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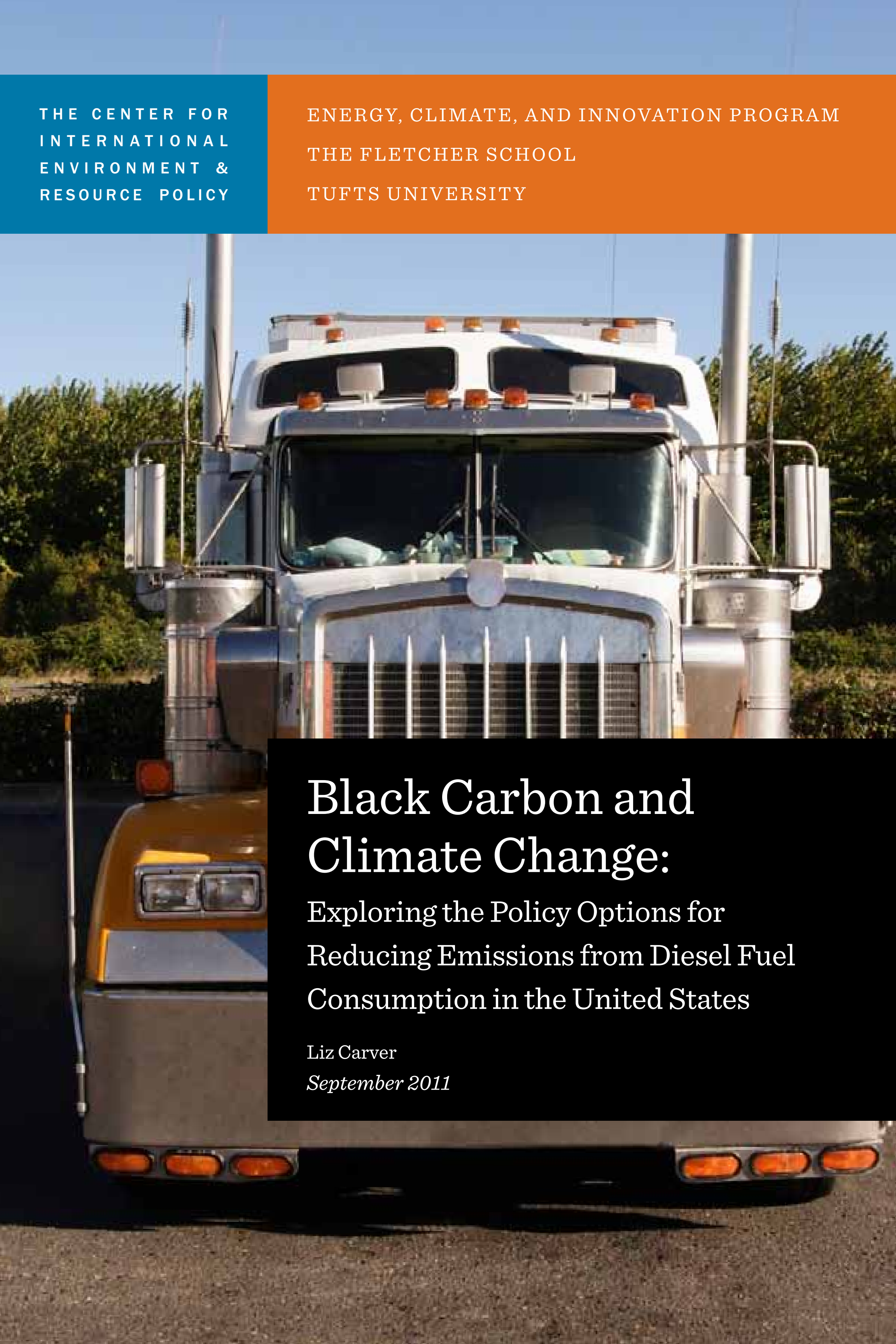

Black Carbon and Climate Change:

Exploring the Policy Options for Reducing Emissions from Diesel Fuel Consumption in the United States

Liz Carver

September 2011

Abstract

Black carbon (BC), the main component of soot, is produced by the incomplete combustion of carbon-rich fuels. Over the past decade, it has been recognized as a potent climate warmer, yet to date, BC has not been explicitly targeted through any global, regional, or national climate change policies or regulations. The U.S. Environmental Protection Agency (EPA) has taken no formal position on BC as it relates to climate. This study explores ways that the United States can best address the climate impacts of BC, reviewing the policies or policy frameworks that could facilitate broad reductions in domestic BC emissions, with particular emphasis on the leading sources of domestic BC emissions: on-road and nonroad diesel engines. Results of this study indicate that the United States has a number of national- and sub-national policy mechanisms that could facilitate accelerated BC emissions reductions from mobile source diesel fuel consumption but has no coordinated national BC strategy. Better coordination of air-quality and climate policies and planning is urgently needed, with a priority placed on fast action by leveraging existing regulatory authority and policy mechanisms. Detailed policy recommendations are offered specific to the regulatory purview of EPA, Congress, and regional, state, and local governments to accelerate BC emissions reductions from mobile source diesel fuel consumption.

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Energy, Climate, and Innovation Program (ECI)
Center for International Environment and Resource Policy (CIERP)

The Fletcher School
Tufts University
Cabot Intercultural Center, Suite 509
160 Packard Avenue
Medford, MA 02155

www.fletcher.tufts.edu/cierp

The Fletcher School at Tufts University was established in 1933 as the first graduate school of international affairs in the United States. The primary aim of The Fletcher School is to offer a broad program of professional education in international relations to a select group of graduate students committed to maintaining the stability and prosperity of a complex, challenging, and increasingly global society.

The Center for International Environment and Resource Policy (CIERP) was established in 1990 to support the growing demand for international environmental leaders. The Center provides an interdisciplinary approach to educate graduate students at The Fletcher School. The program integrates emerging science, engineering, and business concepts with more traditional subjects such as economics, international law and policy, negotiation, diplomacy, resource management, and governance systems.

The Energy, Climate, and Innovation Program (ECI) advances policy-relevant knowledge to address energy-related challenges and opportunities, especially pertaining to climate change. ECI focuses particularly on how energy-technology innovation can be better harnessed to improve human-well being, and the role of policy in the innovation process. Although ECI's outlook is global, we concentrate mainly on energy and climate policy within, and between, the United States and China. We also focus on how these countries influence the international negotiations on climate change, and the role of technology in the negotiations.

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Tables and Figures

Section 1: Introduction

Black carbon (BC), the main component of soot, is produced by the incomplete combustion of carbon-rich fuels. While the climate impacts of BC and other aerosols have been recognized for over 30 years, scientific understanding of BC as a climate-warming agent has evolved substantially over the last decade based on the results of field and satellite observations and modeling studies (Bond and Sun 2005; Ramanathan 2010). With better scientific understanding of BC's climate impacts and growing attention to global climate change have come increased calls in the climate science and policy literature to consider BC and other non-CO_2 climate warming agents alongside the traditional greenhouse gases (e.g., methane, nitrous oxide, hydrofluorocarbons) in climate mitigation policies (cf. Hansen et al. 2000; Jacobson 2002; Bond and Sun 2005; Bond 2007b; Ramanathan and Carmichael 2008; Molina et al. 2009; Grieshop et al. 2009). Yet to date, BC has not been explicitly targeted through any global, regional, or national climate change policies or regulations. Rather, BC has been considered as a component of particulate matter (PM) and addressed as such in the policy and regulatory arena to control its public health and air quality impacts.

Domestically, the U.S. Environmental Protection Agency (EPA) has taken no formal position on BC as it relates to climate. The EPA is currently evaluating BC in the context of the Agency's climate change mitigation strategy and trying to identify policy options for reducing emissions of BC. Among EPA's policy options are: 1) to integrate BC into the widely used "basket of gases" CO_2-equivalency framework established under the Kyoto Protocol; 2) to incorporate BC into a multi-pollutant climate policy but implement specific measures to deal with BC outside of the "basket of gases" framework; and/or 3) to address BC through existing air quality policy mechanisms, as a constituent of particulate matter, but take additional actions that acknowledge BC's particular climate importance (Ben DeAngelo, pers. comm., Aug. 8, 2009). EPA must also decide whether to develop policies that target BC on its own, or jointly, with other short-lived climate forcing agents.

The goal of this research is to explore how the United States can best address the climate impacts of BC and to review the policies or policy frameworks that could facilitate broad reductions in domestic BC emissions. Because heavy-duty diesel engines are the largest source of BC-rich emissions in the United States, discussion of specific policy instruments will focus on options for controlling BC from on-road and nonroad diesel sources.

Section 2: Methods

This research seeks to contribute to U.S. climate change mitigation efforts by identifying policies and strategies that can help reduce the climate impacts of domestic BC emissions. The main research questions this study will explore are:

1. What policies or policy frameworks are needed to address the climate impacts of domestic black carbon emissions?

2. What are the drivers and barriers — scientific, technological, political, economic, institutional, and logistical — to implementing such policies?

To address these questions, this research employed: 1) in-depth, semi-structured interviews with climate scientists, EPA and state regulators and researchers, environmental policy analysts and NGOs, and industry stakeholders; and 2) a review of the scientific, public health, and environmental policy literature.

Interviews: The climate impacts of BC and other short-lived climate forcers is an emerging area of scientific inquiry. Consequently, consideration of the climate impacts of BC and other short-lived climate forcing agents is in the formative stages in the policymaking and regulatory arena. There is currently a substantial and rapidly growing body of scientific research literature exploring BC and climate, as well as recorded Congressional testimony on the science of BC from several prominent climate scientists. By contrast, the available literature that addresses the policy implications of BC and climate is much more sparse. For that reason, interviews were focused on stakeholders and practitioners on the front lines of developing and implementing BC-related policy, while the scientific aspects of BC were addressed largely through the literature review. See Appendix A for a complete list of interviews conducted for this research.

Individuals were solicited for interviews based on their involvement with policymaking and regulatory bodies considering the climate impacts of BC, including the U.S. EPA and the California Air Resources Board. Because BC-related science and policy involves both climate and air quality concerns, staffers from several EPA offices and divisions, including the Office of Atmospheric Programs, Office of Transportation and Air Quality, and Office of Air Quality and Planning Standards, were consulted. Additionally, several of the EPA staffers interviewed are involved in producing the upcoming EPA Report to Congress on Black Carbon. Non-governmental interviewees were solicited based on their involvement with climate and air quality policy advocacy related to BC, either directly or through air quality or clean diesel initiatives.

A few preliminary interviews were conducted with EPA staffers in the summer of 2009, as part of a research report on BC and EPA regional clean diesel initiatives that I wrote as an EPA National Network for Environmental Management Studies (NNEMS) fellow (Carver 2010). The bulk of the interviews for this study were conducted between July and September 2010. Interviews were conducted in person whenever possible and generally ran 60 to 90 minutes. All interviews were recorded with the permission of the interviewees, and quotations are included with the interviewees' consent.

Interviews were semi-structured in format, with questions based on a central interview guide and then tailored to interviewees' areas of expertise. Interviewees were asked to identify the most promising national and sub-national policies and strategies for achieving accelerated reductions in BC emissions and to assess those policies and strategies in terms of potential effectiveness, political and technological feasibility, cost, and any other criteria they deemed relevant. Interviewees were also asked to identify and evaluate potential drivers and barriers to the policies and approaches they identified, and to suggest exemplary state, regional, or international BC- or diesel-reduction policies and strategies that could serve as models for national application.

Literature review: A review of the scientific, public health, and environmental policy literature was conducted with two distinct, but interrelated, objectives:

1. To assess the state of scientific understanding of BC and climate and identify research gaps; and

2. To identify and analyze climate and air quality policies and policy frameworks that have achieved, or could facilitate, reductions in the climate impacts of domestic BC emissions.

Types of literature consulted included scientific and policy-related documents and data, such as EPA rulemaking and guidance documents; national and state legislation, legislative documents, and public hearing testimony; domestic and international scientific assessment reports, research studies, and conference proceedings; policy analyses; white papers and reports from government agencies, environmental NGOs, and industry associations; and popular media coverage.

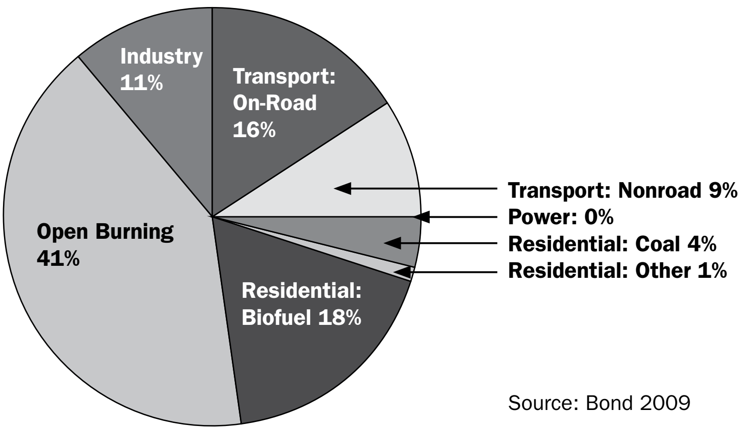
Electronic databases consulted included Science Direct, Web of Science, WorldCat, JStor, PubMed, Google Scholar, and LexisNexis Academic. Key searches and terms included "policy AND [black carbon/aerosols/diesel/diesel exhaust/particulate matter]," "[climate change/climate/greenhouse gas] AND [black carbon/aerosols/diesel/diesel exhaust/particulate matter]," and "[air quality/air pollution] AND [climate/climate change]."

Section 3: Background

3.1 BLACK CARBON: COMPOSITION, SOURCES, AND DISTRIBUTION

Black carbon, a component of both man-made and naturally occurring soot, is a carbonaceous primary aerosol (particle suspension) made up of dark, strongly light-absorbing particles that are generally less than 1.0 micrometer (μm) in diameter. Also known as "elemental carbon," BC is a product of incomplete combustion of fossil fuels, biofuels, or biomass. BC is emitted through "contained" combustion processes, as occur in diesel engines, industrial applications, and residential heating and cooking, or "uncontained" combustion processes, such as open burning of agricultural and solid waste and forest and savannah fires.

Figure 1: Global Black Carbon Emissions Sources by Sector (based on 2000 energy data)



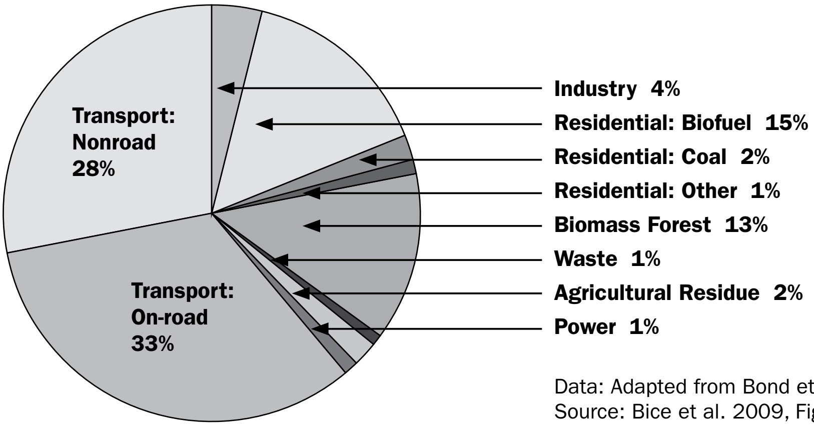
Source: Bond 2009

Annual global emissions of BC are estimated at 8.0 Tg, with a range of 4.3 to 22.0 Tg/year, due to uncertainties discussed in Section 3.4 (Bond et al. 2004). Nearly 90 percent of global BC emissions come from three main sources, as shown in Figure 1: Open biomass burning from forest fires and controlled agricultural fires (41%), fossil fuel combustion for on-road and nonroad transportation (25%), and solid fuel combustion for cooking and residential heating (23%) (Bond 2009).

"Pure" BC is not typically encountered or measured. Rather, as part of the solid fraction of particulate matter (PM) emissions, BC is co-emitted with other substances — especially organic carbon (OC), another product of incomplete combustion. The amount of BC found in PM emissions, as well as the ratio of BC to OC, varies with the type of fuel and combustion process, efficiency of combustion, and whether emissions control technologies are employed.

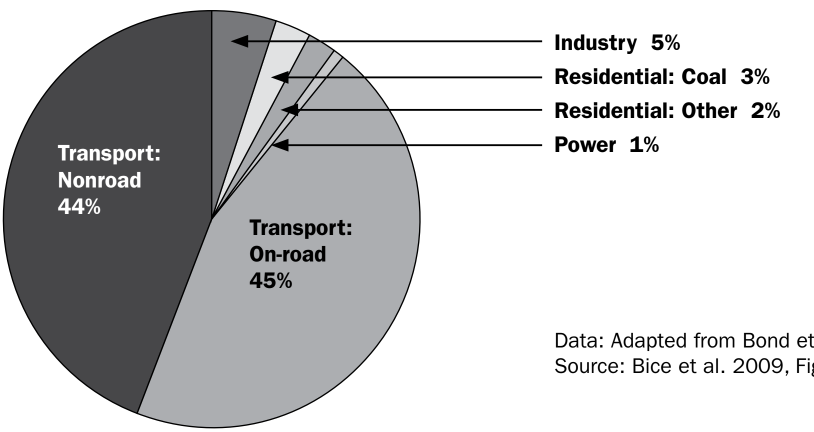
Black carbon aerosols absorb sunlight and have a strongly warming effect on the atmosphere, while OC, sulfate, and nitrate aerosols scatter solar energy towards space, and thus have a moderately cooling effect. The atmospheric warming produced by roughly 1 gram of BC can be offset by roughly 5 to 10 grams of cooling aerosols (Bice et al. 2009). Emissions from contained combustion processes typically produce a high BC-to-OC ratio, resulting in a net positive radiative forcing (warming effect), while emissions from uncontained combustion processes typically yield a low BC-to-OC ratio and a resultant net negative radiative forcing (cooling effect). In the United States, an estimated 49 percent to 63 percent of BC emissions come from the on- and nonroad

Figure 2: U.S. Black Carbon Emissions, by Source



Data: Adapted from Bond et al. 2004
Source: Bice et al. 2009, Figure 3.1

Figure 3: U.S. Black Carbon Emissions, by Source — Weighted by Relative Radiative Forcing[1]



Data: Adapted from Bond et al. 2004
Source: Bice et al. 2009, Figure 3.2

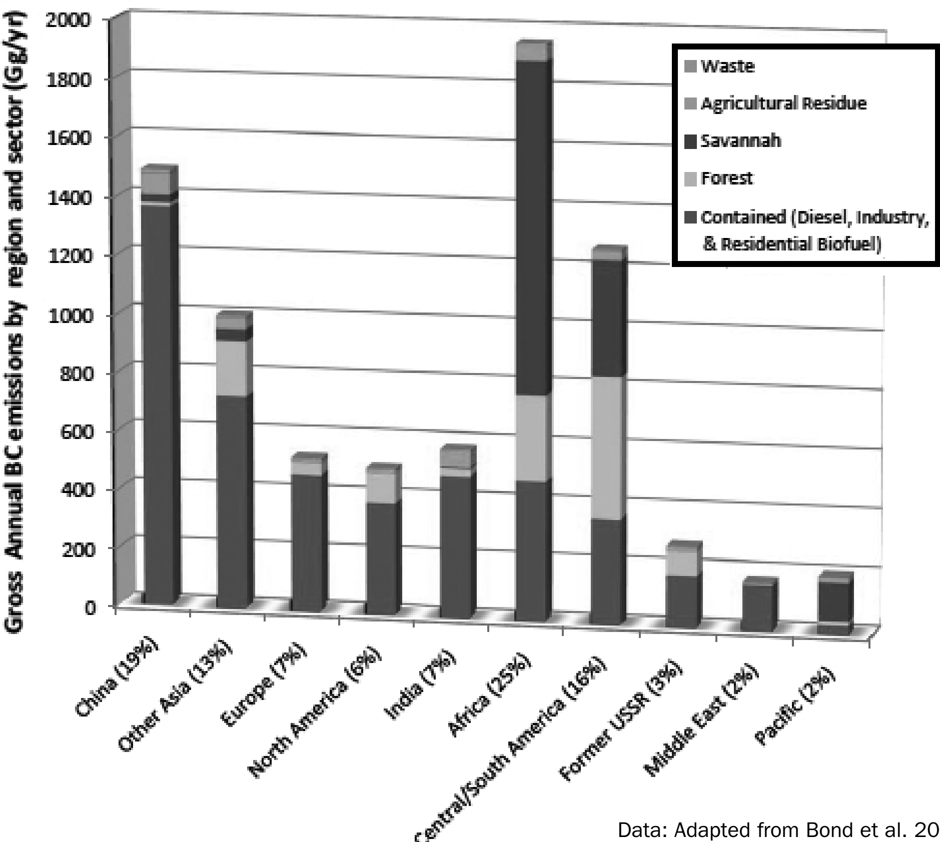
[1]Bice et al. use an OC:BC "penalty" of -0.27 to calculate the relative radiative forcing (RF) from each BC emissions sector. See Bice et al. (2009) Table 2.1, Figure 4.2, and Appendix 2.1 for further details of how these calculations were derived.

transport sectors and are attributable mainly to diesel emissions (Sarofim et al. 2009; Bice et al. 2009; Terry 2010).[2] Approximately 92 percent of U.S. mobile-source BC emissions is produced by diesel engines (Terry 2010).

Figure 2 shows one estimate of U.S. BC emissions, broken down by source sector. Figure 3 shows U.S. sectoral emissions weighted by relative warming potential due to BC-to-OC ratio. In these emissions breakdowns, while on- and nonroad mobile sources contribute an estimated 61 percent of total U.S. BC emissions, they account for an estimated 89 percent of the potential warming impact of those emissions, because mobile source emissions have a high BC-to-OC ratio and make up the largest share of total U.S. BC emissions (Bice et al. 2009).

The sources of BC emissions vary considerably by region. Roughly 80 percent of gross

Figure 4: Gross Annual Black Carbon Emissions, by Region and Source Sector



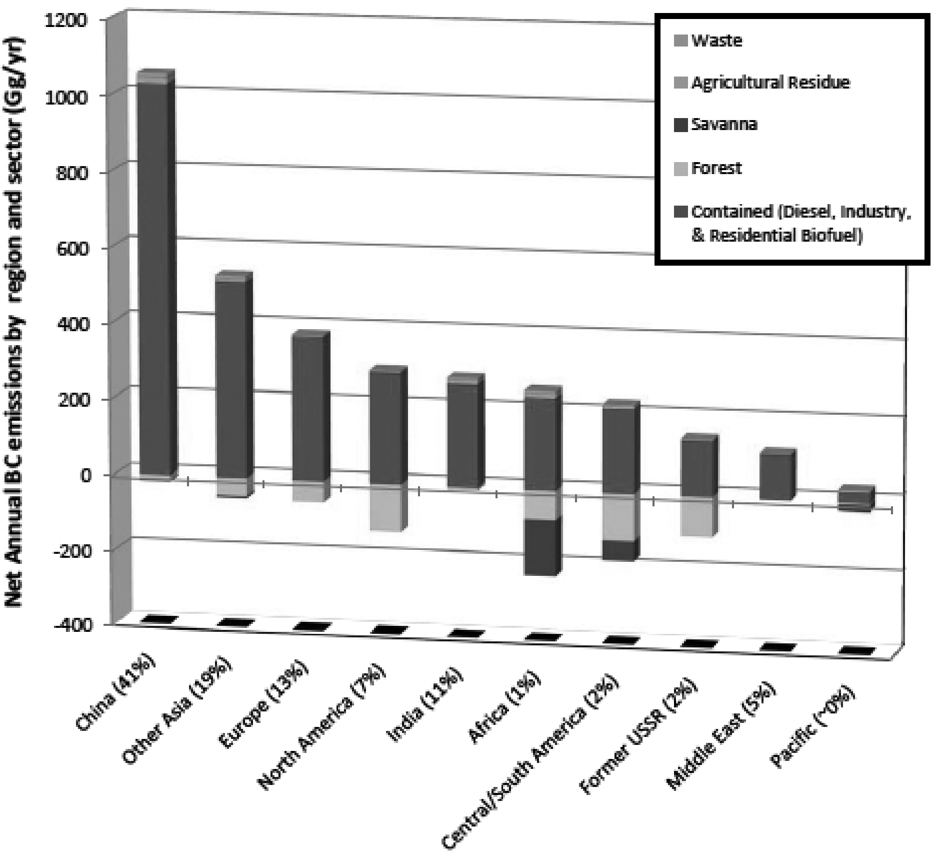
Data: Adapted from Bond et al. 2004
Source: Bice et al. 2008, slide 42

[2]The range reflects discrepancies between different emissions inventories; see Section 3.4.1 for discussion.

global BC emissions come from developing countries, as shown in Figure 4. Together, North America (United States and Canada) and the European Union contribute about 13 percent of gross BC emissions. While U.S. BC emissions account for less than 6 percent of the global total, the United States is the largest per capita emitter of BC, largely due to diesel mobile source emissions (Ramanathan and Feng 2009).

However, gross emissions of BC do not accurately reflect the radiative forcing impacts of various sectoral emissions. As noted above, emissions from contained combustion sources, such as diesel vehicles, industry, and residential biofuels, are dominated by warming aerosols, such as BC, while emissions from open combustion sources, such as agricultural and forest fires, contain a much higher proportion of cooling aerosols, such as organic carbon. As Bice et al. (2009) observe, net BC emissions, adjusted for the varying BC-to-OC ratios of different combustion sources, can serve as a proxy for

Figure 5: Net Annual Black Carbon Emissions (BC – 1/6 OC), by Region and Source Sector



Data: Adapted from Bond et al. 2004
Source: Bice et al. 2008, slide 43

impact on radiative forcing balance, as seen in Figure 5. Thus, while North America and Europe contribute an estimated 13 percent of gross global BC emissions, the two regions account for approximately 20 percent of the warming impact of net BC emissions. By contrast, while BC emissions from Africa make up 25 percent of gross global totals, most of that BC is emitted from open burning, which has a low BC-to-OC ratio. When adjusted for net warming impacts, BC emissions from Africa account for roughly one percent of global totals.

3.2 BLACK CARBON: HEALTH IMPACTS

There is a substantial body of literature documenting the adverse health impacts of exposure to PM from highway exhaust, diesel engine emissions, and indoor air pollution from smoky heating and cooking stoves. Diesel exhaust has been classified as a probable, likely, and reasonably anticipated human carcinogen by the International Agency for Research on Cancer, U.S. EPA, and U.S. National Toxicology Program, respectively, and regulated as a toxic air contaminant in California (IARC 1989; EPA 2003; NTP 2005; CARB 1998). Fine particulate matter ($PM_{2.5}$) is regulated as a criteria air pollutant in the National Ambient Air Quality Standards (NAAQS) established under the Clean Air Act. The size of particles is directly linked to their potential for adverse health effects, with greater morbidity and mortality associated with fine ($PM_{2.5}$) and ultrafine ($PM_{1.0}$) particles. Black carbon particles vary in size, but are generally less than 1.0 μm in diameter. Exposure to particle pollution has been positively associated with premature death in people with heart or lung disease, as well as with a range of chronic and acute adverse cardiovascular and respiratory impacts, including non-fatal heart attacks, asthma, chronic bronchitis, reduced lung function, and irregular heartbeat (EPA 2010a).

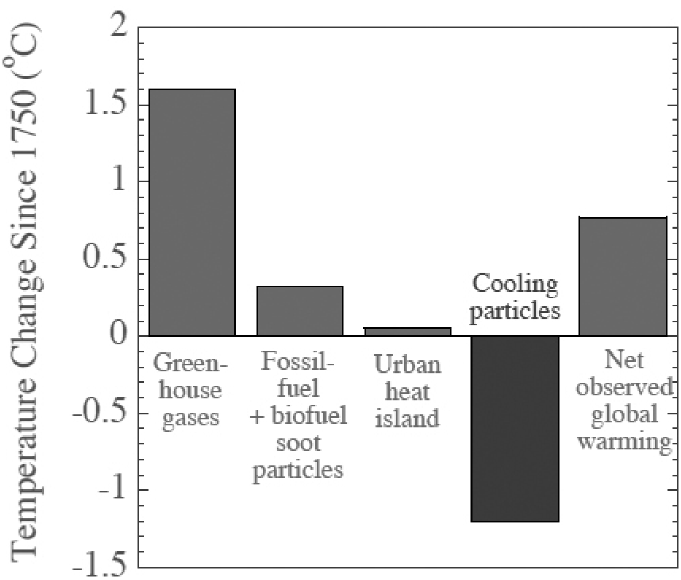
Worldwide, preliminary results of global atmospheric chemistry and transport modeling show that "anthropogenic air pollution causes 2 million to 3 million premature deaths due to cardiovascular and respiratory disease and 150,000 to 250,000 premature deaths due to lung cancer each year" (Casper et al. 2008, p.S221). Annually, 1.6 million deaths are attributable to exposure to indoor air pollution from solid fuel use. Indoor air pollution constitutes a major health threat in high-mortality developing countries, where exposure to indoor smoke from solid fuels is the fourth leading cause of premature death (WHO 2005). In the United States, an estimated 21,000 premature deaths in 2010 were attributable to exposure to mobile-source fine particle emissions, according to a 2005 analysis performed by Abt Associates (Schneider and Hill 2005).

The literature looking at the health impacts of exposure to BC per se is much smaller than the PM literature. Studies of BC exposure have found associations with decreased lung function in urban women and with decreased cognition in urban children (Suglia et al. 2008a; Suglia et al. 2008b). A June 2009 report from the Health Effects Institute found a 24 percent risk of premature death from cardiovascular disease attributable to soot exposure — twice as high as previously thought (Barringer 2009; Krewski et al. 2009). And results from the first published cohort study looking at the long-term health effects of BC in 66 cities over 18 years confirmed BC's negative health effects. The study also found some preliminary evidence to suggest that BC may be more damaging to health than undifferentiated $PM_{2.5}$ particles (though the evidence was not unequivocal) (Smith et al. 2009; Smith 2010).

3.3 BLACK CARBON: CLIMATE IMPACTS

Black carbon is a potent, short-lived climate-forcing agent, estimated to be the second or third greatest contributor to global warming after CO_2 and possibly methane (Ramanathan and Carmichael 2008; Bond and Sun 2005). It has been estimated that BC is responsible for 0.3°C, or roughly one-sixth of global warming since 1750 (See Figure 6) (Jacobson 2009). Although BC has a much shorter atmospheric lifetime than CO_2, it is a much stronger warming agent while aloft. According to testimony by climate scientist Tami Bond, a given mass of BC "adds 2-3 orders of magnitude more energy to the climate system than an equivalent mass of CO_2" (Bond 2007a, p.8).

Figure 6: Primary Contributions to Observed Global Warming, 1750 to Today (from Global Model Calculations)



Source: Jacobson 2009, slide 2

BC impacts climate primarily in three ways: through direct radiative effects, through reductions in snow albedo, and through interactions with clouds. The Intergovernmental Panel on Climate Change (IPCC) characterizes the direct effect as "the mechanism by which aerosols scatter and absorb shortwave and longwave radiation, thereby altering the radiative balance of the Earth-atmosphere system" (Forster et al. 2007, p.153). While aloft, BC aerosols absorb direct sunlight and re-emit it into the atmosphere as heat, producing changes in the hydrological cycle (reduced precipitation and evaporation) and surface visibility. Additionally, BC intercepts sunlight reflected by the earth's surface and clouds, thus reducing the amount of solar radiation reflected back into space by the earth-atmosphere system (Ramanathan 2007).

Black carbon particles that settle out of the atmosphere over snow- and ice-covered areas darken the normally bright surfaces, diminishing their reflectivity (albedo) and causing warming and melting (snow-albedo effects). As snow and ice melt, they absorb more heat, inducing more melting and warming and further lowering albedo, in a positive feedback loop. Additionally, BC aerosols exert more complex climate effects, such as so-called indirect effects on cloud formation and precipitation and semi-direct effects that lead to increased cloud burn-off (Sarofim et al. 2009).

Black carbon has a very short atmospheric lifespan. It is estimated that BC particles wash out of the atmosphere in a matter of days to weeks, "but this can vary by a factor of three depending on the combustion process and the location of the emission" (ICCT 2009, p.5). By contrast, methane emissions remain in the atmosphere for 8 to 12 years, and CO_2 molecules are gradually removed from the atmosphere, with 50 percent being removed within 30 years and the rest remaining for centuries. Thus, BC mitigation has immediate benefits for radiative forcing and can influence the rate of near-term climate change. CO_2 mitigation, by contrast, does not have the same near-term climate impacts, but avoids the emission of long-lived GHGs (LLGHGs) that contribute to the magnitude of long-term climate change.

Black carbon also exerts strong regional effects, and it is very important to distinguish between BC's global and regional climate impacts. Because BC has such a short atmospheric lifetime, BC-induced warming is often experienced in the region in which it is emitted. The magnitude of BC's radiative effects varies, depending on the region of emission, which can impact how easily particles are removed from the atmosphere and settle on solid surfaces (Reddy and Boucher 2007). The regional warming effects of BC are especially damaging over climatically sensitive regions, such as Asia, Africa, and the Arctic. Atmospheric Brown Clouds (ABCs) composed of BC mixed with sulfates, nitrates, organic acids, and dust produce climate dimming (a reduction in the amount of solar radiation reaching the Earth's surface), which has been especially pronounced over large cities in Asia, some of which experience dimming of 10 to 25 percent (Ramanathan 2007).

Black carbon emissions from regions north of 40° latitude — including parts of North America, Europe, and the former USSR — are most likely to travel to the Arctic, where they play a disproportionate role in the melting of Arctic sea ice (Ramanathan and Carmichael 2008). Most U.S. BC emissions don't travel as far as the Arctic, but are transported to Greenland (Ellen Baum, pers. comm., Sept. 16, 2010). Recent climate modeling studies have implicated BC in up to 50 percent of Arctic sea ice melting (Shindell and

Faluvegi 2009; Ramanathan and Feng 2009; Quinn et al. 2008; Jacobson 2010).

BC may be as important as CO_2 in causing rapid loss of glaciers over the Himalayas and Tibet (Ramanathan and Carmichael 2008; Xu et al. 2009; Menon et al. 2010). And within the United States, deposition of BC in the Sierra Mountains is causing early melting of snowpack, which is a contributor to severe water problems in California (Hadley et al. 2010). Additionally, some of BC's regional warming effects are amplified seasonally. For example, even though open burning typically has a net cooling effect due to the high OC-to-BC ratio of its emissions, springtime agricultural fires in Russia, Kazakhstan, and northeast China have been shown to contribute disproportionately to Arctic sea ice melting because they occur at a time when Arctic sea ice is already vulnerable to increasing daylight hours and seasonal melting (Pettus 2009).

3.4 AREAS OF SCIENTIFIC UNCERTAINTY/RESEARCH NEEDS

Black carbon has been described as "the 'dark horse' in the current climate debate" due to substantial uncertainties surrounding its atmospheric behavior, climate impacts, measurement, and sources (Gustafsson et al. 2009, p.495). This section explores some of the current areas of uncertainty regarding BC and provides a context for the complexity involved in formulating policy and regulatory approaches to reducing BC emissions. Several scientific assessments of the climate impacts of BC are currently underway or have been recently completed, including an international study bounding the role of BC in climate,[3] a report to Congress by the U.S. EPA (due in Spring 2011), and research being conducted by the United Nations Environment Program, the Arctic Council, and the United Nations Economic Commission for Europe's Convention on Long-Range Transport of Air Pollution. The climate science and policymaking communities eagerly anticipate the findings of these assessments.

3.4.1 BLACK CARBON EMISSIONS INVENTORIES

A number of global and regional inventories of BC have been published or reviewed in the scientific literature (cf. Bond et al. 2004; Kupiainen and Klimont 2007; Cofala et al. 2007; Sarofim et al. 2009). Total global emissions of BC have been estimated at 8.0 Tg/year, with an uncertainty range of 4.3 to 22 Tg/year (Bond et al. 2004). Various estimates of the uncertainty in published global BC inventories range from ±50% to about a factor of two (Ramanathan and Carmichael 2008; Bond et al. 2004). Global BC emissions figures are easier to come by than more localized data (Ben DeAngelo, pers. comm., Aug. 8, 2009), and even greater uncertainty — a factor of two to five — accompanies regional-scale estimates of BC emissions (Ramanathan and Carmichael 2008). Uncertainties in inventories are especially large for BC emissions from non-

[3] "Bounding the Role of Black Carbon in Climate" is being conducted by the IGAC (International Global Atmospheric Chemistry)/SPARC (Stratospheric Processes and their Role in Climate) Atmospheric Chemistry & Climate Initiative.

OECD countries and for BC emissions from open biomass burning, such as wildfires and savannah burning (Bice et al. 2009; DeAngelo 2009). Additionally, uncertainties in emissions inventories are one of the main constraints on accurate modeling of BC's climate impacts within climate models (Ramanathan 2010).

Several factors contribute to the uncertainty found in BC emissions inventories. The amount of BC emitted during combustion can vary widely, depending on the fuel source, type of combustion technology, efficiency of the combustion process, and whether any emissions control technologies or practices are employed (DeAngelo 2009; ICCT 2009). "[E]missions can vary even among similar technologies" (Bond et al. 2004, p.2) and "for different kinds of use of a single combustion source" (Sarofim et al. 2009, p.16). For some BC emissions sources, such as cookstoves, biomass burning, traffic, and construction equipment, the large number of dispersed, individual combustion units, operating at varying efficiencies, adds an additional layer of uncertainty relative to CO_2 or SO_2 emissions (Bachmann 2009). For example, 10 percent to 20 percent of the units in a vehicle fleet can be responsible for up to 50 percent of emissions from that fleet (Bond 2007a).

Variation in methods for defining and measuring BC also contributes to the level of uncertainty regarding emissions inventories. Different researchers may define BC differently (Sarofim et al. 2009). Measurements of BC can vary by up to a factor of two depending on whether thermal or optical measurement techniques are employed (Sarofim et al. 2009; Hitzenberger et al. 2006). Measurement techniques can also vary with the nature of the study, with health and climate communities favoring different measurement methods (Smith 2010). Different inventories may use different size thresholds in measuring BC (Sarofim et al. 2009). Additionally, top-down studies that rely "on measured ratios of BC to total carbon or other aerosol components" have been shown to reach different conclusions regarding source apportionment of BC than bottom-up studies that derive BC emissions from fuel consumption and laboratory-derived emissions factors (Gustafsson et al. 2009, p.495; Sarofim et al. 2009).

3.4.2 MAGNITUDE OF BLACK CARBON RADIATIVE EFFECTS

Radiative forcing (RF) is a measure of the change in the Earth's energy balance produced by a climate agent. RF is typically measured in watts per square meter (Wm^{-2}), and can be estimated from climate models or derived from observations. In the IPCC 2007 Assessment Report, the model-based estimate of the globally averaged RF attributable to all major sources of BC (the so-called "direct effects") was 0.34 (±0.25) Wm^{-2}. The IPCC estimate of RF attributable to BC deposited on snow- and ice-covered surfaces (the "snow-albedo effects") was 0.1 (±0.1) Wm^{-2} (Forster et al. 2007). Ramanathan and Carmichael's (2008) more recent estimate of BC-attributable direct RF of 0.9 Wm^{-2}, based on airborne, surface, and satellite observations, differs from the IPCC estimates by a factor of three.

Table 1: Estimates of Globally Averaged Radiative Forcing/ Atmospheric Radiative Impact from Black Carbon

	IPCC (2007)	Ramanathan & Carmichael (2008)	Bond (2010)*
Direct effects	0.34 Wm^{-2} [±0.25]	0.9 Wm^{-2} [range: 0.4 to 1.2 Wm^{-2}]	0.46 Wm^{-2} [range: N/A]
Snow-albedo effects	0.1 Wm^{-2} [±0.1]	0.1 to 0.3 Wm^{-2}	0.05 Wm^{-2} [range: N/A]
Total RF effects	0.44 Wm^{-2} [±0.35]	1.0 to 1.2 Wm^{-2} [±0.4]	0.51 Wm^{-2} [range: N/A]

Source: Forster et al. 2007; Ramanathan and Carmichael 2008; Ramanathan 2007; Bond 2010

Table 1 compares some of the different estimates of BC's globally averaged radiative forcing. To place these figures in context, the IPCC estimates the RF from BC as 9 percent to 48 percent as large as the RF attributable to CO_2. Ramanathan and Carmichael estimate BC-attributable forcing as 25 percent to 88 percent that of CO_2, which would make BC the second greatest contributor to global warming.

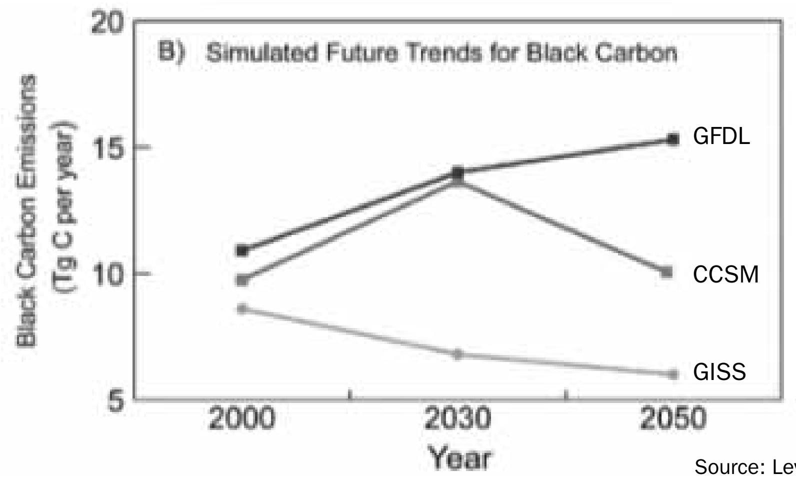
As described in a summary of BC's climate impacts produced by the International Council on Clean Transportation (ICCT), the radiative properties of BC depend on its "mixing state" — that is, whether it is incorporated within other particles ("internally mixed") or separate from other particles ("externally mixed"). "Model simulations and lab studies show that black carbon is predominantly internally mixed, which is associated with larger positive radiative forcing than external mixing" (n.7, p.10). Since most of the climate models IPCC used to estimate the direct RF of BC didn't take mixing state into account, the IPCC figures are conservative (ICCT 2009). Tami Bond estimates BC's atmospheric radiative impact, including mixing, as about 0.46 Wm^{-2}, with an additional 0.05 Wm^{-2} forcing by BC on snow.

3.4.3 NET CLIMATE IMPACT OF BLACK CARBON AND ORGANIC CARBON EMISSIONS AND CONTROL TECHNOLOGIES

BC is a potent climate-warming agent, but there are substantial uncertainties involved in accurately determining BC's net climate impacts. BC is typically co-emitted with OC and other substances that scatter sunlight, partially offsetting BC's warming effects. While BC warms more than OC cools on a per-ton basis, uncertainties surrounding BC (and OC) emissions inventories, including the measurement and definitional issues

*Bond's estimates are for "atmospheric radiative impact" rather than radiative forcing. Bond describes "atmospheric radiative impact" as "similar to forcing, except that it refers to all the material in the atmosphere, not the difference between present day and 1750. IPCC's estimate of atmospheric radiative impact would have been similar to this one. Because emissions in 1750 are poorly known, and because all present-day emissions could be considered for mitigation, I prefer to present the total impact rather than subtracting a pre-industrial baseline. Models summarized by IPCC did not include the mixing effect in some models, but did include some models with high emissions." (Bond 2010, n.ii) described above, make it difficult to accurately determine the net climate impacts of BC and OC globally and regionally. A 2008 report of the U.S. Climate Change Science Program (CCSP) attributes uncertainties in future climate impacts of short-lived gases and particles in part to the large range of future emissions projections for short-lived climate forcers such as BC (Levy et al. 2008, p.3). The report presents three "plausible but very different emission trends" for BC through 2050, based on the results of three widely used comprehensive climate models.[4] While all three models followed the A1B socioeconomic scenario used in the IPCC's Fourth Assessment Report (IPCC 2007), they projected different emissions trends for BC. The difference in projected direction and magnitude of BC emissions is shown in Figure 7.

Figure 7: Three Simulated Black Carbon Emissions Trends Based on Different Global Comprehensive Climate Models



Source: Levy et al. 2008, p.30

The interaction of both BC and OC with clouds is poorly understood and one of the greatest contributors to the continued uncertainty regarding BC's net climate impacts (Bond 2010). As the abovementioned CCSP report notes, "The climate modeling community as a whole cannot yet produce a credible characterization of the climate response to particle/cloud interactions" (Levy et al. 2008, p.5). Several of this study's interviewees pointed me to recent research that suggests that the cooling produced by BC's indirect and semi-direct effects on clouds may potentially "cancel" its direct global warming impacts, resulting in a minimal net positive or even net negative global radiative forcing (i.e., cooling) (Koch and Del Genio 2010; Chen et al. 2010;[5] Bauer et al. 2010). Other factors that contribute to uncertainties in determining the net climate

[4]The global comprehensive climate models employed were produced by the National Oceanic and Atmospheric Administration's Geophysical Fluid Dynamics Laboratory (GFDL), NASA's Goddard Institute of Space Studies (GISS), and the Community Climate System Model (CCSM) developed in part at the National Center for Atmospheric Research.

[5]One important limitation of the study by Chen et al. (2010) is that it did not consider the snow-albedo effects of BC when estimating net climate impacts (Levitan 2010).

impacts of BC include the short atmospheric lifetime of both BC and OC; the timing and location of BC and OC emissions, both of which impact their relative warming and cooling effects; particle mixing state; and the fact that BC can react chemically with other short-lived species in polluted areas (Keating and Sarofim 2009; Bachmann 2009; Penner et al. 2010).

As with determining net climate impacts of BC emissions, predicting the net climate impact of BC control strategies also involves uncertainties because control strategies that reduce warming BC emissions also reduce cooling co-emitted species, such as OC and sulfates (Smith et al. 2009). Generally, control measures that reduce emissions with the highest ratio of warming BC to cooling OC particles will result in net climate cooling. Yet, as noted in Section 3.3 and further explored in Sections 5.1 and 5.2, both the location and timing of emissions of BC and co-emitted species can influence the net climate impact of emissions control strategies.

Additionally, some BC-reduction technologies may increase net CO_2 emissions. For example, replacing inefficient-burning biomass and biofuel heating and cooking stoves with more efficient modern units that use cleaner fuels, such as natural gas or liquefied petroleum gas, could virtually eliminate BC emissions, but could also potentially increase net emissions of CO_2 from increased fossil fuel consumption (Bachmann 2009). Similarly, retrofitting diesel engines with tailpipe diesel particulate filters (DPFs), a strategy used to control BC emissions from diesel vehicles, can reduce warming BC emissions by up to 99 percent, but may slightly decrease fuel economy, resulting in increased CO_2 emissions (Sarofim et al. 2009; Boucher and Reddy 2008). As Hill (2009, p.6) observes, "The net climate benefit of a diesel particle filter is limited to the extent that it overcomes incremental CO_2 and black carbon emissions resulting from any related increased fuel use ('fuel penalty')." Yet Hill's analysis of retrofitting Class 8 trucks with DPFs finds a CO_2-equivalent climate benefit to DPF use as long as the DPF-associated fuel penalty is less than 22 percent — far higher than the typical or highest documented fuel penalties found in the published literature on DPF use.

Section 4: Why Act Now? Arguments for Addressing the Climate Impact of Black Carbon Emissions

A review of the climate science and policy literature as well as interviews with climate scientists, regulators, and advocates reveals several arguments for addressing the climate impacts of BC emissions.

4.1 REDUCING BLACK CARBON EMISSIONS OFFERS AN OPPORTUNITY TO ACHIEVE NEAR-TERM CLIMATE IMPACTS AND TO AVERT DANGEROUS CLIMATE TIPPING POINTS

Many GHGs remain in the atmosphere for decades to centuries and longer. Fifty percent of a given emission of CO_2 will leave the atmosphere within 30 years, an additional 30 percent will be removed within a few centuries, and the balance will remain for millennia (Denman 2007). Some of the most potent, high-GWP GHGs, such as some perfluorocarbons (PFCs) and sulfur hexafluoride (SF_6), remain in the atmosphere for millennia. Because of the relatively long atmospheric residence time of LLGHGs, atmospheric concentrations, temperatures, and impacts such as sea-level rise will continue to increase long after global CO_2 emissions are reduced. By contrast, BC washes out of the atmosphere in a matter of days to weeks. As one of the shortest-lived climate-forcing agents, BC offers an opportunity to achieve near-immediate climate impacts through reduction strategies, which have been advocated for several reasons.

In its 2007 Assessment Report, the IPCC recommended that global atmospheric concentrations of GHGs be held to under 450 parts per million (ppm) carbon dioxide equivalent ($CO_{2\text{-}e}$) in order to produce a greater than 50 percent chance of keeping mean global warming under 2°C. More recently, evidence of faster-than-expected warming has led some scientists to argue for even lower stabilization targets of 350 ppm $CO_{2\text{-}e}$. While the magnitude and speed of $CO_{2\text{-}e}$ emissions reductions required to achieve these stabilization targets have been the subject of much scientific and academic debate, most emissions scenarios and emissions reduction proposals have been based exclusively on emissions of LLGHGs and have not factored in the climate-warming effects of BC and other short-lived climate forcers (SLCFs).

In the last decade, as awareness of BC's warming impacts has grown among scientists and climate policy advocates, there have been increasing calls for rapid reductions in BC emissions as a way to prevent crossing temperature thresholds for abrupt climate change and to avoid irreversible climate tipping points, such as the melting of the Arctic sea ice, disintegration of the Greenland ice sheet, and retreat of the Himalayan glaciers (cf. Hansen et al. 2008; Bluestein, Rackley, and Baum 2008; Quinn et al. 2008; Jacobson 2010; Molina et al. 2009; Xu et al. 2009). Quinn et al. (2008, p.1724) have pointed to targeted reductions in SLCFs as a potential fast-action lever to reduce Arctic warming in a timeframe that GHG reductions cannot achieve: "Reductions in the atmospheric burden of CO_2 are the back-bone of any meaningful effort to mitigate climate forcing. But even if swift and deep reductions were made, given the long lifetime of CO_2 in the atmosphere, the reductions may not be achieved in time to delay a rapid melting of the Arctic." Similarly, Mark Jacobson, whose research suggests that aggressively eliminating BC emissions from fossil fuel and biofuel combustion could reduce Arctic warming by up to 1.7°C within 15 years, has stated, "Controlling soot may be the only method of significantly slowing Arctic warming within the next two decades" (Jacobson 2010; ClimateWire 2010, n.p.).

Scientists and climate advocates have suggested that substantial reductions in BC emissions may be equivalent to one to two decades of $CO_{2\text{-}e}$ emissions reduction efforts (Ramanathan 2007; Wallack and Ramanathan 2009; Kopp and Mauzerall 2010). Some have argued that substantial BC mitigation efforts could "buy" valuable time for countries to develop and implement GHG reduction efforts or allow for a more gradual GHG emissions reduction schedule (cf. Bice et al. 2009; Baron, Montgomery, and Tuladhar 2009; Ramanathan and Victor 2010). Conversely, failure to initiate global BC reduction efforts could "cost" one to two decades, necessitating swifter or deeper cuts in GHG emissions to hold to the same climate stabilization targets (Bice et al. 2009). One to two decades is not a trivial amount of time, given the threat of abrupt climate change. A widely referenced 2009 report by McKinsey & Company on using current technologies to achieve GHG reductions stresses the urgency of implementing $CO_{2\text{-}e}$ abatement actions: "A 10-year delay in taking abatement action would make it virtually impossible to keep global warming below 2 degrees Celsius" (McKinsey & Co. 2009, p.8).

It should be noted, however, that a recent National Research Council report (2010, p.72) has rejected the "buying time" rationale for reducing SLCF emissions as "fallacy," arguing that SLCFs and LLGHGs impact completely different climate phenomena. Reducing BC and other SLCFs, the authors argue, can limit peak warming, which can impact tipping points and affect the rate of near-term climate change. However, reduction of BC and other SLCFs don't actually "buy" any time for reducing CO_2 because only efforts to mitigate CO_2 and other LLGHGs can achieve long-term climate stabilization.

Another compelling reason to reduce short-lived climate warmers, such as BC, that has been proposed by Penner et al. (2010, p.587) is to facilitate better understanding of the climate system:

"We argue that ... to provide short-term relief from climate warming, the short-lived compounds that induce warming need to be brought under control within a timescale of a few decades. The resulting changes in atmospheric composition and climate forcing must be accurately measured and modelled for the duration of these emissions reductions. Following this strategy, we will then be able to disentangle the warming and cooling contributions from carbon dioxide and short-lived pollutants, hence placing much tighter constraints on climate sensitivity, and therefore on future climate projections."

4.2 REDUCING BLACK CARBON EMISSIONS IS NEEDED TO BALANCE THE CLIMATE IMPACTS OF A MULTI-POLLUTANT AIR QUALITY STRATEGY

While BC has potent climate warming effects resulting from its absorptive properties, many other aerosols — especially organic carbon, sulfates, and nitrates — scatter solar radiation, resulting in atmospheric cooling. In its 2007 Assessment Report, the IPCC estimated the total direct radiative forcing from all anthropogenic aerosol emissions as -0.5 (-0.9 to -0.1) Wm^{-2} and an indirect cloud albedo forcing of -0.7 (-1.8 to -0.3) Wm^{-2} (IPCC 2007). Approximately two-thirds of this cooling effect can be attributed to sulfate aerosols produced from sulfur dioxide (SO_2) emissions (Bice et al. 2009).

Over the last three decades, U.S. air quality regulation has resulted in a substantial decrease in SO_2 and nitrogen oxide (NO_x) emissions. The EPA, for example, reports a 56 percent reduction in U.S. SO_2 emissions from 1980 to 2008 (EPA 2009a). Yet the same air quality policies that produce strong public health and environmental benefits also produce climate disbenefits in that they also reduce the climate cooling impacts of the air pollutants they target. Thus, another frequently cited reason to pursue reduction of warming BC emissions is to counteract the "unmasking" of greenhouse gas warming brought on by air pollution controls on cooling aerosols (Ramanathan 2010). As interviewee Marcus Sarofim, a AAAS science and technology policy fellow, explained, "One of the important roles of BC is to allow us to keep reducing other air pollutants that have cooling influences and counterbalance [them] by reducing a pollutant that has a warming influence. That's one of the key issues" (Marcus Sarofim pers. comm., July 28, 2010). Moreover, reducing BC emissions allows us to counterbalance rapid reductions of short-lived cooling aerosols with reductions of a short-lived warming agent whose atmospheric lifetime operates on a similar timescale.

4.3 REDUCING BLACK CARBON EMISSIONS YIELDS STRONG HEALTH AND AIR QUALITY CO-BENEFITS

The health and air quality co-benefits of reducing BC emissions provide another argument to pursue BC abatement strategies. Generally, the public health benefits from controlling emissions of PM apply to BC. Given the morbidity and mortality associated with exposure to PM and BC, even if BC emissions had no climate impact, the public health benefits alone of BC reductions provide compelling reason to pursue mitigation strategies (cf. ICCT 2009; Molina et al. 2009). In this sense, the strong scientific evidence for health and air quality benefits of BC reductions functions as a policy "hedge" for any remaining uncertainty regarding the climate benefits of BC reductions. Many interviewees referred to BC emissions reduction as a "win-win" or "no-regrets" strategy because of the potential to achieve both health and climate "wins" through BC reduction (cf. Marcus Sarofim pers. comm., July 28, 2010; Ben DeAngelo, pers. comm., Sept. 15, 2010; John Guy and Michael Geller, pers. comm., Aug. 14, 2010). Moreover, there are equity dimensions to reducing some sources of BC, such as heavy-duty diesel emissions, as the negative health and air quality impacts from some BC emissions sources tend to disproportionately affect urban environmental justice communities (EPA 2001).

Additionally, because of the local and regional nature of the health and air quality impacts associated with BC emissions, the health and air quality benefits that accrue from BC abatement measures tend to be experienced where they are implemented, which may contribute to the political attractiveness of those measures (Wallack and Ramanathan 2009).

4.4 THE TECHNOLOGY NEEDED TO REDUCE BLACK CARBON IS WIDELY AVAILABLE

As scientists and policymakers look for ways to achieve broad reductions of GHG emissions, many of the technologies being considered, such as carbon capture and sequestration, cellulosic ethanol, and hydrogen-powered vehicles, are still in the early stages of development, or have not yet been deployed at the scale needed to achieve a broad climate impact. By contrast, the technologies shown to be effective in reducing the major sources of BC emissions, such as diesel particulate filters and more efficient or low-emission stoves for residential cooking and heating, are currently available, and widespread deployment can result in substantial reductions in BC emissions. Recent studies have estimated that full deployment of existing BC-mitigation technologies, mainly in the mobile source and residential sector, could yield a 50 percent reduction in global BC emissions by 2030 (Cofala et al. 2007; Wallack and Ramanathan 2009).

Section 5: Reducing the Climate Impacts of Black Carbon — Policy Challenges

Just as the science of BC's climate impacts is complex, developing a policy response to reducing the climate impacts of BC is not a straightforward proposition. There is a broad range of expert opinion as to the most effective policy approaches to addressing BC's climate impacts. Before discussing specific policy instruments, it is worth exploring some crosscutting challenges to developing and implementing a policy response to the climate impacts of BC.

5.1 SCIENTIFIC UNCERTAINTY REGARDING THE TOTAL CLIMATE IMPACTS OF BLACK CARBON AND OTHER SHORT-LIVED CLIMATE FORCERS

There are areas of emerging consensus on some aspects of BC's climate impacts. The scientific evidence for BC's net warming impacts is strongest for closed combustion of low-sulfur fossil fuels, which produce emissions with a high BC-to-OC ratio, and for emissions near snow- and ice-covered regions, where the warming impacts of BC deposited on high-albedo surfaces add to its direct radiative warming impacts (ICCT 2009). Additionally, over highly reflective surfaces like snow and ice, local positive forcing from normally cooling species co-emitted with BC, such as OC, may partially or wholly offset their cooling impacts (ICCT 2009). Nonetheless, continued scientific uncertainty over BC's net climate impacts is one of the main obstacles to crafting BC-specific control policies. In its 2009 GHG endangerment finding, the U.S. EPA stated that it "recognizes that black carbon is an important climate forcing agent and takes very seriously the emerging science on black carbon's contribution to global climate change in general and the high rates of observed climate change in the Arctic in particular" (EPA 2009b, p.66520). Nonetheless, the EPA decided not to include BC among the global warming agents it seeks to regulate under the Clean Air Act, due in part to "...significant scientific uncertainties about black carbon's total climate effect."

While BC's strongly warming absorptive properties are widely acknowledged, there is lack of expert agreement as to whether the scientific evidence is sufficient to warrant a policy response to BC's global or regional climate impacts at this time, or what that policy response should look like. Some climate scientists and policy advocates conclude that despite the lingering scientific uncertainty regarding BC's total climate impact, we know enough to begin acting on BC as a climate-warming agent for some emissions sources (cf. Molina et al. 2009; Grieshop et al. 2009; Wallack and Ramanathan 2009; Jacobson 2010). As interviewee Terry Keating, a senior environmental scientist with EPA's Office of Air and Radiation, explained (pers. comm., July 28, 2010):

"For particular source categories, like diesel, where it's very clear which direction overall net forcing implications are, it's very easy to make the argument we should do something

about those. Other source categories, because of the multi-pollutant mix, you're not just reducing BC—you're also reducing a mixture of pollutants (BC, OC, sulfates, nitrates, NO_x *itself, HCs) which have an impact on the overall chemistry and overall RF coming out. Our understanding of the interlinkages and counterbalancing of those effects is still evolving. I'm not sure we do know enough to design strategies to address all the potential sources of BC."*

Others argue that uncertainty regarding BC's net global climate impacts warrants a cautious approach to acting on BC as a target of climate mitigation. For example, in an online NASA/GISS science brief, atmospheric scientist Dorothy Koch writes that the results of recent global modeling studies of soot effects on clouds "suggests the need for caution when pursuing mitigation of soot in order to cool climate" (Koch 2010, n.p.).

5.2 RANGE OF EXPERT OPINION ON PRIORITY BLACK CARBON MITIGATION TARGETS, CRITERIA, GOALS, AND SCALE

Within the climate literature and among interviewees, BC emissions from the diesel mobile source sector and BC emitted in proximity to snow and ice rise to the top as potential mitigation targets, based on the strength of the scientific evidence for BC's warming impacts from those sectors and regions. However, interviews conducted for this study and review of the relevant literature offered a wide range of opinion regarding priority targets for BC mitigation efforts and the best way to determine them.

Emissions sources and sectoral targets: Sources and sectors with the highest net proportion of warming emissions to cooling co-emissions are prime targets for BC reduction efforts. Within the climate science and policy literature and in the interviews I conducted, there is broad support for controlling BC emissions from the on- and nonroad diesel mobile source sectors, which, among BC sources, produce emissions with the highest BC-to-OC ratio (cf. Jacobson 2010; Ramanathan and Xu 2010; Kopp and Mauzerall 2010; Unger, Shindell, and Wang 2009). A 2009 ICCT white paper resulting from an international meeting of experts on BC's climate impacts includes on-road transport and off-road agricultural and construction equipment among its "No-regret" BC mitigation targets (ICCT 2009). A 2010 Yale Climate and Energy Institute workshop of climate scientists and policymakers reportedly reached a similar conclusion regarding diesel vehicles as an unambiguous BC reduction target (Banerjee 2010).

Some studies have identified the residential heating and cooling sector as a priority target for BC reduction efforts, especially in developing countries where this sector is the largest contributor of BC emissions (cf. Ramanathan and Carmichael 2008; Levy et al. 2008; Molina et al. 2009; Jacobson 2010). Yet there is greater uncertainty regarding net climate impacts from this sector compared to the diesel vehicle sector, due to the climate impacts of co-emissions. For example, a recent modeling study conducted by Bauer et al. (2010, p.7439), which accounted for both direct radiative and indirect microphysical properties, found that "...black carbon mitigation scenarios generally showed reduced radiative fluxes when sources with a large proportion of black carbon, such as diesel, are reduced" but did not find a consistent net warming from biofuel combustion. Research by Kopp and Mauzerall (2010) suggests that strongly warming lower-temperature residential and industrial coal combustion (common in developing countries) may be a better mitigation target than residential biofuel-based cookstoves from a climate perspective.

Potential priority sub-sectoral targets for reducing the climate-warming properties of BC emissions include off-road diesel vehicles and equipment and poorly tuned or older "superemitting" on-road diesel vehicles (Bond 2007; Bachmann 2009 citing Bond 2009), and low-sulfur coal combustion in residential heating and cookstoves and industrial brick kilns (ICCT 2009; Kopp and Mauzerall 2010).

Regional and seasonal targets: Within the climate science and policy literature, a strong case is emerging to reduce BC emissions produced in or near snow- and ice-covered regions, where BC's snow-albedo effects add to its direct warming effects (cf. Quinn et al. 2008; Bluestein, Rackley, and Baum 2008; Xu et al. 2009). Additionally, there is evidence that emissions from sources that are typically net cooling, such as residential biofuels, high-sulfur fossil fuels, and open burning, may be less cooling, or even net warming, when produced in proximity to highly reflective snow- and ice-covered surfaces (Bachmann 2009; Quinn et al. 2008; Flanner et al. 2009).

Molina et al. (2009, p.20617) recommend reducing BC emissions as a "fast-action mitigation strategy" to lessen the risk of abrupt climate change, "giving priority to emissions that affect regions of snow and ice, including the Arctic, Greenland, and the Himalayan-Tibetan glaciers." The aforementioned ICCT white paper includes near-Arctic emissions from biomass (forest and agricultural fires) and commercial shipping, as well as near-glacier emissions from residential heating and cooking with biofuels, among its "No-regret" BC climate mitigation targets. Among the interviews I conducted, targeting regional BC emissions near snow and ice was mentioned frequently. For example, John Bachmann, environmental consultant and former science director for EPA's Office of Air Quality Planning and Standards, suggested (pers. comm., Aug. 10, 2010), "We know so much more about BC on ice that we should focus on snow and ice areas for BC." Similarly, Ben DeAngelo, senior analyst in the Climate Change Division of EPA's Office of Atmospheric Programs, observed (pers. comm., Sept. 15, 2010), "The Arctic may be one of the places where it makes most sense to address BC for regional climate change reasons." Additionally, as noted in Section 3.3, some of BC's regional warming effects are amplified seasonally, suggesting that targeted seasonal mitigation strategies should also be considered (Quinn et al. 2008; Flanner et al. 2009).

Health/air quality considerations: Despite any lingering scientific uncertainty regarding the net climate benefits of BC reductions, the evidence for the health and air quality benefits of reducing BC-rich emissions is robust. Thus, some interviewees suggested trying to maximize health co-benefits by prioritizing BC reductions in areas with the greatest concentration of emissions sources and receptors, such as urban

PM non-attainment areas or ports in the U.S. or from residential heating and cooking stoves in developing countries (Terry pers. comm., Aug. 11, 2010; Durwood Zaelke, pers. comm., July 27, 2010). Others suggested prioritizing "win-win" BC reduction efforts that maximize climate and health/air quality co-benefits simultaneously (John Bachmann, pers. comm., Aug. 10, 2010; Marcus Sarofim, pers. comm., July 28, 2010; Conrad Schneider, pers. comm., Sept. 21, 2010), a view that also appears in the climate science and policy literature. A 2008 synthesis and assessment report from the U.S. Climate Change Science Program concludes: "Reductions of short-lived gas and particle emissions from the domestic fuel-burning sector in Asia appear to offer the greatest potential for substantial, simultaneous improvement in local air quality and reduction of global warming. Reduction in emissions from surface transportation would have a similar impact in North America" (Levy et al., 2008, p.2). Similarly, in April 2010 testimony to the House Select Committee on Energy Independence and Global Warming, NASA/GISS senior scientist Drew Shindell states:

"Research suggests that strategies to simultaneously improve air quality and mitigate global warming differ from region to region. Preliminary results from ongoing work at my institute suggest that in the United States, reductions in overall emissions from diesel vehicles appears to be a method to achieve both goals, with a substantial part of the climate benefits coming from reduced black carbon." (Shindell 2010, n.p.).

Cost-effectiveness considerations: As is the case with CO_2 mitigation, there is a broad range of costs associated with different BC emissions reduction strategies and technologies, and those costs necessarily impact the feasibility of different policy options for addressing BC's climate impacts. Preliminary cost assessment of BC emissions reduction technologies conducted by Bond and Sun (2005) suggests that BC reductions range from inexpensive to quite costly relative to other CO_2 reduction strategies when climate benefits are compared on a $CO_{2\text{-}e}$ basis. In Bond and Sun's analysis, diesel emissions reduction strategies do not appear cost-effective relative to the per-ton cost of CO_2 reductions (assuming $10/ton for CO_2, at 2005 prices) when evaluated over a 100-year time horizon, but may be more cost-effective relative to CO_2 reductions when evaluated over a 20-year horizon (which captures more of the near-term value of reducing BC — see Section 5.3 for further discussion). Nonetheless, Bond and Sun's research suggests that BC emissions reductions from diesel sources are far more expensive, on a per-ton $CO_{2\text{-}e}$ basis, than reductions from residential solid fuel combustion sources, such as wood or coal cookstoves. Research conducted by Rypdal et al. (2009a, p.625) concludes "that prioritizing emission reductions in Asia represents the most cost-efficient global abatement strategy for BC because Asia is (1) responsible for a large share of total emissions, (2) has lower abatement costs compared to Europe and North America and (3) has large health cobenefits from reduced PM emissions."

It is typically easier to estimate the costs of climate mitigation measures than to estimate the value of avoided climate-related damages (Nemet, Holloway, and Meier 2010), which complicates consideration of the cost-effectiveness of reducing BC emissions. As interviewee Ben DeAngelo observes (pers. comm., Sept. 15, 2010):

"... It's really hard and it's not necessarily clear what climate change impacts to attribute just to black carbon and then how to monetize those climate damages/benefits due to black carbon. The main climate justifications for reducing BC are 1) near-term benefits that help reduce Arctic ice loss and glacier loss elsewhere in world, and 2) less disruption of local/regional precipitation patterns, and none of those lend themselves easily to monetization."

The cost-effectiveness of reducing BC emissions depends on whether one looks at climate impacts exclusively or whether the health and air quality benefits of BC reductions are also considered. For example, "When the economic benefits from avoided health impacts are included, many projects to control black carbon and carbon monoxide may have higher benefits than costs even without including the value of reduced warming" (Shindell 2010, n.p.). Similarly, the estimated value of health benefits of reducing U.S. mobile source PM emissions may exceed diesel retrofit costs by a factor of 10 (Bachmann 2009; Fann, Fulcher, and Hubbell 2009). Additionally, widespread adoption of particular BC-reduction technologies, such as retrofitting in-use diesel engines with DPFs, can reasonably be expected to drive down mitigation costs due to technology learning curves and economies of scale, increasing the cost-effectiveness of some BC abatement strategies.

Geographic scale considerations: Because BC exerts both global and regional climate impacts, there is a range of opinion as to the most effective geographic scale for policy mechanisms to drive BC reductions. Some in the climate community urged inclusion of BC and other SLCFs in a global climate change agreement prior to the 2009 COP-15 talks in Copenhagen (Moore and MacCracken 2009; Garderet and Emmett 2009). Others, such as Rypdal et al. (2005), view BC as a poor candidate for global climate agreements due to continued uncertainties regarding BC's climate effects and emissions inventories. Rather, they argue, regional climate agreements may be better suited to address the regional climate impacts of aerosols and tropospheric ozone (O_3) precursors, including negative RF, as these impacts tend to be confined to the regions in which emissions occur. Additionally, air quality and climate concerns may be more easily integrated into regional agreements, which are also potentially more amenable to addressing additional sources of climate forcing, such as changes in albedo from land-use change. Ultimately, the authors conclude that aerosols may be best addressed through regional climate agreements with links to a global agreement, though they question whether incorporating short-lived gases would threaten "the political feasibility of an agreement that includes them — in terms of both added complexity and perceived fairness" (p.41).

Wallack and Ramanathan (2009) also propose regionally tailored agreements as better suited to reducing BC and O_3, whose sources vary by region. Regional agreements are more adaptive and easier to update than global agreements with many signatories, they argue, and thus better suited to quickly addressing the complex links and evolving science related to climate change, emissions, and human activities.

5.3 DIFFICULTY COMPARING CLIMATE IMPACTS OF LONG-LIVED GREENHOUSE GASES AND SHORT-LIVED CLIMATE FORCERS

Having a common scale or metric for comparing the climate impacts of different emissions is a very useful tool for multi-gas climate policy and planning. A climate metric allows policymakers to compare and weigh the relative climate impacts and cost-effectiveness of different GHG reduction measures or facilitates market-based trading within a "basket" of GHG reduction options, as in the Kyoto Protocol.

One widely used climate metric is the global warming potential (GWP), which was created by the IPCC in 1990 to compare the climate impacts of different GHGs to CO_2. GWP measures the integrated radiative forcing of a pulse emission of a gas or aerosol over a defined time horizon — typically 20, 100, and 500 years — and can be used to convert various GHG emissions into their CO_2 equivalents. For example, the 100-year GWP (GWP_{100}) of methane, according to the IPCC 2007 Assessment Report, is 25 — meaning that "a pulse emission of methane will produce over its lifetime twenty-five times the radiative forcing of the same quantity of carbon dioxide within a 100-year period" (ICCT 2009, p.6). GWP_{100} is the dominant CO_2-equivalency framework currently employed in many global, regional, and national climate policies, including the United Nations Framework Convention on Climate Change (UNFCCC), the EU Emissions Trading System, and California's Global Warming Solutions Act (AB32).

While GWP is suitable for comparing the climate impacts of LLGHGs to each other, it is widely regarded as a problematic metric for comparing the climate effects of LLGHGs and SLCFs (cf. Rypdal et al. 2005; Sarofim 2010; Bachmann 2009). Part of the problem with using GWP to compare SLCFs and LLGHGs is that GWP is a globally averaged metric, which assumes that "any two emissions produce equivalent radiative forcing regardless of their location" (ICCT 2009, p.7). This assumption is generally true for LLGHGs, which are well dispersed in the atmosphere. However, it does not hold for SLCFs, which, due to their short atmospheric residence time, are not evenly dispersed globally, travel short distances, and exert strong regional warming effects that can vary substantially, based on the location and timing of the emission. Because GWP compares globally averaged measures, it fails to capture the strong regional differences in BC's climate impacts.

The GWP metric also fails to capture the dramatically different atmospheric residence times of SLCFs and LLGHGs. Over a 100-year period, a pulse emission of a long-lived gas like CO_2 will continue to heat the atmosphere for the entire 100-year period. A comparable pulse of BC will exert a strong direct radiative effect over the days to weeks in which it remains in the atmosphere and will then have no further climate effect. Since the GWP_{100} integrates BC's radiative effects over 100 years, it fails to convey BC's short, powerful climate impact, greatly undervaluing BC's near-term climate impacts relative to a long-lived climate forcer like CO_2.

As Figure 8 demonstrates, the choice of a metric with a shorter time horizon will change the value of a short-lived climate agent, like BC, relative to a long-lived climate warmer, like CO_2. A metric reflects value judgments about what is important in the parameters measured. As ICCT asserts, the choice of an appropriate metric ultimately depends on one's policy goal. A GWP_{100} metric is best suited to policies addressing long-term climate change, while near-term climate impacts are better captured using a GWP_{20} metric:

"The parties to the Kyoto Protocol chose to use primarily the 100-year time frame in calculating their emission inventories, which shows a preference for long term impacts and therefore, long-lived greenhouse gases. The choice of the shorter 20-year time scale would have indicated a concern for short-term climate impacts and placed greater emphasis on the role of black carbon and other short-lived forcing agents" (ICCT 2009, p.6).

Figure 8: GWP_{100} vs. GWP_{20} to Compare BC and CO_2 Emissions

Share of CO_2-equivalent emissions from an uncontrolled on-road diesel engine

Data source: Argonne National Laboratory. GREET. Version 1.8c.
BC GWP values are 520 for 100-year and 1830 for 20-year.
Source: Adapted from Minjares 2010, slide 11

The choice of metric also impacts the relative cost-effectiveness of strategies to control emissions of LLGHGs and SLCFs. Several authors have noted that when using a GWP metric to compare the costs of CO_2 mitigation strategies, retrofitting diesel vehicles with DPFs becomes more cost-effective per unit of $CO_{2\text{-}e}$ reduced by employing a GWP with a shorter time horizon (e.g., GWP_{20} vs. GWP_{100}) (cf. Bond and Sun 2005; Bachmann 2009; Sarofim 2010). The shorter time horizon gives more credit to the faster climate response of SLCF mitigation strategies, producing a higher GWP value and making more retrofits cost-effective.

Boucher and Reddy (2008, p.193) identify a "pressing need" to develop a metric that accurately accounts for the relative climate impacts of both long-lived and short-lived climate forcing agents. Such a metric would allow policymakers to make more accurate choices and more efficient tradeoffs in multi-pollutant strategies that address both climate and air quality. Proposed alternatives to the GWP include global temperature potential (Shine et al. 2005), which uses temperature change produced after a given time period rather than integrated radiative forcing over a given time horizon to compare the climate impacts of an emission to the climate impacts of CO_2. As Sarofim (2010, p.138) notes, a temperature metric "is a better proxy than radiative forcing for those impacts that are of interest to humans and ecosystems (e.g. sea level rise, ice retreat, heat waves)." Several recent metrics have been proposed that attempt to more accurately convey the temporal and regional climate impacts of SLCFs (cf. Bond et al. 2010; Berntsen, Tanaka, and Fuglestvedt 2010).

Recognizing the "serious limitations" of using GWP to compare SLCFs and LLGHGs, the IPCC declined to use GWP to calculate a $CO_{2\text{-}e}$ value for BC in its 2007 Assessment Report (IPCC 2007, p.211). Nevertheless, a GWP value can be calculated for BC; several versions appear in the climate literature, as shown in Table 2. The range of values reflects the regional variability in BC climate forcing, differences in which climate effects were included in the calculations, and uncertainties discussed in Section 3.4.

Table 2: Published Global Warming Potentials for Black and Organic Carbon

Black Carbon		Organic Carbon		Reference
20-year	*100-year*	*20-year*	*100-year*	
2200	680	-250	-75	Bond and Sun (2005)[a]
2530	840-2240	N/A	N/A	Jacobson (2007)[b]
2900	830	-100 to -290	-28 to- 82	Rypdahl et al. (2009)[c]
~2000	~500	N/A	N/A	Hansen et al. (2007)[d]
1600	460	-240	-69	Fuglestvedt et al. (2009)[e]

[a] See also Bond (2007) for details on calculating GWP-like metrics shown.
[b] Estimate for fossil soot, including black carbon, organic carbon and sulfate. Upper bound assumes a shorter CO_2 lifetime.
[c] Ranges for organic carbon reflect different regions.
[d] Uses incremental temperature, estimated emissions from absorption measurements.
[e] Results equivalent to those using IPCC (Forester et al., 2007) models and forcing. Unlike the other studies listed, does not account for particle aging effect.

Source: Bachmann 2009, p.25

5.4 LACK OF AGREEMENT OVER WHETHER TO INTEGRATE BLACK CARBON INTO CLIMATE POLICIES THAT TARGET LONG-LIVED GREENHOUSE GASES

Closely related to the metrics issue is the question of whether the climate impacts of BC (and SLCFs, in general) are best addressed by integrating BC into broader climate frameworks that target LLGHGs (either within or outside of the Kyoto "basket") or by targeting BC's climate impacts separately through existing air quality regulations. The U.S. EPA is grappling with this question as it considers how to address the climate impacts of BC. As EPA's Ben DeAngelo has noted, "Climate evaluation of BC mitigation strategies and formal linkage of BC strategies with climate change policies can be thought of as separate issues" (DeAngelo 2010, slide 17).

A number of articles in the climate literature have explored whether and how SLCFs, including BC, should be considered in broader climate frameworks (cf. West, Hope, and Lane 1997; Hansen et al. 2000; Rypdal et al. 2005; Bond 2007b). Bond (2007b, p.2) identifies, and ultimately refutes, four conceptual barriers to addressing warming particles, like BC, in global climate agreements: 1) that carbon particles "will soon be addressed by local air quality regulations" so they need not be included in global or hemispheric climate agreements; 2) that BC's impacts are primarily local, so "it is inappropriate to consider them in global regulations"; 3) that aerosol physics and chemistry are "too complex" to be addressed by policymakers; and 4) that there is too much uncertainty regarding BC's climate impacts to address them in the policy arena.

In advance of the UNFCCC COP-15 negotiations in December 2009, several policy proposals emerged urging consideration of BC and other SLCFs as part of the broader climate negotiations in Copenhagen. Moore and MacCracken (2009) proposed a "lifetime leveraging" architecture that incorporated SLCFs into a tiered post-Kyoto agreement, whereby high-income nations would commit to steep GHG reduction targets while developing middle-income nations, such as India and China, would commit to sharply reducing emissions of methane, BC, and O_3 precursors and to lowering the carbon intensity of their energy-intensive industries. Grieshop et al. (2009) proposed a suite of BC-emissions reduction measures as a 16th Pacala-Socolow climate mitigation "wedge."[6] Garderet and Emmett (2009) advocated for partial, and ultimately, complete integration of BC into a global climate agreement and outlined the policy mechanisms necessary to move towards such integration, including development of market mechanisms to incentivize BC reductions and creation of measurement, reporting, and verification systems to certify that such reductions had occurred. And on the eve of the December 2010 UNFCCC negotiations, an op-ed in the New York Times continued to advocate for consideration of BC and other SLCFs in Cancún (Ramanathan and Victor 2010).

One of the main arguments for integrating SLCFs into broader climate agreements is cost-effectiveness, as Rypdal et al. (2005, p.35) explain:

"By expanding the comprehensiveness of the agreement, states will expand their portfolio of abatement options, which means that they will be able to choose the options that represent the lowest cost. This will help shift the marginal abatement cost curve downwards, thus increasing the agreement's political attractiveness."

Integrating BC into broader climate agreements via a CO_2-equivalency metric also opens up the possibility of including BC in market-based emissions trading programs,

[6] See Stephen Pacala and Robert H. Socolow. 2004. "Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies." *Science* 305(5686):968–972. Each conceptual wedge represents one billion tons of carbon mitigated over a 50-year period (2005–2055).

such as the Kyoto Protocol's Clean Development Mechanism. Providing access to carbon-offset funding can create financial incentives for implementing BC reduction projects that might not otherwise occur. One practical reason BC and other SLCFs are excluded from current climate mitigation frameworks is because "no credit is given for such species under the present Kyoto Protocol, and thus no reward accrues for including the additional complexity" (Bond 2007b, pp.1–2).

Garderet and Emmett argue that allowing developing nations to receive credit for at least some of their national BC reductions within a global climate agreement gives developing countries the flexibility to set national climate change priorities in a manner consistent with their regulatory capacity and national development goals. Such flexibility, they argue, may be the element needed to persuade developing countries to sign on to a binding global climate agreement. It should be noted, however, that the appropriateness of trading emissions of BC has been questioned in the climate literature. Sarofim (2010, p.143) cautions that using CO_2-equivalency metrics to facilitate emissions trading may be "unwise, or at least premature" due to disparities between LLGHGs and SLCFs in terms of climate characteristics, uncertainty of radiative forcing impacts and emissions inventories, and the availability of measurement and reporting systems to verify emissions reductions. Bice et al. (2009) recommend regulatory rather than trading approaches to control BC emissions, because BC's localized health impacts are incompatible with a trading system that would result in emissions hot-spots. Even advocates of integrating BC into broader climate agreements, such as Garderet and Emmett, acknowledge the need to limit the amount of BC trading permitted within their framework.

Scientific arguments to exclude BC from broader climate agreements are grounded in both the different climate effects of SLCFs and LLGHGs and the disparity in scientific understanding of those effects. Bond and Sun (2005, p.5921) identify three main scientific arguments for excluding BC from climate-mitigation strategies: that the climate effects of BC are 1) too uncertain, 2) too different from those of GHGs in their regional impacts, and 3) "unquantifiable" within the metric of top-of-atmosphere, globally averaged radiative forcing. While they acknowledge the differences between BC and LLGHGs, Bond and Sun (p.5922) ultimately reject these scientific arguments for excluding BC from climate policy frameworks:

"The UNFCCC's guidelines call into question the scientific reasons for excluding BC from the climate framework. The effects of BC are uncertain, but within bounded limits, there is no question that BC alters the Earth's radiative balance and participates in the climate change targeted by the UNFCCC. The impacts of aerosols are unlike those of GHGs, but they may qualify as adverse effects of climate change. The effects are as yet unquantifiable by TOA-averaged forcing, but that metric's failure to gauge climate change is not a reason to disregard the species."

Sarofim (2010, p.142) notes that uncertainties in BC inventories raise "significant implementation issues" for addressing BC and LLGHGs in a single framework, as they "may make it difficult to meet standards for measurable, reportable, and verifiable reductions, as does the small, mobile, variable, or area nature of many BC sources." Political and logistical arguments can also be made that addressing SLCFs and LLGHGs through separate frameworks allows for a more nimble, adaptive approach that may be better suited to the fast-action climate mitigation opportunities that SLCFs can offer.

One frequently encountered objection to incorporating BC into broader climate policies is that action on BC (and other SLCFs) in a climate policy context distracts from and potentially undermines the more pressing need for efforts to mitigate CO_2, which is the main contributor to anthropogenic climate change. Many papers in the academic and popular literature that urge consideration of BC/SLCF abatement for climate purposes are quick to note that BC reductions must complement, not substitute for, reductions in CO_2 and other LLGHGs (cf. Molina et al. 2009; ICCT 2009; Wallack and Ramanathan 2009). Nevertheless, the concern persists that reducing BC emissions will distract or detract from CO_2 mitigation efforts, as is reflected by the title of a recent letter in the climate science literature: "Does black carbon abatement hamper CO_2 abatement?" (Berntsen, Tanaka, and Fuglestvedt 2010).

The "distraction" argument has scientific, political, and logistical dimensions. On a scientific level, the issue is that while reducing SLCFs can slow the rate of climate warming and has potential to avert near-term climate impacts, reducing SLCFs will not impact long-term climate stabilization. Addressing LLGHGs and SLCFs through a single policy framework, especially one that would allow or enable emissions trading, suggests that short-term and long-term climate agents are fungible. Yet, as the abovementioned National Research Council (2010, p.73) report warns, control of LLGHGs and SLCFs should be approached as "two separate control knobs that affect entirely distinct aspects of the Earth's climate, and should not be viewed as substituting for one another."

To address this concern, some in the climate science and policy communities have suggested multi-target policy approaches (see Fuglestvedt et al. 2000; Rypdal et al. 2005) that keep SLCFs and LLGHGs in separate policy "baskets," obviating the need to employ a problematic CO_2 equivalency metric (though, as Rypdal et al. (2005, p.38) caution, "the relative weights between the baskets would still be a problem that needs to be solved in order to derive and balance the two targets"). Stacy C. Jackson (2009, p.527) advocates for separate, but parallel, policy frameworks for addressing long-lived and short- and medium-lived climate agents. Such a two-pronged strategy "would reflect the evolving scientific understanding of near-term climate change, the scientific certainty around long-term climate change, and the opportunity to separately adjust the pace of near-term and long-term mitigation efforts."

The "distraction" argument also reflects concerns that integrating BC into a global climate framework would inject political and logistical complexity into politically fraught, slow-moving climate policy negotiations, a strategy that would "likely delay progress on both BC and GHG emission reductions" (Bice et al. 2008, slide 58). A

June 2010 news report, for example, quoted a UN Environment Program spokesman's assessment that climate policymakers were nervous about "...taking the eye off the CO_2 ball and focusing it on something else" (Euractiv 2010).

The "distraction" argument also reflects equity concerns. Several interviewees noted that adding BC to a global climate framework could be (and has been) perceived as a strategy on the part of developed nations to divert attention from their own historic CO_2 emissions by shifting the focus of climate negotiations to the BC contributions of developing economies, which generally have much higher unregulated SLCF emissions than industrialized countries (John-Michael Cross and Sam Sherer, pers. comm., Sept. 13, 2010; Ben DeAngelo, pers. comm., Sept. 15, 2010). Wallack and Ramanathan (2009, p.113) acknowledge this concern:

"Putting black carbon and ozone on the table in high-level climate talks could backfire if developing nations thought that they would be tacitly admitting responsibility for global warming by committing to reducing emissions of black carbon and ozone precursors or believed the issue was an effort by developed countries to divert attention from the need for them to reduce their carbon dioxide emissions."

5.5 BLACK CARBON'S "DUAL IDENTITY" AS A CLIMATE FORCER AND AIR POLLUTANT

Black carbon's "dual identity" as a climate forcer and air pollutant presents both policy opportunities and challenges. To the extent that BC reduction policies can achieve both climate and health/air quality co-benefits, the potential for a health-climate "win-win" makes BC a compelling mitigation target, as discussed in Section 4. However, the potential also exists for climate-health tradeoffs or missed synergies if climate-driven policies do not account for BC's health impacts or if health- or air quality-driven policies do not account for BC's climate impacts.

The fact that reducing BC emissions can positively impact air quality and health as well as climate has both political and economic appeal that can be leveraged by policymakers. Domestically, as one interviewee suggested, BC's dual identity may enhance the feasibility of legislation targeting BC emissions, because some legislators who oppose acting on climate acknowledge the health impacts of BC and may be willing to support legislation that addresses those health impacts (Paul Miller, pers. comm., July 20, 2010). Indeed, in 2009, Senator James Inhofe (R-OK), a notorious climate-science denier, co-sponsored a BC study bill, motivated largely by his personal experience witnessing the negative health impacts from inefficient cookstoves in Africa.[7]

[7] Additional sponsors of S.849 were Senators Thomas Carper (D-DE), John Kerry (D-MA), and Barbara Boxer (D-CA). In a statement to the Senate Committee on Environment and Public Works, Inhofe explained his co-sponsorship of the bill: "Rest assured, to all those who may be concerned, this does not in any way change my position about global warming or cap and trade. Rather, unlike CO_2, which does not pose any public health threats, decreasing emissions of black carbon or soot will immediately improve public health. In addition, focusing research efforts on black carbon helps

BC's dual identity may be able to help bridge the political differences of developed and developing nations with regard to climate policy (cf. Haines et al. 2009; Smith and Balakrishnan 2009). As Ramanathan and Victor (2010, n.p.) observe in a recent New York Times op-ed, "...people everywhere care about the quality of the air they breathe and see — even if most of them are not yet very worried about global warming. A desire to clean up the air is a rare point of commonality between developing and industrialized nations." To this end, Rypdal et al. (2005) suggest that the health/air quality benefits of BC reductions can increase the political attractiveness of implementing BC reductions as part of a broader climate agreement.

In part, the opportunity afforded by BC's dual identity stems from differences in how climate and air-quality/health benefits are valued, both spatially and temporally. Moore (2009) observes that air quality policies that reduce BC and ozone may have lower barriers to implementation than climate mitigation-driven policies because the proportion of benefits that accrue locally from air quality policies is often larger than from climate policies. Smith and Balakrishnan (2009) argue that initiatives with both health and climate co-benefits, such as BC reduction projects, can help developing countries further their own development goals while serving broader climate goals. Further, they suggest, "...the health benefits can be more immediate and certain than the climate benefits, which accrue more slowly, in that they provide a more concrete return on the investment..." (p.10). While beyond the scope of this paper, it is interesting to note recent research on reframing climate change as a public health issue (Maibach et al. 2010), which reflects, in part, the greater saliency of near-term/local health benefits relative to future/global climate benefits. In this regard, BC may have a unique role to play in framing the climate change debate, as its dual identity offers opportunity to achieve both near-term health and climate benefits.

Including the value of health/air quality co-benefits stemming from BC emissions reductions can improve the cost-effectiveness of climate mitigation policies that may be prohibitively expensive when evaluated solely on the basis of their climate costs and benefits. Rypdal et al. (2005, p.37) cite several studies that demonstrate "that the near- to medium-term co-benefits of climate policies, in terms of reduced damage to human health from air quality improvements, can offset a large fraction of the mitigation costs, even exceeding the costs significantly in some cases." Similarly, Tollefsen et al. (2009) have found that efficiency gains on the order of 2.5 billion euros can be achieved in the EU by accounting for climate change impacts in air pollution control policies.

Yet BC's dual identity as a climate warming agent and air pollutant also presents policy challenges. While there are often climate co-benefits to health-driven policies that reduce BC emissions and health co-benefits to climate-driven policies that reduce BC emissions, the potential for climate-health tradeoffs and missed synergies exists unless both BC's health and climate impacts are considered and valued in policy goals.

prioritize spending of money on real and immediate health problems, such as addressing indoor pollution of soot from cook stoves on the poor and developing countries in Africa, which I have great interest in" (Inhofe 2009, n.p.).

For example, not all strategies to reduce BC emissions from inefficient cookstoves capture both health and climate co-benefits. While improved stove design and use of cleaner fuels can positively impact both health and climate, increased use of chimneys, as has been implemented in China, may achieve health benefits through improved indoor air quality but fail to reduce the climate impacts of sooty stove emissions (Smith and Balakrishnan 2009). Similarly, climate-driven policies that do not consider or value BC's health impacts may trade climate gains for increased health risks or fail to maximize co-benefits. Shifting from gasoline to more fuel-efficient diesel engines, for example, can reduce CO_2 emissions but exacerbate health risks (and ultimately reduce climate benefits) due to increased BC and PM emissions (Swart et al. 2004; Mazzi and Dowlatabadi 2007; Walsh 2008).

An emerging literature on climate and health/air quality co-benefits stresses the need for better integration of research, policy, and planning for climate change and air pollution abatement, which are typically addressed independently (cf. Swart et al. 2004; Smith and Haigler 2008; Hicks et al. 2008; Tollefsen et al. 2009; Arneth et al. 2009; Nemet, Holloway, and Meier 2010; Haines et al. 2009; Rypdal et al. 2009b). A subset of this literature specifically explores air quality/health/climate co-benefits of reducing BC and other SLCFs (cf. Highwood and Kinnersley 2006; Smith et al. 2009; Moore 2009). If a policy goal is to maximize health and climate co-benefits, integration or at least better coordination of climate and air quality policies is required. Integration is frequently mentioned in the climate literature as an aspirational goal, but is in the earliest stages of being operationalized in policy and planning fora.[8] While it is beyond the scope of this paper to fully examine the challenges to an integrated air pollution/climate policy framework, some of the barriers identified in the literature include the different spatial and temporal scales on which climate and air pollution policies tend to operate (Swart et al. 2004) — which mirror some of the policy challenges of addressing SLCFs and LLGHGs in an integrated framework; the threat of "regime congestion" within integrated policy frameworks, which can overly complicate the policymaking process (Rypdal et al. 2005, p.36); large uncertainty over the benefits of avoided climate change, which complicates comparison to air quality benefits, discourages quantitative representation of benefits in general, and shifts the policy discourse to cost-minimization rather than an integrated assessment of climate/air quality costs and benefits (Nemet, Holloway, and Meier 2010); and institutional barriers in both the scientific and political arenas, which separates institutions and individuals working on air quality and climate change (Swart et al. 2004; Nemet, Holloway, and Meier 2010).

[8]See, for example, the work of SEI's GapForum on development of an integrated co-benefits assessment framework: http://sei-international.org/rapidc/gapforum /html /issues /airpollutionclimatechange.php.

Section 6: Policy Mechanisms for Reducing Black Carbon Emissions from On-road and Nonroad Diesel Mobile Sources in the United States

The mobile source sector is the main contributor to U.S. BC emissions. As noted in Section 3.1, on-road and nonroad transport account for roughly 61 percent of U.S. BC emissions, and nearly 89 percent of the potential net warming impact of those emissions, when BC-to-OC ratio of emissions from U.S. sources is considered (see Figures 2 and 3). Diesel engines emit more BC per ton than gasoline engines, so most U.S. mobile-source-related BC emissions come from on- and nonroad diesel engines (Bice et al. 2009; Bond et al. 2004). Thus, I have chosen to focus discussion of specific policy instruments for controlling U.S. BC emissions on on-road and nonroad diesel sources.

This section begins with a review of strategies and technologies to reduce BC emissions from diesel mobile sources. I then examine federal regulations that apply to new diesel engines and move on to explore a variety of national and state regulatory and policy mechanisms that are currently reducing, or have the potential to reduce, BC emissions from the approximately 11 million U.S. diesel engines in use today that do not comply with current emissions regulations for new diesels.

6.1 STRATEGIES AND TECHNOLOGIES TO REDUCE BLACK CARBON EMISSIONS FROM ON-ROAD AND NONROAD DIESEL SOURCES

Black carbon comprises the largest fraction of diesel particulate matter (PM) mass — an estimated 50 percent to 80 percent (Hill 2009). The most effective diesel emissions control technology is the diesel particulate filter (DPF), which traps both PM and BC particles by filtering them out of engine exhaust. Passive DPFs use the heat of the exhaust gas to burn off the accumulated particles, while active DPFs require additional fuel or driver action to achieve temperatures high enough to combust the accumulated particles. Other diesel emissions control technologies include flow-through filters (FTFs), which are less efficient than DPFs but also less prone to plugging, and diesel oxidative catalysts (DOCs), widely used emissions control devices suitable for a large variety of applications, which use a precious-metal-coated substrate to catalyze pollutants from the diesel exhaust stream (EPA 2011a).

Table 3: On-Road Heavy-Duty Diesel Retrofit Technologies: PM/BC Reduction Estimates and Costs

Retrofit Technology	PM Reduction Achievable	BC Reduction Achievable	Cost
Diesel oxidative catalyst	20% - 30%	0% - 10%	$1,000 - $3,000 per engine
Flow-thru filter	50% - 70%	20% - 50%	$4,000 - $10,000 per engine
Diesel particulate filter	85% - 99%	85% - 99%	$6,000 - $30,000 per engine

Source: Lowell 2010, slide 15

DOCs, FTFs, and DPFs reduce BC and PM emissions to varying degrees, as shown in Table 3. DPFs can eliminate up to 99 percent of both PM and BC emissions when used with ultra-low sulfur diesel (ULSD) fuel, which is required for their operation; DOCs have a minimal impact on BC emissions. DPFs are considered the "gold standard" retrofit technology for reducing BC emissions, but some older diesel engines cannot be retrofitted with DPFs because of differences in engine duty cycles. Moreover, DPFs are significantly more expensive than DOCs and require ongoing maintenance to remain effective.

Beyond use of emissions control devices, EPA's National Clean Diesel Campaign identifies several additional strategies for reducing diesel PM emissions, including replacing or repowering older diesel engines; switching to cleaner fuels; engaging in timely engine maintenance and repair; promoting idle reduction policies and practices; and improving operational strategies (EPA 2011b).

6.2 NATIONAL ON-ROAD AND NONROAD HEAVY-DUTY DIESEL REGULATIONS

Increasingly stringent U.S. engine emission and fuel standards are projected to significantly reduce BC (and OC) emissions from new on-road and nonroad vehicles in the coming years. Acting under authority established in Section 202(a) of the Clean Air Act (CAA), the EPA implemented the 2007 Heavy-Duty Highway Diesel Rule, which regulates PM emissions from new on-road heavy-duty vehicles (HDVs).[9] The 2007 Highway Rule sets strict engine emission standards for new heavy-duty diesel engines and mandates reduction of fuel sulfur content to enable use of sulfur-sensitive emissions-control technologies, such as DPFs. Reduction of fuel sulfur content from 500 parts per million (ppm) to 15 ppm began in 2009. 2004 PM emissions regulations for nonroad vehicles and equipment lowered the sulfur content of nonroad diesel fuel from 3,000 ppm to 15 ppm ultra-low sulfur diesel (ULSD) by 2010 and required the

[9] See "Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements," Federal Register 66, no. 12 (Jan. 18, 2001):5001–5193.

use of advanced engine emissions control technologies.[10] Still, regulation of nonroad vehicles and equipment has lagged behind on-road vehicles. While Tier 3 engines are now being delivered in new construction equipment and Tier 4 engines will be phased in from 2008 to 2015, nonroad engines are not anticipated to reach parity with on-road engines until at least 2015 (STAPPA/ALAPCO 2006).

Under the on-road and nonroad diesel regulations, diesel equipment manufacturers must ensure that any new equipment they sell meets the emission standards. These are technology-forcing regulations that provide equipment manufacturers both the incentive to develop cost-effective emissions controls and the flexibility to determine how they will meet the standards. While the regulations do not mandate the use of specific technology, all new on-road diesel engines are now equipped with high-efficiency DPFs in order to meet the emissions standards. The on-road and nonroad diesel rules are projected to significantly reduce U.S. BC emissions in the coming decades. Based on emissions modeling of $PM_{2.5}$, BC, and OC conducted by EPA for its $PM_{2.5}$ National Air Quality Standards (NAAQS) Regulatory Impact Analysis, U.S. BC emissions from on-road and nonroad mobile sources are projected to decline almost 70 percent from 2001 to 2020 (assuming full compliance with the $PM_{2.5}$ NAAQS) (Sarofim et al. 2009). Mobile-source OC emissions are projected to decline approximately 43 percent in the same period. Of the total U.S. BC emissions reductions projected by 2020, 90 percent will come from reductions in the mobile source sector (Sarofim et al. 2009).

6.3 NATIONAL AND STATE DIESEL EMISSIONS REDUCTION PROGRAMS

While EPA's heavy-duty diesel regulations are projected to result in significant reductions in BC emissions, the regulations only apply to new engines. Of the approximately 20 million on-road and nonroad diesel engines in use today in the United States, about 11 million do not meet EPA's current engine standards (EPA 2009c). Given that the working lifetime of a well maintained on-road diesel engine can be on the order of 20 to 30 years and up to 40 years for nonroad diesel engines (MECA 2009; STAPPA/ALAPCO 2006), pre-regulation, in-use diesel engines represent a substantial opportunity for additional BC reductions in the United States.

6.3.1 NATIONAL CLEAN DIESEL CAMPAIGN/DIESEL EMISSIONS REDUCTION ACT

Through its National Clean Diesel Campaign (NCDC) and participation in seven regional diesel collaboratives that it helped to form, EPA is engaged in a variety of voluntary partnerships and programs to achieve diesel emissions reductions from

[10] See "Control of Emissions of Air Pollution From Nonroad Diesel Engines and Fuel," Federal Register 669, no. 124 (Jun. 29, 2004):38957-39273.

existing on-road and nonroad diesel engines. In 2008, under the Energy Policy Act of 2005, Congress established the Diesel Emissions Reduction Act (DERA) Program to target emissions from the nation's existing diesel fleet.[11] Through DERA, EPA administers three national competitive grant and loan programs as well as a formula allocation state clean diesel grant and loan program. In addition, the NCDC has established several voluntary sectoral programs aimed at reducing diesel emissions from industry sectors with high diesel consumption.[12]

In its first year (FY08), EPA's NCDC awarded $49.2 million in DERA funding to a variety of diesel reduction projects and programs across the country. The DERA program has enjoyed bipartisan support and has proven cost-effective, generating over $13 in health and environmental benefits per dollar of program costs, according to EPA estimates (L.P. Jackson 2009). Additionally, in 2009, DERA grant applicants offered over $2b in matching funds for clean diesel projects (EPA 2009c).

Despite DERA's successes, the program has been "chronically underfunded" and oversubscribed, according to clean diesel advocates (Schneider 2010). Congress authorized $1 billion for DERA for FY 2007-2011, yet Congressional appropriations for the program have lagged significantly, averaging $50 to $60 million a year. While DERA was awarded an additional $300 million in American Reinvestment and Recovery Act stimulus funding in 2009, DERA applications for those funds totaled $2 billion, exceeding available funding almost sevenfold (Schaeffer 2011). In December 2010, with bipartisan support, Congress reauthorized the DERA program at $100 million annually for the next five years — a 50 percent reduction from the previous program authorization. On January 4, 2011, President Obama signed the Diesel Emissions Reduction Act of 2010 (S. 3973/H.R. 6482) into law, but the White House reversed its position just five weeks later when it proposed eliminating the DERA program beginning in FY2012 as part of the Administration's budget deficit reduction measures. Ironically, DERA may become a victim of its own success, as the White House justified its proposed elimination of DERA on the fact that the program had "achieved its short term objective to remove or retrofit the oldest and dirtiest engines," making the program less cost-effective in the future "because the same amount of grant funding results in less substantial emissions reductions" (U.S. OMB 2011, p.21). In fact, as DERA supporters have responded, the DERA program has cleaned up an estimated 50,000 diesels, or about 0.45 percent of the 11 million in-use legacy diesels, by the beginning of 2011 (Diesel Technology Forum 2011).

[11]Energy Policy Act of 2005, Public Law 109-58, Title VII, Subtitle G (Sections 791 to 797)

[12]Sector-specific programs that comprise the National Clean Diesel Campaign include Clean School Buses, Clean Ports, Clean Construction, Clean Agriculture, and the SmartWay Transport program, which targets the freight goods movement sector.

6.3.2 STATE AND SECTORAL DIESEL PROGRAMS

Currently, all 50 states and the District of Columbia have clean diesel programs. Several of these programs were established in FY08 as a precondition of receiving DERA formula funding through EPA's State Clean Diesel Grant and Loan Program, but many states already had active clean diesel programs underway. As of May 2010, at least 20 states had adopted or proposed voluntary state policies to reduce diesel emissions employing a variety of technologies and strategies (CATF 2010a). As of September 2010, at least 22 states and numerous counties and cities had adopted mandatory anti-idling restrictions (American Transportation Research Institute 2010) and, as of 2008, a variety of heavy-duty vehicle inspection and maintenance programs were operating in 17 states (van Houtte and Niemeier 2008).

EPA's authority to regulate in-use diesel engines is limited under the Clean Air Act, but states have clearer authority to regulate in-use diesels (STAPPA/ALAPCO 2006). Most state clean diesel programs are voluntary, but a handful of states have adopted mandatory clean diesel policies or programs of varying scope. It is instructive to mention a few of these programs as potential models for accelerating BC emissions reductions nationally or in other states.

Under New Jersey's Diesel Retrofit Law adopted in 2005, all publicly owned or contracted on-road diesel vehicles and nonroad diesel equipment, as well as commercial buses registered in the state, must be retrofitted to meet Best Available Retrofit Technology ("BART") standards.[13] Retrofit costs are fully reimbursed by the state, financed, in part, by corporate business tax proceeds (NJDEP 2009). The program is projected to avoid 75 premature deaths and provide the state $700,000 million in economic savings (Hanna 2010).

California's Diesel Risk Reduction Program (DRRP) is the most comprehensive and stringent state diesel control program in the country. Adopted by the California Air Resources Board (CARB) in 2000 with the goal of reducing in-state PM emissions 85 percent by 2020, the DRRP emphasizes the use of retrofit technologies, such as DPFs, that can reduce PM emissions by at least 85 percent (and are most effective in reducing BC emissions) (CARB 2008a). Between 2000 and 2007, CARB approved mandatory clean diesel regulations for a wide variety of in-use diesel fleets, including school and transit buses, refuse trucks, port drayage trucks, transportation refrigeration units, cargo-handling equipment, and public heavy-duty and utility fleets. Phase-in of regulations mandating retrofit or replacement of on-road heavy-duty diesel trucks and buses and off-road heavy-duty diesel equipment was originally scheduled to begin in January 2011. But in December 2010, after years of push-bask from targeted industry sectors that argued that the regulations presented an unfair burden in light of the economic recession, CARB voted to relax some of the requirements and delay start of implementation by two to four years (Bailey 2011a; CARB 2011a; CARB 2011b).

[13] Other state standards have incorporated comparable regulatory standards, including Best Available Control Technology (BACT) and Best Available Technology (BAT).

California complements its regulatory diesel programs with several voluntary incentive programs to help finance diesel emissions reductions achieved in advance or in excess of state regulatory requirements. California voluntary programs include the Carl Moyer Program, which provides approximately $140 million in grant funding annually to cover the incremental cost of replacing, repowering, or retrofitting on-road and nonroad diesels (MECA 2009), and California's Goods Movement Emissions Reduction Program, which has appropriated $1 billion through state general obligation bonds to fund diesel emissions reductions from trucks, locomotives, and marine craft operating in goods movement corridors (CARB 2010a). Altogether, California's Diesel Risk Reduction Program has been attributed with cutting the state's BC emissions in half over the last 20 years (Bahadur et al. 2011) and is expected to cut state emissions 75 percent by 2020 (Bailey 2011b).

Targeted sectoral programs can be very effective in reducing BC emissions from diesel-intensive industry sectors, such as ports, construction, and agriculture. The construction industry, for example, accounts for 37 percent of mobile-source fine particle emissions in the United States, and almost one-third of in-use diesel construction equipment was manufactured prior to current emissions regulations (NEDC 2011). New York, Illinois, and Rhode Island, as well as several cities and counties,[14] have adopted clean construction contract specifications that require the use of ultra-low sulfur fuel and diesel retrofit technologies for off-road, and in some cases, on-road, vehicles and equipment used on publicly funded construction projects. Contract requirements vary in stringency regarding the level of emissions reduction required, from use of DOCs (which remove very little BC) to Best Available Technology that remove at least 85 percent PM (and up to 99 percent BC). While equity concerns have been raised that clean construction contract requirements may give a competitive advantage to larger, well-capitalized construction firms that can better afford to retrofit their equipment, contract specifications can be structured to address this concern by including diesel emissions control costs in the project contract and requiring that contractors be reimbursed for adopting retrofit technologies (Diesel Technology Forum 2006). Building on state and local models, the Clean Air Task Force, an environmental NGO at the forefront of efforts to reduce diesel pollution, and the Associated General Contractors of America, a leading trade association, have called on Congress to include a Clean Construction Provision in the upcoming Transportation Bill reauthorization, which would mandate and fully fund the use of clean construction equipment on all federally funded transportation projects (AGCA and CATF 2009).

Currently over 30 U.S. ports are located in counties that do not meet National Ambient Air Quality Standards (see Section 6.4) for emissions of $PM_{2.5}$ and/or ozone (AAPA 2011). Targeted clean diesel programs can be instrumental in reducing PM/BC emissions from the diesel-powered marine vessels, drayage and heavy-duty trucks,

[12]Municipal and county clean construction policies include New York City's Local Law 77 (http://www.nyc.gov/html/ddc/downloads/pdf/lowsulfur.pdf), Cook County Illinois' Green Construction Ordinance, and San Francisco's Clean Construction Ordinance (http://www.sfenvironment.org/downloads/library/lawfactsheetsfenrdc4.16.08.pdf).

cargo-handling equipment, and rail lines operating at state and regional ports. Several major U.S. ports have adopted comprehensive clean air strategies that, when fully implemented, will be effective in reducing BC emissions from port-related activities. The Clean Air Action Plan adopted by the ports of Los Angeles and Long Beach, for example, aims to reduce port-related diesel PM 72 percent (from 2005 levels) by 2014 (Ports of Los Angeles and Long Beach 2010).

6.4 CLEAN AIR ACT

Beyond Section 202 of the Clean Air Act, which authorizes EPA to regulate emissions from "any class or classes of new motor vehicles or new motor vehicle engines that ... cause or contribute to air pollution which may reasonably be anticipated to endanger public health or welfare," several other CAA mechanisms could potentially facilitate further reductions in U.S. BC emissions (Chang 2010; Moore 2010). A few of these mechanisms are explored below.

$PM_{2.5}$ NAAQS: Title I of the CAA directs EPA to set National Air Quality Standards (NAAQS) for six "criteria" air pollutants, including particulate matter (PM). PM is composed of directly emitted particles, such as BC, and secondary particles, such as sulfates and nitrates, which are formed in the atmosphere from the oxidation of gases, such as SO_2 and NO_x. EPA sets both primary air quality standards designed to protect public health and secondary standards designed to protect public welfare from ecosystem damages, including decreased visibility and damages to crops, vegetation, and buildings. Beginning in 1997, EPA established separate NAAQS for coarse PM ("PM_{10}," or particles less than 10 μm in diameter) and fine PM ("$PM_{2.5}$," or particles less than 2.5 μm in diameter). As noted in Section 3.1, BC particles, which are generally less than 1.0 μm in diameter, fall into the $PM_{2.5}$ category.

EPA is required to review the NAAQS every five years and revise them, if needed, based on the latest scientific information. EPA last revised the $PM_{2.5}$ NAAQS in 2006 and is currently conducting its next $PM_{2.5}$ NAAQS review, which presents a potential opportunity to further drive reductions in BC emissions. While the NAAQS are federal standards, each state determines how it will achieve those standards. For each criteria pollutant, states are required to submit for EPA approval a State Implementation Plan (SIP) detailing how the state intends to achieve or maintain the NAAQS for each criteria pollutant. In some states, such as California, non-attainment of the $PM_{2.5}$ standards has been an important driver for the development of aggressive state diesel emissions reduction programs, which have been effective in reducing BC emissions (Walsh 2009). Under EPA policy, states can receive SIP "credit" for a portion of the voluntary diesel emissions reductions implemented in the state to achieve the NAAQS.

Currently, BC accounts for about 5 percent of projected PM reductions under the NAAQS (Sarofim et al. 2009). In theory, a lower $PM_{2.5}$ standard could drive reductions in BC by requiring greater reductions in total $PM_{2.5}$. One major challenge of using the

$PM_{2.5}$ NAAQS to drive BC reductions, however, is that the standards are based on the total mass of PM and do not distinguish between individual PM constituent species (e.g., BC, sulfates, nitrates, etc.). Under the primary NAAQS, PM is regulated as a single entity, since all PM constituents are bad for health, and EPA has found no health-based justification to date for preferential reduction of any individual PM constituent, such as BC (Erika Sasser, pers. comm., Aug. 11, 2010). However, the different constituents of PM have very different climate effects: BC is strongly warming, while OC, sulfates, and nitrates are generally cooling. Those different climate impacts are not considered in setting the NAAQS or in designing SIPs to achieve the standards.

While cost considerations cannot be used in setting the NAAQS, costs can be taken into account when states develop their SIPs. In practice, a least-cost approach to developing SIPs has produced preferential reduction in the cooling fraction of PM (John Bachmann, pers. comm., Aug. 10, 2011; Bachmann 2010). Thus a potential climate-health tradeoff exists under the NAAQS, in that the primary NAAQS can be met by reducing total PM for health reasons, without regard to the climate impacts of the PM constituent species. This tradeoff could potentially be addressed by including consideration of the climate impacts of PM constituents in the upcoming NAAQS review. As Chang (2010) notes, the Clean Air Scientific Advisory Committee (CASAC), the independent body of experts that provides technical advice to EPA for the NAAQS review process, has urged EPA to consider the climate impacts of PM constituent species in revising the NAAQS (CASAC PM Review Panel 2009). In its response to CASAC, EPA acknowledged the differential climate impacts of PM constituent species but declined to address climate considerations in either the primary or secondary NAAQS, pointing instead to continued scientific uncertainty regarding the climate impacts of aerosols:

"Due to the spatial and temporal heterogeneity of PM components that contribute to climate forcing, uncertainties in the measurement of aerosol components, inadequate consideration of aerosol impacts in climate modeling, insufficient data on local and regional microclimate variations and heterogeneity of cloud formations, it is not currently feasible to conduct a quantitative analysis for the purpose of informing revisions of the current NAAQS PM standard based on climate. Based on these considerations, we conclude that there is insufficient information at this time to base a national ambient standard on climate impacts associated with current ambient concentrations of PM or its constituents" (EPA 2010b, p.5–11).

Some of the people I interviewed suggested addressing the climate impacts of BC emissions through the secondary, welfare-based NAAQS as an environmental welfare or visibility issue or potentially through a separate, targeted black carbon NAAQS. Other interviewees — particularly EPA staff — questioned the potential effectiveness and practicability of using the NAAQS to target BC emissions because of the mismatch between where BC emissions occur and where the climate impacts of those emissions would be experienced, since BC impacts climate both regionally and globally.

Engine Rebuild Rule: A diesel engine is typically rebuilt several times over the course of its working lifetime, which can last decades.[15] EPA has limited authority under the CAA to regulate emissions from existing engines and vehicles. Under CAA §202, the EPA

"...may prescribe requirements to control rebuilding practices, including standards applicable to emissions from any rebuilt heavy-duty engines (whether or not the engine is past its statutory useful life), which in the Administrator's judgment cause, or contribute to, air pollution which may reasonably be anticipated to endanger public health or welfare taking costs into account."

As Chang (2010) notes, while EPA has exercised similar authority under CAA §213 to regulate the remanufacture of marine engines, it has failed to exercise its authority to rebuild existing on-road heavy-duty engines. The Clean Air Task Force has proposed that the EPA issue an "Engine Rebuild Rule" to require that all Class 8 trucks built between 1998 and 2006 be retrofitted at the time of engine rebuild to meet current emissions standards. While such a rule would apply to about 1 million of the 11 million pre-regulation diesels in use today (less than 10 percent), Class 8 trucks, which include large combination tractor-trailer trucks, waste haulers, and transit buses, account for about 75 percent of the BC emissions from on-road trucks in the U.S. (Schneider 2010). Assuming a 20-year GWP, CATF estimates that the proposed rule "could achieve the same climate benefits as removing 21 million cars from the road and would save approximately 7500 lives through reduced particulate matter" (Schneider 2010, p.5).

Greenhouse gas endangerment finding: As noted in Section 5.1, EPA declined to include BC among the global warming agents it seeks to regulate in its 2009 endangerment and cause or contribute finding under Section 202(a) of the Clean Air Act, citing uncertainties regarding BC's climate effects and the metrics issues involved in comparing BC and LLGHGs in a single framework. During the public comment period, EPA received many comments urging it to include BC in its GHG endangerment finding. One comment, from a coalition of environmental legal advocacy organizations,[16] typifies the concern that EPA missed an important opportunity by neglecting its "duty" to address BC's climate impacts as it developed its regulatory approach to global warming:

"*Given the scientific evidence and the clear mandate of section 202(a), we submit that the Administrator could not credibly decline to make a positive endangerment and contribution finding with respect to black carbon. Moreover, limiting black carbon*

[15] Well-maintained on-road diesels can last 20 to 30 years. Nonroad diesel engines typically remain in operation longer than on-road diesels — up to 40 years, with proper maintenance (STAPPA/ALAPCO 2006)

[16] Commenting organizations included the Center for Biological Diversity, Clean Air Task Force, Clean Water Action, Coastal Conservation League, Earthjustice, Environment America, Environment Washington, Environmental Defense Center, Faiths United for Sustainable Energy, Fall-line Alliance for a Clean Environment, Friends of the Earth, Greenpeace USA, International Rivers, National Audubon Society, National Wildlife Federation, Natural Resources Defense Council, Safe Climate Campaign, Sierra Club, Southern Alliance for Clean Energy, Southern Sustainable Resources, and Western Resource Advocates.

emissions ... would have immediate and appreciable mitigation effects and benefits to public health and welfare, which would augment the benefits that will accrue more slowly from its regulation of the long-lived greenhouse gases included in the proposed endangerment finding." (Segall et al. 2009, p.44)

Additionally, the commenters argued that although EPA exercised its §202(a) authority by addressing BC emissions from new diesel engines, additional Agency action is needed because the heavy-duty diesel regulations phase in too slowly to adequately protect public health and welfare or to achieve "the rapid climate change mitigation that is otherwise possible."

However, it should be noted that the need for an endangerment finding to address BC is an open legal question. While the EPA could amend the GHG endangerment finding to include BC or issue a separate BC endangerment finding, such a finding may not be needed since BC is a constituent of PM and EPA already has the authority to regulate PM under the Clean Air Act (Moore 2010; Ben DeAngelo, pers. comm., Sept. 15, 2010).

Action on other BC sources under the Clean Air Act: In 2007 and 2008, a coalition of environmental advocacy groups petitioned EPA to exercise its Clean Air Act authority to regulate GHG and BC emissions from marine and aviation sources, and more recently, from locomotives (Earthjustice 2010; Friends of the Earth 2010). Absent a response to those petitions, these groups filed suit in federal district court in June 2010, challenging the Agency over its failure to regulate global warming pollutants, including BC, from ships, aircraft, and nonroad vehicles and engines.

6.5 NATIONAL AND STATE CLIMATE LEGISLATION

In 2009, as Congress considered adopting national climate policy, several proposed bills included provisions related to BC emissions. In the House, the "American Clean Energy and Security Act" (also known as the "Waxman-Markey" bill) directed EPA to study and report to Congress on BC and to exercise its existing authority under the CAA to regulate BC from in-use diesel engines (see Section 6.4 for further discussion). In the Senate, the "Clean Energy Jobs and Power Act" of 2009 (the "Kerry-Boxer" bill) incorporated the Waxman-Markey BC provisions but also allocated proceeds from the auction of emissions allowances to finance a heavy-duty diesel retrofit grant program to reduce BC emissions. Similarly, the 2010 "American Power Act" (the "Kerry-Lieberman" bill) included BC study and reporting provisions and authorized EPA to establish a "Black Carbon Reduction Retrofit Program" to "cost effectively mitigate the adverse consequences of global warming by means of early action to reduce black carbon emissions" from pre-2007 heavy-duty vehicles. Attempts to pass national climate legislation ultimately failed, but the proposed EPA report to Congress on BC survived as an amendment to an Interior appropriations bill; the report is due to Congress by end of April 2011.

While the prospect of comprehensive, national climate policy appears dead for the foreseeable future, climate planning continues on the state level. To date, several states have adopted or are considering climate action plans that, to varying degrees, recognize the climate-warming impacts of BC. Many state climate plans include mitigation strategies that could significantly reduce BC emissions — particularly in the transportation sector — but the strategies are proposed to achieve GHG reductions and are not expressly designed to reduce BC's climate impacts. For example, New York's State Climate Action Plan Interim Report recommends establishing a low-interest revolving loan fund to facilitate the accelerated turnover of the state's heavy-duty vehicle (HDV) fleet. While this policy would result in reduced BC emissions through early retirement of pre-2007 diesel vehicles, the report authors calculate the climate impacts of accelerated HDV fleet turnover based on GHG reductions resulting from the increased fuel efficiency of newer HDVs; reduction of BC emissions is mentioned only as an air quality co-benefit of this policy (New York State Climate Action Council 2010). Similarly, California's Climate Change Scoping Plan estimates a 17 percent reduction in state diesel fuel usage in 2020 from a variety of climate mitigation strategies, including ship electrification and system-wide goods movement efficiency measures, but does not base its projected GHG emissions estimates on quantified BC reductions (CARB 2008b).

Other states' climate action plans acknowledge the climate impacts of non-GHG climate forcers, such as BC and OC, but stop short of integrating BC into baseline GHG emissions inventories and projections. For example, both Alaska and Arizona include $CO_{2\text{-}e}$ estimates of the states' historic BC emissions in their climate plans, but exclude those estimates from the plans' GHG emissions inventories and projections because of continued scientific uncertainty regarding BC's climate impacts and the lack of commonly accepted CO_2-equivalency metrics (Alaska Mitigation Advisory Group 2009; Arizona Climate Change Advisory Group 2006). The authors of the Arizona climate plan, however, also recommend incorporating BC emissions in the state's future annual GHG reporting requirements and recommend that the state develop and implement an incentive program to "reduce GHG black carbon emissions from heavy-duty diesel vehicles" through early retirement or replacement of 25 percent of vehicles that do not meet 2007 emissions standards (Arizona Climate Change Advisory Group 2006, p.15).

At least two states are currently exploring integrating the climate impacts of BC emissions reductions into state climate planning through a CO_2-equivalency framework. Connecticut's 2005 Climate Action Plan recommends reducing BC emissions by establishing a state clean diesel program, and estimates the $CO_{2\text{-}e}$ GHG emissions reductions achievable by this strategy (Connecticut Governor's Steering Committee on Climate Change 2005). Subsequent technical analysis contracted by the state as part of its climate planning process explores specific diesel reduction strategies, such as idle reduction on long-haul trucks and retrofitting nonroad equipment with DPFs, and estimates alternate $CO_{2\text{-}e}$ values for the projected BC emissions reductions, using both GWP_{20} and GWP_{100} metrics (NESCAUM 2010).

While California's 2008 Climate Change Scoping Plan does not incorporate the $CO_{2\text{-}e}$ climate impacts of BC-reducing measures into its GHG reduction estimates, the state is exploring the use of BC's GWP value in proposed regulations. The California Air Resources Board (CARB), a state agency charged with implementing some of the Plan's mitigation strategies, is looking at integrating the warming value of BC into proposed 2017–2025 LEVIII emissions standards for light-duty vehicles (LDVs), one of the mitigation measures included in the state's climate plan (CARB 2010b). While LDVs are currently a minor source of BC emissions compared to heavy-duty diesel engines, CARB anticipates that climate-driven adoption of new fuel-efficient gasoline direct injection (GDI) technology will increase BC emissions from the LDV fleet. Additionally, California's formal regulatory recognition of BC as a climate warmer has potential national impact, as CARB is working with EPA and the U.S. Department of Transportation to jointly develop 2017–2025 national LDV standards.

6.6 TRANSPORTATION-RELATED STRATEGIES

Strategies to reduce transportation-related GHG emissions include improving fuel efficiency, reducing the carbon content of fuels, reducing total vehicle-miles travelled (VMT), and improving the operational efficiency of transportation networks (Urban Land Institute 2009). To the extent that these strategies reduce diesel fuel consumption, they represent a potential "double win" for climate in that they can simultaneously reduce both CO_2 and BC emissions, which can be more effective than targeting CO_2 and BC individually (ICCT 2009). For example, some of the idle-reduction technologies advocated by the National Clean Diesel Campaign, including truck-stop electrification, auxiliary power units for heating and cooling, and use of shore power, can reduce BC emissions by reducing diesel fuel consumption. In FY2008, DERA-funded idle-reduction programs saved over 3.2 million gallons of diesel fuel, equivalent to reducing 35,600 tons of CO_2 (EPA 2009c). Intermodal goods movement strategies that shift cargo transport from trucks to more fuel-efficient trains can also reduce both BC and CO_2 emissions, as can operational efficiencies and use of aerodynamic technologies and low-resistance tires to increase the fuel efficiency of trucks.

Mark Jacobson (2007) advocates for conversion to battery-electric and plug-in hybrid electric vehicles or hydrogen fuel-cell vehicles, with an accompanying shift to renewable sources of electric power, as the best method of reducing both BC and CO_2 emissions. Shifting to renewable transportation fuels and energy generation is ultimately the most sustainable means of achieving the greatest reductions in both BC and CO_2 emissions. However, as these are typically longer-term strategies with major infrastructure development needs, they may not be implementable on a broad scale in time to capture the near-term climate benefits of BC reduction for rapidly warming areas such as the Arctic.

Section 7: Discussion

7.1 ACCELERATING REDUCTION OF BLACK CARBON EMISSIONS FROM IN-USE DIESEL ENGINES

Given the longevity of diesel engines, it may take decades for the estimated 11 million uncontrolled on-road and nonroad heavy-duty diesel vehicles in the United States to be completely replaced by ones that comply with current U.S. HDV standards. While waiting 20 to 30 years for the legacy fleet to completely turn over is an option, the health, air quality, and climate costs of waiting decades are considerable. Analysis conducted by Abt Associates for the Clean Air Task Force in 2005 (using EPA methodology) estimated the total monetized health costs of exposure to U.S. mobile-source diesel in 2010 as $139 billion (Schneider and Hill 2005). International transportation consultant Michael Walsh (2009) has estimated that retrofitting or replacing the majority of pre-2007 heavy-duty trucks and off-road diesel engines in the United States over the next decade would eliminate approximately 360 MMT $CO_{2\text{-e}}$ of BC that would otherwise be emitted from those diesels by 2030.[17] The Clean Air Task Force has identified diesel particular filter (DPF) retrofit of in-use diesels that do not comply with current emissions standards and adoption of policies to accelerate the turnover of the legacy diesel fleet as the best opportunity to reduce BC emissions in the United States (Schneider 2010). So what are the drivers and barriers to achieving additional, accelerated reduction of BC emissions from the legacy diesel vehicle fleet?

Drivers: As discussed in Section 6, on the national level, the main drivers for moving forward with additional U.S. BC emissions reductions are health and air quality. The Diesel Emissions Reduction Act, coupled with EPA's voluntary National Clean Diesel Campaign, is currently achieving reductions in diesel emissions, though progress is limited by available funding, and BC reductions vary according to the diesel emissions technologies employed by program participants. Health and air quality improvements are also driving state (as well as county and municipal) diesel and sectoral policies and programs that can facilitate BC emissions reductions from the in-use diesel fleet. While slowing the rate of climate change is an important reason to accelerate BC reductions from in-use diesels, given the current lack of federal climate policy and EPA's reluctance to date to formally integrate BC's climate-warming properties into its GHG rulemaking process, climate concerns are effectively driving further reductions in BC emissions from in-use diesels only in states, regions, and cities currently engaged in climate planning.

Economic barriers: The greatest barrier to accelerating BC emissions reductions from in-use diesels is, arguably, financial. The abovementioned estimate to retrofit or replace the majority of pre-2007 heavy-duty trucks and nonroad diesels in ten years would cost approximately $69 billion (Walsh 2009). By contrast, Congress recently

[17] Walsh's estimate assumed DPF retrofit or replacement of all heavy-duty diesel trucks from model years 1994–2006 and all off-road diesels of at least 75 horsepower and meeting at least Tier 2 emissions standards. The estimate assumed a GWP_{100} of 680; using a GWP_{20} metric would result in much higher $CO_{2\text{-eq}}$ benefits, according to Walsh.

reauthorized the DERA program for a total of $500 million for the next five years — and that funding is currently slated for elimination from the president's proposed budget. As demonstrated by the enthusiastic demand for DERA funding, the program has potential to further reduce BC emissions from the sizeable U.S. inventory of in-use, pre-regulation diesel engines. Yet Congress would need to appropriate — and allocate — far more funding to DERA for the program to make a sizable dent in BC emissions from the U.S. legacy fleet.

Despite the demonstrated health/air quality and climate benefits of reducing BC emissions from in-use diesels, someone has to pay to clean up in-use heavy-duty diesels, and many emissions control strategies, while cost-effective, are expensive. Low-cost diesel oxidation converter (DOC) filters are ineffective at reducing BC emissions, while retrofitting on-road heavy-duty diesels with DPF technology that can effectively eliminate BC emissions averages $12,000 to $15,000 per vehicle plus ongoing maintenance costs (Bachmann 2009). In some cases, the cost of a retrofit device can exceed the remaining value of an in-use engine, in which case vehicle replacement or engine repowering would be a preferable, though also expensive, strategy (EPA 2009c). For nonroad diesel engines, such as those used in construction, retrofit costs "may be similar to those for comparable sized on-road vehicles," but the wide variety of nonroad equipment can require custom applications, limiting economies of scale (Bachmann 2009, p.27).

Some of the oldest and dirtiest on-road heavy-duty diesel vehicles are owned by small businesses or independent contractors with limited access to capital to retrofit, replace, or properly maintain diesel equipment or invest in emissions reduction technologies. Larger fleet and equipment owners face competing business uses for capital that could be spent on emissions reductions. At the same time, economic incentives to retrofit or retire diesel engines are often lacking, especially for private vehicle and equipment owners.[18] As a recent Diesel Technology Forum report on retrofit funding notes:

"... because a diesel retrofit does not improve fuel efficiency or provide economic benefits, it is a hard sell for truckers, school districts and contractors who must justify the investment costs while operating under tight budgets and profit margins. As a result, the growth of federal and state funding programs will be critical to expedite the adoption of these new, cleaner technologies." (Diesel Technology Forum 2007, p.3)

Even diesel emissions reduction strategies that do convey economic benefits to vehicle owners, such as idle reduction technologies that reduce fuel use and have a relatively short payback period, are often not adopted by vehicle and fleet owners because of up-front capital constraints (Lowell 2010).

The unequal allocation of diesel clean-up costs and benefits means that vehicle and equipment owners often bear the costs of emissions controls, while the public benefits

[18] Current DERA funding guidelines limit grants to public entities. Private companies must partner with public entities, such as port authorities or municipalities, in order to be eligible for DERA funding.

from clean air and reduced climate warming. At the same time, the health/air quality and climate costs of BC emissions are externalized in the absence of mandatory or voluntary policy mechanisms to account for those costs through adoption of emissions controls. A 2006 report by EPA's Clean Air Advisory Committee (CAAAC) recommended large-scale public investment that can creatively leverage private capital, coupled with the expansion of a suite of public and privately funded incentives tailored to the needs of various diesel-intensive industry sectors, as the best way to clean up emissions from legacy diesels.

Development and expansion of innovative public and private funding mechanisms are urgently needed to facilitate further, accelerated reductions in BC emissions from in-use U.S. diesel sources. Grants, loans, rebates, and tax incentives can provide effective financial incentives across on-road and nonroad diesel sectors (CAAAC 2006). Examples of innovative sector-specific financing mechanisms include a CATF-proposed "Credit for Clunkers" program using federally backed low-interest loans to facilitate trade-in of older, polluting diesel trucks for newer trucks equipped with both DPF filters and SmartWay fuel economy technologies that would facilitate loan repayment through fuel savings (CATF 2010b); proposed Clean Construction provisions in the upcoming Transportation Bill reauthorization to both mandate and fund retrofits of diesel equipment on all federally funded construction projects (AGCA and CATF 2009); and lease-to-own, revolving low-interest loan funds to help drivers and fleet owners replace older diesels with new, regulation-compliant vehicles (Cascade Sierra Solutions 2011).

Regulatory barriers: Due, in part, to limited funding, EPA's voluntary diesel clean-up programs are not adequate to address the magnitude of BC emissions from in-use diesels in the United States (Chang 2010). While mandatory emissions reduction programs often meet with considerable pushback from affected industries, they can be very effective, as evidenced by California's Diesel Risk Reduction Program, which has been attributed with cutting the state's BC emissions in half over the last 20 years (Bahadur et al. 2011). While EPA has limited authority to regulate in-use engines under the Clean Air Act, Congressional action would be needed to grant EPA additional authority to more broadly regulate in-use diesels. The Engine Rebuild Rule proposed by the Clean Air Task Force (see Section 6.4) could achieve substantial health and climate benefits through BC reductions, and its feasibility should definitely be explored. However, given that the CAA rulemaking process can drag on for years, it is unclear how quickly leveraging existing CAA regulatory authority over in-use engines can be mobilized to achieve near-term reductions in BC emissions.

Other regulatory barriers bar states and local authorities, such as ports, from regulating truck prices, routes, or services (TruckingInfo.com 2011). The Clean Ports Act of 2011 (H.R. 572) would address these barriers and help maximize BC emissions reductions at ports by amending the Federal Motor Carrier Act "to allow ports to enact and enforce clean truck programs and implement environmental programs above the current federal requirements" (Nadler 2011).

Political barriers: National U.S. climate legislation is mired in politics and effectively stalled for the foreseeable future. While regional, state, and municipal progress on climate continues, national climate policy could help drive accelerated BC reductions, just as it has in some states that have implemented state-level climate policies. National climate legislation could also provide a source of funding for BC emissions reduction efforts, as was included in the proposed American Power Act.

EPA's authority to regulate GHGs is currently under attack in Congress, which does not lessen the need to reduce the climate impacts of BC, but complicates EPA's strategic approach to the issue. In the context of partisan political hostility towards climate science and climate policy, BC's dual identity as a climate warmer and conventional air pollutant may present an opportunity, insofar as addressing the health and air quality impacts of diesel emissions appears to have more political traction in Congress than dealing with climate, as demonstrated by recent bipartisan support for the reauthorization of the DERA program.

Technological barriers: Overall, the technological barriers to accelerating BC emissions reductions from in-use diesel vehicles and mobile equipment are minor relative to some of the other barriers discussed in this section. Effective technologies to reduce PM/BC emissions, such as diesel particulate filters, are readily available domestically. Both EPA and CARB verify the effectiveness of emissions control technologies and require use of verified technologies in projects they fund, and EPA dedicates some of its National Clean Diesel Campaign grants for development and evaluation of emerging emissions control technologies. Nonetheless, there are some technological obstacles to achieving further BC reductions from the legacy diesel fleet. Some of the oldest, most polluting on-road diesel engines cannot be outfitted with DPFs, which are the most effective after-treatment technology for reducing BC emissions. Additionally, verified emissions control technology for nonroad and marine diesel engines is limited (EPA 2009c). While the availability of ultra low-sulfur diesel (ULSD) fuel required to operate diesel retrofit technology is no longer an issue in the United States now that ULSD regulations are fully phased in, availability of ULSD is a barrier to deployment of effective emissions control technology in many developing countries.

Scientific barriers: Lingering scientific uncertainty regarding BC's climate impacts (see Section 3.4) and lack of agreed-upon metrics for comparing the climate impacts of LLGHGs and SLCFs (see Section 5.3) have been invoked frequently as a barrier to addressing BC as a climate warmer in regulatory action and climate-related policy. Yet as the scientific evidence mounts for BC's warming effects, when do we know enough to act? Lack of scientific certainty should not impede action to accelerate reduction of BC emissions, especially when the health co-benefits of BC emissions reductions make these "no-regrets" strategies. A precautionary approach to reducing the climate impacts of BC emissions could begin by prioritizing policies and strategies where the scientific evidence is strongest for climate benefits, such as reducing BC emissions near or transported to snow- and ice-covered regions like the Arctic and Greenland, and targeting sectors and areas with a high ratio of BC:OC diesel emissions, such as superemitting heavy-duty diesel vehicles, ports, and goods movement corridors. Similarly, while alternatives to the GWP metric are needed to improve comparisons of SLCFs and LLGHGs, lack of a perfect metric should not delay formally accounting for BC's warming impacts in climate policies and regulations that could drive further, or faster, reductions of BC emissions.

Structural/institutional barriers: Better integration of climate and air quality policy and planning within and across institutions, agencies, and disciplines could help drive reductions in BC emissions by aligning policy goals and prioritizing strategies for reducing BC's climate impacts. Within EPA, BC emissions reduction presents some institutional challenges, since BC emissions control cuts across the different Agency divisions responsible for climate and air quality planning (Terry Keating, pers. comm., July 28, 2010). Additionally, emissions inventory data for the various criteria pollutants and greenhouse gases are housed in different Agency databases, which further complicates integrated multipollutant planning (Tesh Rao, pers. comm., Aug. 10, 2010).

EPA's National Clean Diesel Campaign provides one small example of how better integration of climate and air quality planning goals could potentially drive further BC emissions reductions in the legacy diesel fleet. To date, climate concerns have not been reflected in national DERA grant evaluation criteria. Similarly, BC is not included in the Diesel Emissions Quantifier, an online support tool EPA created to help clean-diesel funding applicants estimate the emissions reductions, cost-effectiveness, and health benefits of their proposed projects and strategies.[19] Yet, as discussed in Section 6.1, different diesel emissions control strategies have variable impact on reducing BC, and thus, have varying climate co-benefits. Of the 9,891 vehicles retrofitted with emissions control devices using DERA funding in FY08, 75 percent employed diesel oxidative catalysts, which are considerably less expensive than diesel particulate filters but far less effective in reducing BC emissions (EPA 2009c). By incorporating specific BC-reduction or climate criteria in its application evaluation process and incorporating BC emissions and climate considerations into its grant support tools, the EPA could more effectively reduce BC emissions from in-use diesels by giving more weight to clean diesel projects that maximize both health and climate co-benefits.

On a broader scale, one of the central arguments for targeting BC emissions is to balance air quality policies that are effectively reducing air pollutants with climate-cooling properties, such as SO_2 and NO_x. An integrated air quality and climate strategy that seeks to maximize health/air quality and climate benefits could drive accelerated reductions of short-lived climate warming agents, like BC, to counterbalance current U.S. health- and air quality-driven strategies, which reduce air pollutants that contribute to climate cooling. EPA is currently conducting pilot projects in three U.S. cities to evaluate comprehensive air quality management plans that integrate multi-pollutant control with land-use, transportation, energy, and climate change concerns,

[19] See EPA, Office of Transportation and Air Quality. 2010. Diesel Emission Quantifier — Frequently Asked Questions. EPA-420-F-10-045. Accessed April 12, 2011. http://www.epa.gov/cleandiesel/documents/420f10045.pdf.

and developing analytical tools to facilitate integrated multi-pollutant planning.[20] Expanding this approach EPA-wide could help facilitate BC emissions reduction efforts within the Agency by capturing synergies and avoiding tradeoffs between air quality- and climate-driven policies and programs.

Implementation barriers: In addition to the barriers discussed above, there are some implementation challenges to accelerating BC emissions reductions from legacy heavy-duty diesels. While technology to effectively reduce BC emissions from in-use diesel vehicles and equipment is available, identifying, inventorying, and targeting the sheer number of widely dispersed diesel vehicles and machines presents a daunting logistical and administrative undertaking (Bice et al. 2009). Some reports have suggested prioritizing BC emissions control efforts on "superemitting" on-road vehicles whose higher-than-fleet-average emission rates account for a disproportionate share of BC emissions (Bice et al. 2009). Yet focusing on this subset of high-polluting diesels presents implementation challenges, as there are no rigorous guidelines for classifying a vehicle as a "superemitter" (Subramanian et al. 2009). Other implementation barriers include the need to establish a baseline of BC emissions and to develop effective measurement, verification, and reporting systems to track actual BC emissions reductions (Sarofim 2010).

7.2 EPA POLICY OPTIONS FOR ADDRESSING BLACK CARBON CLIMATE IMPACTS

The United States needs a coordinated national strategy to control the climate impacts of BC emissions. As noted in the Introduction, EPA is currently evaluating its policy options for addressing the climate impacts of BC emissions, including integrating BC into the widely used Kyoto Protocol "basket of gases" CO_2-equivalency framework; including BC in multi-pollutant climate policies but excluding BC from the "basket of gases" framework; and/or addressing BC through existing air quality policies that target PM, while taking additional actions that acknowledge BC's climate-warming impacts (Ben DeAngelo, pers. comm., Aug. 8, 2009). Given the complexity of addressing BC's climate impacts as well as the urgent need to take action to slow the rate of near-term climate change, a pragmatic strategy could plausibly incorporate elements of all three approaches in order to capture the near-term climate mitigation opportunities that reducing BC emissions can afford.

As the discussion of BC and state climate plans in Section 6.5 demonstrates, recognition of BC's climate warming impacts can drive diesel and BC reduction policies, with or without the use of a GWP metric. At the same time, existing air quality-driven clean diesel and Clean Air Act policy mechanisms have greater potential to accelerate

[20] See, for example, EPA's pilot Air Quality Management Plan (http://www.epa.gov/oaqps001/ aqmp/basic.html) and the work of EPA's Atmospheric Modeling and Analysis Division (http://www.epa.gov/amad/Climate/index.html).

reductions in domestic BC emissions. It makes sense to take advantage of existing air quality policies to the extent that they can facilitate faster action on reducing BC emissions than developing and implementing new climate policy mechanisms. This appears to be the case on the national front, in the absence of climate policies that could accelerate further BC emissions reductions. However, leveraging existing air quality policy mechanisms to most effectively drive accelerated BC emissions reductions will require better coordination, if not integration, with climate policy and planning goals. Additional funding sources, expanded EPA authority to address in-use diesel engines, and the political will to act quickly are also needed.

Whichever policy approach it takes, EPA should develop a coordinated national strategy to control the climate impacts of BC emissions, beginning by recognizing the climate warming impacts of BC and other SLCFs in future air quality and climate regulatory and program activities. This would be an important step towards aligning the Agency's air quality and climate goals and strategies. Despite the uncertainties and challenges, such a move can drive further reductions in domestic BC emissions, continue U.S. leadership on air quality, and demonstrate a commitment to addressing near-term climate change.

7.3 LIMITATIONS

While this research has focused on heavy-duty diesel mobile sources as the largest contributor to U.S. BC emissions and the greatest domestic net warming source of BC, other sources and sectors of BC need to be considered. Some sectors such as residential combustion in wood and pellet stoves, for example, while smaller contributors to U.S. BC emissions than diesel mobile sources, may be less effectively controlled for BC emissions. Others, such as wildfires, may be less amenable to emissions control strategies. Yet all need to be considered in a comprehensive approach to continuing to reduce domestic BC emissions.

Additionally, this research has focused exclusively on the climate warming contributions of BC emissions, but policy discussions of near-term climate change often evaluate BC reduction strategies in conjunction with strategies to reduce other non-CO_2 climate forcers, such as tropospheric ozone. An integrated, multi-pollutant strategy to improve air quality and mitigate climate change would need to systematically evaluate BC emissions reduction efforts in conjunction with strategies to control other comparably short-lived climate warmers in order to maximize health and climate benefits and assess the cost-effectiveness of individual control measures and policies.

Section 8: Policy Implications

Currently, the United States has a number of national- and sub-national policy mechanisms that could facilitate accelerated BC emissions reductions from mobile-source diesel fuel consumption, but no coordinated national strategy. While most current policies achieving BC reductions are driven by health and air quality goals, such as national and state clean diesel policies and sectoral programs, some, particularly on the regional, state, and municipal level, are climate-driven. Better coordination of air-quality and climate policies and planning is urgently needed to harmonize national air quality and climate goals, capture cost-effective synergies, and minimize climate-health tradeoffs.

In the absence of an integrated framework that considers both the climate and health/air quality benefits of reducing BC emissions, the United States should take a pragmatic approach, prioritizing fast action by leveraging existing regulatory authority and policy mechanisms wherever possible. To take full advantage of the near-term opportunity that reducing BC emissions offers to slow the rate of climate change, the following actions to reduce BC emissions from domestic diesel fuel consumption are recommended.

RECOMMENDATIONS FOR EPA:

1. Develop and implement a coordinated, national strategy to control the climate impacts of BC emissions. As a first step, integrate the climate warming impacts of BC in upcoming air quality and climate regulatory programs and rule-making activities, including the $PM_{2.5}$ NAAQS review, the National Clean Diesel Program, and upcoming GHG regulatory action.

2. Exercise existing EPA authority under the Clean Air Act to regulate in-use diesel engines at the time of engine rebuild and to pursue other sources of directly emitted particulate matter.

3. Fast-track the integration of climate and air quality management planning Agency-wide, by developing the necessary models and analytical tools internally and coordinating with other relevant federal agencies.

RECOMMENDATIONS FOR CONGRESS:

1. Reauthorize and fully fund DERA, and consider expanding the program.

2. Expand EPA authority to regulate in-use diesel engines.

3. Support and expand funding sources for diesel retrofits, such as through clean construction provisions in the upcoming Transportation Bill reauthorization.

4. Pass the Clean Ports Act of 2011 and other legislation that will facilitate BC emissions reductions in some of the most polluting diesel sectors.

5. Consider a carefully designed "Credit for Clunkers" program to incentivize accelerated turnover of the legacy heavy-duty diesel vehicle fleet. Such a program should include a verified scrappage provision to ensure that polluting diesels are not simply exported to developing countries.

6. Continue to fund and pursue transportation- and energy-related policies and strategies that can simultaneously reduce GHG and BC emissions, including accelerated deployment of electric vehicles and infrastructure and renewable electricity generation.

7. Advance and implement domestic policies to mitigate long-term climate change by reducing GHG emissions and to slow the rate of near-term climate change by prioritizing accelerated reductions in emissions of BC and other short-lived climate warming agents, such as tropospheric ozone.

RECOMMENDATIONS FOR REGIONAL, STATE, AND LOCAL GOVERNMENTS:

1. Support and expand regulatory and voluntary clean diesel programs and financing mechanisms, including inspection and maintenance programs, and tighten existing clean diesel policies and programs to require use of Best Available Control Technologies, which will be most effective in reducing BC emissions.

2. Include diesel-reduction strategies that most effectively reduce BC emissions in state climate plans, policies, and strategies.

3. Fund and pursue transportation-related strategies that can simultaneously reduce GHG and BC emissions.

While the barriers to accelerating domestic reductions in BC emissions are not trivial, compared to other climate control strategies that require substantial technology research and development to even prove feasible, BC control is not an insurmountable problem. Additional and accelerated reduction of BC emissions from in-use diesels provides a no-regrets opportunity to slow the rate of near-term climate change while delivering substantial health and air quality benefits to the American people. We are already making progress in this effort, but we could be doing a lot more.

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Appendix A: Interviews

The following interviews were conducted for this study:

Name	Affiliation	Interview date
George Allen	Senior Scientist, NESCAUM	July 20, 2010
Praveen Amar	Director of Science and Policy, NESCAUM	July 20, 2010
Susan Anenberg	Environmental Specialist, Office of Air Quality Planning and Standards, U.S. EPA	August 11, 2010
Alberto Ayala	Chief, Climate Change Mitigation and Emissions Branch, California Air Resources Board	September 29, 2010
John Bachmann	Vision Air Consulting; former Science Director for Science/Policy and New Programs, Office of Air Quality Planning and Standards, U.S. EPA	August 10, 2010
Ellen Baum	Senior Scientist, Clean Air Task Force	September 16, 2010
Bart Croes	Chief of Research Division, California Air Resources Board	September 28, 2010
John-Michael Cross	Director of Research, The Climate Institute	September 13, 2010
Ben DeAngelo	Senior Analyst, Climate Change Science and Policy, Office of Atmospheric Programs, U.S. EPA	August 8, 2009; September 15, 2010
Dale Evarts	Group Leader, Climate, International and Multimedia Group, Office of Air Quality Planning and Standards, U.S. EPA	August 11, 2010
Michael Geller	Office of Transportation and Air Quality, U.S. EPA	August 14, 2010
John Guy	Acting Deputy Director, Transportation and Regional Programs Division, Office of Transportation and Air Quality, U.S. EPA	August 14, 2010
Terry Keating	Senior Environmental Scientist, Office of Air and Radiation, U.S. EPA	July 28, 2010
Drew Kodjak	Executive Director, International Council on Clean Transportation	July 27, 2010
Paul Miller	Deputy Director, NESCAUM	July 20, 2010
Ray Minjares	Policy Analyst, International Council on Clean Transportation	September 27, 2010; September 30, 2010
Tesh Rao	Office of Air Quality Planning and Standards, U.S. EPA	August 10, 2010
Marcus Sarofim	AAAS Science and Technology Policy Fellow, U.S. EPA	August 8, 2009; July 28, 2010
Erika Sasser	Office of Air Quality Planning and Standards, U.S. EPA	August 11, 2010
Allen Schaeffer	Executive Director, Diesel Technology Forum	September 17, 2010

Name	**Affiliation**	**Interview date**
Sam Sherer	Senior Fellow, The Climate Institute	September 13, 2010
Carl Spector	Executive Director, Boston Air Pollution Control Commission	August 12, 2010
Sara Terry	Office of Air Quality Planning and Standards, U.S. EPA	August 11, 2010
Matt Vespa	Senior Attorney, Center for Biological Diversity	September 27, 2010
Erik White	Chief, Heavy Diesel Strategies Branch, California Air Resources Board	September 28, 2010
Catherine Witherspoon	Consultant, ClimateWorks Foundation; former Executive Officer, California Air Resources Board	September 28, 2010
Durwood Zaelke	President, Institute for Governance & Sustainable Development	July 27, 2010

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THE FLETCHER SCHOOL
TUFTS UNIVERSITY

Energy, Climate, and Innovation Program (ECI)

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Cabot Intercultural Center, Suite 509
160 Packard Avenue
Medford, MA 02155

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