high-level advocacy and global education campaign; (2) expansion of the Spark Fund (see below) to include a special tranche of pre-investment grant support for projects that reduce emissions of SLCPs; and (3) the development of standards and testing protocols to evaluate emission reductions of SLCPs and to measure other co-benefits from the widespread adoption of clean cookstoves, heatstoves, and fuels.

The Global Alliance for Clean Cookstoves is a public-private partnership working to create a global market for clean and efficient household cooking solutions. Its stated goal is to foster the adoption of clean cookstoves and fuels in 100 million households by 2020. Its different work streams address consumer awareness, distribution models, access to finance, and technology improvement. The Global Alliance's Spark Fund provides early stage grant funding to businesses, helping them build their size and capacity to attract impact investors. Typical grant recipients include companies manufacturing cookstoves that use biogas and ethanol. At a later stage, the Global Alliance will look to offer performance-based, project-level finance. At the time of writing, it was working with the Gold Standard and other partners to develop a methodology for measuring and verifying black carbon emission reductions from cooking and stoves.

World Bank stove activities. Under the Efficient Clean Cooking and Heating Partnership, a World Bank—GACC partnership announced in November 2014, the World Bank committed to mobilizing \$60

BOX A1. Experience with Fuel-switching in Cooking

While the promotion of cleaner substitute fuels for households has often been implemented in the form of a fuel or equipment subsidy, the experience has been mixed. Attempts to increase the use of LPG and kerosene in Africa, for instance, have largely failed due to costs and complexities having to do with fuel supply, transportation, and usage. Nonetheless, there have been success stories. In Senegal for example, a major initiative to switch to LPG stoves to avoid deforestation was facilitated through a combination of tax breaks (including exemptions from customs duties on LPG equipment and imports) and LPG fuel subsidies. LPG use grew from less than 3,000 tons in 1974, to 15,000 tons in 1987, and to nearly 100,000 tons in 2006 (UNEP 2011).

million to support the GACC's stated goal of 100 million households adopting clean and efficient cookstoves and fuels by 2020, as well as the global Sustainable Energy for All goal of universal access to modern energy services by 2030. The partnership will support in-country programs managed under the World Bank's Energy Sector Management Assistance Program (ESMAP).

This program will build on the World Bank's many ongoing activities to promote cleaner cookstoves. For example, under the East Asia and Pacific Clean Stove Initiative (EAP CSI), the World Bank is collaborating with the governments of China, Mongolia, Indonesia, and the Lao People's Democratic Republic to introduce results-based financing using stove certification as a means of spreading the use of cleaner cookstoves. In Lao PDR, the World Bank is working with C-Quest Capital, the University of California (Berkeley), Berkeley Air, SNV, the Lao Institute for Renewable Energy, and the Lao Government to assess the feasibility of a pay-for-performance mechanism that rewards both the climate and health benefits resulting from the adoption of cleaner cooking technology.⁴¹ The pilot has conducted surveys on the social acceptability of the improved cooking technologies on a small scale and will continue to monitor this aspect closely. While this moves forward, South Pole Carbon Asset Management is developing a

⁴¹ Climate benefits will be captured using an existing CDM methodology to measure and monitor greenhouse gas reductions. The measurement of health benefits will be based on third-party verified, averted disability-adjusted life years (ADALYs) for women and children, estimated based on reductions in household PM_{2.5} and CO pollution. The latter will be worked into the applicable CDM methodology.

BOX A2. Adoption of DPFs in the U.S. and Chile

The United States' regulations on particulate matter emissions from new engines have been effective in reducing black carbon from on-road vehicles—mainly diesel trucks—and non-road diesel engines, locomotives, and commercial marine vessels. Since the 2007 model year, virtually all new road diesels in the United States have been equipped with DPFs. The U.S. EPA estimates that the new standards under the Clean Air Non-road Diesel Rule will cut PM and black carbon emissions from non-road diesel engines by more than 90 percent.

Santiago, Chile, is considered a role model for Latin America when it comes to the successful adoption of DPFs in public transportation. Responding to public concern about air pollution, municipal authorities adopted a new emission standard for urban buses, requiring installation of DPFs (in addition to Euro III standards already in place in 2006). This was possible as low-sulfur diesel fuel was already widely in use in the city. Currently, about one third of the municipal bus fleet is equipped with filters; it is expected that the entire fleet will be retrofitted by 2018.

social benefits metric (largely focused on gender) that could also be used to finance cleaner cooking in Lao PDR.⁴²

The Africa Clean Cooking Energy Solutions (ACCESS) initiative is promoting enterprise-driven dissemination and household adoption of cleaner cooking solutions in Sub-Saharan Africa, using results-based financing in some cases. Projects involving cookstoves and biomass are either underway or in the pipeline in Senegal, Mozambique, Ethiopia, Rwanda, Burkina Faso, Uganda, the Democratic Republic of Congo, and Benin. In South Asia, relevant activities include the South Asia Household Energy project and the Rural Electrification and Renewable Energy Development II Project in Bangladesh, which conducted stove-user consultations. Clean cooking solutions are also a core focus of the Reducing Short-lived Climate Pollution in South Asia Project, spanning India, Nepal, and Bangladesh. The Latin America region has the SE4ALL Central America Clean Cooking Initiative (CACCI) and is undertaking or planning cookstove activities in Honduras, Nicaragua, and Guatemala.

In the lighting arena, Lighting Africa is a joint initiative of the International Finance Corporation (IFC) and the World Bank that has been accelerating the development of markets for clean off-grid lighting products in Sub-Saharan Africa—most of them solar powered—since 2007. Now, through Lighting Global, IFC and

the World Bank jointly support market development by promoting product quality and supporting a network of regional programs focusing on specific country markets. IFC also manages programs in India and Papua New Guinea through the Lighting Asia program, and is developing new country programs in Bangladesh, Pakistan, and Indonesia. These programs offer a model for diffusing solar lanterns at scale.

Energising Development (or EnDev), a partnership involving Norway, Germany, Netherlands, Switzerland, Australia, and the United Kingdom, aims to improve sustainable energy access for poor households, social institutions, and small and medium-sized enterprises in Latin America, Africa, and Asia. Around two thirds of its portfolio is devoted to cooking solutions (biogas, cookstoves), and largely oriented to creating a market structure for providing energy services and products to end-users on a commercial basis. The remainder of its portfolio focuses on electrification, lighting, and solar systems, among others.

Carbon finance. In recent years, cookstove projects have succeeded in attracting private sector finance through the sale of greenhouse gas emission reductions on carbon markets. Clean development mechanism (CDM) projects issue certified emission reductions (CERs) for projects that offer energy efficiency improvements and fuel-switching on the basis of greenhouse gas reductions; however, the demand for CERs has decreased significantly in recent years. As a result, the voluntary market has become an increasingly popular market for sale of emission reductions from clean cookstoves. In a 2013 survey administered to carbon project developers, Ecosystem Marketplace and Bloomberg New Energy Finance found that the sale of verified emission reductions (VERs) on voluntary carbon markets alone has helped to buy down the cost of at least four million cookstoves or other cleaner household devices. No existing CER or VER methodologies take into account the climate or health benefits of black carbon emission reductions.

Other relevant activities include those of WPower, devoted to women's entrepreneurship in renewables; Envirofit, a for-profit organization involved in the sector through the design, production, and sale of energy-efficient cookstoves; the Base of the Pyramid Impact eXchange Fund, a joint venture between the Shell Foundation and BIX Fund promoting the use of impact certification mechanisms (related to climate, health, or other forms of social impact) to strengthen value chains, lower the costs, and improve the marketing of household appliances, including improved cookstoves for the base of the pyramid consumers in developing countries. It is exploring how it could offer up-front investment in the cookstove value chain in exchange for a claim on certified health benefits.

⁴² Willingness to pay for freeing up women's time (related to collecting cooking fuel) could be higher than current carbon prices according to initial surveys.

Transportation

Leading Abatement Options and Associated Potential

The use of diesel particulate filters (DPFs) on new or in-use vehicles has the potential to result in large reductions in black carbon emissions from diesel engines.⁴³ The effectiveness of DPFs, however, is dependent on the simultaneous use of ultra-low sulfur diesel (ULSD) fuel. While many developed countries in Europe and Asia have adopted low-sulfur fuel requirements along with vehicle emission standards,⁴⁴ this is not the case across much of the developing world. In general, abatement technology is penetrating non-road transportation more slowly than on-road. Based on the abatement measures identified by the UNEP (2011), the technical potential for abatement in the transportation sector is estimated at over 1,100 Gg BC by 2030.

Other important abatement options—though associated potential is not quantified—include the adoption of fuel efficiency retrofits on existing vehicles (mostly trucks); improved vehicle inspection and maintenance; the early retirement of vehicles and their substitution with lower-emission vehicles; demand management; mode shifting; and fuel-switching in the commercial shipping sector. Some of these options, such as energy efficiency retrofits for trucks, are relevant where high speed road and mature logistics systems are in place.

Abatement Costs/Savings

Abatement options in transportation are generally achievable at a high cost, ranging from \$36,000 to \$815,000 per ton of black carbon from the social planner's perspective and from \$80 to \$2,000 per ton of CO₂-e from the private investor's perspective (UNEP 2011).⁴⁵ However, some interventions involving fleet efficiency could be achieved at a negative abatement cost. The overall cost of emission reductions could be lowered through bundling engine efficiency improvements with filters in the process of retrofitting.

⁴³ ClimateWorks (2011) assumes the abatement potential associated with DPF retrofits in OECD countries, where a significant proportion of older vehicles do not meet current emission control standards for new vehicles. The abatement potential of DPF retrofits on heavy-duty trucks alone would be 0.06 GtCO₂-e in 2020 (20-year GWP: 0.2 GtCO₂-e).

⁴⁴ Europe's past emission control standards have served as a model for a large number of countries in the Americas and Asia. Most recently, Euro V standards, in effect since 2009, require the use of DPFs on new light-duty diesel vehicles. Stage IIIB standards started to phase in DPFs on non-road vehicles in 2011. Euro VI standards imposed DPFs on new heavy-duty diesel vehicles starting in 2013. Some diesel locomotives are required to have DPFs, but commercial ships remain unregulated (U.S. EPA Report to Congress 2012).

⁴⁵ As noted in a previous footnote, the social costs of abatement do not factor in the external benefits of abatement (i.e., health, climate, economic spillover, ecosystem, or other benefits).

Practical Obstacles

Obstacles to reducing black carbon emissions vary by abatement opportunity and geography. The unavailability of low-sulfur diesel fuel in much of the developing world is a barrier to the adoption of vehicle emission control technologies (DPFs).⁴⁶ Upgrading refining capacity to enable a switch to low-sulfur diesel fuel and to pave the way for the adoption of vehicle emission controls requires tremendous institutional capacity and political will to develop, coordinate, engineer, and finance complex, multi-billion-dollar transactions. Importing low-sulfur diesel from existing refineries is a low-cost option within reach for many countries, but one that can encounter political resistance (e.g., due to national goals for energy independence).

In contexts where economic incentives, policies, and inadequate infrastructure contribute to fuel quality issues, the introduction of low-sulfur fuel may be ineffective on its own. In India, for instance, it is widespread practice to mix preferentially-priced (high-sulfur) kerosene with diesel. Moreover, in order to fully benefit from the introduction of DPFs, vehicles need to be properly operated and maintained. Where low-sulfur fuels are available and vehicles are well maintained, obstacles to the adoption of low emission standards and emission control technologies can reflect political, technical, or enforcement weaknesses on the part of public agencies, and a lack of economic incentives (e.g., where DPFs represent a high percentage of vehicles' market value). Municipal-level abatement projects have the advantage of involving fewer stakeholders than other sectors' abatement opportunities (e.g., fewer stakeholders than households in the case of cookstoves, family producers in the case of bricks).

Obstacles to the adoption of freight efficiency measures include low awareness, entrenched behaviors, and limited access to finance (small transaction size, lack of access to credit). It is also worth noting that retrofitting trucks with aerodynamic tires, skirts, and other equipment only enhances fuel efficiency when trucks are able to travel at high speeds and, hence, where developed expressway networks are in place.

Sector Momentum and Opportunities

Although efforts remain more focused on health benefits relative to harder-to-measure climate ones (at least with respect to black carbon), public-private efforts to curb transportation emissions—particularly in urban contexts—are at advanced stages of development in countries that have already switched to low-sulfur diesel fuel. For instance, considerable momentum is propelling the adoption of vehicle emission standards and controls forward in multiple Latin American municipalities. Efforts to improve fuel quality, which will pave the way for later emission controls, are in

⁴⁶ Sulfur in fuel will quickly render DPFs ineffective.

the works in other parts of the developing world, but these generally have longer timelines intertwined with national and regional politics. Though investment in refinery capacity may lubricate the transition, needed and ongoing efforts are largely political in nature. Separately, where modern roadways and logistics are the norm—that is mostly in high and upper-middle income countries—programs are ramping up to seize existing, near-term opportunities to improve fuel efficiency among the truck fleets of mid-sized freight companies.

Some of the most promising opportunities in this sector, based on discussions with experts, include truck fleet fuel efficiency retrofits; DPF retrofits and upgrades on bus and other vehicles in municipalities or geographies where low-sulfur fuel is available or can be adopted; vehicle inspection and maintenance; and scrapping of low-performance vehicles. Other key opportunities include refineries' upgrades and low-sulfur fuel imports, mode switching (e.g., truck to rail or shipping), and demand management.

Ongoing Activities/Key Players

The relevant CCAC Sectoral Initiative is the *Reducing Black Carbon Emissions from Heavy-Duty Diesel Vehicles and Engines*, led by Canada, the U.S., UNEP, and the International Council on Clean Transportation. The initiative aims to catalyze major reductions in black carbon from heavy-duty diesel vehicles by laying the political and technical groundwork for the adoption of clean fuel and vehicle regulations and supporting policies. For this, the initiative is deploying a three-pronged strategy that involves: (1) encouraging policies that will usher in low-sulfur diesel fuel plus tighter emission standards and vehicle emission-control technologies⁴⁷; (2) promoting incentives for the uptake of fuel-saving technologies, with an initial focus on Latin America and Asia⁴⁸; and (3) pursuing programs to address elevated emissions from existing vehicle stocks through retrofits, scrappage, inspection, and maintenance.

The Sector Initiative is involved in the following:

- Developing and promoting a global fuel sulfur strategy that addresses major hurdles to the spread of low-sulfur fuel, including financing constraints, obstructive subsidies, and political inertia.
- Steering a high-level coalition of industry, country, and NGO leaders in support of the Green Freight Call to Action, working

to improve the energy efficiency and environmental performance of freight operations worldwide.

- Supporting the development of national programs and policies, including standards for vehicle emissions and for low-sulfur fuels, to address emissions from the existing vehicle stock.
- Conducting a range of activities to inform, motivate, secure, and support the implementation of official commitments to move to soot-free urban bus fleets in 20 target cities.

The UNEP's Partnership for Clean Fuels and Vehicles (PCFV), launched in 2002, promotes low-sulfur fuels and cleaner vehicle standards and technologies. The partnership has over 100 members from the oil and gas industry, engine and retrofit manufacturers, government agencies, and environmental NGOs (U.S. EPA 2012).

World Bank diesel transportation activities. Various World Bank projects are supporting the phase-out of high-emitting diesel vehicles and the establishment of tighter vehicle emission standards. In the Philippines, the \$222.5 million Cebu Bus Rapid Transit project will introduce buses that meet Euro IV emission standards, reducing PM emissions while saving fuel costs. In China, the \$14 million Guangdong Green Freight Demonstration Project will attempt to scale up heavy-duty truck efficiency improvements and fuel savings achieved in the Guangzhou Green Trucks Pilot Project in 2010. Transportation is also a core focus of the Reducing Short-lived Climate Pollution in South Asia Project, spanning India, Nepal, and Bangladesh (alongside bricks and cookstoves). The project is in the stages of completing in-depth analytic work to draw and adapt lessons learned in the U.S. to the region. The Green Freight Transport for Brazil Project aims to devise and test strategies to promote energy efficiency and reduce emissions from freight transportation in Brazil, drawing lessons from U.S. SmartWay and other programs.

Industry (including bricks)

Leading Abatement Options and Associated Potential

Industrial abatement of black carbon emissions is likely to involve the phasing out of small, uncontrolled operations and the adoption of emission-control and energy-efficiency technologies in larger operations. Modern coking plants minimize emissions by recovering coke oven gas, burning it for heat or refining it into byproducts (RTI 2008 in U.S. EPA 2012). Techniques for controlling fugitive emissions exist at different stages of the coking process and can reduce emissions by up to 98 percent (RTI 2006 in U.S. EPA 2012). Mitigation can also result from increasing the energy efficiency of operations and minimizing coal use (Polenske and McMichael 2002 in U.S. EPA 2012). The UNEP estimates

⁴⁷ The current work program involves carrying out studies to assess the magnitude of the challenge of moving to low-sulfur fuel and to lay out a vision for the switch. This effort will leave behind an inventory of refining capacity, focused on the near-half of refineries that produce high-sulfur fuel (>50 ppm). The initiative is also carrying out analytic work looking at how fuels flow across global markets—and specifically from refineries to markets—which will result in a series of maps.

⁴⁸ At the country level, the initiative is working with policy makers in Latin America, Africa, and Asia around the adoption of fuel and vehicle standards. The initiative is also developing programs in Latin American (Colombia, Peru) to spread the use of DPFs on buses in cities where low-sulfur fuel is already available—replating the Chilean model.

abatement potential in coking at 200 Gg BC by 2030. Judging from scholarship published in intervening years on the coke industry in China, however, it is possible that some of this mitigation potential has already been realized.⁴⁹

Black carbon abatement in brick production primarily involves the replacement of inefficient kilns with more energy-efficient ones, such as the vertical-shaft brick kiln (VSBK), the tunnel kiln, the zig-zag kiln, and the hybrid Hoffman kiln (HHK) (U.S. EPA 2012). Switching to cleaner kiln technologies can improve energy efficiency by 40–60 percent and reduce PM emissions by more than 80 percent. Brick production is largely concentrated in China, South Asia, and Latin America, where simple brick ovens are still commonly used.⁵⁰ Based on the abatement measures identified in the UNEP report (2011), the technical potential for black carbon abatement in the brick industry is estimated at 40 Gg BC by 2030.

Other measures to abate brick-related emissions include fuel-switching, substituting other materials for bricks in the construction sector, and equipping other industrial sources with particulate matter controls. For instance, opportunities exist for retrofitting power plants in China and off-grid diesel generators in India and other countries with well-established control technologies.⁵¹

Despite the larger role that coke production may potentially play in total black carbon emissions and abatement potential, the following discussion on investment obstacles, opportunities, and sector momentum focuses primarily on the brick industry. This is because information was more readily available for this sector and because it aligns with the BCFSG mandate to focus on sectors with ongoing CCAC Sectoral Initiatives.

Abatement Costs/Savings

The UNEP (2011) estimates industrial abatement of black carbon to be feasible at low to negative cost. Abating black carbon by modernizing coking operations could cost from \$0.3 to \$1 per ton of CO₂-e from the private investor's perspective, or \$140 to \$500 per ton of black carbon from the social planner's perspective. Abating emissions by modernizing brick kilns could have a negative cost of

⁴⁹ See Ho et al. 2012: "China is the largest coke producer in the world, accounting for over 60 percent of the world coke production, which makes the coke industry in China a significant coal consumer and air pollutant emitter. Recently, China has taken a series of measures to improve energy efficiency and reduce emissions from the coke industry, including eliminating old and low energy-efficiency coking technologies, promoting advanced technology, and strengthening energy and environmental requirements on coking processes. As a consequence, China's coke industry is experiencing an unprecedented technology shift, which was characterized by the elimination of old, inefficient, and polluting indigenous ovens and small machinery ones within 10 years."

⁵⁰ There are an estimated 35,000 facilities in India using Fixed Chimney Bull's Trench Kiln (FCBTK)—the most widely used firing technology in South Asia—11,500 in Pakistan, 4,500 in Bangladesh, and 450 in Nepal. There are also considerable numbers of traditional facilities in Latin America, including 6,898 in Brazil, 300 in Chile, 2,453 in Colombia, 17,000 in Mexico, and 2,222 in Peru (CCAC Sectoral Initiative fact sheet).

⁵¹ In fact, opportunities for retrofitting diesel generators exist across sectors.

–\$8 to –\$5 per ton of CO₂-e abated for the private investor, or a cost of –\$5,600 to –\$4,400 per ton of black carbon abated from the social planner's perspective.

Practical Obstacles

Obstacles to abatement in this sector vary to some extent depending on whether they involve family owned or family run production units or more industrialized facilities. Broadly speaking, however, incentives for technology upgrades are often weak in developing country contexts, where there is often low capacity to enforce emission or air quality standards. One challenge in this sector—shared with the residential sector—is that abatement involves changing long-standing practices among a plethora of generally small, loosely organized, artisanal or semi-industrialized producers, who often lack an understanding of the benefits of using cleaner technologies and have limited access to finance. In some cases, insecure land tenure or access weaken producers' investment incentives. An additional challenge with industrial abatement involves the issue of livelihoods. To the extent that measures (e.g., the enforcement of emission standards) could force the closure of large numbers of family owned and run units that depend on this industry, abatement measures in this sector could face broad socioeconomic and industrial policy challenges from policy makers' perspective.

Despite these obstacles, initiatives to reduce air pollution from traditional kilns through a combination of regulations and economic incentives have proven effective, as illustrated in Box A3.

Sector Momentum and Opportunities

Within industry, the brick subsector has attracted substantial donor attention in a number of countries. Several initiatives are attempting to coax what remains a highly informal, energy-inefficient and polluting sector in various parts of the developing world to modernize, invoking both business and welfare rationales. There is no CCAC Sectoral Initiative focusing on reducing SLCP emissions from the coking process. Experts have pointed to brick kiln efficiency as a promising intervention area. Other promising opportunities include brick kiln fuel-switching and demand management (e.g., adoption of brick alternatives in the construction sector).

Ongoing Activities/Key Players

The relevant CCAC Sectoral Initiative is *Mitigating SLCPs and Other Pollutants from Brick Production*, led by Colombia, Mexico, Switzerland, the Center for Human Rights and Environment, the World Bank, and the Institute for Governance and Sustainable Development. Its aim is to encourage the adoption of integrated approaches for cleaner brick production through technical assistance, the dissemination of information about highly energy-efficient

BOX A3. Success Stories in Industrial Abatement

China has come a long way in modernizing its brick sector through a combination of command-and-control regulation and economic incentives (e.g., fiscal incentives, preferential loans) and strategies targeting the entire brick value chain, from the sourcing of raw materials to end use in construction (e.g., the use of solid clay bricks is now banned or controlled in a large number of cities). Long dominated by small, artisanal producers, the industry is experiencing consolidation (the number of producers declined from roughly 100,000 to 80,000 between 2005 and 2010) and phasing out outdated technology (including the Hoffman kiln) (World Bank 2011).

In Mexico, the *Ciudad Juarez Brickmakers Project*, led by the Mexican Federation of Private Health and Community Development Associations (FEMAP)— started working with the largely informal brickmaking sector in the 1990s. Through a combination of regulation, community-assisted enforcement, education, and technology subsidies, the project led the majority of the city's 300 brickmakers to switch to cleaner fuels, and to adopt improved brick kilns which use familiar material and construction techniques yet reduce fuel use by 50 percent and PM emissions by 80 percent (UNEP/WMO 2011; Allen Blackman 1998).

technologies, cost-benefit analyses, awareness raising, capacity building, and the implementation of pilot projects. As noted, there is no CCAC Sectoral Initiative focusing on reducing SLCP emissions from the coking process.

The initiative completed its first phase of work in July 2013. Thus far, it has prepared an awareness-raising toolkit and developed an online clearinghouse to facilitate knowledge sharing and capacity building among experts and stakeholders. In a series of reports focusing on Mexico, Brazil, Peru, Chile, Colombia, and Nigeria, it has researched brick production practices, policies and opportunities to modernize these, and proposed national strategies to identify and define approaches to mitigation. In addition, with initiative assistance, the governments of Colombia and Mexico have established national strategies, and Mexico and Nepal have held regional workshops to promote more efficient technologies for brick production.

The second phase of the initiative started in November 2013. Its activities are focusing on establishing networks of experts, conducting training in proven technologies, facilitating knowledge-sharing and capacity building, and creating business cases on the brick kiln sector to be presented to financial institutions. It is also working to develop

protocols to measure climate-relevant emissions and efficiency for brick kilns. Expected outcomes include: (1) increased awareness of opportunities to improve local and regional policies to reduce SLCPs from brick production; (2) pilot projects to demonstrate best practices in brick production; and (3) creating synergies with ongoing work to reduce SLCPs at the national and regional levels.

World Bank activities in the industry or brick sector. In South Asia, the World Bank is pursuing brick sector modernization through several activities. Several lending and carbon finance operations are under way in Bangladesh, as illustrated in Box A4. In India, the World Bank has worked with manufacturers to leverage carbon finance for compressed bricks, a brickmaking process that does away with the use of coal. Brickmaking is also a focus of the Reducing Short-lived Climate Pollution in South Asia Project spanning Nepal, India, and Bangladesh. The project is developing national policy options and building stakeholder support for pollution reduction measures. In China, the Liaoning Third Medium Cities Infrastructure Project, focused on improving energy efficiency in this province, replaced several hundred small and highly polluting boiler plants with eight new boiler plants, reducing black carbon emissions.

Other prominent activities focusing on the Bangladesh brick sector are noted in Box A4.

Oil and Gas

Leading Abatement Options and Associated Potential

The central abatement opportunity for reducing black carbon emissions from flaring involves the capture and utilization of natural gas. Reducing black carbon emissions from flaring generally requires compression stations (which can be expensive) to enable the use of natural gas for on-site power generation or to enable its capture, distribution, and marketing.⁵² Additional mitigation is possible through improvements to flaring performance, including through the separation and removal of light hydrocarbon liquids from the gas stream before it is flared. Indeed, new uses of technology are making it increasingly feasible to recover, rather than flare, these highly valuable liquids that are often found in flare streams and that contribute significantly to black carbon emissions. The potential for abatement in the oil and gas sector is not estimated in the 2011 UNEP report due to the fact that it is not deemed to be among the largest opportunities.

⁵² Options include gas reinjection, pipeline gas, compressed natural gas (CNG), liquefied natural gas (LNG), gas to liquids (GTL), gas to power/wire (GTW), gas to methanol, and gas to (other) chemicals (GTC).

Abatement Costs/Saving

In certain circumstances, once the value of recovered natural gas is factored in, black carbon can be abated at negative cost in the oil and gas sector. Substituting flaring with the recovery and utilization of natural gas can occur for an estimated negative cost of –\$6,400 to –\$143 per ton of black carbon abated (equivalent to \$7/ton CO₂-e_{GWP-100} to 14/ton CO₂-e_{GWP-20}) from the social planner’s perspective (based on ClimateWorks 2011). That said, the economic attractiveness of flaring is highly dependent on the magnitude and certainty of natural gas volumes, the distance of extraction operations from markets, and the availability of infrastructure to process, transport, and distribute the gas. By contrast, the removal of light hydrocarbon liquids from flare streams for alternative uses—resulting in higher combustion efficiency—represents a lucrative abatement opportunity, according to interviewed experts.

Practical Obstacles

Despite attractive project economics in some cases, natural gas continues to be flared across numerous oil extraction operations. One reason for the lack of action is that, though positive, the returns on waste-gas utilization projects are lower than other priority investments for oil and gas companies. Gas is generally worth a fraction of oil and is more difficult to handle.⁵³ Other barriers to reducing flaring include high capital costs for equipment, low or uncertain volumes, and restricted pipeline capacity for transporting recovered methane. Legal issues can also come into play. For example, in some countries extraction companies have unclear or no rights to byproduct gas—a legacy of days when gas was considered a waste product. In other instances, contracts allow operators to use gas for on-site energy production but not for commercialization. Accessing pipelines to carry gas to markets also raises a number of legal issues in some contexts. Thus, achieving abatement potential may require regulatory measures and their enforcement.

Sector Momentum and Opportunities

Momentum in this sector is high and long-standing if one considers efforts that have for years been mounted to encourage profitable methane capture and recovery, a subset of which—specifically those related to flaring—are relevant to reducing black carbon emissions. But not all of these efforts are relevant (those aiming for reductions in leakage and venting are not), and more political muster is needed to clear political and economic hurdles. There is a strong push now for an international commitment to cease flaring in the Arctic and globally, which would create tremendous impetus

⁵³ Even with large amounts of gas, the relative value of associated gas is very low compared to oil (just 3–6% of the revenue stream based on an oil field with a gas-oil ratio of 1,500 scf/bbl at \$70/bbl oil, \$2/mmbtu gas and \$20/CER.

BOX A4. Modernizing Bangladesh’s Brick Sector

Of the more than 4,000 bricks kilns operating in the country, the vast majority use energy-intensive and highly polluting technology—primarily fixed chimney kilns. In North Dhaka’s brickmaking cluster, brick kilns are the leading source of urban fine particulate pollution, accounting for 40 percent of emissions during the 5-month operating period. Although several technologies could reduce emissions, save fuel, and improve brick quality, implementation challenges have delayed uptake by brick producers.

Bangladesh’s brick sector has attracted significant attention in recent years, including (*inter alia*):

- The World Bank’s *Clean Air and Sustainable Environment Project*, a \$62 million loan, is improving urban air quality by reducing emissions in brickmaking as well as transportation.
- The Hoffman Hybrid Kilns Carbon Finance CDM Project, developed by the World Bank, is leveraging carbon finance through the Community Development Carbon Fund (CDCF) to buy down the cost of upgrading to a technology that is cleaner than that commonly in use, through the sale of certified emission reductions (CERs).
- The ADB’s *Financing Brick Kiln Efficiency Improvement* is lending \$50 million to Bangladesh Bank to on-lend to participating financial institutions, which is providing loans to brickmakers to upgrade to or build cleaner kilns. The Government of Japan is offering \$750,000 in technical assistance to help the government formulate supportive policies and regulations.
- The UNDP-GEF’s \$14 million *Improving Kiln Efficiency in the Brick Making Industry Project* is demonstrating and financing hybrid Hoffman kilns as an alternative to fixed chimney kilns.

for investment. In addition, efforts to make the business case for mitigation through hydrocarbon fluid recovery—with or without the use of climate finance—could spur industry investment with little need for subsidies. Key relevant opportunities in this sector include the recovery of light hydrocarbon liquids from flare gas prior to flaring and reductions in flaring with gas recovery and utilization.

Ongoing Activities/Key Players

The relevant CCAC Sectoral Initiative is *Accelerating Methane and Black Carbon Reductions from Oil and Natural Gas Production*, led

by Nigeria and the U.S. The initiative's activities include: (1) identifying—through measurement, mapping, and monitoring—where venting and flaring of volatile organic carbon-rich (VOC) natural gas occurs to identify economic opportunities to reduce SLCP emissions as well as to develop policy tools; (2) piloting projects to stimulate the commercial deployment of technical approaches that reduce SLCPs from venting and flaring; (3) developing a single communication portal to share information on tools, emerging technologies, best practices, and approaches; and (4) engaging public and private sector financiers to help scale up investment in SLCP emission reduction projects associated with recovery of hydrocarbon liquids.

The initiative is pursuing two work streams: one focused on reducing fugitive emissions of methane (not expected to impact black carbon emissions) and the other on reducing black carbon emissions through the recovery of readily condensable hydrocarbon liquids. The initiative is working with large oil and gas companies in Mexico, Canada, Colombia, and China to study the feasibility of specific technical options and to explore avenues for financing their deployment with public and private sector participation (including climate finance). The anticipated outcome of this work stream will be the identification of cost-effective investment opportunities, laying the foundation for their transfer and replication in other markets.

The World Bank's Global Gas Flaring Reduction Partnership (GGFR), launched in 2002, is a public-private partnership between the governments of oil-producing countries and major oil and gas companies.⁵⁴ It supports partners' efforts to increase the use of associated natural gas, and to reduce flaring and venting. One of its accomplishments has been to establish a global standard for gas

flaring. It also provides a framework for stakeholder consultation and collaboration aimed at expanding project boundaries and reducing barriers to recovered gas utilization. Projects have successfully been undertaken in Angola, Indonesia, Nigeria, and the Russian Federation under the GGFR—some taking advantage of the flaring methodology developed under the Clean Development Mechanism (UNEP/WMO 2011). In parallel to the GGFR, the World Bank is pushing for a global agreement to eliminate routine flaring globally by 2030. This is a high-level, political initiative focused on summoning commitments from public and private sector stakeholders.

The Arctic Council is a high-level forum for political discussion on issues common to the governments of arctic states. Its members include Canada, Denmark (including Greenland and the Faroe Islands), Finland, Iceland, Norway, Sweden, Russia, and the U.S.; six organizations representing indigenous peoples of the Arctic; and multiple inter-governmental and nongovernmental organizations. In 2013, the Arctic Council established a Task Force on Black Carbon and Methane to coordinate mitigation actions. The task force is co-chaired by Canada and Sweden, and reported to the Arctic Ministerial Meeting in 2015.

The U.S. EPA's Natural Gas STAR Program is a voluntary partnership that encourages oil and natural gas companies—both in the U.S. and internationally—to adopt cost-effective technologies and practices that improve operational efficiency and reduce methane emissions. The program showcases facilities that are achieving reductions, encourages facilities to identify opportunities to reduce emissions, provides a framework for transparent reporting, and recognizes progress at the company and facility levels.

⁵⁴ GGFR partners include: Algeria (Sonatrach), Angola (Sonangol), Azerbaijan, Cameroon (SNH), Ecuador (PetroEcuador), Equatorial Guinea, European Bank for Reconstruction and Development (EBRD), France, Gabon, Indonesia, Iraq, Kazakhstan, Khanty-Mansiysk (Russia), Mexico (SENER), Nigeria, Norway, Qatar, the United States (DOE), and Uzbekistan; BP, Chevron, ConocoPhillips, ENI, ExxonMobil, Marathon Oil, Maersk Oil & Gas, Pemex, Qatar Petroleum, Shell, Statoil, and TOTAL; European Union, the World Bank Group; and associated partner: Wärtsilä.