Black Carbon

A Review and Policy Recommendations

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Front Cover: Aerosol pollution over Northern India and Bangladesh, provided courtesy of The National Aeronautics and Space Administration , The Visible Earth (http://visibleearth.nasa.gov/)

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Methodology

This report was researched and written by a group of Masters in Public Affairs students, PhD candidates, a Masters in Public Policy student, and a postdoctoral research fellow at the Woodrow Wilson School at Princeton University. Led by a Princeton University professor—an atmospheric scientist—the project was sponsored by the School as part of the annual graduate policy workshop program. The goal of the workshop program is for the students to contribute to addressing critical policy problems. This particular workshop arose out of the Environmental Protection Agency's (EPA) desire to develop a comprehensive plan to integrate air quality and climate mitigation efforts, with a focus on black carbon. The group set out to address that need and hopes it has succeeded in offering recommendations that will be useful to the EPA as it confronts growing challenges in air quality and climate change. In developing the report, the group first met with the director and staff of EPA's Office of Air and Radiation, Office of Policy Analysis and Review to discuss the interests and needs of the client. Over the following weeks, members reviewed the latest science behind black carbon and researched possible mitigation policies. The latter included discussions with almost 50 experts and stakeholders, including government agencies, business networks, academics and advocacy groups. The group met with experts in California, Colorado, Finland, New Jersey, the Northeast, and Russia. Through careful research and deliberation, the group developed a framework for assessing the air quality and climate impacts of black carbon, and provided a suite of policy options focused on reducing black carbon emissions both domestically and internationally.

The Woodrow Wilson School of Public and International Affairs, founded at Princeton University in 1930, provides an interdisciplinary program that prepares undergraduate and graduate students for careers in public and international affairs. The school is one of the world's premier academic and research institutions devoted to public and international affairs. The views expressed in this report are the views of the authors and do not represent the views of Princeton University, the Woodrow Wilson School, the Environmental Protection Agency, or those who provided advice. Any errors of fact are the responsibility of the authors.

This report can be accessed online at:

http://www.wws.princeton.edu/research/PWReports/F08/wws591e.pdf

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Executive Summary

This report examines the climate-warming air pollutant black carbon (BC). BC is a significant contributor to global warming; mitigation of its emissions is likely required to avoid exceeding the commonly discussed 3.6ºF (2ºC) end of century target. BC also has substantial adverse impacts on public health and large resulting economic costs. In the United States, BC emissions are produced primarily by diesel engines. While the U.S. has among the tightest diesel emissions regulations in the world, we outline a variety of feasible short and long term policy solutions to further reduce domestic BC emissions and reach emissions sources not covered by current regulation. In developing countries, which produce the majority of global BC emissions, BC is emitted from a wide variety of sources, each of which would benefit from the tailored approaches to mitigation that we outline in this report. There are also a variety of international agreements and policy options that could be used to incentivize reduced BC emissions globally. In this report, we describe the complex nature of black carbon emissions and impacts and explore a variety of domestic and international emissions reduction strategies that would provide substantial benefits to public health and climate. Our final chapter summarizes our recommendations.

Introduction (Chapter 1) and Scientific Background (Chapter 2)

We first introduce black carbon, discuss the composition and distribution of emissions by region and source, and detail some of the challenges and opportunities of reducing emissions. In Chapter 2 we then provide additional detail on the scientific understanding of the climate and health effects of BC. BC is emitted during the incomplete combustion of fossil fuels and biomass. Chemically, it is primarily elemental carbon, similar to graphite in pencils. Though it is not currently regulated explicitly, it is controlled as part of the class of air pollutants called particulate matter (PM). BC predominantly falls within the PM_1 category - ultrafine particulate matter with a diameter less than 1 micrometer. Both diffuse and concentrated BC particles, like all fine particles, have adverse impacts on human health, including increased rates of premature mortality and detrimental effects on child development and on respiratory and cardiovascular health.

BC also acts as a powerful global warming agent. It has a global radiative forcing that may exceed that of methane (the second most important greenhouse gas) and may equal as much as one-third of the radiative forcing from all long-lived greenhouse gases (GHG). Because BC has a short atmospheric lifetime of less than a week, it is not well-mixed through the atmosphere. Its climate and health impacts therefore have strong local and regional characteristics.

The potency of BC as a warming agent varies among source types and regions due to differences in co-emitted aerosols, transport, and deposition location. BC is generally co-emitted with another type of carbonaceous (carbon-based) aerosol, organic carbon (OC). Because OC has a cooling effect on climate, the net warming effect of carbonaceous aerosol emissions decreases as their OC:BC ratio increases. Primarily for this reason, carbonaceous aerosols produced by contained combustion of fossil fuels – particularly diesel and coal – have a significantly greater net warming effect than carbonaceous aerosols produced by contained combustion of biomass. These, in turn, have a significantly greater net warming than carbonaceous aerosols produced by open burning of biomass, which likely have a net cooling effect. In addition to causing warming when it is lofted in the atmosphere, BC also causes warming when it is deposited out of the atmosphere onto snow and ice. This effect contributes significantly to the warming of the Arctic and the Himalayas. The net warming effects of BC are therefore magnified when it is transported to the Arctic (where it accelerates melting of sea and land ice) or emitted from South and East Asia (where it can accelerate Himalayan glacier and snowpack melting with resulting impacts on water supplies).

Though BC emissions are abundant globally, South and East Asia are the largest sources of warming carbonaceous aerosols. As a whole, Asia accounts for over 45% of contained BC emissions, while North America and Europe account for approximately 18% [Bond, 2004][1]. BC emission reductions have great promise as part of climate change mitigation efforts. Since BC is a potent short-lived warming agent with emissions that can be considerably reduced using currently available technology, emission reductions can provide rapid short-term reductions in radiative forcing and hence slow global warming significantly in the short-term. Targeted BC reductions can also partially offset the warming caused by reductions in the emission of similarly short-lived cooling aerosols, such as sulfate.

Furthermore, the benefits of BC reductions for climate purposes provide additional motivation for many economic development and public health projects. Reducing BC thus has greater political viability than many approaches to reducing greenhouse gases because it can be easily linked

1 Bond, T. C., Streets, D. G., Yarber, K. F., Nelson, S. M., Woo, J.-H. and Z. Klimont (2004), A technology-based global inventory of black and organic carbon emissions from combustion, *J. Geophys. Res.*, 109, D14203.

financially and politically with programs to improve local air quality, promote urban transport infrastructure, and develop green industry and transport. Technologies which reduce BC, as diverse as cook stoves and mass transit systems, are also often energy efficient, simultaneously yielding carbon dioxide emission reductions and economic savings in operating and life-cycle costs. Furthermore, these economic and health-related co-benefits mean that BC can be used to create linkages in international negotiations that facilitate broad climate change mitigation efforts.

Attempts to reduce BC emissions face a number of difficult challenges. Because BC has complex and variable warming properties, policy decisions are less straightforward than for the major greenhouse gases. Furthermore, the concentration of BC emissions in developing countries and the predominance of small and mobile emissions sources create additional mitigation challenges related to monitoring, funding, institutional capacity, and coordination. As a result of these difficulties and scientific uncertainty, BC has not yet been prominently incorporated into domestic or international climate policy.

Black Carbon in the United States (Chapter 3)

As Chapter 3 discusses, the transport sector accounts for nearly 90% of net climate-warming BC emissions in the United States. The majority of these emissions are from diesel engines.

Stringent regulation by the EPA has managed to curb the environmental and public health impacts of new diesel engines through the use of particulate filters and Ultra Low Sulfur Diesel (USLD) fuel. However, older vehicles are still cause for concern. Retrofitting these vehicles using Diesel Particulate Filters (DPFs) is shown to be a highly effective and cost-efficient mechanism for reducing emissions. Unfortunately, there are few mandatory requirements or economic incentives in place to encourage retrofitting. .

In addition to a continued emphasis on improving vehicle fuel efficiency, we recommend increased effort and funding for retrofitting older diesel vehicles, particularly "super-emitters" which can emit over ten times more BC than normal vehicles. In the long run, however, we recommend that the federal government undertake strategies to replace trucks with rail and barge systems for cargo transport, and invest in the development and commercialization of non fossil-fuel technology, such as plug-in hybrid electric vehicles. Funding for these programs should be drawn from the Obama Administration's ambitious stimulus package to create green jobs and improve health and climate outcomes.

Black Carbon Abroad (Chapter 4)

The majority of BC emissions, both in terms of gross particulate mass and in terms of net impact on radiative forcing, are produced by developing nations. Efforts to address the health and climate impacts of global BC emission must therefore include significant reductions in countries outside the OECD. From the perspective of the U.S., encouraging these BC reductions is attractive for three reasons. First, non-OECD nations account for 77% of gross global BC emissions and are expected to comprise an ever-increasing percentage of the global total. Second, facilitating BC reductions in the developing world provides an excellent entrée for developing countries into the discussion of climate change efforts more broadly. Third, emissions of BC in Asia are projected to have a significant warming impact on the U.S. Several factors make BC reductions attractive from the perspective of the developing world.

As noted by the Intergovernmental Panel on Climate Change (IPCC), economically fragile countries are more vulnerable to the impacts of climate change, which can be mitigated in the near term through BC reductions. Moreover the concentration of BC sources and exposure in non-OECD countries means that BC emissions have a greater impact on public health in developing countries. Finally, as rapid infrastructure development is now underway in non-OECD countries, there is an opportunity to reduce future BC emissions before they evolve into an intractable problem.

We discuss focused strategies for addressing four separate combinations of sectors and regions that constitute a significant portion of gross BC emissions. Emissions from diesel vehicles in Asia can be reduced through the accelerated adoption of emissions controls and deployment of ULSD. BC emissions from residential biofuel in China and India can be reduced by working to gather, consolidate, and disseminate information about biomass use, rural emissions inventories, and best practices concerning cookstoves. The emission of BC from open biomass burning in Africa and Latin America can be reduced primarily through developing comprehensive environmental strategies for agriculture and encouraging best practices. Industrial sector BC emissions in China and Russia can be addressed through gathering emissions inventory data and facilitating the transfer of technology necessary to upgrade industrial infrastructure and maintain economic development. Broader themes for EPA efforts to reduce BC emissions abroad include a renewed public sector focus on developing best practices for BC reduction, as well as an expansion of public-private partnerships to create a sustainable market for appropriate technologies.

Black Carbon in Transnational Arenas (Chapter 5)

Chapter 5 explores a variety of international agreements and policy options that could be used to facilitate reductions of BC emissions globally. We find that BC is unsuitable for inclusion in an emissions trading scheme with GHGs. Unlike the GHGs, BC is short lived in the atmosphere and has strong local and regional effects on health and climate that make it a poor commodity for trading. In addition, the multitude of small sources such as vehicles and stoves make transaction costs for monitoring and verification high for a trading scheme.

We have instead identified several options for international agreements to reduce BC emissions. First is an agreement between developed countries under existing international air pollution agreements such as the Convention on the Long Range Transport of Air Pollution (LRTAP) to reduce BC emissions. A second option is a regional hot-spot treaty to restrict emissions that affect particularly sensitive regions such as the Arctic or the Himalayas. An additional option is to structure international institutions to help developing countries reduce BC emissions through technology assistance, global technical standards and multi-lateral funding.

The U.S. already has the legal authority to reduce domestic BC emissions under the U.S. Clean Air Act by implementing many of the policies recommended here. Our analysis shows that although not yet a key topic in the international climate debate, BC mitigation provides a cost-effective target for slowing climate warming and improving public health. This report encourages the U.S. Government to recognize the importance of BC emission reductions for climate and public health and to take a leading role in both domestic and international mitigation efforts. We explore the dimensions of the challenges and opportunities of BC emissions mitigation in the following five chapters, and present our consolidated recommendations in the conclusion.

Chapter 1: An Introduction to Black Carbon and Mitigation Approaches

1.1 Profile of Global Black Carbon Emissions

Black carbon (BC) is a significant contributor to global warming, responsible for 0.3°C, or approximately one-sixth of historical warming (Figure 1.1). In some areas, the current regional climate impacts of BC may exceed those of long lived greenhouse gases (GHG).

1.1.1 Composition and Sources of Emissions Containing BC

BC and organic carbon (OC), with which BC is often co-emitted, are aerosols (fine particles suspended in the atmosphere) composed of elemental carbon and carbon compounds. OC is a less reflective form of carbon which tends to scatter sunlight and thus is a net cooling agent under most conditions, except in the Arctic (Section 2.1.5). Both BC and OC (as well as SO_2 and other commonly co-emitted compounds) are major components of soot, a carbonaceous substance generally defined by its means of production, incomplete combustion, rather than by chemical or physical properties. The terms "BC" and "soot" are often used interchangeably despite the fact that they are not synonymous, leading to terminological confusion. In addition, BC is rarely measured in its pure form; instead, it is generally measured as part of particulate matter pollution (PM_1, $PM_{2.5}$ and PM_{10}, particulate matter less than 1µm, 2.5µm and 10µm, respectively), of which it forms a variable fraction. The international scientific and policy communities should work to establish universal conventions and standards relating to BC to lay the groundwork for future collaboration.

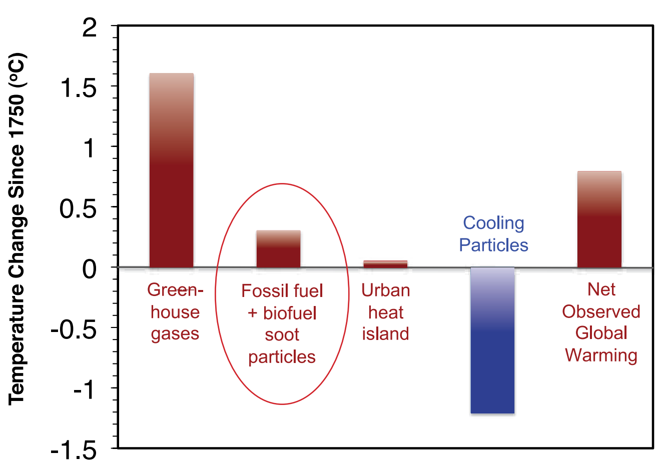

Figure 1.1. Estimated total contribution (in °C) to global warming since 1750 of BC-containing soot particles. *Data included through 2005. [Jacobson, 2004]*

Carbonaceous aerosol emissions can be divided into two categories – those derived from contained or uncontained combustion. Contained combustion is dominated by fossil fuels (FF) and includes industrial sources, diesel engines, heat generation, and cooking. Uncontained combustion or "open burning" includes most outdoor burning of solid and agricultural waste as well as forest and savannah fires. BC emitted via open burning contains much more OC than BC, and the net effect of the OC and BC emissions may in fact be cooling (when excluding CO_2 emissions from burning). Consequently, contained combustion BC emissions probably contribute nearly all of BC's share of global warming [*Jacobson*, 2004].

> *TYPES OF BLACK CARBON EMISSIONS*
>
> ◆ Contained BC emissions sources
> - Dominated by fossil fuel combustion
> - Organic carbon (OC) co-emitted in low concentrations
> - Strong warming effect
>
> ◆ Uncontained BC emissions sources
> - Dominated by agriculture, forests, and savannah burning
> - High OC co-emissions
> - Negligible warming or net cooling effect from aerosols

1.1.2 Global Distribution of BC Emissions by Region

Approximately 8,000 kilotons of BC are emitted globally each year [*Bond et al.*, 2004]. These emissions, particularly the contained combustion emissions that dominate BC's contribution to global warming, come predominantly from the northern hemisphere *(Figure 1.2)*. This fact is particularly important given that BC emissions north of 40°N are most likely to be transported to the Arctic region, where their warming impact is amplified [*Ramanathan and Carmichael*, 2008].

A regional breakdown shows that the developing world emits roughly 80% of total BC emissions, while Europe and North America represent a combined 13% (*Figure 1.3*). However, Europe, North America, and the former USSR emit BC primarily from fossil fuel combustion and largely above 40°N, thereby contributing disproportionately to warming due to the OC:BC ratios and the impact of latitude on arctic melting. Africa emits 25% of global BC, but nearly all from open burning, thus the overall effect is probably negligible or even negative due to the cooling properties of the co-emitted OC (excluding warming from CO_2 released by forest burning) [*Naik et al.*, 2007]. China, India and the rest of Asia account for 39% of global

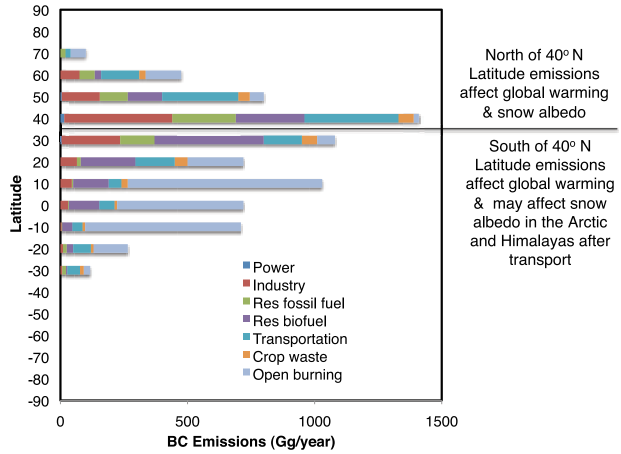

Figure 1.2. Latitudinal breakdown of global BC emissions (all types), with sector split. *BC emissions north of 40°N have a significant likelihood of atmospheric transport and deposition in the Arctic. All categories except crop waste and open burning are contained burning responsible for warming. Residential biofuel and biofuel used in transportation are contained, but distinct from fossil fuel. Data from 2000. Source: Bond, unpublished.*

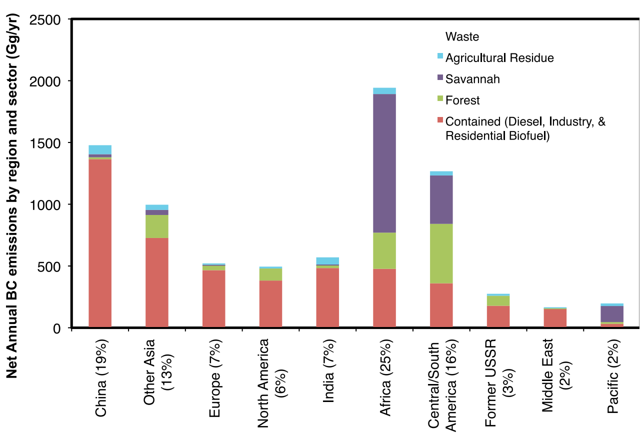

Figure 1.3. Global annual emissions (in kilotons, or gigagrams) of BC by region and source type. *Adapted from [Bond et al., 2004]. Source regions are ordered left to right by decreasing emissions of BC from contained combustion, which has a lower OC:BC ratio (and stronger warming effect) than open burning sources. Percentages given in parentheses are the portion of total global emissions (all sources) from the region.*

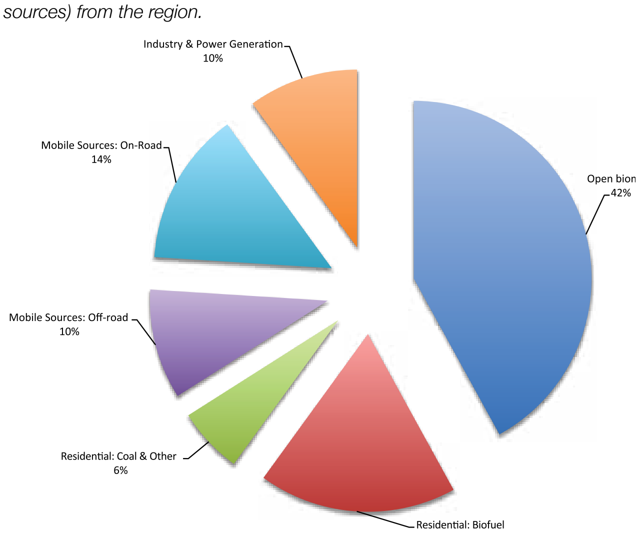

Figure 1.4. Global breakdown of BC Emissions by Source. *Adapted from [Bond et al., 2004].*

BC emissions, and about 54% of warming BC emissions. In Central and South America, contained combustion, forest burning and savanna burning each contribute about 5% of global BC [*Bond et al*., 2004].

1.1.3 Global Distribution of BC Emissions by Sector

BC emissions are distributed amongst three categories of contained sources - industry (10%), residential (24%), mobile (24%) - and uncontained sources (42%; *Figure 1.4*). Contained combustion (i.e. within stoves, furnaces or engines) includes power generation, industrial and residential combustion, and transportation. Contained combustion that generates BC includes combustion using gasoline, diesel fuel, heating oil, hard coal, coking coal, wood, and animal and agricultural waste (all of which produce BC at different rates, and co-emit OC in variable amounts). In Figure 1.4, "open biomass" refers to open burning. With a 42% share, this source type dominates overall world emissions of BC, but probably contributes little to climate warming from aerosols because of a high fraction of co-emitted OC.

When sector shares of emissions are adjusted for radiative forcing, it is clear that most of the warming effect of BC comes from contained combustion (Figure 1.5). Higher radiative forcing implies greater trapping of solar heat, which, if sustained, tends to warm the climate. The greatest potential to reduce warming through BC emissions reductions therefore lies in reductions of on-road and off-road diesel fuels use (Chapter 3) and coal combustion (Figure 1.5). The share of total global BC-induced radiative forcing from these sources, particularly those in the northern hemisphere, increases further if the snow albedo effect is taken into account (Chapter 2). Thus, we recommend targeting diesel and coal-burning sources for BC emissions mitigation.

1.2 The Challenges of Reducing BC Emissions

1.2.1 Uncertainties regarding BC emissions and global warming magnitude must be reduced

Scientific uncertainties exist regarding the exact magnitude of radiative forcing attributable to BC and the relative importance of BC emitted from various sources and regions. Chapter 2 presents our best understanding of the science of the problem based on available model and observational data. Uncertainties create difficulties in including BC in existing climate change frameworks that address long-lived greenhouse gases

(*Chapter 5*). Furthermore, estimates of BC emissions contain considerable uncertainties [*Bond et al.*, 2002], particularly for emissions in non-OECD countries and for all open burning sources. Consequently, feasibility and cost/benefit scenarios for BC mitigation based on current data would have significant uncertainties. Immediate efforts must be made to ensure that incomplete scientific data and emissions inventories do not hinder government efforts at formulating good policy. To address this challenge, more coordinated BC emissions data collection and analysis are needed, as well as improved estimates of climate forcing by BC based on models and observations.

1.2.2 A large and growing fraction of BC emissions comes from developing countries

Throughout history, most climate warming agents (such as carbon dioxide) have been emitted by developed countries where most of the world's energy and resources are consumed. By contrast, in this report we show that the majority of BC emissions comes from the developing world [*Bond et al.*, 2004]. India, China, and Southeast Asia – three leading sources of BC emissions – are also disproportionately affected by the health problems associated with BC (Chapter 4), since concentrations are extremely high in urban areas with very high population density, and also in rural homes due to use of dirty cook stoves. Furthermore, these countries have trouble with administrative capacity, as indicated by surveys that can be used as proxies: for example, India, China, and Indonesia, the most populous countries in the region, rank 83rd, 122nd, and 129th, respectively, in the World Bank's Ease of Doing Business Index [*World Bank*, 2008], and 72nd, 85th, and 126th respectively in Transparency International's Corruption Perceptions Index [*Transparency International*, 2007] (both

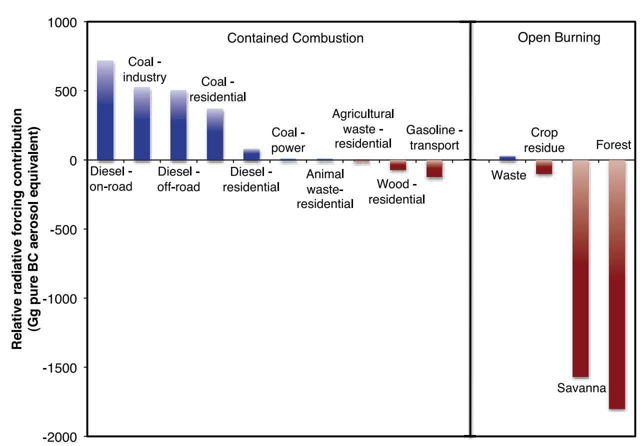

Figure 1.5. Relative radiative forcing due to BC emissions by source type. Annual total emissions from each source [Bond et al., 2004] are weighted by the combined effects of direct and indirect radiative forcing (and excluding snow albedo effects) based on the average OC:BC ratio from each source type. Forest and savanna burning are not included (see Table 2.1).

surveys out of 180+ countries). Furthermore, these countries have GDP per capita of 10% or below that of developed countries [*CIA*, 2008]. Consequently, where benefits from BC emissions reduction are greatest, constraints on funding and institutional capacity are the greatest as well.

The problem of mitigating developing country BC emissions is amplified by the expected exponential growth in energy demand (Chapter 4). These trajectories suggest that the introduction of new technologies that reduce BC emission factors per unit activity is critically needed. Examples of this include the production and use of fuel-efficient hybrid cars or CNG buses instead of diesel vehicles (Chapters 3 and 4). Low-emissions energy R&D, infrastructure, and urban and industrial planning are critical components of a strategy for the developing-world to avoid BC emissions from sources that do not yet exist.

1.2.3 BC sources are widely dispersed and difficult to target

Unlike carbon dioxide emissions, much of which arise from power generation in the U.S. (approximately 40%) and large industrial sources (15%) [*EPA*, 2008], less than 13% of world BC emissions come from large industrial facilities and little comes from power plants [*Bond et al.*, 2004]. Rather, the sources of BC are more widely dispersed: diesel cars, trucks, and other mobile construction and agricultural machinery account for 42% of radiative forcing-weighted global BC emissions. Meanwhile residential coal, biofuel, wood and agricultural combustion account for another 16%. The latter sources include small-scale cook stoves, small man-made fires of all kinds, and furnaces and boilers. To fully inventory all emissions and create unique solutions for each would require identifying and addressing hundreds of millions of sources, a daunting undertaking from a logistical, administrative, political, and financial perspective.

1.2.4 Technological approaches to mitigation can be costly and difficult to implement

Technologies to reduce BC emissions from industrial and other contained sources generally come in four varieties: retrofits, replacement, reducing rates of future demand, and efficiency and conservation gains (Chapter 3). Retrofits refer to repairs or mechanical modification of existing emissions sources, while replacement refers to the decommissioning or retiring of old machinery which is replaced by newer equipment that emits less. Reducing future rates of growth of emissions could be accomplished through the development of alternative technology or through behavior change.

Efficiency and conservation gains refer to the reduced use of existing BC emitting sources through streamlined processes or through demand reduction. This could take the form of fewer car-miles driven due to greater use of mass transit, less use of a wood-burning stove resulting from improving home insulation, or lower use of diesel trucks with improved inventory management.

Retrofits are the first option pursued because the up-front costs, while still high, are relatively smaller, and because logistically they are often the easiest option. Efficiency and conservation can also be cost-effective, but gains are difficult to calculate since they are often indirect. Efficiency gains also depend on adequate infrastructure, strong institutions, and management capacity. Replacement costs for local power and heat generation, machinery, and vehicles not near the end of their useful life can be prohibitively expensive, and/or require access to ample sources of long-term credit. Even retrofits themselves are very expensive, particularly diesel engine filters. The best hope for employing the economics of BC mitigation is for tipping the scales on investment in clean and efficient energy technology being considered for other reasons. When monetized, the climate and health benefits of BC mitigation can make projects viable that would otherwise be marginal when considering only greenhouse gas mitigation (carbon finance), efficiency (lifetime energy cost savings) and functionality (heating, cooking, and transport efficacy).

1.2.5 Significant institutional challenges exist for developing and administrating mitigation policies

Most types of BC reduction call for regulation (e.g. fuel and vehicle standards), monitoring (vehicle exhaust and factory smokestacks), and/or distribution of millions of clean devices (cook stoves, cars, trucks). In addition, for potential new sources (e.g. new diesel vehicles) alternative technology must be made available. Successfully meeting these challenges will be difficult, particularly in rural and far-flung areas distant from capitals.

In addition to in-country administrative capacity shortfalls, international coordination on BC is essential to the generation of political momentum for addressing the problem. Currently, BC is an unknown entity outside the confines of a small group of air quality and climate change specialists. Even amongst the specialists, much data fails to be exchanged internationally, and there are terminological and definitional problems that bedevil discussions of BC. Greater international coordination between the science and policy communities is needed to establish scientific definitions and terminology, exchange data and best practices, and to develop mitigation strategies and policy mechanisms. Further detail and recommendations are provided in Chapter 5.

1.3 The Benefits of Reducing BC Emissions

Like other greenhouse gases and aerosols, BC emissions should be reduced to combat climate change. The difficulties mentioned above might suggest that BC is an unattractive target for emissions mitigation. Yet BC has two trump cards that set it apart from most other warming pollutants. First, BC emissions mitigation can lead to a major reduction in short-term global warming. Second, reducing BC emissions can yield local and regional climate and health benefits that are much greater than those associated with GHG emissions reductions. Short-term impacts and major co-benefits represent powerful practical and political arguments for focusing on BC.

1.3.1 Short-term climate benefits are possible with BC mitigation

BC has a large radiative forcing as well as a short atmospheric lifetime. Consequently, aggressive action on BC reduction can significantly reduce short-term climate change, allowing societies to implement large-scale carbon emissions reduction programs at both a more reasonable pace and with a lower risk of disastrous rapid short-term climate change. BC reductions may also be necessary to reach 450 ppm CO_2e atmospheric concentration targets by 2100 (Chapter 2). Reducing BC emissions can also reduce the warming expected to result from future reductions in the emissions of cooling agents, particularly sulfur dioxide, which are being driven by air quality regulations.

1.3.2 BC mitigation provides targeted protection of the Arctic and the Himalayan glaciers

Climate change disproportionately affects the Arctic, and scientists believe Arctic warming may be fueling dangerous feedback loops that will lead to serious climate tipping points (WWF 2008). BC also has an outsized impact on the Arctic (Chapter 2) and on the Himalayan glaciers which supply water to much of Asia (Chapter 4). The indirect effect of the absorption of solar energy by BC particles deposited on the ground, particularly on ice and snow, has alone led to 0.5-1.0°C local warming in the Arctic [*Ramanathan and Carmichael*, 2008]. Consequently, identifying and reducing BC sources that lead to Arctic and Himalayan deposition can have a disproportionately large impact on climate change mitigation. Measures in the Arctic and the Himalayas should be pursued vigorously through international forums such as the Arctic Council and the Convention on Long-Range Transboundary Air Pollution (LRTAP, Chapter 5).

1.3.3 Attractive immediate technological solutions are readily available

Despite difficulties with the logistics and cost of disseminating BC-reducing technologies, most of the needed technologies already exist. Unlike advanced, cost-effective CO_2 mitigation options, such as carbon capture and storage (CCS), solar power, cellulosic ethanol and other renewable energy sources, BC technologies for diesel fuel and vehicles, cook stoves, industry, and other biomass burning could be commercially viable immediately given well-designed models for production and distribution (Chapters 3 and 4).

1.3.4 BC mitigation has a wide variety of non-climate benefits that make it politically attractive

Climate change mitigation is often a secondary policy priority, following economic development and public health. BC mitigation strategies should embrace rather than fight this reality, and employ the argument of climate change benefits (and possible carbon finance) to tip the scales in favor of BC-reducing policy proposals under consideration for health, infrastructure, energy efficiency, agricultural and political motivations.

Health gains - In recent years, studies have demonstrated conclusively that airborne fine particulates, of which BC is a major component, have serious detrimental health effects (Chapter 2). Even at low concentrations, fine particulates increase premature mortalities and morbidity [*Schwartz et al*., 2002, 2008; *Laden et al*., 2000, 2006; *Dockery et al*., 1993]. By conjoining climate change mitigation efforts with national and WHO health initiatives, BC becomes an attractive target. Embracing the co-benefits can also yield political momentum for international collaboration on climate change.

Infrastructure development - Infrastructure development and well-conceived urban planning can generate an array of benefits, among them reduced BC emissions. The construction of new mass transit systems (subways, light rail, natural gas-run bus fleets), shipping infrastructure such as railroad networks and ports, and the application of “smart development” urban design, could reduce present and potential future growth in diesel vehicle use, and with it BC emissions. Building low-pollution power sources and industrial plants also provides the dual benefit of economic development and better air quality.

Energy efficiency and quality service provision gains - Many replacement and retrofit technologies result in efficiency gains, particularly when obsolete boilers, central heating systems, and low-tech rural stoves for cooking and heating are replaced (Chapter 4). By bringing better services and greater efficiency in fuel use to consumers, BC can become a win-win proposition that is commercially attractive.

Agricultural yield and sustainable land use - Biomass burning accounts for 42% of global BC emissions, making agriculture and land use management substantial targets for reduction. Even if co-emitted OC levels are high, meaning the net warming effect of open biomass combustion may be negative, health effects and overall climate impacts of reduced biomass burning, and climate benefits in certain regions (e.g. the Arctic), are unequivocal.

There is evidence that farming and agriculture best practices that reduce biomass burning generate significant environmental, cost-saving, and output-increasing co-benefits in addition to BC reductions. These fixes are not technological, but are changes to commodity supply chains and local practices that incorporate sustainability standards (Chapter 4).

Tangible political advantages and funding sources for co-benefits - One of the biggest challenges of climate change mitigation in general is the diffuse and uncertain quality of the benefits of actions taken. BC emissions do not face this challenge because both the climate and health benefits are predominantly local, particularly in urban areas. In developed, wealthy countries, initiatives to reduce urban air pollution may provide local political support for BC mitigation that is absent from the current climate debate. This incentive also creates an opening for international funding of local BC emissions reduction in exchange for developing country participation in international climate change agreements. For example, developed nations could pledge funding support for BC-reduction projects in exchange for India, China, and other G-77 nations’ national GHG emissions caps, strong national emissions reduction programs, and co-funding on those same projects. Such a scenario would allow BC emissions reduction efforts to have an amplification effect for climate change mitigation globally (Chapter 5).

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Chapter 2: The Role of Black Carbon in Climate Change

2.1 Black Carbon is a Powerful Warming Agent; Targeted Mitigation has Important Climate Benefits

2.1.1 Black carbon is a much stronger short-term warming agent than carbon dioxide

Although the effects of BC on climate are complex, ton for ton, as long as it remains lofted in the atmosphere, BC acts as a far stronger warming agent than carbon dioxide. One gram of BC spread instantaneously and evenly through the Earth's atmosphere would produce a direct radiative forcing comparable to that of at least a ton of carbon dioxide (Box 2.1 and Appendix 2.1).

However, aerosols like BC have atmospheric lifetimes of only a few days, while carbon dioxide lingers for millennia (Figure 2.1). Because of their short lifetimes, changes in aerosol emissions are hard to compare to changes in carbon dioxide emissions but can be readily compared to changes in atmospheric carbon dioxide concentrations. Any total global radiative forcing can be expressed in terms of equivalent carbon dioxide (CO_2e) concentrations, the amount of CO_2 that it would take to produce the same total forcing were all other agents at their pre-industrial concentrations. Reducing BC emissions would lead to nearly immediate reductions in equivalent carbon dioxide (CO_2e) concentrations.

The Intergovernmental Panel on Climate Change (IPCC) estimated that the radiative forcing in 2005 of long-lived greenhouse gases was 2.63 Watts/m^2 (W/m^2) which corresponds to an equivalent carbon dioxide concentration of 454 ppm. Factoring in the direct effects of carbonaceous aerosols (BC and co-emitted organic carbon, OC) produced by fossil fuel combustion raises equivalent carbon dioxide concentrations by roughly 15 to 25 ppm (0.2 to 0.3 W/m^2) [*Forster et al.*, 2007; *Ramanathan and Carmichael, 2008*]. The direct radiative forcing of BC alone (without adjusting for co-emitted OC, discussed in section 2.4.1) is about 0.4 to 0.9 W/m^2 – an amount that may exceed the radiative forcing of methane (about 0.48 W/m^2). On the margin, reducing BC emissions by one thousand tons/year is comparable to decreasing CO_2e concentrations by roughly 5 ppb (Box 2.1).

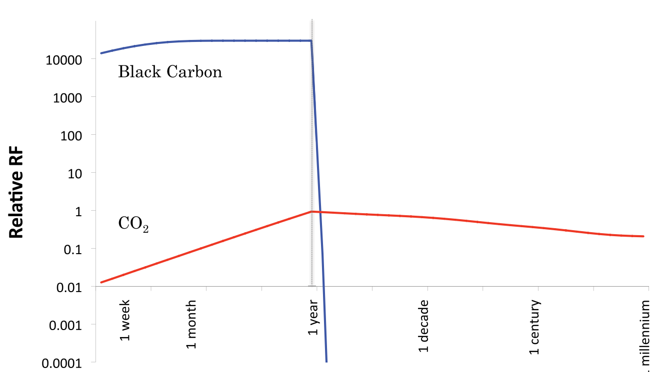

Figure 2.1: Relative direct radiative forcing of one ton of black carbonaceous aerosol (blue) emitted over the course of one year, compared to the radiative forcing of one ton of CO_2 (red) emitted over the same period of time. *Both axes are logarithmic. Although the radiative forcing of BC is about 20 to 60 thousand times stronger while the BC is being emitted, its effect plunges to zero shortly after the end of emission. The effects of CO_2, in contrast, linger for millennia.*

2.1.2 Stabilizing radiative forcing at 450 ppm CO_2e by the end of the century likely requires mitigating BC emissions

Failing to act soon on BC emissions reductions would require that CO_2 emissions action occur one to two decades sooner. Stabilizing radiative forcing at 450 ppm CO_2e by the end of the century, a target that provides approximately a 50% chance of keeping mean global warming below 2ºC [*Meehl et al.*, 2007], may be impossible without significant reductions in BC emissions. Assuming that emissions producing sulfate and other non-carbonaceous aerosols are reduced for air quality reasons, and their climate effects become negligible by the end of the century, achieving 450 ppm CO_2e while maintaining current levels of carbonaceous aerosol emissions would require a target CO_2 concentration of roughly 370-385 ppm. Eliminating carbonaceous aerosol emissions from fossil fuels would raise the target CO_2 concentration to about 400 ppm. A simple model of radiative forcing and mitigation cost (Appendix 2.2) suggests that achieving the former target would require that global net CO_2 emissions are reduced approximately 50% below 2005 levels between about 2018 and 2028. Achieving the latter target is more feasible, as it would delay the 50% reduction to around 2035 (Figure 2.2).

In other words, because aggressive mitigation of BC emissions allows for a more gradual reduction in CO_2 emissions, action on black carbon is "worth" about 1-2 decades of action on carbon dioxide. However, the most commonly discussed greenhouse gas emissions scenarios aimed at reaching 450 ppm CO_2e focus exclusively on long-lived greenhouse gases and do not consider BC emissions in their calculations [e.g., *Fisher et al.*, 2007; *Meinshausen et al.,* 2006]. Compared to these scenarios, failing to act on BC costs 1-2 decades.

2.1.3 Accelerated, targeted BC emissions reductions can reduce the warming effect caused by reductions in sulfur dioxide emissions

BC is not the only aerosol with a strong effect on climate, but most other aerosols have a cooling effect. The IPCC estimates that the total cooling aerosol radiative forcing in 2005 was -1.35 W/m^2 [*Forster et al.*, 2007]. Thus, despite a long-lived greenhouse gas radiative forcing of about 450 ppm CO_2e, the net radiative forcing in 2005 was about 380 ppm CO_2e. Roughly two-thirds of the cooling effect is due to sulfate aerosols, approximately 72% of which are produced from fossil fuel-related sulfur dioxide emissions. Compelling health concerns currently motivate sulfur dioxide emission controls and could provide additional motivation for reductions in BC emissions. Because both cooling aerosols and BC have comparably short atmospheric lifetimes, accelerated, targeted BC emission reductions provide an ideal approach for partially offsetting the warming effects of reduced sulfur dioxide emissions.

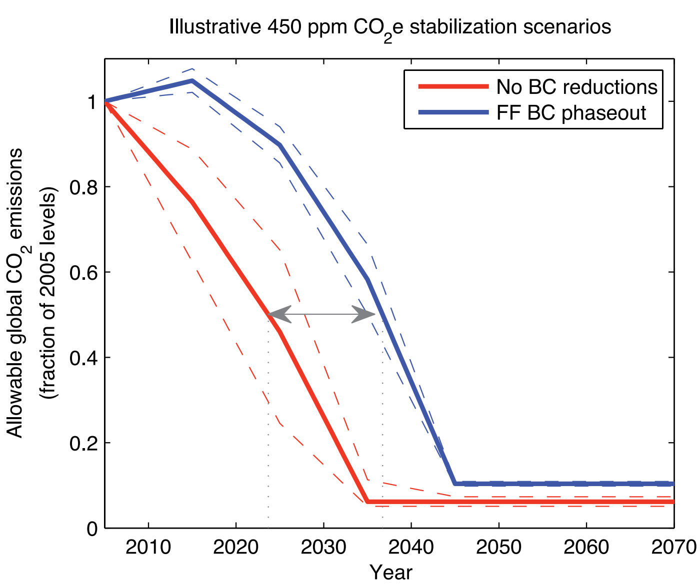

Figure 2.2. Illustrative global CO2 emission pathways required to stabilize the combined radiative forcing of long-lived greenhouse gases and carbonaceous aerosols at 450 ppm CO2e by 2100. *In the lower, red pathway, BC emissions are continued at the current levels (based on the inventory of Bond, 2004). In the upper, blue pathway, fossil fuel BC emissions are phased out, starting in 2010. The solid lines employ a medium estimate of fossil fuel and biomass BC net radiative forcing, while the upper and lower dashed lines respectively employ low-end and high-end estimates (see Appendix 2.2 for details). The grey arrow highlights the years in which required emissions in the medium scenarios reach 50% of 2005 emissions and the ~1-2 decades of CO2 emissions lost by failing to phase out fossil fuel BC. Our radiative forcing estimates include the direct and indirect effects of BC and co-emitted OC, as well as the snow albedo effect of BC. We assume that emissions giving rise to non-carbonaceous aerosols like sulfate and nitrate will be phased out for air quality reasons. See Appendix 2.2 for more details.*

2.1.4 Because of differing co-emittants, the climate impacts of BC emissions depend heavily on the sources

The main sources of BC aerosols are fossil fuel combustion and biomass burning, but neither releases "pure" BC. Instead, they release a mixture of aerosols and gases, some of which have warming effects and some of which have cooling effects. While BC is strongly warming, organic carbon, sulfate, and nitrate aerosols are moderately cooling. The direct radiative forcing of about five to ten grams of these cooling aerosols can offset the direct radiative forcing of roughly a gram of BC (Appendix 2.1). Most carbonaceous aerosols released by fossil fuel combustion have an OC:BC ratio less than one. It is therefore very likely that they have a net warming effect. Biomass carbonaceous aerosols resulting from open burning may have a net cooling effect due to a higher OC:BC ratio. Contained combustion of agricultural residue, wood, and animal waste results in intermediate OC:BC ratios.

Table 2.1 shows the approximate relative net radiative forcing of BC and OC aerosols from different sources, expressed in terms of grams pure BC equivalent per gram BC emitted (see Box 2.1 and Appendix 2.1 for details). OC emitted by different sources varies considerably in composition, which gives rise to a variability in cooling effect not taken into account here. These values also do not include the effects of sulfur dioxide emissions, which vary greatly depending upon fuel and technology, but, when present, further reduce net radiative forcing.

2.1.5 BC has strong regional warming effects in sensitive areas, including the Himalayas and the Arctic

Because of their short atmospheric lifetimes, aerosols are not spread evenly around the world. BC therefore gives rise to concentrated regional warming over and downwind of high emitting regions. As mentioned in Chapter 1, this effect is of particular concern in climatically sensitive areas such as the Himalayas and the Arctic. Warming in these regions hastens snowpack and ice melting, which lowers the reflectivity of the planet as a whole and thus enhances global warming. In the Himalayas, these changes also threaten the freshwater supply for more than 10% of the world's population [*Cruz et al.*, 2007]. In the Arctic, warming drives melting of the Greenland Ice Sheet, thereby accelerating sea level rise. Increasing loss of Arctic sea ice is endangering Arctic ecosystems and threatening the survival of many species, such as the polar bear. Thawing Arctic permafrost may also enhance methane release, a strong and long-lived greenhouse gas [*ACIA*, 2005].

BC-induced regional warming is stronger for a given particle load in snow and ice-covered areas like the Arctic and high mountain ranges than in other areas because of the high albedo contrast between the dark aerosols and the bright surfaces beneath them [*Chung and Seinfeld*, 2005]. Because of their contrast with the high albedo surfaces, even organic carbon aerosols can produce net warming over the Arctic and glaciated mountains. After BC settles out of the atmosphere in these regions, it continues to warm for a period of weeks to months by darkening the surfaces on which it falls [*Forster et al*., 2007]. The effects may be particularly pronounced when deposition occurs in late winter and spring, a period when accelerated melting of snow and ice can be particularly damaging [*Hansen and Nazarenko*, 2004].

The Himalayas are particularly vulnerable to BC-induced warming due to their proximity to China and India, two of the world's biggest BC emitters [*Ramanathan and Carmichael*, 2008]. Although no appreciable BC is emitted above 70ºN latitude, the Arctic is exposed to aerosols transported from Europe which is largely north of 40ºN as well as lower latitudes. The likelihood that aerosols emitted in a given location will travel to the Arctic differs among chemical transport and climate models, but is generally higher for sources at higher latitudes. In addition, particles emitted by open biomass burning loft higher into the atmosphere than particles emitted by contained fossil fuel combustion and can therefore be transported farther [*Chung and Seinfeld*, 2005; *Penner et al*., 2003]. The sixteen models in the AeroCom aerosol model comparison study predicted that 4.3% (±3.1%) of the atmospheric BC load is at latitudes higher than 80º [*Textor et al*., 2006].

In addition to surface warming, BC aerosols also lead to the redistribution of heat within the atmosphere, which affects atmospheric circulation and precipitation. Changes in atmospheric circulation driven in large part by aerosols also contribute to changing significant weather patterns on which many people rely, such as the weakening of the Indian monsoon [*Ramanathan et al*., 2005].

	Relative Radiative Forcing (Probability > 0)			Approximate 1998 world emissions (Gg BC/y)	
	Approx. Global Average OC: BC	direct + indirect effects	Including globally-averaged snow albedo effect	Unweighted	Weighted by direct + indirect effects
Open Burning					
Crop residues	4.8	-0.3 (28%)	0.2 (43%	330	-70
Forest	9.1	-1.5 (7%)	-0.9 (13%)	1240	-1600
Savannah	7.1	-0.9 (13%)	-0.4 (22%)	1720	-1300
Waste	1.3	0.6 (83%)	1.1	40	30
Contained combustion					
Agricultural waste	3.8	0.0 (39%)	0.4 (56%)	390	20
Animal waste	3.6	0.0 (42%)	0.5 (59%)	210	20
Coal	0.8	0.8 (90%)	1.2 (97%)	1130	900
Diesel fuel	0.4	0.9 (95%)	1.3 (99%)	1460	1300
Gasoline	7.2	-0.9 (12%)	-0.4 (22%)	130	-100
Wood	4.0	-0.1 (37%)	0.4 (53%)	880	0
Pure BC	*0.0*	*1.00*	*1.39*		
Penalty per unit OC:BC		*-0.27*	*-0.27*		

Table 2.1. Approximate relative net radiative forcing of black carbon and co-emitted organic carbon from different sources. *Values are expressed in terms of the equivalent amount of pure black carbonaceous aerosol necessary to produce the same forcing through its direct and indirect effects as one gram of BC from the source (g pure BC equivalent/g BC). OC:BC ratios and world emissions data are from Bond et al. (2004). (1 Gg is equal to 1 kiloton). Percentages in parentheses indicate the probability that the radiative forcing of carbonaceous aerosols from a source is positive. These percentages take into account only uncertainties in forcings, not in OC:BC ratios. The details of the calculations are provided in Appendix 2.1. The 67% confidence interval for the OC:BC penalty is -0.6 to -0.1. The 67% confidence interval for the relative net radiative forcing of pure BC including the snow albedo effect is 1.1 to 1.8.*

2.2 BC Particles have Broad Negative Impacts on Human Health

While few studies focus on the health effects of BC specifically, many have examined the impacts of particulate matter (PM), of which BC is often a significant fraction. BC particles are predominantly less than one micron in diameter [*Hitzenberger and Tohno*, 2001], and thus mostly fall into the category of PM_1. While PM_1 is not commonly measured, these ultrafine particles are also counted in more common measurements of $PM_{2.5}$ (fine particles, with a diameter of up to 2.5 microns) and PM_{10} (small particles, with a diameter of up to 10 microns).

PM emissions have serious negative impacts on human health, with effects per unit mass likely increasing with decreasing diameter. These effects can be either acute or chronic in nature and result from both discrete and continuous exposure. PM emissions negatively impact child development, respiratory and cardiovascular health, and increase the incidence of premature mortality [*Schwartz*, 1996; *Schwartz et al*., 2005; Schwartz et al., 2008; *Pope III et al*., 2002]. Though PM_{10} measurements are the most commonly used indicator of health hazard, fine particles are able to penetrate deep into the lungs and appear to have the greatest health-damaging potential [*World Health Organization*, 2006]. As a result in 2006 the U.S. EPA strengthened the $PM_{2.5}$ standards to require 24-hour average concentrations to not exceed 35 μg/m^3, and retained the current annual average concentration standard at 15 μg/m^3 [*Environmental Protection Agency*, 2006]. BC emissions are therefore likely to pose a greater health hazard than many of the larger particles in PM_{10}.

Both widely distributed and point source PM emissions create health problems, and there appears to be no safe threshold below which exposure to $PM_{2,5}$ does not increase death rate [*Schwartz et al*., 2008]. Exposure to fossil fuel-related BC emissions has been shown to cause a significant decrease in lung function in urban women [*Suglia et al*., 2008a] and a significant reduction in cognitive functions in urban children [*Suglia et al*., 2008b]. Patients with homes closer to major roadways have a higher mortality risk after hospitalization with acute heart failure [*Medina-Ramón et al*., 2008]. It is estimated that the cost in health impacts of $PM_{2.5}$ emitted from vehicles in urban areas ranged from $16,000 to $207,000 per ton (in 2008 dollars) [*McCubbin and Delucchi*, 1999].

Populations in the developing world are strongly impacted by PM point sources such as indoor combustion of biomass for cooking. Such sources can lead to local PM concentrations that exceed those in urban centers by orders of magnitude. The WHO estimates that indoor air pollution is responsible for 1.6 million deaths annually and constitutes 2.7% of the global burden of disease [*World Health Organization*, 2006]. To put that threat in perspective, only malnutrition, unsafe sex, and poor sanitation and hygiene are more potent health threats in the developing world [*Ezzati and Kammen*, 2002]. Therefore, a reduction of BC emissions in the developing world through technologies as simple as improved cookstoves could have significant benefits for both climate and health. Replacing biofuel cookstoves with BC-free stoves would reduce the effect of BC radiative forcing from South Asian sources by 70-80% and from East Asian sources by 20-40% [*Ramanathan and Carmichael*, 2008]. In addition to avoided deaths, the replacement of 50% of the traditional biofuel stoves used globally with improved stoves could result in savings of about $90 billion annually due to the avoided health care and improved efficiency [*World Health Organization*, 2006]. It is thus at least as critical to mitigate BC emissions to reduce their human health impacts as it is to reduce their climate effects.

2.3 Areas of uncertainty

The IPCC highlights several areas of uncertainty in the scientific understanding of aerosol radiative forcing, including emissions sources, the vertical distribution of aerosols, the optical properties of aerosols in their atmospheric mixing state, and the mixing behavior of BC particles and snow [*Forster et al*., 2007] (Table 2.2). These uncertainties give rise to an "insufficient" degree of consensus, exhibited clearly by the discrepancy between the IPCC's model-based estimate of BC radiative forcing (0.20 ± 0.15 W/m^2) and estimates inferred from observations (0.9 W/m^2, with a range of 0.4 to 1.2 W/m^2) [*Forster et al*., 2007; *Ramanathan and Carmichael*, 2008]. There is also significant uncertainty and variability in total annual BC emissions; Bond et al., [2004] offers a best estimate of about 8 Tg/y, with a range of 4 to 22 Tg/y. In addition, models exhibit significant differences in predictions of atmospheric transport of aerosols [*Textor et al*., 2006]. Because the climate efficacy of BC is sensitive to elevation and surface albedo [*Hansen et al*., 2005], the details of transport can have a large impact on estimates of total global effects. The contribution of different sources to the snow albedo effect is also highly dependent upon transport and would benefit from further scientific study.

Table 2.2. Major sources of uncertainty

Emissions
Emission factors and their variability
Variability of OC composition
Quantification of sources
Direct Radiative Forcing
Mixing state of atmospheric aerosols
Vertical and horizontal transport of aerosols
Efficacy of the BC and OC radiative forcings
Indirect Cloud Albedo Effect
Aerosol size distributions
Effects of aerosol speciation and mixing
Physical complexity
Snow Albedo Effect
Transport of aerosols to vulnerable regions
Efficacy of the snow albedo radiative forcing

BOX 2.1: Why Global Warming Potentials (GWPs) are inadequate for measuring the climate impact of aerosols

GWPs are a metric commonly used for comparing greenhouse gases. They are the ratio of the globally-averaged radiative forcing caused by a single pulse emission of a greenhouse agent, integrated over some period of time (typically one hundred years), to the globally-averaged radiative forcing of a CO_2 emission. GWP is thus controlled both by the strength of a greenhouse agent and its lifetime.

GWPs have two limitations that are particularly acute when applied to aerosols. First, GWPs are globally averaged metrics. Unlike long-lived greenhouse gases, aerosols are not well-mixed and their warming effects are therefore patchy. With sufficiently accurate aerosol models, this problem could be addressed by substituting a regional warming metric for globally-averaged radiative forcing, an approach suggested by Berntsen et al., [2006].

The second problem is more severe. There is a drastic mismatch in lifetimes between carbon dioxide and aerosols. Whereas about 10% of carbon dioxide emitted today will remain in the atmosphere for 10,000 years [Archer, 2005], the typical aerosol has a lifetime of a few days (Figure 2.1). One century from now, the radiative forcing caused by one kilogram of CO_2 emitted today will be about one-third of its current value. While one kilogram of BC emitted today has a direct radiative forcing more than one million times that of one kilogram of carbon dioxide, in a few months it will cause no direct radiative forcing at all. Comparing CO_2 and aerosols using GWPs fails to capture this difference. Thus, while it is possible to calculate a measure of GWP for aerosols (see Appendix 2.1), they are highly misleading and not comparable to GWPs of non-aerosols.

To compare aerosol emissions to carbon dioxide, it is more useful to think in terms of changes in equivalent CO_2 concentrations (CO_2e) at a particular point in time. In Table A2.1.1, we report the marginal CO_2e concentration change caused by a constant aerosol emission. In the case of the direct radiative forcing of BC, this value is 3.1 ppb per Gg/year (with a 90% confidence range of 0.7 to 6.1 ppb per Gg/year) using models compiled by the IPCC [Forster et al., 2007]. If instead we use the observation-driven analyses of Ramanthan and Carmichael [2008], this value is 8.0 ppb per Gg/year (range of 2.6 to 12.2 ppb per Gg/year1). By contrast, a 1 Gg emission of CO_2 increases CO_2 concentrations by only about 0.00013 ppb, though it contributes to an atmospheric stock that has accumulated over a long period of time.

As detailed in Appendix 2.1, we use the ratios of these marginal CO_2e changes to calculate the relative warming effects of aerosols from the different BC sources shown in Table 2.1.

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Chapter 3: Addressing Domestic Black Carbon Emissions

Public health concerns and environmental impacts associated with $PM_{2.5}$ have been key drivers in regulating emissions in the U.S. However, in light of recent research linking BC to global warming, regulators are faced with the dilemma of whether or not to enhance or adapt existing regulations to respond to these results. This chapter provides an overview of existing regulations and a roadmap for both short- and long-term strategies for action domestically.

3.1. Diesel Engines are by Far the Largest Contributors to Climate-Warming BC Emissions Domestically

As shown in Fig. 3.1, the largest sources of domestic BC emissions are: transport (both road and non-road), mainly through diesel vehicles, residential biofuel burning, and open burning of forests. Together, these three sources account for nearly 90% of all emissions.

However, both biofuel burning and forest burning tend to emit a mixture of BC and organic carbon (OC). As discussed in Chapter 2, OC has a negative radiative forcing, so that emissions with OC:BC ratios over 4:1 are likely to have a net cooling effect (Appendix 2.1). Using the OC:BC "penalty" of -0.27 from Table 2.1 to calculate the relative radiative forcing for each sector, Figure 3.2 demonstrates a breakdown of sources weighted by the relative radiative forcing. It is evident that between on- and off-road vehicles, the transport sector alone accounts for nearly 90% of all radiative forcing due to BC. This is due to its large share in emissions (Fig. 3.1) and its low OC:BC ratio of 0.4 [*Bond et al., 2004*].

As discussed in the next section, diesel engines emit far more BC than gasoline engines. As a result, policies that aim to mitigate the climate change effects of BC should focus almost exclusively on diesel. This chapter will focus on strategies to mitigate diesel emissions, along with a brief discussion of the possibility of BC emissions trading.

3.2 Although Regulatory Steps have been Taken, Older Heavy-duty Vehicles are Still Cause for Concern

The 1990 U.S. Clean Air Act has been instrumental in reducing vehicular air pollution. In addition to addressing PM emission through air quality legislation and Corporate Average Fuel

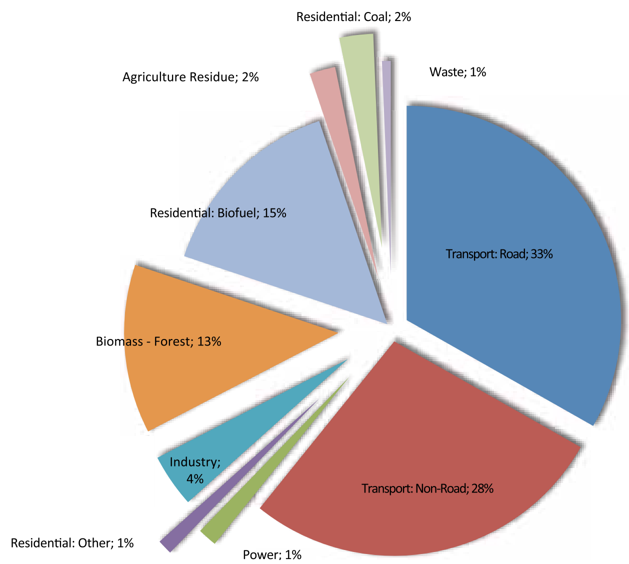

Figure 3.1: Sources of BC Emissions in the U.S. *Adapted from [Bond et al., 2004]*

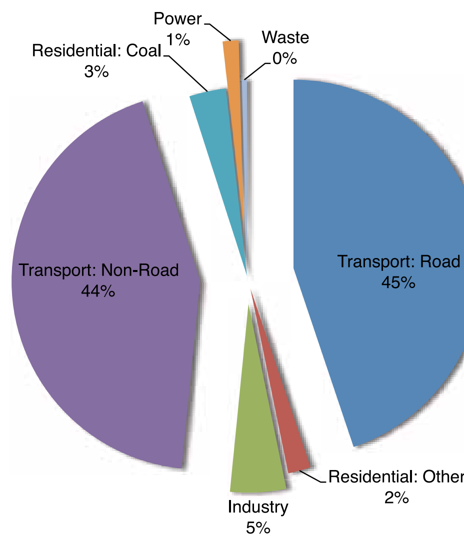

Figure 3.2: Sector emissions by relative warming potential due to OC:BC ratios *Note: The emission percentages from Figure 3.1 have been adjusted using the OC:BC "penalty" derived in Table 2.1.*

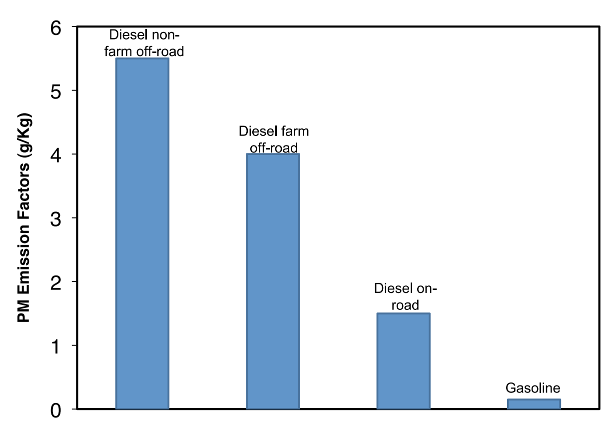

Figure 3.3: PM emission factors, (g PM / kg fuel). *Adapted from [Bond et al., 2004].*

Economy (CAFE) standards for cars and trucks, the U.S. has also been proactive in implementing relatively stringent emissions standards for diesel engines. Table 3.1 compares U.S. and Euro standards to a number of other countries.

Diesel vehicles are a key concern because they emit higher levels of particulate matter (PM) than gasoline vehicles (Fig 3.3). As discussed in Chapter 2, BC is an important component of the PM emissions. The emission factor for gasoline vehicles is approximately 0.15 g/kg of PM to fuel in areas with strict emission standards and 0.5 g/kg for other regions. Diesel vehicles, on the other hand, have an approximate emission factor of 1.5 g/kg in the U.S. and Europe and 3.5 g/kg in other regions. [*Bond et al*., 2004] estimates that 86% of particulate emissions from diesel fuel are submicron and that 66% of those particles are BC. Hence, roughly 57% of diesel particulate matter is composed of black carbon [*Bond et al*., 2004].

Current regulations on diesel vehicles include stringent requirements on new highway and non-road mobile vehicles such as the 2007 Heavy-Duty Highway Engine Rule – which requires the use of Ultra Low Sulfur Diesel (ULSD) – and the Clean Air Non-road Diesel Rule, which was phased in mid-2007 (see Appendix 3.1 for details). Thus, the concern lies primarily with vehicular emissions from existing heavy-duty vehicles. Many of these vehicles will be in use for another 20-30 years. Their emissions are currently only addressed at the national level through voluntary programs. These programs work with, encourage, and provide funding for local and state agencies to implement diesel retrofit programs.

3.3 The Technology Required to Curb Emissions from Existing Vehicles is Available and Cost-effective

Currently available diesel retrofit technologies, such as diesel oxidation catalysts (DOCs) and diesel particulate filters (DPFs), are highly effective in reducing particulate matter emissions. Compared to particulate filters, DOCs are cheaper to implement ($1,000-$3,000), have lower failure rates, lower fuel penalties, and can be installed in a greater variety of diesel engines. They are particularly suitable for older vehicles and vehicles running on fuel with higher sulfur levels. As a result, they have been used in approximately 30% of domestic diesel retrofit programs [*Emissions Advantage*, 2005]. However, DOCs are much less effective than DPFs in reducing BC emissions. DOCs reduce mainly the "wet" organic carbon portion of PM and only small amounts of the smallest carbon particles. It has been estimated that they reduce only 0-5% of elemental carbon (e.g., black carbon) [*Hill*, 2005].

DPFs, on the other hand, reduce a higher percentage of particulate matter (90% for DPF vs. 20-50% for DOC) and are effective in reducing more than 95% of elemental carbon (e.g., black carbon) emissions [*Hill*, 2005]. However, they are more expensive ($5,000-$8,000) and can typically only be employed on newer vehicles with electronic controls. They also require ultra-low sulfur fuel and high operating temperatures [*Emissions Advantage*, 2005].

The EPA has estimated the cost effectiveness of oxidation catalysts and particulate filters for a variety of heavy-duty on-road and off-road vehicles. The cost of retrofit technology for on-road vehicles ranges from approximately $11,000 per

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
European Union	EURO 3				EURO 4			EURO 5		
United States	TIER 1			TIER 2						
Australia	EURO 1		EURO 2				EURO 4			
Brazil	EURO 2					EURO 3				
China	EURO 1		EURO 2				EURO 3			EURO 4
Hong Kong	EURO 3					EURO 4				
Taipei	US TIER 1 FOR DIESEL							US TIER 2 FOR DIESEL		
Singapore	EURO 2					EURO 3				
India	EURO 1				EURO 2					EURO 3
India (10 cities)	EURO 1		EURO 2		EURO 3					EURO 4

Table 3.1: Global Emission Standards for Diesel Engines. *For a detailed breakdown of the requirements for European and U.S. emissions standards, see Appendix 3.1. [Source: Asian Development Bank, 2003; www.implats.co.za/market/emission_standards.asp]*

ton of PM emission reduced – a low estimate to implement an oxidation catalyst on a Class 8b Truck (trucks weighing over 30,000 lbs.) – to approximately $70,000 per ton of PM emissions reduced – a high estimate to implement a particulate filter on a Class 6&7 Truck (trucks weighing between 19,501 and 30,000 lbs). The costs of diesel retrofit technologies for off-road vehicles range from approximately $21,000 to $88,000 per ton of PM reduced, with DPFs being slightly more costly [*EPA*, 2007a; b]. In light of the corresponding health benefits discussed in Chapter 2 (16,000 to $207,000 per ton of PM2.5 reduced) [*McCubbin and Delucchi*, 1999], these retrofits, particularly DPFs, appear increasingly attractive.

Furthermore, the EPA's own analyses have shown the cost effectiveness of diesel retrofit technology. For example, the EPA has estimated public health benefits of more than $70 billion per year arising from the Heavy-Duty Highway Engine Rule; which is more than 17 times the compliance costs. Health benefits for the Non-road Diesel Rule are approximately $80 billion, equivalent to 40 times the compliance costs [*EPA*, 2006]. Solely for public health reasons, a diesel retrofit program, given the proper incentive and funding structure, should be undertaken for both on-road and off-road vehicles. The additional climate related benefits discussed in previous chapters that would result from diesel retrofitting programs provide further impetus for action.

In addition to diesel retrofit programs, a number of policy actions need to be taken simultaneously to address vehicle emissions from in-use trucks, construction equipment and agricultural equipment. Many of these actions could be supported and funded by President Barack Obama's comprehensive plan to invest in alternative and renewable energy, address global climate change and create millions of new green jobs.

In the short term, steps must be taken to place more stringent requirements on vehicle fuel efficiency, target and mitigate emissions from super-emitters, and create economic incentives for retrofit programs. In the long run, however, it is imperative that we move away from diesel vehicles as a means of transport, both by switching to other modes of transport, and by switching fuels used in current forms of transport. In this report each of these prescriptions is dealt with in turn.

3.4 Short-term Policy Actions

3.4.1 Auto manufacturers should continue to be pressured to improve fuel economy standards

Studies have shown that technological advancements in vehicle fuel efficiency have successfully reduced BC emissions. Research on BC concentrations and diesel vehicle emission factors in California over the period 1967-2003 shows that as diesel fuel consumption steadily increased over the period, BC concentrations in the atmosphere actually decreased, especially around the early 1990s, as a result of new emission controls and a switch to lower sulfur fuel [*Kirchstetter et al*., 2008].

Although current standards on new vehicles have been highly effective in mitigating PM emissions, more can be done to improve vehicle fuel efficiency of both light and heavy-duty diesel and gasoline vehicles. Diesel vehicles using less fuel would likely emit less BC as well as less carbon dioxide, provided that the current DPF technology is still used. In addition to requiring fuel-saving and emission-reduction technologies, such as those that reduce drag and increase aerodynamics, the EPA would also see significant benefits from setting higher standards on fuel economy. In particular, the conditions associated with the federal loans recently given to the auto industry could require that the companies focus on manufacturing more fuel-efficient vehicles. Higher fuel economy standards would also help decrease foreign oil imports and advance U.S. energy security, key elements of the Obama-Biden energy plan.

3.4.2 Super-emitters should be located and replaced through a combination of enforcement and market-based mechanisms

Super-emitting heavy-duty vehicles comprise a small proportion of the total fleet, roughly estimated at 5%, but are responsible for a disproportionate amount of total emissions. Super-emitters have large emissions factors of approximately 12g/kg compared to a 1.5 g/kg - 3.5 g/kg for normal vehicles [*Bond et al*., 2004].

Roadside inspections and other enforcement programs should concentrate their efforts on targeting super-emitters. These programs should target vehicles based on factors that focus on the intensity of use, such as engine type (mechanical or electronic), age, mileage, space available for retrofit installation, horsepower rating, operating characteristics and fuel used, maintenance history, emissions certification levels and operating environment (urban stop-and-go traffic vs. rural long-haul driving), to the extent that such information is available [*Kassel and Bailey*, 2004].

Enforcement programs should also target non-road super-emitters, particularly those near urban areas (i.e., construction equipment), where health impacts are highest. In particular, the Bush administration's stringent off-road diesel standards, which aimed to reduce 90% of "harmful PM emissions" by 2010 when they were first announced (*USA Today*, 2003), should not be allowed to fall by the wayside.

We also recommend that the EPA consider market-based mechanisms to identify and remove super-emitters. These could take the form of cash-for-clunkers type programs, under which vehicle owners can trade-in their old vehicles for cash [Blinder, 2008]. However, these programs may have unintended effects and should be used with caution. For example, some owners may have retrofitted even in the absence of a subsidy, or they may take advantage of the system (i.e., if cash-for-clunkers programs accepts only vehicles of a certain age, owners may decide to hold on to their vehicles until the stipulated age). Further, these programs also do not typically focus on the intensity of use. Cash-for-clunker programs typically target older vehicles, yet removal of newer vehicles (not "clunkers") that have been poorly maintained but used often may provide larger benefits than targeting older vehicles that are rarely used.

3.4.3 Retrofit Programs should be expanded with different incentives for large and small fleet owners.

Although the benefits of retrofit programs locally and globally greatly exceed their costs, a major impediment to expanding these programs is the disparity between those who bear the costs, i.e. fleet operators, and those who benefit, i.e. the general public. Funding through voluntary programs currently covers only an estimated 10-20% of a diesel retrofit project [Sperling Personal Communication].

We recommend that the EPA and state governments focus on making additional sources of funding available to fleet operators by targeting large and small fleet owners separately. Larger fleets of on- and off-road diesel vehicles owned by corporate entities, such as retail firms, trucking companies, and construction firms, should be subject to a "dirty vehicle tax" (commensurate with the health costs of the emissions). This would provide an incentive to retrofit their worst emitters.

Box 3.1: Case Study – California Air Resources Board (CARB)

California is unique among states in that it can implement its own motor vehicle emission standards; provided that they are as stringent as those set federally and that it first obtains a waiver from the EPA. California also acts as a trailblazer for other states, which can adopt either federal or California standards.

Whereas the EPA has established voluntary programs to address PM emissions from existing diesel vehicles, California has implemented mandatory regulations and plans to continue doing so. On July 26, 2007, the California Air Resources Board approved a regulation to reduce PM and NO_x emissions from in-use off-road diesel vehicles in construction, mining and other industries. A proposed regulation on in-use on-road heavy-duty diesel vehicles was recently adopted in December 2008 and a rule to reduce emission from in-use agricultural equipment will be presented to CARB by the end of 2009.

CARB has estimated that the in-use off-road diesel vehicle rule will reduce approximately 33,000 tons of PM and 187,000 tons of NO_x emissions between 2009 and 2030 and will result in public health benefits of approximately $18-$26 billion in total at a compliance cost of $3-$3.4 billion. Compliance dates range from 2010 (for larger fleets) to 2015 (for smaller fleets, which don't have to meet the NO_x requirements.) CARB has also established various incentive programs reducing or spreading out compliance costs for early action on installing DPFs, employing newer engines, or retiring older vehicles. It has also organized an Off-Road Diesel Showcase to demonstrate the viability of new diesel emission control and retrofit technologies to address the variety and diversity of off-road vehicles operating in rough conditions

California's policies highlight the sizeable benefits that can accrue from mandatory diesel retrofit requirements. Its actions also provide guidance on a variety of issues that should be addressed when considering implementing a retrofit program. For example, more flexibility in terms of compliance dates or emissions reductions could be given to smaller fleets, or those in attainment areas. In addition, programs should also provide incentives to fleet owners to take earlier measures to retrofit, replace, and/or retire their old vehicles. The EPA may also want to consider a national Off-Road Diesel Showcase to further promote and encourage technology to address the challenges of eliminating particulate matter and black carbon by off-road diesel vehicles.

It also provides a costless regulation mechanism by shifting the burden of the retrofit onto companies that are able to afford it.

Smaller fleet owners and farmers, on the other hand, should be eligible for loan guarantee programs to ensure access to capital for retrofitting. Since banks may perceive these operators as higher-risk borrowers, their access to low-cost financing for retrofit projects may be otherwise limited [*Mui Personal Communication*]. A loan guarantee scheme would provide banks with a government guarantee in case of default and allow them to make loans for retrofit projects to small fleet owners. It is important to note, however, that loan guarantee schemes also require an implementation of oversight programs to monitor and audit loans in order to mitigate moral hazard concerns, such as banks engaging in riskier lending activities than they would if their loans were not guaranteed.

Part of the funding for these guarantees could come out of the dirty vehicle tax on larger firms, and additional funding could be drawn from the Obama administration's stimulus package. Mandatory retrofit programs are a viable contender for stimulus funding because they will create new green jobs and stimulate the domestic manufacturing industry. Additional investment to promote research to improve DPFs, particularly for non-road vehicles and maritime vessels, could help the U.S. become a leader in, and exporter of, clean technology.

3.5 Long-term Policy Actions

3.5.1 Feasible alternatives for intermodal transportation of cargo could be provided by EPA and DOT collaboration

The EPA, in conjunction with state authorities, would benefit from looking into industries and regions in which trains or ships can be used for transportation of cargo instead of trucks. On routes for which railroad tracks already exist, policies could be implemented to bundle industry cargo to avoid multiple trips by diesel trucks. This approach would facilitate reductions in both BC and carbon dioxide emissions as trains are more fuel efficient than trucks.

Facilitating intermodal freight transport is already a priority of the Department of Transportation's (DOT) Congestion Mitigation and Air Quality (CMAQ) program [*Westcott*, 2005]. Although, they may have different motivations, the DOT and EPA share the same goal of removing vehicles from highways. We recommend that the two agencies work together to develop a permanent cargo transportation infrastructure, not simply limited to one-off projects. Especially in light of the Obama administration's plan to create a National Infrastructure Reinvestment Bank with funding of $60 billion over ten years to finance transportation infrastructure development, measures to dramatically improve rail infrastructure and expand cargo transportation options are well within reach in the near-term [*Change.gov*, 2009].

The DOT has undertaken a number of successful projects that can be used as case studies. A good example is the Red Hook Container Barge Project in New York City, for which the DOT purchased a barge to reroute highway traffic and ship cargo along the Hudson River. As a result, 54,000 trucks were removed from the New York and New Jersey highways [*Federal Highway Administration*, 2008].

It is important to note, however, that such projects require not only substantial capital investment, but also significant research. Thus, even if funding is available, each project needs to be evaluated on a case-by-case basis. Three factors in particular should be carefully assessed to develop a consistent cost-benefit analysis in order to determine the tradeoffs involved and the feasibility of a particular project.

First, the emissions from the new train or ship must be included in the analysis. Ships, for example, may emit as much as 100,000 metric tons of BC per year by 2012 [*Corbett et al*., 2007], and no regulations currently exist to mitigate these emissions. However, once cargo is traveling en masse, the sources of BC emissions (i.e. trains and ships) will be centralized and much easier to monitor and regulate than individual trucks on the highways. Second, a framework should be developed to monetize the health and climate costs of train and marine emissions, so that the benefits of reducing these emissions can be easily evaluated. Third, the long-run discounted capital costs of the project should be estimated.

Using these three metrics, the EPA could conduct a thorough analysis of the costs and benefits of each project facilitating intermodal transport. If the emissions from the new mode of transport exceed those of the trucks it is replacing, then the project is undesirable. If not, the capital costs should be compared with an evaluation of the health and climate costs in order to determine feasibility.

3.5.2 The commercialization of electric vehicles is a viable long-term means of reducing transport-related BC emissions

As shown in Table 3.2, diesel can be produced more efficiently, and emits fewer greenhouse gases than gasoline. Although diesel BC emissions can be about 3 times higher than those from gasoline combustion, these can be significantly reduced by installing DPFs (see Section 3.3). Engines with filters may have reduced fuel efficiency, in which case they could emit more GHGs and BC than a regular gasoline engine per mile traveled. However, most studies show a small and not always statistically significant reduction in efficiency and some studies show no detectable difference at all [*Emissions Advantage*, 2005]. Thus, this report finds diesel engines with DPFs to be a feasible alternative to gasoline, particularly for large trucks and less fuel-efficient vehicles. Compressed Natural Gas (CNG), which has no BC emissions and similar GHG emissions as gasoline, is another viable option in the short-term, particularly for municipal light-vehicle fleets, such as buses and taxis, which are already being converted from diesel to CNG in a number of cities in developed and developing countries.

However, neither diesel nor CNG is a viable long-term means of mitigating the climate-warming and health impacts of transportation. Both emit significant amounts of greenhouse gases and neither is renewable. Ideally, policymaking should focus on developing and promoting fuels that are renewable, clean, and have low radiative forcing.

	Production Efficiency (%)	Range of GHG Emissions (g CO_2 equivalents/ MJ)	Range of BC Emissions (g/kg)	Range of BC Emissions (g/MJ)
Gasoline	80-87	15-26	0.08-0.43	0.002-0.009
Diesel	83-90	12-18	1.3-3.6	0.03-0.08
CNG	83-91	10-27	0	0

Table 3.2: Comparison of Greenhouse Gases (GHG) and BC emitted by Fuel Type Source: [MacLean and Lave, 2003] and [Bond, 2004].

Note: Production efficiency (%) is defined as the amount of energy (in MegaJoules (MJ)) of energy in the fuel delivered to consumers per 100 MJ of energy inputs to produce and deliver the fuel, e.g. 100 MJ of energy input results in 80–87 MJ of gasoline delivered to the consumer.

A CO_2 equivalent is defined as the amount of carbon dioxide by weight emitted into the atmosphere that would produce the equivalent radiative forcing as a given weight of another greenhouse gas. It is calculated by taking the product of the weight of the gas being considered and its Global Warming Potential (GWP) The energy densities used in converting g/kg to g/MJ in the fourth column are gasoline: 45.9 MJ/kg, and diesel: 43.3 MJ/kg, derived using values from <http://bioenergy.ornl.gov/papers/misc/energy_conv.html>

In their current form, at least in the U.S., biofuels do not appear to be a viable solution to this problem. In many cases, the costs and lifecycle impacts of biofuel production outweigh the climate benefits from their use. This is particularly true of current technology such as corn ethanol or biodiesel, which in the U.S. can have greater CO_2 emissions over their lifecycle than regular gasoline engines [Delucchi, 2006].

Although other technologies may become available in the future, the most promising technology currently available is the Plug-in Hybrid Electric Vehicle (PHEV), which combines the features of Battery-powered Electric Vehicles (BEVs) and gasoline-fueled Hybrid-Electric Vehicles (HEVs). However, these vehicles are still not ready to replace diesel in the marketplace, particularly in the case of large cargo trucks, due in part to their inferior range and performance and their exorbitant up-front costs (Table 3.3).

We recommend that the EPA work with the new administration to implement a three-stage strategy for the commercialization of PHEVs. First, determine exactly what the obstacles are in making this technology commercially viable, not only for passenger vehicles but for trucks and especially off-road vehicles as well. Second, offer generous funding to organizations and companies who will research how the technology might overcome those obstacles. Finally, once commercialization is viable, subsidize the cost of the vehicles to spur consumption and support the new industry while it generates economies of scale and eventually becomes self-sustainable.

Funding these research grants and subsidies should not be particularly difficult in light of the Obama administration's commitment to invest $150 billion over the next 10 years in renewable energy, low-emission coal plants, a smart electricity grid, and the commercialization and development of PHEVs, with the aim of putting 1 million American-made PHEVs on the road by 2015 [*Change.gov*, 2009]. Aside from the climate and health benefits that are the focus of this report, investing in PHEV technology can be justified politically because it has the potential to revitalize the U.S. economy by realigning the auto industry and creating many new jobs in the process. In the early stages, technically skilled labor will be necessary for research and development, but as commercialization becomes more viable, manufacturing labor will need to be employed to set the new industry in motion.

	Diesel	CNG	BEV	HEV
PM Emissions	- -	+	++	+
Fuel Cycle Emissions	+	+	- -	+
Global Warming	+	++	=	+
Fossil Fuel Depletion	+	+	=	++
Energy Independence	+	+	+	+
Fuel Cost	+	+	- -	+
Vehicle Range	+	- -	- -	++
Vehicle Performance	=	-	++	-
Vehicle Cost	-	-	- -	- -

Key: Much Better: ++ Better: + Same: = Worse: - Much Worse: - -

Table 3.3: Comparison of environmental impacts, performance and costs of vehicles operated using diesel, compressed natural gas (CNG), battery electric vehicle (BEV) and hybrid electric vehicle (HEV) relative to a conventional gasoline vehicle. *Source: [MacLean and Lave, 2003]*

Electric vehicles may not reduce CO_2 emissions due to the processes that generate the electricity used to charge them [*MacLean and Lave*, 2003]. However, switching to these vehicles will entail a reduction in BC emissions, because U.S. power generation facilities do not emit BC. Thus, to reduce all emissions which warm the climate, the EPA should ensure that any policies aimed at promoting electric vehicles simultaneously target the sources from which the vehicles are powered [*Minjares*, personal communication]. In particular, the EPA should encourage the new administration to stand by its commitment to ensure that 10% of electricity comes from renewable sources by 2012 and 25% by 2025 [*Change.gov*, 2009].

Box 3.2: The Potential for Emissions Trading Mechanisms for Black Carbon

Emission trading is a useful means of mitigation because it provides a macro-level, market-based mechanism for achieving environmental goals by granting flexibility to the emitters to select the lowest cost of abatement. However, in the long run, the costs of reduction do not disappear and the emitting parties must make the appropriate changes in order to reduce emissions [Ellerman et al., 2003].

Unfortunately, there are four main obstacles for an emissions trading program focused on BC reductions to be successful. First, successful emissions trading programs deal mostly with stationary emissions, whereas BC emissions sources tend to be widely distributed and mobile (Fig. 3.1). Second, for any emissions trading program to be successful, emissions levels should be easily measurable and compliance verifiable, which is difficult with BC. Third, it is not feasible to use GWPs as a common metric for trading BC with GHGs (see Chapter 2 for a more detailed discussion). Finally, trading BC internationally is also fraught with challenges, as outlined in Chapter 5.

Nonetheless, the possibility of using emissions trading BC for BC within the U.S. should not be entirely discarded. For instance, a fleet-wide emissions cap could be placed on companies that use diesel trucks for cargo transportation. However, significant research must be done in order to determine more clearly whether such trading is feasible, and is beyond the scope of this report. In particular, the measurability of mobile emissions needs to be carefully addressed before any such scheme can be designed.

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Chapter 4: Addressing Black Carbon Emissions Abroad

Energy resources and land use practices are significantly different in the developing world, a fact reflected by the diversity of BC emission sources. As such, the health and climate impacts of BC emissions vary considerably in the developing world, which motivates a much different set of incentives and approaches to BC reduction. This chapter details the characteristics of emissions, the nature of the impacts, and the opportunities for mitigation by sector and by region.

As this report has detailed, there are two fundamental concerns motivating a reduction in BC emissions. The first is the role that the emissions of gross BC have on public health. As shown in Figure 4.1 below, the majority of BC is emitted from developing countries, where health impacts are the largest.

The second and more recent concern is the impact of BC and co-emitted particulates on atmospheric radiative forcing. Figure 4.2 depicts the net annual BC emissions as a proxy for impact on radiative forcing balance. This graph highlights the impact of BC emission on the climate and underscores the relative importance of sources of contained combustion in the radiative forcing balance. Again, the importance of emissions from the developing world is obvious.

Taken together, Figures 4.1 and 4.2 underscore the tradeoffs between and health and climate that must be considered when targeting BC reductions in different regions and sectors. Regardless of which is given more importance, it is evident that any efforts to address the health and climate impacts of global BC emission must include reductions in the developing world.

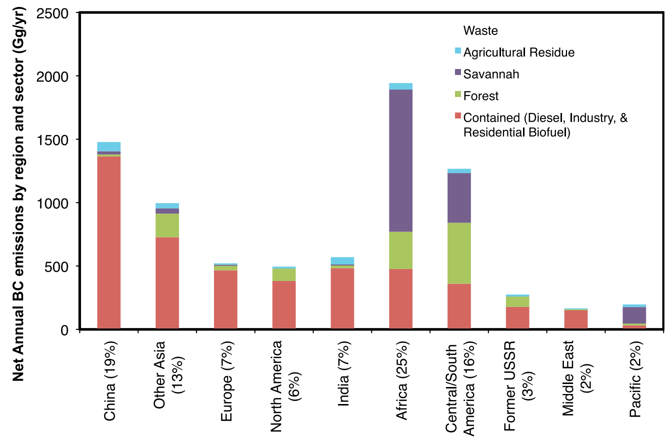

Figure 4.1: Gross annual BC emission by region and sector: *Adapted from [Bond et al., 2004]. Percentages reflect respective region's contribution to gross annual BC emissions and may not sum to 100% due to rounding. Region of North America excludes Mexico while Pacific region includes Japan.*

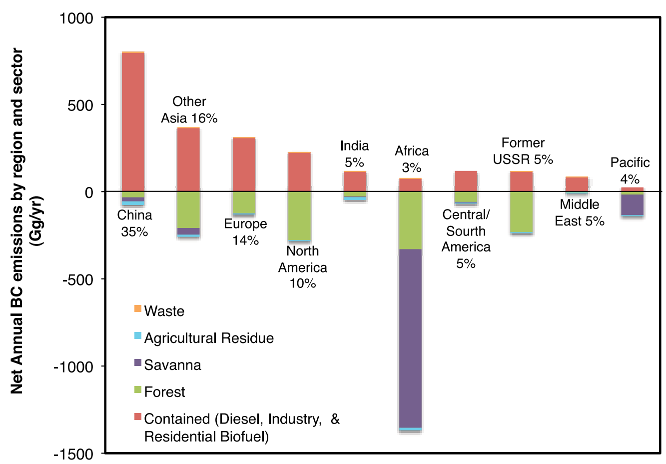

Figure 4.2: Net annual BC inventory by region and sector: *Adapted from [Bond et al., 2004]. Pursuant to finding of Table 2.1, BC inventory from Figure 4.1 is offset by corresponding OC inventory using the formula Net BC=Gross BC*(1-0.27*OC:BC). This disregards the possible impact of BC on snow albedo and the co-emission of other aerosols or GHG upon RF balance. Percentages reflect respective region's relative contribution to total contained BC emission (corrected for OC) and may not sum to 100% due to rounding. Region of North America excludes Mexico while Pacific region includes Japan.*

4.1 BC Reduction Opportunities in Developing Nations

There are several compelling reasons why any efforts to reduce BC emissions should include the developing world.

4.1.1 BC Emissions from developing countries are a major and growing fraction of the global total

Over 77% of global gross BC emissions originate from non-OECD countries [Bond et al., 2004]. Furthermore, population growth rates in these countries significantly outstrip those of the OECD, which suggests that without changes in technologies and high emitting practices, these countries will emit a growing percentage of BC. Yet as per capita GDP increases, populations in these countries will move farther up the energy ladder to cleaner[1] fuels that mitigate the increased per capita BC emissions [*World Health Organization*, 2006]. However, it is highly unlikely that this effect will significantly mitigate non-OECD emissions, and thus total emissions will increase rapidly.

1 This term refers to the reduction of particulate emissions as fuels which undergo more complete combustion (e.g. LNG) are utilized. This does not address the corresponding increase in co-emitted GHGs.

4.1.2 The developing world is more vulnerable to the effects of climate change

As noted by the IPCC, countries in the weakest economic condition are the most vulnerable to the impacts of climate change [*IPCC*, 2007]. Thus, developing countries have a vested interest in forestalling the effects of climate change in the near-term with strategies such as the reduction of BC emissions. Therefore, the linkage between implementation of BC reduction strategies and avoidance of large-scale economic, social, and environmental damage should create the impetus for BC reductions in the developing world.

4.1.3 Black Carbon emissions have a greater impact on public health in the non-OECD

The use of small biomass stoves in unventilated homes increases the exposure of individuals in the developing world to concentrated sources of BC emissions, contributing to a deterioration in public health. In addition to the conventional concerns this health burden poses, it also threatens economic development and engenders a cycle of poverty. This is reflected in the role that the reduction of Indoor Air Pollution (IAP) has in supporting achievement of the Millennium Development Goals [*World Health Organization*, 2006]. The improvement of public health through BC emission reductions should therefore also provide leverage for the implementation of national BC reduction strategies.

4.1.4 Nascent infrastructure development can incorporate BC reduction strategies

As emerging market economies grow richer and develop, new infrastructure will be built rapidly. As such, enormous opportunities exist in these countries for building sustainability into physical infrastructure and socio-cultural norms. The scope for new infrastructure development is generally broader in non-OECD countries. Thus, these countries can capitalize upon the opportunity to develop around principles that avoid future BC emissions. Particularly in urban areas where diesel fuel is used in passenger vehicles, measures can be taken to design transportation infrastructure in conjunction with urban planning so as to minimize BC emissions. Such initiatives should be phased in before other behavioral patterns become ingrained in the national and cultural landscape, and thus evolve into an intractable problem.

4.1.5. BC provides an avenue for engaging developing nations in climate-related discussions

Participation by representatives of the developing world in efforts surrounding BC reduction provides an excellent entrée into the discussion of climate change efforts more broadly. In going through the mechanics of developing programs to reduce BC in the developing world, parties will build rapport and confidence that should facilitate future efforts to address climate change mitigation and adaptation.

4.2 Areas of Opportunities by Sector and Region

The strategies for reducing BC emissions in the developing world are different depending on the challenges particular to each country and region. To provide strategies for BC reductions that have both a broad scope and sufficient resolution, we focus on four separate combinations of sectors and regions that address a significant portion of the gross BC emissions impacting public health and the net BC emissions impacting climate.

4.2.1 Diesel: Asia

Mobile diesel engines from on- and off-road vehicles accounted for 24% of global gross BC emissions in 1996, of which 5% occur in Asia [*Bond et al*., 2004]. Diesel fuel consumption continues to increase exponentially in Asia, having reached nearly 180 billion liters (47 billion gallons) consumed per annum in 2003, up approximately 90% from 1990 levels [*ADB*, 2008]. Across Asia, diesel is anticipated to maintain its share of on-road vehicles (among all fuel type vehicles) close to current levels through 2030 – roughly 30% for China, 60% for India, and 50% for the rest of emerging Asia [ADB, 2008], meaning that total diesel related emissions will increase dramatically alongside total vehicles.

BC emission levels from diesel depend primarily on three factors: fuel quality (i.e. sulfur content), amount of fuel consumed, and vehicle emissions standards & controls. Most short- and medium-term BC mitigation options, which would reduce emissions below BAU projections, revolve around implementing stricter vehicle emissions standards, usually denominated in the Euro I-V system (see Chapter 3), concurrently with improving fuel quality including lowering sulfur fuel sulfur content. For effective reduction of particulate matter, both vehicle and fuel improvements are necessary [*ADB*, 2008].

India's history is indicative of the challenge of implementing stricter vehicle emissions standards in Asia. Vehicular BC emissions in India increased by 112% from 1991-2001, increasing their share of total Indian BC emissions from 26 to 34% [*Sahu et al.*, 2008] (summarized in Table 1). During the same period, the share of BC emissions from biomass burning fell from 20 to 13%. Two important economic factors make the problem of diesel emissions particularly acute in India. First, a lopsided tax scheme creates a huge price differential in India between diesel and gasoline. The price of diesel is roughly 60% that of gasoline [*Agarwal*, 1999], and nearly 50% of new cars currently sold have diesel engines [*CSE*, 2008]. Unfortunately, the history of preferential treatment of diesel pricing makes a tax re-alignment politically infeasible as the resultant tax increase would be strongly regressive.

Finally, the number of new car purchases is projected to increase exponentially as the Indian economy grows. It is estimated that by 2030, the average Indian will travel 3 times as much as in 2001 [*Singh*, 2006]. A particular area of concern is the advent of the new low-cost car model. The middle class is expected to grow from 53 million to 583 million by 2025 [*McKinsey*, 2007]. As a result, the auto industry is expanding sales, particularly among first-time car buyers. Over the past few years, price wars have provided a strong incentive for car manufacturers to produce a large inventory of cheap automobiles with poor emissions control, before the implementation of the much stricter Euro IV standards outlined in Chapter 3.

The other component for PM reduction from diesel sources, ULSD, would necessitate major capital investments in refineries. However a switch to low-sulfur diesel, as necessitated by the Euro standard implementation shown in Table 3.1, would likely drive half of existing refineries out of the market, primarily small ones ill-equipped to adapt to new technology [*ADB*, 2008]. Thus, government intervention in the market (e.g. subsidy for small refineries) would be necessary to ensure ULSD supply.

Fuel switching to CNG the near term and increasing fuel efficiency in the longer term may be viable options for reducing aggregate diesel fuel consumption and thus BC emissions [*Reynolds*, 2008]. The conversion of New Dehli's public transport fleet to CNG in 2002 has already led to significant air quality improvements [*Jain*, 2004]. Furthermore, reduced fuel consumption through construction of mass transit systems, promotion of intermodal cargo transport, and use of urban and industrial planning to minimize truck transport-miles are all important long-term strategies.

4.2.2 Residential Biofuel: China & India

BC emissions from combustion of residential biofuel constituted approximately 880 of the roughly 8,000 Gg of gross BC emitted globally in 1996 [*Bond et al.*, 2004]. Of that total, approximately 300 Gg (34.5%) came from India and approximately 350 Gg (39.0%) came from China [*Bond et al.*, 2004]. A review of The Indian National Programme for Improved Chulhas (NPIC) illustrates the factors that influence the success or failure of deploying improved cookstoves, which can be used to reduce the health and climate impacts of BC emission. Although it distributed some 90 million improved cookstoves between 1983 and 2002, the NPIC was widely regarded as having failed to meet its primary objective of improving fuel efficiency and secondary objectives of saving user time and avoiding deforestation [*Smith*, 2007]. Critical failures in this top-down approach appear to include a national scope without an attempt to target well-suited regions, a failure to adapt stove designs to local conditions, and the absence of any monitoring and evaluation program following deployment.

In contrast, the Chinese National Improved Stove Program (NISP), which ran from 1983-1996, is widely regarded as one of the most successful Chinese projects in energy efficiency and rural development [*Smith*, 2007]. Important characteristics included the targeted selection of projects, the bypassing of bureaucracy and empowerment of local governance to run the program, and the implementation of a monitoring and evaluation program that involved random spot checks of cookstove usage. During this time the Chinese government deployed 120 million improved cookstoves, and it estimated that 7 out of every 10 households dependent on biofuel for cooking began using the improved stoves [*Smith*, 2007].

The Partnership for Clean Indoor Air (PCIA)[2] incorporates the characteristics espoused by NISP, and couples them to sustainable market enterprises to deploy and maintain improved cookstoves. While PCIA has an excellent framework for achieving this objective, some principles merit elaboration:

- *Gathering information*

  Efforts to characterize the nature and extent of BC emission from biofuel combustion are chronically hindered by a shortage of information about the inputs to and outputs of residential biofuel combustion. Concerning inputs, the effort to measure biofuel collection in the developing world has largely fallen by the wayside. Until recently, the Regional Wood Energy

2 http://www.pciaonline.org/

Development Programme (RWDEP) in Asia maintained a Wood Energy Database for 16 member nations under the aegis of the UN Food and Agriculture Organization (FAO). This database provided detailed information on the amount of biomass collected, fuel characteristics, the type of technology used to utilize the fuel, and socioeconomic indicators of the populations using the fuel. Such information would be of great value in characterizing BC emissions and reducing variability in emission estimates. Moreover, this information could be used to determine those regions where individuals incur significant costs in the collection or purchase of biomass, which can provide strong impetus for the adoption of improved cookstoves. Unfortunately, RWDEP is no longer funded and the FAO Statistical Database (FAOSTAT) compiles information on industrial forestry products, not biomass production and consumption. Similarly, the International Energy Agency is focused on BC emission from more modern combustion forms (e.g. diesel engines) and not production of energy through biomass. PCIA should utilize existing relationships to advocate for RWDEP funding in order to capture information vital to understanding the extent of BC emissions from residential biofuel.

Concerning emissions from residential biofuel use, a comprehensive characterization of BC emissions is lacking. Efforts to capture this information to date have been forestalled in part by the prohibitive dispersion of sources and impracticality of monitoring. However, technological improvements in aethalometers (portable BC monitors) could provide the means to drastically improve the measurement of indoor BC emissions in the developing world. This tool could be used to monitor long-term cookstove performance and facilitate the verification of BC reductions through distributed data collection. Berkeley Air Monitoring Group, a PCIA partner, has expressed interest in using aethalometers to measure IAP and emissions. The broader PCIA should support this effort and design survey protocols to utilize this tool in gathering emission inventories from combustion of residential biofuel.

- *Consolidating and disseminating information*

As a corollary, PCIA should work to define clearinghouses of information on efforts surrounding BC reductions in this sector. Often organizations aiming to reducing the impact of PM emissions in developing countries suffer from a lack of information on efforts that preceded them, or that are even running concurrently. By collecting, analyzing, and consolidating this knowledge, PCIA can disseminate information on best practices and lessons learned that would better coordinate efforts and magnify impact.

- *Promulgating standards*

PCIA can also support cookstove deployment by working to create consensus around standards of cookstove quality and performance. Some efforts to deploy cookstoves in India have been frustrated by the obscure quality standards required by the Bureau of Indian Standards [Mozer, 2008]. Building consensus around a quality assurance standard such as ISO, with a concurrent effort to ensure developing nations accept this standard, would help accelerate deployment. Standards of performance are more difficult to standardize as cooking practices vary widely from region to region due to the significant impact of the operator in overall cookstove performance. However the PCIA could endorse a well-known standard such as the VITA International Standard Water Boiling Test [*VITA*, 1985] to standardize some broad indication of comparative performance between cookstoves.

4.2.3 Open Biomass Burning: Africa and Latin America

Open biomass burning in Africa and Latin America accounts for roughly thirty-one percent of global gross BC emissions. Of that, ten percent is forest burning, nineteen percent savannah burning and just under two percent agricultural residue burning [*Bond et al.*, 2004]. However, open biomass burning is associated with exceedingly high OC:BC ratios, mitigating much of the aerosol impact on climate. However, as noted above, this sector contributes significantly to gross BC emissions and thus extensively impacts global health.

Much of the savannah and forest burning is directly or indirectly caused by land use changes associated with agriculture. Two strategies for mitigating these emissions involve the expansion of biochar production and engaging with global food companies in their push for greater sustainability.

In biochar production, instead of undergoing inefficient combustion, biomass is subjected to chemical decomposition via pyrolysis. The resulting product, biochar, can then be used as a soil amendment. The benefit of expanded biochar production in reducing BC emission is predicated on the condition that the input biomass would have otherwise been fodder for open burning. Given that open burning is an expedient agricultural land clearing technique, it is unlikely that BC emissions from forest or savannah burning could be reduced without a large-scale restructuring of incentives. While the burning of agricultural residue is similarly motivated by expediency, it is conceivable that this biomass could be reallocated to biochar production. The vast majority of this waste, it is assumed, is composed of chaff generated during the labor-intensive harvesting process. Through provision of incentives (e.g. profit sharing from sale of soil amendment) and facilitation of biomass collection and pyrolysis, this reallocation of agricultural residue to biochar production could prove feasible.

Engagement with the private agricultural sector to improve sustainability in their practices could change systemic incentives in such a way as to dramatically reduce BC and GHG emissions caused by agriculture. Developing a comprehensive environmental strategy is increasingly important for food companies. Through the forum of PCIA or the Sustainable Food Laboratory or the Sustainable Agriculture Initiative, the EPA could engage with and advise private corporations on how to incorporate BC reductions into their environmental objectives and strategies. These efforts, by promoting best practices, have successfully contributed to improving land use patterns and the use of agricultural waste in supply chains as diverse as global tea, green beans, palm oil, and poultry [*Sustainable Food Laboratory, 2008*].

4.2.4 Industrial Sources: China & Russia

Slightly over 10% of Russian gross BC emissions and nearly 25% of Chinese emissions come from industry and power generation, and combined they account for approximately 6.5% of gross BC emission globally [*Bond et al*., 2004]. Much of the BC is emitted from smaller industries such as coke ovens and brick kilns that escape regulation. Unfortunately a lack of regulation begets a paucity of data on these sources.

Both the Chinese and Russian economies have exhibited high rates of GDP growth over recent years (7.3% and 10.3% respectively between 2003-2007), suggesting that their BC emissions will continue to grow in the near-term [*Economist*, 2008a; b]. In China however, it is expected that BC emissions will decline slightly by 2020 because of improving technology and declining reliance on biomass [*Streets et al*., 2001]. In addition to the impact of BC emissions on radiative forcing, Russian BC emissions are of particular concern because of the likelihood that they are deposited in the Arctic, and are addressed in further detail in Appendix 4.1.

Industrial source emissions in these countries are inextricably linked with economic development and social welfare. In Russia, many remote Arctic and Siberian cities are "mono-industrial," i.e. supported by a single industry that represents its economic lifeblood. In China, the closure of factories leads to job losses that threaten social stability [Wong, 2008]. However, political mandates to clean up industrial pollution have begun to show results in China, where 83 small, dirty coal plants were closed in the first three and a half months of 2008 [*MEN*, 2008]. Similar government attention in Russia, coupled with adequate financing for industrial upgrades, could lead to significant BC emissions reductions. Governments should also pursue local economic development efforts to help diversify the economy away from coal and dirty industry.

4.3 The Role of EPA in Developing Countries

In addition to the specific recommendations listed in the sectoral and geographic areas of opportunity above, there are two wider themes for the EPA to incorporate in its strategic approach towards reducing BC emissions in developing countries.

4.3.1 As a science and technology leader, the EPA could advise other public sector entities on BC emissions reductions

In order to improve the efficiency and efficacy of direct assistance used to achieve BC reductions in the developing world, we recommend that the EPA make use of its strength in science and technology.

With respect to science, it would be beneficial for the EPA to serve as a clearinghouse of information for the various organizations engaged in BC reduction-related direct assistance overseas. Many of these organizations, such as the Gates Foundation, the World Bank, and Inter-American Development Bank, are only minimally aware of the impact of BC on health and climate and would welcome expertise and advice from the EPA on how to effectively link BC mitigation to direct assistance programs. In providing a forum for these stakeholders, the EPA can, in coordination with aid agencies, consolidate and disseminate information concerning ongoing assistance efforts, lessons learned, and best practices.

With respect to technology, we recommend that the EPA prioritize and support the development of technology to assist in BC reductions. Internally, the EPA should emphasize BC as an area of concern for its Environmental Technology Verification Program.[3] Monitoring and verification of BC emissions is vital for an improved understanding of the sources and levels of BC emissions, as well as the impact of BC reduction efforts. In addition, the EPA could convene a Technology Assessment Committee to determine what technologies exist or could be developed to facilitate BC reductions in the developing world.

4.3.2 The EPA could contribute to, and would benefit from engaging with public-private partnerships

In addition to developing the role of the public sector in supporting BC reduction efforts in the developing world through aid based assistance, it would be advantageous for the EPA to explore the potential of public-private partnerships to achieve the same objectives through market based assistance. Engagement with the private sector could be used to harness the flexibility and speed of market mechanisms in deploying BC reducing technologies in the developing world. Furthermore, the creation of a market in these areas could result in a sustainable flow of technologies that is uncoupled from development funding. Such a partnership for the implementation of BC reduction overseas could be modeled on the framework employed by the Asia-Pacific Partnership on Clean Development and Climate (APP), but restructured to increase its rigor. By reaching out to the private sector and bringing together diverse groups with different expertise, the EPA could enhance its effectiveness at reducing global BC emissions.

3 http://www.epa.gov/etv/

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Chapter 5: Policy Options to Coordinate Transnational Cooperation on Black Carbon

The United States only emits a small fraction of the world's black carbon and cannot substantially reduce global BC emissions unilaterally. This report has outlined some opportunities for cooperation with developing countries through foreign aid and partnerships based on specific regional challenges in Chapter 4. It is also important for the U.S. to take an active role to increase international cooperation, including with both developed and developing countries, and to ensure that the global community coordinates efforts towards reducing BC emissions.

It should be of great concern to U.S. policy makers that BC emissions in other countries can have a strong effect on the future climate in the U.S. Coupled atmospheric chemistry - climate modeling studies carried out by the National Oceanic and Atmospheric Administration (NOAA) and the NASA Goddard Institute for Space Studies (GISS) indicate that projected changes in global concentrations of short-lived air pollutants (primarily resulting from decreases in global sulfur dioxide emissions and increases in BC emissions) lead to an increase in summer time temperature in the U.S. of 1.5 – 2.0 degrees Celsius by the year 2100 beyond warming caused by carbon dioxide [*Levy et al*, 2008; *U.S. Climate Change Science Program Report*, 2008; see figure 5.1]. Although changes in aerosol emissions from the U.S. are projected to be relatively minor compared to changes in Asia, the effect on the U.S. temperature is projected to be higher than almost any other region. Clearly, air pollutants emitted in foreign countries can have considerable effect on the future U.S. climate.

International efforts to negotiate a global climate treaty to

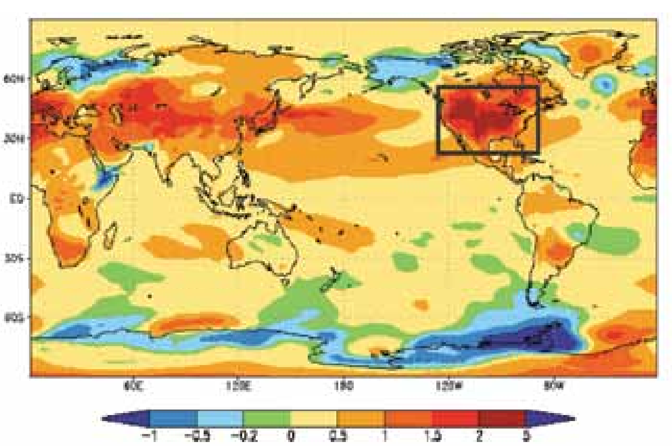

Figure 5.1: Increases in Summer Temperature from 2000s to 2090s (°C) *Resulting from Projected Changes in Black Carbon and Decreases in Sulfate Emissions. Results from NOAA Geophysical Fluid Dynamics Laboratory Climate Model [Levy et al., 2008]*

reduce greenhouse gas emissions are underway, but this process has not been sufficiently linked to policies towards air pollutants such as BC that also affect the climate [*Rypdal et al*, 2005]. Evidence was presented in Chapter 2 showing that BC emissions can be targeted to significantly reduce climate change on a shorter time scale than greenhouse gases. This presents the international community with a crucial opportunity to act. Indeed, it may be not only an opportunity, but also a requirement if the global community wants to stabilize radiative forcing at 450 ppm CO_{2e} by the end of the century. Furthermore, reducing BC emissions has both public health and climate benefits; important synergies may be missed if they are not considered together.

This chapter explores the issue of transnational policies and cooperation to reduce BC emissions. It considers several options, including adding BC to existing air pollution frameworks and agreements, creating regional hot-spot treaties, and developing global technical standards. However, if any of these options are to be realized, an increase in international awareness, research, and dialogue on the challenges and opportunities for BC mitigation is needed. Some suggestions on how to achieve this are considered below.

5.1 Existing International Agreements Could Create a Basis for Cooperation

Experience shows that for the international community to cooperate and supply a global public good, a consensus on both the problem and an effective solution need to be agreed upon. The precedent of the Montreal Protocol, which successfully reduced ozone depleting CFCs over the last two decades, suggests that reaching such a consensus requires a strong scientific basis coupled with public awareness, international debate, creation of international technology assessment committees, and typically the creation of global conferences and institutions [*Barrett*, 2003]. Regarding the issue of BC emissions and their effect on climate, the international community is still poorly aware of the issue, scientific research is sparse, and few forums for discussion and international policy making exist.

The United Nations Framework Convention on Climate Change (UNFCCC) would be a logical venue for discussions on the climate impact of BC emissions; however, this framework was developed around greenhouse gases, which are still the focus of this institution today. The UNFCCC was established in 1992, before evidence of the warming effect of BC emissions was understood, and its stated goal of "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference" is non-inclusive of aerosols such as BC, at least in its present form. This feature was carried over into the major agreement under the UNFCCC – the 1997 Kyoto Protocol – which only requires control and monitoring of six greenhouse gases without mention of aerosols. The IPCC, which is tasked with synthesizing the latest developments in climate change science, included BC in its Fourth Assessment Report published in 2007, and some discussion has begun on the role of aerosols in future climate goals. However, the issue of BC is still not given the attention merited by its radiative forcing on the climate.

A second important venue for future discussions of BC emissions control is the Convention on Long-Range Trans-boundary Air Pollution (LRTAP), which has been successful at coordinating reductions of air pollutants in the western world. LRTAP was established in 1979 under the United Nations Economic Commission for Europe (UN-ECE) and was successful in coordinating reductions of several pollutants including sulfur oxides which have been reduced by over 50 percent [*UN-ECE report*, 2004]. PM is not included in LRTAP's most recent Gothenburg Protocol (1999), although it is being considered for future agreements. A 2007 task force reviewing the Protocol found that inter-continental transport of particulates has significant implications for climate change, and suggested that air quality and climate change policies of member countries be considered together [*CIAM Report*, 2007]. This may provide an opportunity to address BC emissions. LRTAP member countries include several significant BC emitters including the European Union states, Russia, the U.S., and Canada; however, it does not include developing countries.

Budding institutions which coordinate efforts on air pollution in developing countries could play an important role in emissions mitigation in Asia and Africa, which emit a large fraction of global BC. In particular, the East Asia Network on Acid Deposition (EANET) which includes China, Japan, Russia and the Republic of Korea; the Male' Declaration on Control and Prevention of Air Pollution and its Likely Trans-boundary Effects for South Asia, which includes India, Pakistan and Bangladesh; and the Air Pollution Information Network for Africa (APINA) which covers many African countries. Each of these institutions has been playing a role in coordinating regional efforts towards monitoring air pollutants, and in addition holds inter-governmental conferences for scientists and policy-makers. These institutions already monitor PM emissions, and further efforts to mitigate BC emissions in developing countries should be carefully coordinated with them.

If effective transnational policy options to reduce BC are to be developed, an international framework such as those mentioned above would need to emerge as a forum for global discussion on the issue. This report recommends that the following actions be taken by the U.S. government to increase global understanding and discussion of BC as a climate pollutant:

- Request that the UNFCCC commission a 'Special Report on Black Carbon as a Climate Pollutant'. Such reports have already been published on complex issues such as 'Carbon Capture and Storage' and 'Safeguarding the Ozone Layer', and have been effective at raising awareness on these issues.
- Create an annual conference for discussion of scientific research and policies for BC. Such a conference could be included within existing UNFCCC or LRTAP frameworks or organized independently.
- Provide funding for research on BC, development of a current BC emissions inventory, and advocate such research and emissions inventories for all countries.

These important steps will broaden the discussion and awareness of BC, allow BC science and policy options to be developed, and lay a foundation for future international agreements on BC emissions, as discussed in the following section.

5.2 Several Transnational Policy Options Exist for Reducing Black Carbon Emissions

An international environmental agreement on BC could take on a variety of forms depending on the included emissions sources, ambitiousness of reduction targets, and geographical extent. A relatively narrow agreement, for instance scaling up existing $PM_{2.5}$ emissions reduction programs in developed countries, is already within reach. A broader global agreement involving significant transfer of technology and capacity building in developing countries is more complex and politically challenging. In between these options are other alternatives such as development and implementation of global technical standards to target emissions from important sources such as diesel engines, or a regional hot-spot treaty to reduce BC emissions in sensitive regions such as the Arctic and Himalayas.

Before outlining international policy alternatives for BC, this report will discuss some of the important reasons that this pollutant could not be effectively included in the current Kyoto framework of greenhouse gas emissions trading.

5.2.1 Difficulties of Including Black Carbon in Emissions Trading Under the Kyoto Protocol

It is tempting to imagine that BC emissions could be reduced by including them in existing GHG emissions trading schemes such as those used under the Kyoto Protocol, but fundamental characteristics of BC emissions, starting with those discussed in Boxes 2.1 and 3.2, make this an inefficient and problematic solution compared to others.

Emissions trading is an effective policy instrument to reduce emissions of a certain kind of pollutant which displays 'homogeneous environmental impacts' in a given trading zone, and for which emissions trading has relatively low transaction costs [*Sterner*, 2003; *Stavins*, 1995]. In practice, 'homogeneous environmental impacts' has limited emissions trading schemes to pollutants without strong local impacts, for example GHGs, or pollutants which affect a large area such as sulfur oxides which cause regional acid rain. 'Low transaction costs' has meant that emission trading is most effective for large stationary sources such as factories and power stations which are relatively easy to monitor and of sufficient scale to make trading worthwhile.

BC has strong local effects and is emitted from a variety of small or mobile sources including diesel vehicles and cook-stoves, making it unsuitable for emissions trading on both criteria mentioned above. The environmental impact of BC emissions varies depending on its source, its vicinity to human populations and also on local weather conditions - all characteristics that make it a poor tradable commodity. Trading of BC would result in emissions hot-spots that would be at odds with health goals since BC impacts on health are even more local than they are on climate. Because of the large number of small individual sources that emit BC, the transaction costs necessary to monitor and verify emissions and ensure fairness in a trading scheme would be prohibitively expensive. For these reasons, practically all national policies to control particulate matter have used emissions standards or technical regulations instead of emissions trading. This report recommends that, barring new research or methods of effectively trading BC (see Box 3.2), a traditional regulatory approach to be used to meet any future regional/national BC emission caps.

This does not mean that BC could not be included in global climate negotiations or emissions reductions agreements, on the contrary, BC could and should be an important component of climate talks and could be a useful bargaining chip to involve developing countries. For example, it could be feasible for a developing country to negotiate a higher CO_2 emission cap in exchange for stricter BC emission regulations; however due to the problems outlined in Box 2.1 and above, this report recommends that BC emissions not be traded with GHGs in an international marketplace in programs such as the "Clean Development Mechanism" under the Kyoto Protocol.

5.2.2 Adding BC to LRTAP would help reduce BC emissions in developed countries

The U.S. and other developed countries have relatively high per capita emissions of BC, and should make use of existing legislation to further decrease emissions for both health and climate reasons. The U.S. does not account for the climate impacts of PM in current policy decisions, and including them will strengthen already powerful arguments for further action based on health impacts alone. Developed countries have a proven capacity for emissions reduction for diesel vehicles and industry, and by taking a lead in this area these countries can drive new technologies and policies to reduce BC emissions that can be used globally.

The LRTAP agreement coordinates air pollution targets between developed countries. We suggest that $PM_{2.5}$ emissions, which include BC, be considered as an addition to existing pollutants covered by the LRTAP Gothenburg Protocol. Ambient $PM_{2.5}$ levels are being gradually reduced in the U.S., but levels are still high enough to cause several tens of thousands of deaths per year and large health impacts and costs [*Mokdad et al*, 2004; *Laden et al*, 2006]. Such a treaty would save thousands of lives per year and could reduce up to one fifth of climate warming from BC.

5.2.3 Regional hot-spot treaties should be considered for the Arctic and the Himalayas

As detailed in Chapters 1 and 2, BC has a strong warming effect on snow and ice. Therefore, mitigation efforts in regions such as the Arctic are likely to have substantial impact in reducing climate change. The melting of the Arctic ice sheet and the plight of the polar bears are global symbols of climate change and could be a base for political support for a regional hot-spot treaty to protect the region.

A commonly used regulatory response to pollution hot-spots is zoning or differential regulation to reach emission reduction targets [Sterner, 2004]. An Arctic hot-spot treaty could use geographic based restrictions on the use of technology such as diesel engines ranging from severe restrictions or bans in certain areas such as the Arctic itself, to less disruptive regional limits in nearby countries, depending on the portion of emissions carried by atmospheric currents that settle on Arctic snow. Only rough estimates of such emissions and deposition rates are currently available and further scientific research is needed to quantify the effect of current BC emissions, their warming effects in sensitive regions, and identify optimal mitigation levels [*Bond*, 2004].

The Intergovernmental Forum for Arctic Governments, or the Arctic Council, is an institution which is suitable to develop and implement a regional hot-spot agreement for BC in the Arctic. The Arctic Council is an organization active in promoting the protection of the Arctic environment whose member countries include the U.S., Canada, Russia and the Nordic States. The Arctic Council's Arctic Contaminants Action Program (ACAP) and the Arctic Monitoring and Assessment Program (AMAP) provide two examples of this organization's current efforts to reduce pollutant emissions in the Arctic region [*Arctic Council*, 2008].

A similar hot-spot treaty should be considered for the Himalayan mountain ranges and nearby Tibetan Plateau, which has large glaciers and receives a significant amount of BC deposition from neighboring India and China. As discussed in Chapter 2, the Himalayan snow and glaciers are critical water sources for much of South Asia and China. Reduction of regional BC emissions could slow the rate of glacial melting and extend regional water supplies further into the future.

5.2.4 Global technical standards need to be developed and implemented

Global technical standards for BC emissions from small distributed sources such as diesel engines and cook-stoves are a useful policy tool that can be implemented across national boundaries. Such standards focus on manufacturers of technologies rather than users and rely on local government cooperation to implement. Implementing such standards would bring strong co-benefits to public health and the local environment, which gives strong incentives to local governments to join mitigation efforts.

One example are the EURO standards for vehicle emissions, including diesel engines, which were developed in Europe, but are now in use in China, Singapore and many other countries in Asia (see Table 3.1). They have been used to regulate both automobile manufacturers to make cleaner vehicles and oil refiners to produce cleaner low-sulfur fuels. The EURO standards have been used to reduce vehicle emissions in rapidly industrializing countries to great effect, and broadening their use in other countries could be an effective tool to reduce BC [*UN Report*, 2001].

If coupled with technology transfer, global technical standards could also be used as a benchmark to reward efforts of national governments to reduce emissions in developing countries. For the diesel vehicle example, policy and technical experts could assist developing countries to implement policies to reduce BC emissions including for new vehicles and testing and retro-fitting existing vehicle fleets. Incentives such as subsidized technology or project funding could be awarded to countries that make strong improvements in compliance with global technical standards and show corresponding reductions in national BC emissions.

5.2.5 A multilateral assistance fund is important to engage developing countries

The asymmetry of BC emissions between rich and poor countries makes it likely that multilateral assistance and investment will be important options to consider for reaching global environmental goals. BC mitigation projects should be added to the list of target projects for existing multi-lateral assistance funds such as the Global Environmental Facility (GEF), which has already given grants worth $7.6 billion to environmental projects in developing countries. Another precedent for assistance is the multilateral fund used to reduce emissions of CFCs under the Montreal Protocol, which has transferred over $2 billion to developing countries.

A multilateral assistance fund would allow governments from wealthier countries to use a relatively small amount of money to leverage reductions in developing countries; likely at a much lower cost-benefit ratio than for domestic action. Experience has shown that national governments are still the most effective level of intervention for emissions reductions, and that local capacity building is critical to overcoming global environmental challenges [*Victor*, 2007; *McKibben* *and Wilcoxen*, 2007]. International funding, coupled with global technical and policy standards and technology transfer, will add to the already strong incentives for governments in developing countries to tighten BC emissions regulations.

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Chapter 6: Conclusion and Consolidated List of Recommendations

Reducing emissions of black carbon (BC) will slow the rate of global warming and save lives. Mitigating BC emissions is likely necessary to limit global warming to less than 3.6º F (2º C) by the end of this century. In pursuing the reduction of BC emissions, the United States has an opportunity to demonstrate renewed commitment to action on climate change and to improved public health. In particular, the timing of the new Administration's economic recovery package creates an environment that is both politically and financially conducive to introducing policies targeted at reducing domestic BC emissions and stimulating economic recovery. This report outlines opportunities for the U.S. Government to guide these domestic reduction efforts, as well as ways to address BC reductions abroad.

Recommendations:

BC Science

- Focus future research on resolving uncertainties in BC radiative forcing, transport, and emissions inventories. (§2.3)
- Employ an improved understanding of transport processes to develop region- and source- specific climate impact metrics, focusing particularly on impacts on the Arctic and the Himalayas. (§2.1.3, 2.1.5)
- Employ improved transport models to estimate how different BC emissions contribute to the snow albedo effect. Because biomass burning has a negative or small radiative forcing when the snow albedo effect is not counted, this correction will allow identification of regions in which it is climatically important to mitigate biomass emissions. (§2.1.3, 2.1.5)
- Avoid use of Global Warming Potentials (GWPs) in comparing the effects of aerosols and greenhouse gases. (Box 2.1). Instead, use Integrated Assessment Models (IAMs), which couple estimates of climate impacts to realistic economic models, to compare the relative costs and benefits of BC and greenhouse gas emission reductions. In this study, we employ a simple model to estimate that BC emissions are "worth" 1-2 decades of carbon dioxide mitigation. Full IAMs would provide more accurate estimates. (§2.1.2)

BC Reductions in the United States

- Improve vehicle fuel efficiency through more stringent standards. Make federal aid to vehicle manufacturers contingent on improved efficiency. (§3.4.1)
- Locate and replace super-emitters through focused enforcement programs and targeted financial incentives. (§3.4.2)
- Expand funding for retrofit programs by providing loan guarantees for retrofits to small fleet operators and farmers. These could be financed through a "dirty-vehicle" tax on large fleet operators. (§3.4.3)
- Encourage intermodal freight transport by working with the Department of Transportation to factor BC emission mitigation into infrastructure development planning. (§3.5.1)
- Encourage the commercialization of clean transportation vehicles such as Plug-in Hybrid Electric Vehicles (PHEV). (§3.5.2, Box 3.2)

BC Reductions in developing countries

- Disseminate information to the public and private sectors on the scientific merits and technological options for reducing BC emissions. (§4.3.1). Specifically:
  1. Define information clearinghouses and promulgate standards concerning emissions from residential biofuel through coordination with the Partnership for Clean Indoor Air and advocacy for re-funding of the UN Food and Agricultural Organization's Regional Wood Energy Development Programme. (§4.2.2)
  2. Focus R&D on appropriate technologies that can be used in developing countries to accelerate BC emission reductions with an emphasis on reductions from stoves and new vehicles. (§4.3.1)
- Expand engagement with the private sector by increasing the number of public-private partnerships used to facilitate BC reductions in developing

countries (§4.3.2). Specifically:

1. Advise agricultural companies on sustainability as a part of their comprehensive environmental strategy in order to reduce BC emissions from open biomass burning. (§4.2.3)

2. Facilitate technology transfer for clean vehicles and ultra-low sulfur diesel fuel; upgrade industrial infrastructure in China & Russia. (§4.2.1, §4.2.4)

Transnational Cooperation

- Request that the IPCC prepare a special report on BC as a climate pollutant. (§5.1)
- Start an annual conference of scientists, policy makers, and private sector representatives focused on BC-related topics including scientific research, technical mitigation strategies, and policy options for reducing emissions globally. (§5.1).
- Provide funding for research on BC, develop an up-to-date U.S. BC emissions inventory, and facilitate similar research and inventory development abroad. (§5.1)
- Continue to exclude BC emissions from existing GHG emission trading schemes such as the Clean Development Mechanism of the 1997 Kyoto Protocol. (§5.2.1)

- Work towards an international agreement to limit BC emissions, which could make use of one or more of the following options:

1. Incorporate BC to LRTAP in order to strengthen existing efforts in developed countries to reduce particulate matter and black carbon emissions. (§5.2.2)

2. Regional hot-spot treaties to limit BC emissions in and around sensitive areas, particularly the Arctic and the Himalayas, which are disproportionately affected by the warming effects of BC. (§5.2.3)

3. Global technical standards for emissions from diesel engines and other BC-producing technologies. (§5.2.4)

4. A multilateral assistance fund to invest in BC emissions projects and capacity building in developing countries. (§5.2.5)

Appendix 2.1: Metrics of Black Carbon's Climate Impact

Radiative forcing is a measure of the change in Earth's energetic balance produced by an agent. It is an instantaneous measure, associated with the composition of the atmosphere at a single instant in time, and reflects nothing about future radiative forcing. The IPCC estimates that the normalized direct radiative forcing of BC aerosols is about 1100 W/g [*Forster et al*., 2007], while the global radiative forcing estimate of Ramanathan and Carmichael [2008] suggests that the direct radiative forcing of BC is about 2900 W/g. Averaged over the surface of the Earth, the IPCC's estimate is that BC's radiative forcing is 1.2 million times larger than that for CO_2 (with a 90% confidence range of 400 thousand to 2.1 million), while the Ramanthan and Carmichael estimate it is 3.2 million times larger than that for CO_2 (with a 95% confidence range of 900 thousand to 6.6 million times).

Total global radiative forcing is sometimes reported in terms of equivalent carbon dioxide concentrations (CO_2e). CO_2e concentrations report how much CO_2 would be required to produce a given radiative forcing, assuming that all other warming agents were at their pre-industrial concentrations. The current long-lived greenhouse gas radiative forcing of 2.63 W/m^2 corresponds to 454 ppm CO_2e. We define the marginal CO_2e concentration change of an aerosol emission as the change in CO_2e concentrations caused by emitting one ton/year of an aerosol to a baseline atmosphere (Table A1.3.1). We take as our baseline the IPCC's best estimate of radiative forcing in 2005, the same baseline used by the IPCC in calculating Global Warming Potentials (GWPs).

A Global Warming Potential for a radiative forcing agent i is defined as the ratio of the globally-averaged radiative forcing caused by a single 1 kg emission of i, integrated over some time period H (typically one hundred years), to the globally-averaged radiative forcing of a 1 kg CO_2 emission:

$$GWP(H)_i = \frac{\int_0^H a_i c_i(t)dt}{\int_0^H a_{CO_2} c_{CO_2}(t)dt}$$

where a_i and a_{CO2} are the radiative forcing of 1 kg of agent i or CO_2 and c_i and c_{CO2} are the respective concentrations at time t.

Although defined in terms of pulse emissions, the numerator of this ratio, the Absolute Global Warming Potential (AGWP) of agent i, is mathematically equivalent to the radiative forcing produced at the end of time period H by a sustained 1 kg/year emission of agent i. For short-lived agents like aerosols, AGWP rapidly reaches a steady-state value, equal to the product of the immediate radiative forcing of a unit emission and its lifetime. If BC has a lifetime of one week (0.02 years) and a normalized direct radiative forcing of 1100 W/g, then its AGWP is 22 W/(g/y) for any time horizon longer than a few weeks. In contrast, it takes millennia for carbon dioxide concentrations to reach steady-state in response to a change in emissions. Unlike the AGWP of aerosols, the AGWP of CO_2 therefore keeps growing as the time period under consideration lengthens. For this reason, GWPs are poor metrics for comparing aerosols to carbon dioxide and – while we present 100-year GWPs in table A.2.1.2 – we strongly urge that they not be used.

On the other hand, because all tropospheric aerosols have similarly short lifetimes, similarly defined metrics are useful for comparing different aerosols to one another. Table A2.1.1 presents ratios of the steady state radiative forcings of different aerosols and aerosol-related effects to the radiative forcing of BC. We can combine these values to calculate the relative net radiative forcings of different ratios of BC and OC, as shown in Figure A2.1.1. In Table A2.1.1, we present the average of the mean estimates using values derived from Forster et al., [2007] and mean estimates using values derived from Ramanathan and Carmichael, [2008].

We also present in Figure A2.1.1 and Table A2.1.1 estimates, for carbonaceous aerosols with different OC:BC ratios, of the probabilities that they have net positive radiative forcings. These probability estimates are based on combining the distribution derived from Forster et al. [2007] and the distribution derived from Ramanathan and Carmichael [2008].

Methodology of Calculations

We took two parallel approaches to evaluating metrics for BC and other aerosols: one guided by the model results summarized in the IPCC's Fourth Assessment Report, and one guided by the observationally-based estimates of Ramanathan and Carmichael, [2008]. We use a Monte Carlo simulation to estimate uncertainties.

Estimates based on models summarized in IPCC AR4

Direct Radiative Forcings: For our first set of estimates, we drew upon the models of the AeroCom intercomparison exercise [*Textor et al*., 2006], the results of which are summarized in Forster et al., [2007]. These models directly provide estimates of the normalized direct radiative forcings of BC (1100 ± 900 W/g) and co-emittants (-110 ± 90 W/g for OC and -166 ± 80 W/g for sulfate), as well as of aerosol lifetimes (7.3 ± 4.3 days for BC, 7.5 ± 3.4 days for OC, 3.8 ± 1.8 days for sulfate). From these values, it is possible to calculate the steady state radiative forcings.

Forcing efficacy is a measure of how effective a radiative forcing is at producing a change in surface temperature, as compared to CO_2. There is considerable uncertainty in the efficacy of the BC forcing, largely as a result of the semi-direct cloud effect [*Forster et al*., 2007]. Hansen et al. [2005] found a very strong dependence of efficacy on the altitude of the aerosols, with efficacies enhanced near the surface and reduced at higher altitudes. They also found that efficacy is enhanced at high latitudes and reduced at low latitudes. Some of the variability among modeled efficacies, which range from 0.6 to 1.3 [*Forster et al*., 2007], is thus likely attributable to differences in the vertical and latitudinal distribution of aerosols. We do not take variability in efficacy into account in our calculations of the BC direct effect.

Indirect Cloud Albedo Effect: Aerosols both alter the albedo of clouds and alter the fraction of the Earth's surface covered by clouds, two effects that the IPCC refer to collectively as the cloud albedo effect. The IPCC estimates that the global radiative forcing produced by the cloud albedo effect of all aerosols is -0.7 W/m^2, with a range of -1.8 to -0.3 W/m^2. Using the total aerosol load from the AeroCom models, we calculate a normalized cloud albedo radiative forcing of -190 W/g (range of -540 to -80 W/g). We assume that the lifetime of the cloud albedo effect produced by an aerosol particle is the same as the lifetime of the particle.

This simple analysis, which treats all aerosols the same, ignores the fact that, whereas most aerosols increase the albedo of clouds, BC aerosols decrease the albedo of clouds. (All aerosols, however, can raise planetary albedo by increasing cloud cover.) This omission will lead to an excessively negative estimate of the total indirect cloud effect for BC. Jacobson [2006] estimates that the darkening effect of BC on clouds enhances the warming effect of BC by less than about 10%, an amount that might be reasonable to neglect amid the uncertainty of the direct forcing estimate.

Snow Albedo Effect: The IPCC estimates the global radiative forcing produced by the black carbon snow albedo effect (0.1 ± 0.1 W/m^2). The model results of Hansen et al. [2005] indicate that this forcing is considerably more effective than that of CO_2, with an efficacy of 1.71. The effective radiative forcing (the product of radiative forcing and forcing efficacy) is therefore about 0.17 ± 0.17 W/m^2. We assume (incorrectly) that all black carbonaceous aerosols have an equal probability of transport to snowy regions.

In his model of the snow albedo effect, Jacobson [2004] estimates that the average lifetime of BC in the top 50 cm of snow is about 60 days (0.16 years), though the lifetime could be considerably longer for BC deposited in multi-year ice. We assume a lifetime of 60 days, with a 90% confidence interval of 20 to 190 days. Coupling this lifetime to the BC emissions estimates of Bond et al. [2004] (8.0 Tg/y; range of 4.3–22 Tg/y) yields a normalized snow albedo radiative forcing of 66 W/g (range of 7 to 230 W/g).

Estimates based on observation-driven analyses of Ramanathan and Carmichael [2008]

Ramanathan and Carmichael [2008] estimate the global radiative forcing caused by BC and non-BC aerosols based on analysis of satellite and surface observations of aerosol optical density coupled to an aerosol-transport-chemical model and a radiative transfer model [*Chung et al*., 2005]. They estimate that the global BC forcing is 0.9 W/m^2 (range of 0.4 and 1.2 W/m^2) and that the global non-BC aerosol forcing is -2.3 W/m^2 (±50%). We couple these estimates to the Bond et al. (2004) estimate of annual BC emissions and the AeroCom model-based estimates of total aerosol load to calculate a normalized direct radiative forcing for BC of 2900 W/g (range of 850 to 5800 W/g) and a normalized total (direct + indirect) forcing for non-BC aerosols of -610 W/g (range of -290 to -1180 W/g). In this calculation, we neglect the indirect radiative forcing associated with BC, which Ramanathan and Carmichael judge to be minor (~10% of the direct radiative forcing). We adopt the aerosol lifetimes from the AeroCom models.

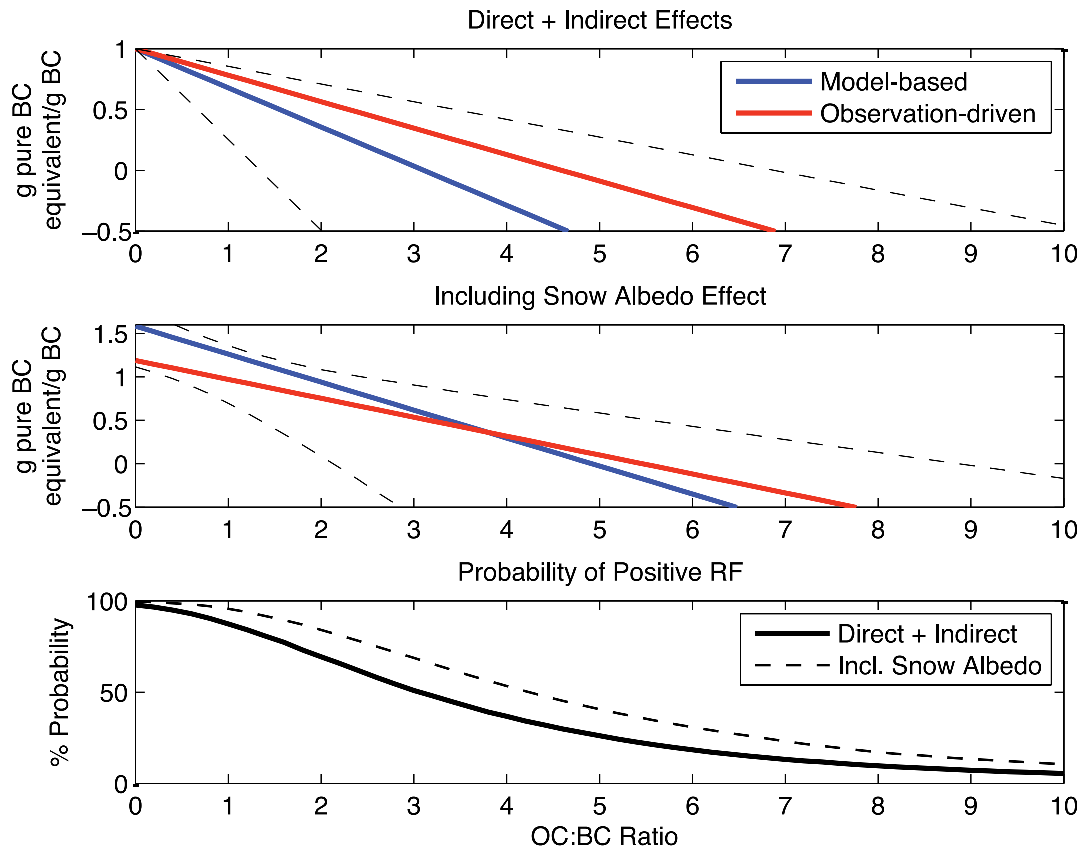

Figure A2.1.1: The top two plots show the ratio of the radiative forcing of different mixtures of BC and OC aerosols, with the upper plot including direct radiative forcing and the indirect cloud albedo effect and the middle plot also including a globally-averaged snow albedo effect. *The lower plot shows the probability that the mixture has a net positive radiative forcing. In the top two plots, the blue lines show the best estimate based upon the models summarized the IPCC's Fourth Assessment Report [Forster et al., 2007], while the red lines show the best estimate based upon [Ramanathan and Carmichael, 2008]. The dashed lines show 67% confidence intervals for the distribution combining the two approaches.*

	Marginal CO2e concentration change (ppb per Gg/y)		Steady State Radiative Forcing/ Radiative Forcing of Black Carbon	
Model-Based [Forster et al., 2007]				
Black Carbon Direct Forcing	3.1	[0.7, 6.1]	1.00	
Organic Carbon Direct Forcing	-0.3	[-0.6,-0.1]	-.10	[-0.42,-0.02]
Sulfate Direct Forcing	-0.2	[-0.4,-0.1]	-.08	[-0.32,-0.03]
BC Cloud Albedo Effect	-0.6	[-1.7,-0.2]	-0.17	[-0.84,-0.06]
OC Cloud Albedo Effect	-0.6	[-1.7,-0.2]	-0.17	[-1.08,-0.05]
SO_4^{2-} Cloud Albedo Effect	-0.3	[-0.9,-0.1]	-0.09	[-0.56,-0.02]
Black Carbon Snow Albedo Effect	1.5	[0.2,3.1]	0.49	[0.07,2.06]
Observation-Driven [Ramanathan and Carmichael, 2008]				
Black Carbon Direct Forcing	8.0	[2.6,12.2]	1.00	
OC Direct + Indirect Forcing	-1.8	[-3.6,-0.7]	-0.22	[-0.93,-0.09]
SO_4^{2-} Direct + Indirect Forcing	-0.9	[-1.9,-0.4]	-0.11	[-0.47,-0.04]

Table A.2.1.1. Comparative Metrics of Radiative Effects of Aerosol Emissions*. Approximate 90% confidence intervals are shown in brackets.*

	100-year GWP	
Model-Based [Forster et al., 2007]		
Black Carbon Direct Forcing	514	[120,1016]
Organic Carbon Direct Forcing	-50	[-98,-11]
Sulfate Direct Forcing	-40	[-66,-18]
BC Cloud Albedo Effect	-85	[-281,-27]
OC Cloud Albedo Effect	-88	[-280,-31]
SO_4^{2-} Cloud Albedo Effect	-45	[-143,-2]
Black Carbon Snow Albedo Effect	250	[42,508]
Average Fossil Fuel Carbonaceous aerosol Direct Effect (OC:BC = 4:5)	263	[44,545]
plus cloud albedo effect	177	[-100,427]
plus cloud and snow effects	316	[0,593]
Average Biomass Carbonaceous aerosol Direct Effect (OC:BC = 6:1)	30	[-40,110]
plus cloud albedo effect	-57	[-260,36]
plus cloud and snow effects	-21	[-232,76]
Observation-Driven [Ramanathan and Carmichael, 2008]		
Black Carbon Direct Forcing	1324	[425,2007]
OC Direct + Indirect Forcing	-288	[-599,-114]
SO_4^{2-} Direct + Indirect Forcing	-147	[-312,-57]
Average Fossil Fuel Carbonaceous aerosol (OC:BC = 4:5)	607	[69,986]
plus snow albedo effect	746	[148,1195]
Average Biomass Carbonaceous aerosol (OC:BC = 6:1)	-58	[-378,105]
plus snow albedo effect	-22	[-351,151]
Prior Estimates		
Black Carbon Direct Forcing *[Bond et al., 2004]*	680	[210,1500]
Average Fossil Fuel Carbonaceous aerosol, plus cloud albedo effect *[Jacobson, 2002; 2005]*	140	[90,190]
Average Fossil Fuel Carbonaceous aerosol, plus cloud and snow effects *[Hansen et al., 2007]*	500	

Table A2.1.2. 100-year Global Warming Potentials for Aerosols. *Approximate 90% confidence intervals are shown in brackets for our values; reported ranges are shown for prior estimates. We again caution that GWPs are ill-suited for comparing a warming agent with the short lifetime of the aerosols to a long-lived greenhouse gas like carbon dioxide.*

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Appendix 2.2: Illustrative Emission Scenarios for Calculating the Effects of Black Carbon on CO_{2E} Targets

In order to assess how black carbon emissions affect the ability of the world to reach a radiative forcing target (Figure 2.2), we developed an extremely simplified atmospheric and economic model and set of emission scenarios. As a result of numerous approximations, the emissions scenarios and associated atmospheric concentrations are not precise, but the differences between them are illustrative of the importance of BC in mitigating climate change.

Our model uses a static approximation of the Bern Carbon Cycle (Bern-CC) model to determine the atmospheric lifetime of carbon dioxide emissions. This approximation assumes that 18.6% of carbon dioxide emissions have a lifetime of 1.186 years, 33.8% has a lifetime of 18.51 years, 25.9% has a lifetime of 172.9 years, and 21.7% has a lifetime of 20,000 years [*Archer*, 2005; *Forster et al*., 2007]. In reality, the lifetime of carbon dioxide changes as a function of temperature and marine carbon dioxide concentrations, but use of a dynamic carbon cycle should produce only relatively minor changes [*Kharecha and Hansen*, 2008].

To calculate illustrative emission scenarios for carbon dioxide and BC, we start with a modified form of the IPCC's A1B "business-as-usual" scenario. We take the atmospheric CO_2 concentrations calculated for the A1B scenario using the Bern-CC reference model and calculate the CO_2 emissions necessary to produce the same concentrations in our simplified model. We assume that CH_4 concentrations follow the trajectory prescribed by A1B, which peaks in 2050 at 2400 ppb and ends in 2100 with a concentration of 1974 ppb (200 ppb higher than today.) We further assume N_2O concentrations constant at their present value of 320 ppb, and that CFCs and halocarbons decay from their present concentrations with no additional emissions. We do not treat the cooling effects of aerosols co-emitted with BC other than OC, under the assumption that health concerns will drive their near-elimination by the end of the century.

This scenario constitutes our baseline. We assume that the cost of emissions reductions is proportional to the square of the fractional reduction from the baseline raised to the 2.8^{th} power, following the example of Nordhaus [2008] and discount costs at 5% annually. We then use constrained nonlinear minimization to find a CO_2 emission trajectory that minimizes cost while achieving a 450 ppm CO_2e target in 2100.

Bond [2004] estimated that in 1996 the world emitted 3.0 Gg BC from fossil fuels (mean OC:BC ratio of 0.8) and 5.0 Gg BC from biomass (mean OC:BC ratio of 6). Using the steady-state radiative forcings described in Appendix 2.1 and including cloud and snow albedo effects as well as direct radiative forcings yields the net radiative forcings and target CO_2 concentrations in table A2.2.1. The "Low" scenario uses the best estimate of steady state radiative forcings based on the models summarized in IPCC AR4, while the "High" scenario uses the best estimate based on Ramanathan and Carmichael [2008]. These scenarios represent only the best estimates; they do not span the 90% confidence interval.

Assuming a phaseout of fossil fuel BC emissions before the end of the century yields a global CO_2 emissions curve generally similar to those frequently discussed. CO_2 concentrations and radiative forcings (expressed in terms of CO_2e concentrations) for these different scenarios are shown in Figure A2.2.1. For the fossil fuel BC phaseout scenarios, we assume the BC emissions decay exponentially starting in 2010, attaining half their present value in 2018.

	Fossil Fuel BC (Mitigatable)	Biomass BC (Constant)	Required CO_2 concentration w/ FF BC phase out	Required CO_2 concentration w/ constant BC
Low	0.17 W/m^2	-0.10 W/m^2	395 ppm	383 ppm
Medium	0.29 W/m^2	-0.14 W/m^2	398 ppm	377 ppm
High	0.41 W/m^2	-0.17 W/m^2	401 ppm	372 ppm

Table A2.2.1. Net BC+OC Forcing Estimates used in scenarios. *For each scenario, biomass BC emissions and RF remain constant, while fossil fuel BC emissions are either phased out by the end of the century or remain constant. Using the expected concentrations of non-CO_2 greenhouse gases and black carbon in 2100, we then calculate the CO_2 concentration which would produce a combined greenhouse gas and carbonaceous aerosol radiative forcing of 450 ppm CO_2e.*

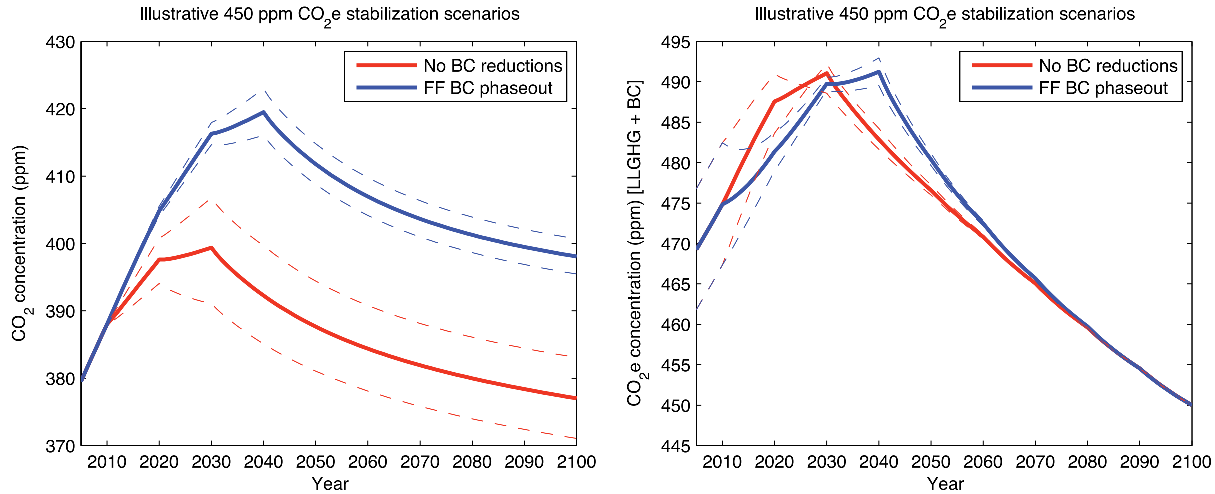

Figure A2.2.1. CO_2 (left) and CO_2e (right) pathways associated with the 450 ppm CO_2e target carbon dioxide emissions trajectories shown in Figure 2.2. *Only long-lived greenhouse gases, BC, and co-emitted OC are included in the calculated CO2e values. The values include the indirect cloud effects and snow albedo effects associated with BC. The blue lines show CO2e concentrations in the scenario with a fossil fuel BC phase out as described in the text, while the red lines show CO2e concentrations in the scenario with BC emissions fixed at present levels. The solid lines employ the medium estimate for 2005 net BC radiative forcing, while the lower and upper dashed lines employ the low and high estimates, respectively.*

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Appendix 2.3: Uncertainties in Estimates of Black Carbon Direct Radiative Forcing from Models

The complexity of the role of black carbon (BC) in the climate system makes it difficult to represent accurately in models. At the same time, these models are the best tools we have for understanding climate forcing by black carbon.

General circulation models (GCM) are numerical representations of the three-dimensional climate system. GCMs include multi-layer atmosphere, ocean and land surface (soil, vegetation and ice) modules. Atmospheric chemistry is represented to varying degrees of complexity within models. The primary components of a GCM are the mathematical equations of basic physical principles (such as conservation of mass, momentum and energy) and parameterizations of physical processes that cannot be calculated from first principles (such as cloud formation and energy absorption and emission by aerosols).

What is a model parameterization and why do they matter for black carbon?

A parameterization is a description of the relationship among physical variables that is inferred from real world observations or experiments. For example, the combination of atmospheric turbulence, relative humidity, temperature, aerosol particle size and chemistry determines water vapor condensation rate and the growth of liquid water droplets to form clouds of varying type, abundance, and distribution. The optical properties of clouds are a primary climate determinate.

Parameterization of processes such as cloud formation is necessary because of model scale. In the example above, the physical variables that interact to ultimately produce clouds operate on sub-millimeter scales, but most models perform calculations on the scale of hundreds of meters to several kilometers. While parameterizations are necessary, they are also the source of substantial uncertainties in model climate predictions.

Estimates of warming due to black carbon: The importance of mixing state

Many model studies have attempted to quantify the direct radiative forcing (DRF) attributed to BC. The DRF, just one of the several ways in which BC forces climate (see Appendix 2.1), is a measure of how much Earth's energy balance is altered by the warming that results from the absorption of solar radiation by BC particles and the re-release of that energy as heat. Model studies usually compare the radiative balance of the system between two model experiments. The difference between the two scenarios yields an estimate of the DRF attributable to BC alone.

The globally averaged, model-estimated mean annual DRF ranges from 0.03 Wm^{-2} (*Haywood and Shine*, 1995) to around 0.6 Wm^{-2} (*Jacobson*, 2001a; *Chung and Seinfeld*, 2005; *Hansen et al*., 2005). The results vary widely because they depend on 1) details of the model, especially aerosol and cloud parameterizations, 2) whether the carbon is assumed to derive from fossil fuel, biofuel, biomass burning or all three, and 3) the assumed nature of the physical mixing of elemental carbon and co-existing aerosols. The details of micro-scale mixing of elemental carbon and other aerosols is one of the most important and most poorly constrained parameterizations needed to properly determine the climate effects of BC using models. Jacobson [2000] describes three mixing treatments that have been used in models:

1) Internally mixed – a single particle is a homogeneous mixture of BC and other components

2) Externally mixed – a BC particle is discrete from other aerosols particles and compounds

3) Core treatment – a BC particle is coated by other compounds

In a model, the assumption of internal mixing strongly amplifies the absorption efficiency of carbon and reduces the scattering efficiency of the admixed sulfate, nitrate or organic carbon compounds [*Schnaiter et al*., 2005], resulting in stronger absorption of incident energy. The net result is higher positive radiative forcing from BC in models that assume internal mixing.

Table A2.2 shows the model-predicted globally averaged mean annual DRF by BC from three studies. The absolute values of the forcing obtained in these studies should not be compared because of differences among specified BC emissions, but it is interesting to note the broad range of values in the ratio of DRF given internal or external mixing. This variability results from differences in the aerosol optical property parameterizations specified in the models. Table A2.2 therefore illustrates the fact that important uncertainty exists not only in the degree and nature of mixing of BC in the atmosphere, but also in the proper parameterization of microphysical properties of aerosols used in a model.

Model	Mixing State	Radiative Forcing Wm^{-2}	Internal RF/ External RF
Haywood and Shine, 1995	External	0.03	8.0
	Internal	0.24	
Jacobson, 2000	External	0.27	2.9
	Core	0.54	
	Internal	0.78	
Chung and Seinfeld, 2005	External	0.33	1.8
	Internal	0.60	

Table A2.2. *Estimates of the global mean annual TOA direct radiative forcing by black carbon from three general circulation model studies, assuming different mixing schemes.*

Jacobson [2000] asserted that an internally well-mixed configuration is physically implausible for soot particles because the carbon in fresh soot forms solid, amorphous aggregates of dozens to thousands of graphite spheres. This mass is not conducive to homogeneous penetration by other compounds. Instead, carbon particles appear to become coated during and after emission (*Martins et al*., 1998). Jacobson [2000] therefore argues that a more realistic mixing treatment is the core/shell configuration. In this state, only energy that is scattered into the core by the shell can be absorbed. The core treatment therefore results in lower absorption efficiency by BC than that obtained for internally mixed BC (Table A2.2). The core treatment produces absorption and radiative forcing that is greater than that of an externally mixed mixture because the non-carbon components of the soot scatter less energy when they exist as a coating than when they occur as discrete particles. If this core/shell structure is indeed the most commonly occurring configuration for BC in the atmosphere, then published model results that assume homogeneous internal mixing overestimate BC forcing and those that assume external mixing underestimate the radiative forcing attributable to BC.

Summary

Policy recommendations requiring comprehensive knowledge of the role of black carbon in climate forcing should obviously not be based on any one model alone. At the same time, when multiple models are used, as in a model intercomparison study such as the AeroCom effort [*Schulz et al*., 2006, *Textor et al*., 2006], the models may converge for a particular parameter value, but whether they converge on the correct solution can only be determined by comparison of that solution with observational data. Based on satellite, airborne and surface observations, Ramanathan and Carmichael [2008], for example, infer that the forcing by black carbon is close to 0.9 Wm^{-2}, much higher than the current IPCC value [*Forster et al*., 2007] or any model results cited here. In the coming few years, we will benefit from the IPCC's need for model-based climate change predictions that better incorporate the role of aerosols. The forthcoming results of International Polar Year studies should contribute to our understanding and may be of major importance to future decision-making about sources and effects of BC on high latitudes. Black carbon is an area in which policy makers will clearly benefit if there is increased funding support for research to further improve both aerosol observations and model development.

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Appendix 3.1: Diesel Emission Standards

	CO (g/km)	NO_x (g/km)	HC+NO_x (g/km)	PM (g/km)	Sulfur Content of Fuel (ppm)
Euro 1	2.72	-	0.97	0.13	0
Euro 2	1	-	0.7	0.08	500
Euro 3	0.64	0.5	0.56	0.05	350
Euro 4	0.5	0.25	0.3	0.025	50
Euro 5	0.5	0.18	0.23	0.005	10

Table A3.1 Euro Standards

Tier 1 Emission Standards, FTP 75, g/mi									
50,000 miles/5 years					100,000 miles/10 years				
THC	NMHC	CO	NO_x	PM	THC	NMHC	CO	NO_x	PM
0.41	0.25	3.4	1	0.08	-	0.31	4.2	1.25	0.1

Table A3.2 US Tier 1 Emission Standards

Tier 2 Emission Standards, FTP 75, g/mi										
	Intermediate life (5 years / 50,000 mi)					Full useful life				
Bin	Non-Methane Hydrocarbons	CO	NO_x	PM	HCHO	Non-Methane Hydrocarbons	CO	NO_x	PM	HCHO
8	0.1	3.4	0.14	-	0.015	0.125	4.2	0.2	0.02	0.018
7	0.075	3.4	0.11	-	0.015	0.09	4.2	0.15	0.02	0.018
6	0.075	3.4	0.08	-	0.015	0.09	4.2	0.1	0.01	0.018
5	0.075	3.4	0.05	-	0.015	0.09	4.2	0.07 (AVERAGE STANDARD)	0.01	0.018
4	-	-	-	-	-	0.07	2.1	0.04	0.01	0.011
3	-	-	-	-	-	0.055	2.1	0.03	0.01	0.011
2	-	-	-	-	-	0.01	2.1	0.02	0.01	0.004
1	-	-	-	-	-	0	0	0	0	0

Table A3.3 US Tier 2 Emission Standards *[Source: www.dieselnet.com]*

Table A3.1 outlines the specific emission restrictions of the Euro Standards for diesel automobiles.

Tables A3.2 and A3.3 illustrate the requirements of the Tier 1 and Tier 2 emission standards for diesel passenger vehicles applicable in the U.S. Note that THC refers to total hydrocarbons, NMHC to non-methane hydrocarbons and HCHO to formaldehyde.

Automobile emissions were tested over the Federal Test Procedure (FTP) test and later, also over the Supplemental Federal Test Procedure (SFTP). The SFTP, which was phased-in between 2000-2004, included additional testing cycles, such as over aggressive highway driving and urban driving with the air-conditioning turned on.

The Tier 2 emission standards are structured into 8 certification levels ("bins"). Vehicle manufactures can certify a particular vehicle according to any certification level, but the average NO_x emissions of all light-duty vehicles sold by that manufacturer must meet an average NO_x standard of 0.07 g/mile.

The Clean Air Non-road Diesel Rule regulates sulfur content and NOx, NMHC and PM emissions from non-road diesel engines. Regulations on the sulfur content in non-road diesel fuels are currently 500 ppm, effective June 2007 for nonroad, locomotive, and marine diesel fuels. The limit will decrease to 15 ppm (ULSD) for nonroad diesel effective June 2010 and for locomotive and marine diesel in June 2012.

The 2007 Highway Rule also requires lower NOx and NMHC emissions, to be phased in from 2007 to 2010, and further regulates PM for 2007 engine models. The rule also required that the sulfur content of highway diesel vehicles decrease from 500 ppm to 15 ppm (ULSD) starting in June 2006 to be completed by 2009. Lowering the sulfur content of these fuels will allow the use of particulate filters, which are highly sensitive to sulfur levels.

Appendix 4.1: Black Carbon Emissions in Russia and Mitigation Strategies

Introduction

This appendix surveys the sources of black carbon (BC) emissions in Russia, focusing on those likely to be deposited in the Arctic, and where they have a disproportionate warming impact (see chapter 2). An examination of potential approaches for Russian BC emissions mitigation follows, with a list of corresponding recommendations for domestic and international action.

Black Carbon, The Arctic, and Russia

Much debate has surrounded the sources of black carbon that reach the Arctic, concerning both location and the type of source. However, it is reasonably clear that Russia, as a proximate industrial power with weak environmental regulation and many dirty mobile and stationary BC emission sources, is a major contributor to Arctic BC accumulation. Despite some ambiguous evidence that significant fractions of Arctic black carbon may come from South and East Asia [*Koch and Hansen*, 2004], it is increasingly clear that emissions sources north of 40°N latitude are primarily responsible for the presence of black carbon in the Arctic [*Bond*, 2004; *Stohl*, 2006]. Modeling and empirical evidence suggest that Russia's share of world BC emissions in this zone is 10-15% [*Bond et al*., 2004; *Quinn et al*., 2007], a figure which rises above 50% north of 60°N [*Bond et al*., 2004; *Klimont*, 2008]. Additionally, recent work suggests that most of the BC in the Arctic is from fuel combustion – for transportation, heating, and industry – rather than from open biomass burning (i.e. forest fires and controlled burning of crop residues) [*Zender*, 2007]. Even should we admit evidence suggesting that forest fires are a significant contributor to Arctic BC [*Kuokka et al*., 2007], diesel fuel combustion and uncontained agricultural burning nonetheless comprise very large shares, and, as anthropogenic BC sources, are readily addressed through policy measures.

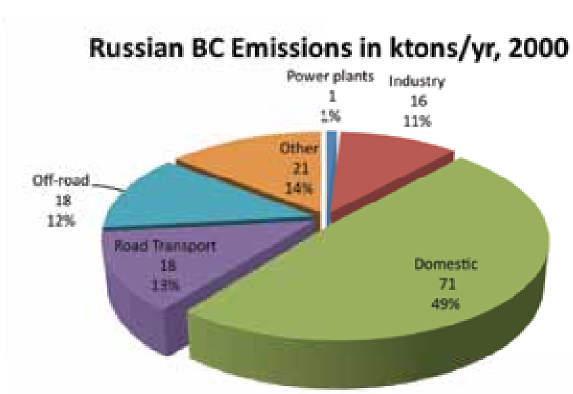

Figure A4.1.1. Russian BC emission in kilotons per year, 2000. *[Kofala et al., 2007]*

Sources of BC Emissions in Russia

Russian black carbon emissions are estimated at approximately 150 kilotons (gigagrams) per year, or roughly 2% of the world total [*Bond*, 2004; *Kofala et al*., 2007]. These sources include small-scale boilers and stoves; vehicular transport; small industry; off-road vehicles and machinery; agriculture; large industry; and waste disposal. The residential and small industry sectors (including municipal facilities such as schools, hospitals, and offices, included in the "domestic" category, Figure A4.1.1) emit BC via combustion of coal, wood or other biofuels; diesel cars and trucks ("road transport") and mobile machinery such as tractors and bulldozers ("off-road") produce BC by burning diesel fuel. Agricultural emissions, such as the open burning of crop waste, and garbage incineration are significant sources as well ("other").

There are several distinguishing features of Russian BC emissions vis-à-vis those of Western Europe and North America. First, Russia does not use ultra low-sulfur diesel (ULSD) fuel and has particularly antiquated diesel-fueled machinery and vehicle fleets [*Bond et al*., 2004]. Second, Russia's small-scale residential and industrial facilities are particularly dirty and inefficient (cumulative emissions are speculative however, since data on their emissions are virtually non-existent). Third, industrial facilities and practices of waste disposal and agricultural burning generate very heavy particulate air pollution, including BC [*Ellen Baum*, personal communication, 2008]. Maritime shipping in the Arctic also contributes to particulate emissions containing black carbon, of which Russia is responsible for a fraction [*AMAP*, 2006].

In sum, Russia's major BC sources are either industry and heavy manufacturing over 20 years old (i.e., predating the USSR's economic crises of the 1980s), or dirty and inefficient cars, trucks, domestic stoves and boilers that roughly resemble those of the developing world. Practices such as waste incineration, open biomass burning (e.g. on farmland), inefficient industrial management, and gas flaring represent black carbon sources with a significant human behavioral component. Some of these sources would not require major investments in physical capital to achieve large emissions reductions. Others, however, require comprehensive and long-overdue modernization.

Russian Emissions Inventories

There are currently no authoritative inventories of Russian BC emissions. Several groups of American and European scientists have approximated annual Russian BC emissions at 150 kilotons [*Bond et al*., 2004; *Kofala et al*., 2007], though these numbers are based heavily on estimates, not collected data [*Bond and Klimont*, pers. comm. 2008]. The Arctic Council and AMAP, the council's Arctic Monitoring and Assessment Programme, track BC and other particulate emissions in the Arctic [*AMAP*, 2006], which are reported to be the most up-to-date and accurate [*Kupiainen*, pers. comm. 2008].

Within Russia, a significant amount of general emissions data comes from RosGidroMet, the national meteorological service, the rough analogue of the National Oceanic and Atmospheric Administration (NOAA) in the US. RosGidroMet runs the greenhouse gas inventory for Russia under the Kyoto Protocol, and directs compliance. Data have been collected since 1994, and annual inventories have been counted back to 1990. The annual inventory system has been recognized as legitimate by the IPCC since 2006. RosGidroMet produces annual reports - both data and text – for the Russian prime minister and for the Kyoto Protocol. RosGidroMet breaks emissions down by sector; 90% of the data come from RosStat, the National Statistical Agency. The rest come from the Ministry of Transportation, the Federal Forest Service, and other agencies, by request [*Vikulova and Gromov*, pers. comm. 2008]. Non-point source emissions inventories are generated using a cadastre system that assesses land use, then estimates emissions per plot of land according to land use emissions rates. However, no major data sources exist for agricultural greenhouse gas emissions, nor is there any significant measurement of them [*Gromov*, pers. comm. 2008].

The European Monitoring and Evaluation Programme (EMEP), under the Convention for Long-Range Transboundary Air Pollution (CLRTAP), in turn administrated under the UN Economic Commission in Europe (UNECE), collects data on particulate emissions and dispersion, but focuses primarily on heavy metals. The Meteorological Synthesizing Centre-East (MSC-East, in Moscow, Russia) directed by Sergei Dutchak, does monitoring of particulate emissions (particularly heavy metals) dispersion in Eastern Europe for LRTAP/EMEP. MSC-East uses only official data from the LRTAP secretariat that have been submitted by the member countries [*Dutchak*, pers. comm. 2008].

The Institute of Global Climate, a modeling laboratory in Moscow, runs Russia's representation in the Acid Deposition Monitoring Network in East Asia (EANET), directed by Sergei Gromov [Gromov, pers. comm. 2008]. EANET-Moscow focuses primarily on aerosols such as SO_x and NO_x and on air pollutants such as CO that are harmful to human health and produces an annual report together with the Russian Federal Technical Oversight Service (RosTekhNadzor) and the Ministry of Natural Resources. It produces annual modeled particulate emissions estimates, including both natural (i.e. forest) and anthropogenic sources. Some of this work, together with that of MSC-East, goes to the LRTAP Convention, and specifically to the Task Force on Hemispheric Transport of Air Pollution (HTAP). The HTAP data cover the European part of Russia well, but the Asian part has very little direct data collection; for this EANET relies on regional authorities for emissions estimates [*Gromov*, pers. comm. 2008].

NII "Atmosfera," a state-owned modelling laboratory in St. Petersburg, compiles the inventory of carbon particulate matter for Russia, which includes coal-fired boilers and power plants; off-road diesel vehicles such as construction equipment; various other stationary sources; and cars and trucks. RosTekhNadzor, the industry regulator, is responsible for particulate rulemaking and oversight for industry. In Russia maximum allowable emissions are established for each individual enterprise. Russia does not recognize black carbon per se as a type of emissions. Rather, it regulates soot as emitted from industrial and mobile sources, as PM-10, and together with the other aerosol species it contains (i.e. not isolating BC).

Diesel Transport Inventories

The Auto Transport Research Institute (NIIAT), is a federal government-owned private enterprise, fully owned by the Ministry of Transport. NIIAT works on evaluations, inventories of fuel use, and cadastre-based, geographically-determined GHG emissions inventories together with the Institute of Global Climate of RosGidroMet. In recent years, NIIAT has produced the section on auto transport emissions for the Ministry of Natural Resources' annual report to the prime minister on the environment. In 2008 for the first time, the Ministry of Natural Resources did not ask for NIIAT to prepare this section, instead relying on the possibly less-accurate, calculated estimates of RosTekhNadzor, the industrial regulator [*Kunin*, pers. comm. 2008].

Agricultural and Forest Fire Emissions

None of the leading modeling laboratories, nor RosGidroMet, has any data for uncontained biomass burning (i.e. firewood, forest and brushfires) and agricultural and waste burning. There exists only an incomplete regional inventory of emissions, which is included in the Ministry of Natural Resources' annual environmental protection report.

An October 2005 Finnish-Russian research mission, dubbed "TROICA", gathered black carbon air samples during a two-week trip on the Trans-Siberian railroad, in one of a very limited number of studies to measure BC atmospheric concentrations [*Kuokka* et al., 2007]. The study found surprisingly high levels of ambient BC even in rural Siberia, far from urban centers. Two of the researchers doubt that these BC emissions are from long-range transport, but also claim the chemical composition of particulates captured does not resemble that of forest fire emissions, suggesting the likelihood of other local open, uncontained combustion [*Kerminen and Teinila*, pers. comm. 2008]. Further study is required to corroborate these findings and study BC atmospheric concentrations over time at fixed locations. West of the Urals in European Russia, heavy seasonal particulate emissions from agricultural burning are well-documented by satellite [*Anttila et al*., 2008; *Kupiainen*, pers. comm. 2008]. In Russia agricultural burning is illegal and data are not collected on the practice [*Gromov*, pers. comm. 2008]. This suggests that international collaboration and increased vigilance could help better track and address BC emissions from Russian agricultural burning.

Key Policy Pressure Points

The following section is broken down into four levels of government engagement, descending in scope from international diplomacy to national leadership, followed by federal agencies, and finally regional and local implementation (see Figure A4.1.2).

I) International Diplomacy

Diplomatic efforts with Russia should focus on areas where Russia stands to receive, or perceive, significant benefits for itself. This array of options, known in international relations theory as the "win set" for reaching an agreement, will almost necessarily include significant monetary transfers ("side payments") to implementing government agencies, to polluting industries with potential to "green" their operations, and to local governments and other groups to promote economic development and sweeten the deal for the residents who would be negatively impacted by economic structural transition. Another viable solution is technical assistance for pollution-reducing projects with economic co-benefits, such as job creation, improved energy efficiency, and energy capture (e.g. from methane- or power-producing waste disposal).

The most important international agreements and organizations regarding black carbon, particulate matter, and other greenhouse gas emissions are the Arctic Council, the Convention on Long-Range Transboundary Air Pollution (LRTAP), the International Maritime Organization (IMO), and the UNFCCC/ Kyoto Protocol (for more on international treaties, see Chapter 5).

- *Arctic Council*

Formally established by the Ottawa Declaration of 1996, the Arctic Council is "a high level intergovernmental forum to provide a means for promoting cooperation, coordination and interaction among the Arctic States… in particular issues of sustainable development and environmental protection in the Arctic" [*Arctic Council*, 2008]. The member states of the Arctic Council are Canada, the Russian Federation, Denmark, Finland, Iceland, Norway, Sweden, and the US. In addition to the Member States, the Arctic Council has the category of Permanent Participants, which include organizations of Indigenous peoples living in the Arctic. Unfortunately, Russia's engagement in Arctic Council activities in recent years has been minimal. Because the Arctic Council includes all of the countries of the far north, it has unparalleled power to influence Arctic emissions. Furthermore, the Arctic Council has been one of the world's most active intergovernmental environmental entities, and is spearheading efforts on BC data collection and emissions reduction (see AMAP and ACAP below). Consequently, reengaging Russia in the Arctic Council is a priority of paramount importance.

—Arctic Monitoring and Assessment Program (AMAP)

This working group, part of the Arctic Council, is responsible for data collection, monitoring, and modeling, and is increasingly focusing directly on BC. In 2006, AMAP produced a comprehensive report on air pollution in the Arctic that remains the most comprehensive published source on the topic [*AMAP*, 2006]. In September 2008, the working group held a workshop that produced a number of policy-oriented recommendations directly addressing BC [*AMAP*, 2008], focusing on policy option feasibility study, limiting springtime crop residue burning in the Arctic, and increased partnership with existing programs, such

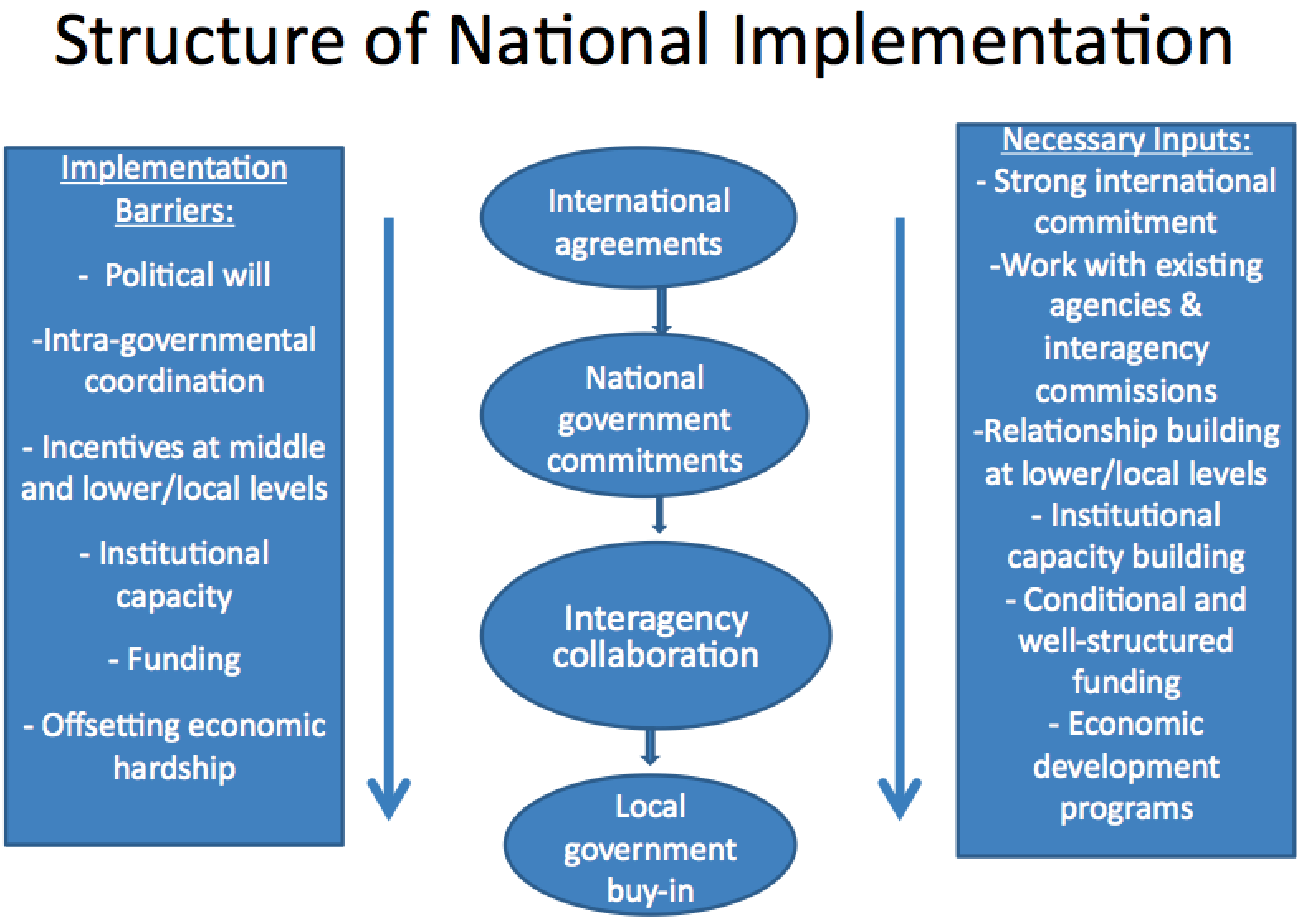

Figure A4.1.2. Hierarchy of influences on Policy for BC Mitigation.

as Methane-to-Markets (US EPA), and the UNFCCC "flexible mechanisms," the Clean Development Mechanism and Joint Implementation.

—Arctic Containments Action Program (ACAP), Sustainable Development Working Group (SDWG)

Potentially a powerful forum for addressing BC emissions in the Arctic, these two working groups focus on implementation programs. A potential Russian Arctic development fund, bandied about in various forms in recent years, could logically be based at the Arctic Council in ACAP and SDWG [*Schreiber*, personal communication]. ACAP already has a mechanism called the Project Support Instrument (PSI) – not yet functional as of 2006 [*ACAP*, 2008] – that could be used to channel funding to programs in Russia, though a brief survey of the website did not reveal any programs. The SDWG in its 2006-2008 work plan included pilot projects to promote sustainable development among indigenous peoples of five regions of the Russian far north, including sustainable reindeer husbandry, small business development, and "aboriginal tourism" [*Arctic Council*, 2008]. It is not clear whether these activities would be extended to non-aboriginal populations responsible for most BC emissions, though such a program would likely be necessary to have any impact on current emissions.

- *Convention on Long-Range Trans-boundary Air Pollution (LRTAP)*

Run under the auspices of the UN Economic Commission in Europe (UNECE), LRTAP is the premier intergovernmental environmental treaty organization addressing air pollution (see Ch. 5). LRTAP includes primarily European countries plus the United States; Russia is also a founding member of the LRTAP convention, having joined in 1979. Throughout the 1980s the USSR valued this treaty for providing a venue for high-level diplomatic talks with the West, and remains one of the most successful and active environmental treaty organizations [*Thompson*, pers. comm. 2008]. Russia has signed but not ratified the Sulphur Protocol (1994), and has neither signed nor ratified the last three protocols dating back to the mid-1990s: Heavy Metals, POPs, and the "Multi-effect" Protocols [*UNECE*, 2007]. The last, "multi-effect" protocol may shortly be extended to include particulate emissions such as BC [*Keating*, pers. comm. 2008]. Should this come to pass, LRTAP may have the mandate to address BC, thereby bringing momentum to efforts to reengage Russia on this issue. Already, LRTAP members, including Finland, are looking to cooperate with Russia, Belorus, and Ukraine on BC and other PM emissions, and that Sweden is currently funding expert work in Russia through LRTAP. These FSU countries already have good emissions inventory data, and that are reportedly interested in European emission data and methodologies, as well as, possibly, regulatory strategies [*Kupiainen*, pers. comm. 2008].

—Cooperative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air Pollutants in Europe (EMEP) and the Task Force on Hemispheric Transport of Air Pollution (HTAP)

EMEP is the data collection and modeling program under LRTAP. This program supporting major data collection, analysis, and modeling efforts, which should be intensified. The Task Force on Hemispheric Transport of Air Pollution (HTAP) is in turn part of EMEP. Russia will be hosting the next HTAP meeting in St. Petersburg on April 1-3, 2009, and air pollution in the Arctic will be one of the three focus topics at the event [*HTAP*, 2008]. The HTAP conference presents an opportunity to increase Russian engagement in air pollution diplomacy generally, and on BC and Arctic issues in particular.

- *International Maritime Organization, Protocol of 1997 (MARPOL Annex VI)*

The International Maritime Organization addresses rules and customs of ships in international waters. MARPOL Annex VI addresses the pollution of maritime vessels. Through this forum, there may be opportunities to focus on the emission of particulate matter in diesel and other fuel exhaust by seafaring ships, a significant contributor to particulate emissions in the Arctic totaling almost 4 kilotons per year [*AMAP*, 2006]. Russia is undoubtedly a major contributor to these emissions, and should be engaged.

- *Kyoto Protocol and UNFCCC*

Many sources that emit black carbon are co-emitters of carbon dioxide, methane, and other GHGs regulated by the Kyoto Protocol. This overlap should be exploited to Russia's benefit in corollary agreements and assistance programs. In particular, joint implementation projects (JI), designed to generate funding for greenhouse emissions reduction efforts, can be targeted to focus on those projects that will simultaneously reduce BC emissions (for which they will not get emissions reduction units, or ERUs, under Kyoto). Currently Russian government approval of ten submitted JI projects is stalled [*Shuster*, 2008], and Russia recently was suspended for failing to pay its dues to the JI program [*Murray*, 2009]. These disputes are unfortunate because Russia stands to gain financially and environmentally from JI projects. The international community should seek to resolve the JI dispute high levels, where the current troubles originated.

The IPCC and other UNFCCC events can also provide a useful occasion to bring together scientists and policy experts for side events that address black carbon, as occurred in Poznan in December 2008 (see Ch. 5).

- *Barents Euro-Arctic Council, Helsinki Commission, NEFCO, etc.*

The Baltic Marine Environment Protection Commission (also known as HELCOM or Helsinki Commission) is the governing body of the Convention on the Protection of the marine Environment of the Baltic Sea Area (Helsinki Convention). HELCOM is dedicated to the protection of the marine environment of the Baltic Sea, and includes Russia as well as all other Baltic states. The Barents Euro-Arctic Council (BEAC), particularly the Working Group on Environment, works intensively on economic development and environmental rehabilitation on the Kola Peninsula, Karelia, and the Russian northwest. HELCOM and BEAC have some funding for environmental cleanup and development projects, which could be deployed effectively for BC emissions reduction, particularly in concert with LRTAP, the Arctic Council, and other, smaller Nordic organizations such as NEFCO and the Nordic Investment Bank (NIB), both of which invest in small-scale environmental projects in Russia.

- *Other international collaboration*

There are other forums as well that may have particular relevance to BC reduction generally, and Russian-European-

American scientific collaboration in particular. Russo-American intergovernmental working groups on climate and environmental protection also exist; past collaborative efforts and exchanges have very useful [Maksimov, pers. comm. 2008]. NII "Atmosfera" staff expressed interest in continuing collaborative work done with the EPA through the joint Russia Air Management Program (RAMP) to monitor atmospheric air quality, focusing on southern cities Voronezh and Volgograd [Milyev, Burenin, and Tsibulskii, pers. comm. 2008]. The Institute of World Climate and EANET would perhaps be well matched to collaborate with the US National Science Foundation, while policymakers at EPA would have more in common with the functionaries at RosTekhNadzor and at the Ministry of Natural Resources and Ecology [*Gromov*, pers. comm. 2008].

Russian collaboration with European entities and conferences is a promising avenue as well. Olga Yusim and four other Russian envoys in October traveled to Goteborg, Sweden for an international training on the Global Warming and Air Pollution Integrated Assessment Modeling System (GAINS), one of a series of recent technical workshops with Russian participation, which is an encouraging sign of Russian engagement [*Kupiainen*, pers. comm. 2008s]. RosGidroMet participates in the annual scientific conference of AEA Technology, a large, UK-based international consultancy. NIIAT, the Russian national transport institute, is a regular participant in the European Conference of Ministers of Transport, which would appear to be a promising forum for addressing transport-sector emissions, particularly through the introduction of alternative fuels to diesel, and ULSD [*Kunin*, pers. comm. 2008]. Regarding current work, he said the Finnish Environmental Institute and the Finnish Meteorological Institute are currently working on promoting BC-related projects, and interested in deepening their engagement with Russian colleagues [*Kerminen, Teinila, Kupiainen*, pers. comm. 2008].

Recommendations:

—Re-engagement through the Arctic Council

—Pressure for ratification of the LRTAP "multi-effect" and other unratified protocols, and inclusion of PM in the multi-effect protocol

—Deeper coordination on data collection, modeling, and policymaking through AMAP, EMEP, RAMP, and other international collaborative efforts

—Work through IMO/MARPOL on reductions of PM emissions from ships in the Arctic

—Work with Arctic Council SDWG, Barents Euro-Arctic Council, NEFCO, NIB and other development agencies to promote sustainable development and diversified economic activity in the Arctic region

—Repair the Joint Implementation (JI) mechanism and fund projects that target greenhouse gas emissions sources also emitting BC.

2) National Government Commitments

Russia has a highly centralized federal government structure, which means attempts to address BC mitigation in Russia should begin at the national level. Though there are a number of autonomous ethnic republics and regions, during his presidency Putin oversaw the transition from locally elected regional governorships to central appointments by the Kremlin, and significantly increased the power of the seven federally-appointed federal district governors (each district consists of a number of smaller regions). Additionally, the federal government has a significant "capacity to govern," and often engages constructively with regional governments, offering assistance where capacity is low. For example, Russian federal government officials from the Ministry of Natural Resources conduct all environmental monitoring in Russia's Murmansk oblast, and cooperate closely with local authorities [*Honneland and Jorgensen*, 2002]. At the national level, policy efforts should focus on strengthening Russia's commitment to and participation in existing international agreements and forums such as the Arctic Council, LRTAP, and the Kyoto Protocol (ratified in 2004).

Beyond formal diplomatic channels, pursuit of national commitments through policies and pronouncements of the executive branch is very important for setting the tone of national government. In Russia, where the president (and now the prime minister, since the ascension of Vladimir Putin to that position) wields enormous power and influence, speeches and decrees by the president and prime minister are often all that is necessary to stimulate a major governmental response. These priorities then set the tone for implementation in lower levels of government. For example, Andrei Peshkov, the Russian chairman of the Arctic Council Arctic Contaminants Action Plan (ACAP) working group, referenced the Russian national Social-Economic Development Plan for 2008-2011 in his speech to the working group in 2007 at the beginning of the Russian chairmanship [*ACAP*, 2008]. Additionally, in the run-up to the G-8 Toyaka, Japan Summit in June 2008, which featured energy efficiency prominently on the agenda, President Dmitriy Medvedev prompted the issue of an executive decree to kick-start a major Russian inter-agency program on energy efficiency. Unlike the existing energy efficiency plan, which had been formally in place since 2000 but had produced few results, this executive order placed tight deadlines for concrete action on the ministries, spurring them to rapid action.

On the flip side, government foot-dragging can have the reverse effect. For example, Russia's approval of Kyoto Protocol Joint Implementation (JI) projects, which will bring tens of millions of dollars in energy investment to Russia and generate valuable ERUs for sale on carbon markets, is now 12 months delayed (and counting) because the top echelon of government has refused to give the Ministry of Economic Development the green light for JI approval [*Shuster*, 2008; *Coelho*, 2009].

Among the Russian national priorities into which BC emissions reduction efforts can tie in are the National Energy Efficacy Program, the National Gasification Program, and the National Socio-Economic Development Program. By tackling transport, municipal heating, and agricultural burning emissions in particular, national and international efforts can address BC emissions.

Transport Emissions

Laws and Regulations

Diesel emissions from mobile sources account for roughly 25% of all Russian BC emissions [*Kofala et al*., 2007]. Russia has a well-established legal framework for regulating particulate emissions from auto transport. Russia (or rather the USSR) is a signatory of the Geneva Convention of 1958. In 2007 State regulators established a timeline for the introduction of Euro vehicle emissions standards, levels 1-5 [*Kunin*, pers. comm. 2008]. Technical regulations are currently under development. According to Russian law, all emissions sources are to be inspected and certified. A new government order has decreed only Euro-3 compliant cars can be manufactured at auto plants and imported to the country. However, factories are complying poorly, and monitoring and enforcement have been weak.

Executive order 118 from February 27, 2008 regulates standards for auto and aviation fuel, including diesel and coal-based fuels. Today fuel in Russia meets Euro-2 standards. It has a high sulfur content of 800ppm, though better than the old rule which allowed 2,000ppm sulfur content. The timeline for adopting a 350ppm sulfur limit is 2009, and 50ppm in 2014.

Inspections and Compliance

Vehicles

The weakest point of control for Russian auto emissions is for in-use cars on the roads. A law exists (Executive Order 28, Technical Inspection, "TekhOsmotr") for vehicle emissions standards, but there is no mechanism for enforcement. While RosStat (the statistics agency) and GIBDD (the traffic police) have in the past conducted empirical studies of road emissions, emissions in recent years have completely fallen off the radar screen of the Ministry of Transportation. This is unfortunate, because the Ministry of Transportation would be the logical base for emissions control efforts. While the Russian National Technical Oversight Service (RosTekhNadzor) might be interested in providing some oversight, it does not have the capacity for work on cars and trucks on the roads [*Kunin*, personal correspondence, 2008].

In the past, mobile sources were regulated by the Ministry of Industry. However, new rules have been developed for passenger vehicle certification at inspection centers (e.g. five centers in Moscow). However, the certification process does not yet include spot checks of vehicles already in use; only those from the factory. The traffic police bureau (GIBDD) is responsible for vehicle performance inspections, and a center is now being built for the analysis of in-use vehicles. There are new rules on the permissible levels of particulates in vehicle exhaust, and all autos are to be inspected using optical rather than chemical techniques. If a vehicle does not meet technical standards, the owner is given 20 days to repair it. It is not standard practice to place particulate filters on old vehicles' exhaust pipes, which traffic police consider ineffectual. Filters tend to block up and need constant upkeep and inspections to be effective, not least where ULSD is not used, as is the case in Russia [*Kunin*, personal correspondence, 2008].

As a strategy for improved inspections, technical assistance and incentives to Russian authorities could be deployed with an incentive structure to induce stricter vehicle emissions inspections and controls on roads.

Fuel Standards

Furthermore, fuel quality lags behind standards. Russia is looking to implement the Euro-2 emissions standard nationwide by 2008, and Euro-3 by 2010. However, the renovation and modernization of industrial facilities is behind schedule, and to date does not meet Euro-2 standards. These factories include those building diesel trucks, and refineries. These facilities are not ready to transition to ultra-low sulfur diesel (ULSD), which will prevent them from meeting standards, including the Euro-3 by 2010. However, the oil refineries are not ready: huge capital investments are needed to improve capacity to remove sulfur and other aromatic aerosols, funding that is no longer in the offing with low oil prices and sky-high interest rates on corporate borrowing. Particularly in the context of the current economic and credit crisis, financing does not appear to be sufficient [*Kunin*, pers. comm. 2008].

There are two production facilities of diesel engine vehicles in Russia, including the famous Kamaz trucks. However, because demand for these trucks is high, there is no commercial incentive to meet more stringent emissions standards. The Euro-2 standard will not be met for at least 2-3 years [*Gromov*, pers. comm. 2008)].

Transport Recommendations

—Concentrated efforts to study Russian on- and off-road emissions

—Legislation on Euro-4 and Euro-5 diesel vehicle emissions standards

—Diesel fuel regulation, and introduction of Ultra-Low Sulfur Diesel (ULSD)

—International funding for vehicle manufacturing and fuel refining upgrades

—Coordination of fuel and vehicle quality standards

—Implementation of better on-road vehicle inspections and enforcement, using incentive-driven funding

—Replacement of worst on-road and off-road superemitters, with international funding

Municipal Heating Emissions

Municipal, or central, heating, comprises a large chunk of "domestic" emissions, the largest sector in Russia, and is typified by inefficient and dirty boilers burning coal and other fossil fuels. Housing reform and infrastructure upkeep remain big issues because much of the Russian housing stock was never privatized after the dissolution of the USSR. The degradation of housing and district heating infrastructure has made its renovation an urgent priority for heating provision – and a major expense – after which efficiency gains and emissions reduction are secondary goals. The installation of energy meters and replacement of old and poorly insulated pipes continues apace, though the task is enormous. There is a major budget shortfall for the necessary maintenance and reconstruction; large cities have been prioritized, though the small cities' infrastructure is in a parlous state [*Maksimov*, pers. comm. 2008].

The World Bank is working with the Russian government on subnational projects, including a boiler rehabilitation program, focusing on coal-fired boilers in municipalities and other district heating systems. While the focus of the program is service quality, increased efficiency and better performance can lead to drastic BC (and GHG) emissions reductions. The program currently is funding the refurbishment or replacement of 60 boilers out of an estimated 40,000 in need of replacement nationwide. With the prime interest rate at 17% in Russia as of late October [*Schreiber*, pers. comm. 2008], it is not financially feasible for governments (or businesses) to raise capital for such infrastructure upgrades. This program dovetails with a major Russian government initiative to switch from coal boilers to gas. The Russian Gasification project, commenced in 2002, is particularly active in Voronezh oblast' (region in south-central European Russia), where about 500 heating systems have been converted. This fuel switch leads to significant reductions in both carbon dioxide and, in all likelihood, BC emissions. The International Finance Corporation (IFC) has issued a loan to replace 60 such boilers, and is now looking at a block loan to replace 300 more [*Schreiber*, pers. comm. 2008].

Municipal Heating and BC Emissions Recommendations

—Provide international funding and technical assistance for the National 2008 Energy Efficacy Program, via the World Bank, International Energy Agency, etc.

—Support the National Gasification Plan by funding gas pipeline networks.

—Tie other programs support into the Social-Economic Development Plan, 2008-11, with focus on international support for the northern regions.

Identifying and Reducing Agricultural Burning

As mentioned above, agricultural burning in Russia is a major source of PM and BC emissions [*Anttila*, 2008; *Kupiainen*, *Baum*, pers. comm. 2008]. Yet, the Russian government, which has banned open agricultural burning since the 1960s, has at once neglected enforcement and turned a blind eye to the problem [*Gromov*, pers. comm. 2008]. Because agricultural burning's seasonal intensity (generally in spring and early summer) can have a particularly deleterious effect on melt rates of snow and ice and therefore regional warming in northern latitudes [*Ramanathan and Carmichael*, 2008; *AMAP*, 2008], this problem must be addressed. International conferences and workshops between scientists to collect data, policymakers to set realistic regulations, and implementing agencies to trade best practices on enforcement are warranted. International funding for enforcement would likely increase the celerity and efficacy of Russian government efforts. Other efforts, as the Finnish Meteorological Institute has proposed, to measure natural BC emissions rates from forests through fires and other natural processes should also be studied to better establish natural and anthropogenic BC emissions rates [*Kerminen and Teinila*, pers. comm. 2008].

Agricultural Burning Recommendations:

—Joint research on agricultural burning and other uncontained BC emissions sources

—Exchange best practices for policy and enforcement at international conferences and workshops

3) Interagency Collaboration

During the summer of 2008, shortly after he became prime minister, Putin undertook a major reorganization of the federal government, leading to number of major changes in the jurisdiction of ministries. Among these changes, the Ministry of Energy and Industry was split in two; the Russian Federal Service for Hydrometeorology and Environmental Monitoring (RosGidroMet) and the Federal Technical Regulatory Service (RosTekhNadzor), both previously an independent agency, were rolled into the Ministry of Natural Resources and Ecology; and the Ministry of Economic Development and Trade was stripped of trade [*Gromov, Vikulova, and Maksimov*, pers. comm. 2008]. The Russian federal government has never been known for extensive interagency working groups or formal interagency structures of any kind. With the recent restructuring, the government is in greater need of these coordinating bodies than ever before. By structuring foreign assistance and aid programs to encourage interagency coordination where appropriate, the international community can play a positive role.

The Russian federal government bureaucracy suffers from "a lack of horizontal integration and a high level of conflict" [*Honneland and Jorgensen*, 2002]. This lack of coordination is visible from the failure of the Russian energy efficacy program to create an inter-agency working group (*Russian government decree*, June 2008). Likewise, the Ministry of Natural Resources and the Ministry of Economic Development and Trade, both tasked with major compliance responsibilities under the Kyoto Protocol, have not succeeded in clarifying interagency roles or effective collaboration [*Korppoo* et al., 2006; *conversation with unnamed MNR employee*, October 2008].

This lack of collaboration must be remedied. Institutional leadership would help; foreign governments can help by designing financial and technical assistance programs such that they foster collaboration rather than competition between government agencies; funding can even be made contingent on satisfactory coordination. Workshops with foreign governments on interagency collaboration might be useful. Additionally, it is very important to build on existing institutional capacity – in the case of black carbon emissions inventories and mitigation programs, with Kyoto Protocol implementation agencies. Trying to impose the creation of new structures can often backfire, and be counterproductive [*Honneland and Jorgensen*, 2002].

A few particular interagency efforts must be spearheaded on programs mentioned above, including municipal heating refurbishment, transport emissions, energy efficiency, emissions data collection and analysis, and JI project implementation.

Municipal Heating

The Ministry of Regional Development is responsible for district heating and housing reform. Currently regional authorities and large energy companies, such as Siberia Ugol' (Coal) are developing projects for JI implementation. The Ministry of Energy is currently working on energy efficiency and energy provision, while the Ministry of Economic Development is responsible for JI projects. The World Bank works primarily with the Ministry of Finance (*Schreiber*, pers. comm. 2008). To minimize BC (and GHG) emissions, the Ministry of Natural Resources and Ecology, led by RosGidroMet, must provide expertise on current emissions levels and best practices. All of these agencies and structures – and others – must collaborate to address the problem of central heating and infrastructure. These entities must jointly commission a study of rural infrastructure to assess the needs and feasibility of infrastructure upgrade programs.

One possible model is the latticework of interagency connections for Kyoto Protocol Implementation. National legislation names the Ministries of Foreign Affairs, Natural

Resources, Transportation, Energy, Atomic Power, Agriculture, and Economic Development, as well as the state Construction and Meteorological Services, as key players in Kyoto implementation [*Maksimov*, pers. comm. 2008].

It is worth noting that liberalizing oil and gas prices would provide a powerful stimulus to conserve energy [*CENEf*, 2008]. However, this cost increase would likely prove counterproductive for the implementation of the National Gasification Program, disproportionately harm lower- and middle-class Russians, and prove politically unrealistic.

Transport Emissions

As mentioned above, transport emissions have to a large degree fallen through the cracks of bureaucratic oversight in Russia. The traffic police, Ministry of Transport, Ministry of Natural Resources and Ecology, Ministry of Health, RosTekhNadzor (the industry regulator), the Ministry of Industry, the Ministry of Energy, and other national stateholders must address transport policy in a holistic manner.

Energy Efficiency

As the National Energy Efficacy Program moves forward, federal agencies delegated with tasks should collaborate to coordinate policy, and incorporate BC and GHG emissions reductions benefits into their policymaking.

Emissions Data Collection and Analysis

While an elaborate structure exists for centralization of GHG emissions collection, inventories are still not adequately measuring transportation, small industry, domestic, and agricultural emissions. In 2006, national legislation created a center, the "Center for Geo-Ecological Systems" under the Ministry of Natural Resources and Ecology (MNRE), for managing GHG emissions inventories and data, and sharing them amongst the relevant ministries. This center is responsible primarily for registries, i.e. verified emissions totals from specific entities (versus inventories, which are interpolated by modelers at RosGidroMet from official statistics) [*Maksimov*, pers. comm. 2008]. RosGidroMet prepares the annual reporting, the Statistical Agency provides the raw data, the Ministry of Natural Resources creates environmental regulations, the Technical Oversight Service (RosTekhNadzor) oversees industry and production regulations related to GHG and other particulate emissions, while the Ministry of Energy is responsible for the "balance" of GHG emissions (i.e., the sale of excess credits, or reduction of emissions from energy production and use). RosGidroMet submits the reports on Kyoto implementation and GHG emissions to the prime minister prior to submission to the UNFCCC secretariat. Improved data collection in the source agencies will improve the quality of the inventories, and subsequent estimates and extrapolations of BC emissions, at all levels.

Social studies of domestic energy use would be particularly enlightening to better establish BC emissions in rural areas.

Joint Implementation (JI) Projects

The Ministry of Economic Development is responsible for ERUs created through JI projects. The review process as well as the specific review of project proposals submitted to the Ministry of Economic Development under the JI has been stalled, waiting for the approval of the Prime Minister. This system was supposed to be launched in January 2008 with the launch of the Kyoto 2008-2012 reporting period, but as of mid-January 2009 was still not functional; moreover, Russia has been suspended from the JI program due to delinquency in its UNFCCC dues [*Coelho*, 2009; *Murray*, 2009]. Due to the large economic and environmental benefits mentioned above, international efforts should refocus attention on the JI program.

Recommendations:

— Create working groups on municipal heating, energy efficiency, transport emissions, BC emissions data collection and analysis, and JI projects

— Enlist US agencies such as EPA, DOE, Department of Agriculture, etc. to lead workshops on coordinating and implementing working group efforts

— Enlist the assistance of international bodies such as the EU, UNFCCC and the IEA

4) Local Government Buy-In

Regional- and local-level initiatives should also be pursued vigorously because they are more manageable in scope, and more targeted to achieve concentrated, rapid results. Regional governments often have strong incentives to work directly with international organizations and development agencies to promote development locally. Additionally, Russian non-governmental organizations have grown rapidly in number, size and professionalism since the fall of the USSR, despite some limitations on their activities [*Powell*, 2003; *Carothers*, 2006], and should be viewed as partners with invaluable local presence and expertise.

The Ministry of Regional Development and the Ministry of Natural Resources – which, unlike most ministries, has strong regional presence [*Honneland and Jorgensen*, 2002] – should team up with international teams focusing on specific regions, such as the northwestern Kola Peninsula, Karelia, and smelter cities such as Pechanga and Nikel [*UNEP, GIWA*, 2005]. The buy-in of local government, and local capacity building, could greatly improve environmental compliance and emissions reduction, particularly where emissions sources are concentrated. The Ministry of Regional Development and the Ministry of Economic Development are key partners in tying environmental protection to economic growth, which is often the only hope of making politically palatable environmental programs that require sacrifices.

In addition to World Bank infrastructure projects, GEF/UNDP are also major funders of environmental initiatives in Russia, including the US-Russian-Nordic Cooperation that focuses on the destruction of chemical stockpiles (PCBs, etc.). The Nordic Environmental Finance Corporation (NEFCO) and the Nordic Investment Bank (NIB) also fund smaller, commercial projects in energy efficiency and clean technologies. NEFCO pilot projects focus on a list of environmental "hot spots" – major industrial emissions sources – concentrated in the Russian Northwest (Kola Peninsula, Karelia, Arkhangel'sk, etc.), including Pechanga, Noril'sk, and Nikel. These are some of the largest point sources of sulfur dioxide and heavy metals in the world [*Thompson*, pers. comm. 2008].

In general, large-scale industrial refurbishment and relocation projects have very limited efficacy because corporate and government management change quickly. Consequently, directors and administrators have a very short time horizon for investment planning, and do not take the long-term approach necessary to address projects with high capital costs and longer-term payback calendars [*Thompson*, pers. comm. 2008].

Shorter-term, smaller projects tend to be more effective because they have a short time horizon, and because the challenges are more technical in nature that managerial. In particular, "Cleaner Production Program," a bilateral Russian-Norwegian program active since 1997 that trains trainers in energy and raw materials management, focusing on engineers, is a fairly successful program [*Thompson*, pers. comm. 2008]. The smaller programs of NEFCO and NIB also would fit into this category. Non-profit organizations like the World Wildlife Fund, the Russian Regional Ecological Center, and Greenpeace have occupied important niches and should be viewed as resources for expertise and local project implementation.

Carbon finance through various World Bank Group funds is being considered as a secondary source of capital for many local infrastructure projects that can reduce BC. Many of these projects, with high capital costs, are ideally suited for the WB's new Carbon Partnership Facility, which can give loans through 2022 – 10 years beyond the expiration of the Kyoto Protocol – for carbon finance projects. Projects are now being developed in Leningrad and Vologda oblasts [*Schreiber*, pers. comm. 2008]. Need for assistance is particularly acute in the regions distant from the capital, including those in the Northwest and Siberia that are likely contributing significantly to Arctic BC deposition. World Bank programs to promote energy efficiency, such as a comprehensive one the oil-rich Khanty-Mansiisk district, have received strong government support [*Schreiber*, pers. comm. 2008].

Recommendations:

— Expand the World Bank's energy efficiency programs in other regions

— Expand the World Bank's Municipal Heating project

— Provide directed international carbon finance for NEFCO and other similar small-scale, regional infrastructure projects

— Increase international technical assistance to the regions for BC emissions source management, particularly through GEF/UNDP

— Create an Arctic Development Program under the auspices of the Arctic Council

— Explore avenues for provision of carbon finance for BC-targeted projects, focusing on small-scale pilots that can be scaled up

Concluding Recommendations

In addition to specific recommendations that have been interspersed throughout the text, the following list of recommendations touches on broad categories for action on BC emissions reduction.

1) Increasing and broadening data collection;

2) Conducting a feasibility study of BC mitigation options;

3) Building political will through diplomacy, policy initiatives, and restructured incentives;

4) Building institutional capacity for collaboration and implementation;

5) Provision of direct funding for projects, particularly from international sources;

6) Provision of international technical assistance;

7) Promotion of local low-carbon economic development programs.

Agency	Responsibility
Ministry of Economic Development (MED)	Preparation of national JI administration Leader in annual reporting to domestic bodies on Kyoto implementation and compliance Assist MNR with preparation of legislation on establishment of GHG registry Effective cooperation of agencies on Interagency Commission on the Kyoto Protocol
Ministry of International Affairs (MIA)	International negotiation Coordination with some outside governments
RosGidroMet (National Meteorological Service)	Establishing system of GHG inventories and sinks (with help from MEDT, other agencies) Implementing inventories for 1990-2004 and submission to UNFCCC (with MNR)
Ministry of Natural Resources (MNR)	Preparation of legislation on establishment of GHG registry (with help from MEDT) Implementing inventories for 1990-2004 and submission to UNFCCC (with RosHydroMet) Forestry and agricultural sinks - inventories and reporting
Ministry of Agriculture	
RosNauka (National Academy of the Sciences)	
Ministry of Industry and Energy (now 2 separate ministries)	Market reform: removal or reduction of policies impeding emissions reduction (with Federal Anti-Monopoly Service) Energy sector: emissions, efficiency improvements, etc. (Ministry of Energy)
Russian Committee on Technical Inspection (RosTekhNadzor)	
Ministry of Industry and Science	
Ministry of Regional Development	Market reform: removal or reduction of policies impeding emissions reduction
Ministry of Education and Science	Research and development of emissions reduction strategies

Table A4.1.1 Russian National Government Kyoto Responsibilities. *Source: A. Korppoo et al., 2006.*

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GLOSSARY

Where possible, definitions given here are based on those given in the glossary of the IPCC Fourth Assessment Report.

Aerosol optical depth – A measure of the absorption of light by aerosols along a vertical path from the surface to the top of the atmosphere.

Albedo - The fraction of solar radiation reflected by a surface or object, expressed as a value between zero and one. Clean clouds and snow- and ice-covered surfaces have a high albedo. Vegetated land and ocean surfaces have a lower albedo.

Atmospheric lifetime – The timescale characterizing the rate of processes (both sources and sinks) affecting the concentration of a trace component in the atmosphere. As used here, the lifetime is calculated as the total atmospheric load divided by the global emission rate, assuming some near-steady state condition where the flux (of BC, CO_2, etc.) into the atmosphere equals the flux out.

Black carbon equivalent – The amount of pure black carbonaceous aerosol necessary to produce the same radiative forcing (through both direct and indirect effects) as a given quantity of BC from the same source.

CAFE standards – Corporate Average Fuel Economy regulations of the U.S. federal government. First enacted by Congress in 1975, the purpose of the CAFE standards is to reduce energy consumption by increasing the fuel economy of cars and light trucks.

Cadastre – A cadastral survey or cadastral map is a comprehensive register of the metes-and-bounds real property of a country. A cadastre commonly includes details of the ownership, the tenure, the precise location (some include GPS coordinates), the dimensions (and area), the cultivations if rural and the around the world, some in conjunction with other records, such as a title register.

Carbonaceous aerosols – Airborne carbon-containing compounds and particles, with a typical size between 0.01 and 10 µm.

Cash-for-Clunkers – The name for a variety of programs under which the government buys up old, polluting vehicles and scraps them.

Clean Air Act of 1990 – An amendment to the original Clean Air Act of 1963, which allows the EPA to set limits on certain air pollutants to ensure basic health and environmental protection from air pollution for all Americans. The Clean Air Act regulates six criteria pollutants: particulate matter, ground-level ozone, carbon monoxide, sulfur oxides, nitrogen oxides, and lead.

Clean fuel - A fuel that produces low levels of pollution (i.e. fewer PM emissions).

Climate efficacy - A measure of how effective a radiative forcing from a given agent or mechanism is at changing the equilibrium global surface temperature compared to an equivalent radiative forcing from carbon dioxide.

Cloud Albedo effect – An interaction mechanism in the climate system wherein a change in cloud cover or cloud albedo leads to a change in the amount of solar radiation reaching the surface, with consequent surface warming or cooling.

CMAQ Program – Authorized by Congress in1991 to fund projects that contribute to air quality improvements and reduce congestion. The CMAQ Program was reauthorized in 2005.

Contained combustion – Fossil fuel and biofuel burning used to meet energy demand. This includes burning for power generation, industry, transportation, cooking and heating.

Diesel Oxidation Catalyst – An emission control device that uses a chemical process to break down pollutants in the exhaust stream into less harmful components. They are cheaper than diesel particulate filters and can be used on a greater variety of vehicles than diesel particulate filters. However, they are less effective overall, especially in reducing black carbon emissions.

Diesel Particulate Filter – An emission control device that collects particulate matter in the exhaust stream. The high temperature of the exhaust breaks down (oxidizes) the particulate matter into less harmful components. They are more expensive than diesel oxidation catalysts and require the use of ULSD. However, they are more effective than diesel oxidation catalysts and eliminate virtually all black carbon particulate matter.

Direct effects of BC – Radiative forcing resulting from the absorption of solar radiation by BC particles and the re-release of that energy in the atmosphere as heat.

Effective radiative forcing – The product of radiative forcing and climate forcing efficacy of an agent.

Equivalent carbon dioxide (CO_2e) - The concentration of CO_2 required to produce the same amount of radiative forcing as a given gas mixture or new pollutant added to the atmosphere.

Gg – Gigagrams. A unit of mass equal to 10e12 grams.

Global Warming Potential (GWP) - An index based on radiative properties of well-mixed greenhouse gases. GWP measures the radiative forcing of a unit mass of a given agent in the present-day atmosphere integrated over a chosen time horizon, relative to that of carbon dioxide.

Group of 77 (G-77) – An intergovernmental organization of developing states in the United Nations aiming to articulate and promote their collective economic interests and enhance their joint negotiating capacity within the United Nations system.

Indirect effects of BC – The radiative forcing resulting from the effects of BC on cloud liquid droplet size and total cloud liquid amount. These changes can in turn affect a broad spectrum of climate variables, including temperature, cloudiness, humidity, short- and long-wave radiation, heat transport and rainfall patterns.

Open burning - Forest, field and savanna burning, as well as uncontained combustion of urban and rural waste. Open burning may be natural or caused by humans.

Particulate matter (PM) - A collection of airborne particles that may consist of a wide variety of substances, with a typical size between 0.01 and 10 µm.

$PM_{2.5}$ - Particulate matter with a diameter of 2.5 microns or less.

PM_{10} - Particulate matter with a diameter of 10 microns or less.

ppb – Parts per billion. An expression of the relative amount of one substance mixed with another.

ppm – Parts per million. The relative amount of one substance mixed with another. An atmospheric concentration of 380 ppm carbon dioxide means that, in a given volume of air, there are 380 molecules of carbon dioxide for every 1 million molecules of dry air.

Radiative forcing – A measure of the change in Earth's global energy balance calculated at the tropopause.

Renewable fuel - A fuel produced from resources that can be replenished by natural resources and at a rate comparable to or faster than its rate of consumption.

Snow albedo effect – Also "ice albedo effect." An interaction mechanism in the climate system wherein decreases in snow cover on the surface leads to a decrease in surface albedo, with consequent surface warming. When the resulting warming causes further snow and ice melt, the effect is also known as the snow or ice albedo feedback.

Super Emitters – Highly polluting vehicles that emit roughly 10 times as much particulate matter as the U.S. average.

Ultra low sulfur diesel – Diesel fuel with a sulfur content of 15 ppm, as compared to low sulfur diesel's 500 ppm sulfur content.

List of Abbreviations

ACAP	The Arctic Contaminants Action Program of the Arctic Council
AMAP	The Arctic Monitoring and Assessment Program of the Arctic Council
APINA	Air Pollution Information Network for Africa
BC	black carbon
BEV	battery-powered electric vehicle
BF	biofuels
CCS	carbon capture and storage
CFC	chloro-fluoro-carbon
CMAQ	Congestion Mitigation and Air Quality Improvement Program of the U.S. DOT
CNG	compressed natural gas
DOC	diesel oxidation catalyst
DOT	United States Department of Transportation
DPF	diesel particulate filter
EANET	East Asia Network on Acid Deposition
EPA	United States Environmental Protection Agency
FF	fossil fuels
G-77	Group of 77
GDP	gross domestic product
GEF	Global Environmental Fund
GHG	greenhouse gas
GISS	NASA Goddard Institute for Space Studies
HEV	hybrid electric vehicle
IAP	indoor air pollution
IPCC	Intergovernmental Panel on Climate Change
LRTAP	International Convention on Long Range Trans-Boundary Air Pollution
NGO	non-governmental organization
NISP	The Chinese National Improved Stove Program
NOAA	National Oceanic and Atmospheric Administration
NPIC	The Indian National Programme on Improved Chulhas
OC	organic carbon
OECD	Organisation for Economic Co-operation and Development
PHEV	plug-in hybrid electric vehicle
PM	particulate matter
R&D	research and development
ULSD	ultra low sulfur diesel
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development
WHO	World Health Organization

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