Reducing Black Carbon May Be Fastest Strategy for Slowing Climate Change

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Black Carbon Is Potent Climate Forcing Agent and Key Target for Climate Mitigation

Reducing black carbon (BC) may offer the greatest promise for immediate climate mitigation. BC is a potent climate forcing agent, estimated to be the second largest contributor to global warming after carbon dioxide (CO_2). Because BC remains in the atmosphere only for a few weeks, reducing BC emissions may be the fastest means of slowing climate change in the near-term.

Addressing BC now can help delay the possibility of passing thresholds, or tipping points, for abrupt and irreversible climate changes,[1] which could be as close as ten years away and have potentially catastrophic impacts.[2] It also can buy policymakers critical time to address CO_2 emissions in the middle and long-terms.

Estimates of BC's climate forcing (combining both direct and indirect forcings) vary from the IPCC's conservative estimate of + 0.3 watts per square meter (W/m^2) $\pm$ 0.25,[3] to the most recent estimate of 1.0-1.2 W/m^2 (see Table 1), which is "as much as 55% of the CO_2 forcing and is larger than the forcing due to the other greenhouse gasses (GHGs) such as CH_4, CFCs, N_2O, or tropospheric ozone."[4]

In some regions, such as the Himalayas, the impact of BC on melting snowpack and glaciers may be equal to that of CO_2.[5] BC emissions also significantly contribute to Arctic ice-melt, which is critical because "nothing in climate is more aptly described as a 'tipping point' than the 0°C boundary that separates frozen from liquid water—the bright, reflective snow and ice from the dark, heat-absorbing ocean."[6] Hence, reducing such emissions may be "the most efficient way to mitigate Arctic warming that we know of."[7]

Since 1950, many countries have significantly reduced BC emissions especially from fossil fuel sources, primarily to improve public health, and "technology exists for a drastic reduction of fossil fuel related BC" throughout the world.[8] Ensuring compliance and enforcement with existing national laws that address black carbon emissions can provide some relief, but new laws and regulations are needed at all levels for further and faster reductions, especially as the emissions at the global level are increasing.[9]

Reducing Black Carbon May Be Fastest Way to Slow Global Warming

In its 2007 report, the IPCC estimated for the first time the direct radiative forcing of black carbon from fossil fuel emissions at + 0.2 W/m^2, and the radiative forcing of black carbon through its effect on the surface albedo of snow and ice at an additional + 0.1 W/m^2.[10] More recent studies and public testimony by many of the same scientists cited in the IPCC's report estimate that emissions from black carbon are the second largest contributor to global warming after carbon dioxide emissions, and that reducing these emissions may be the fastest strategy for slowing climate change.[11]

BC is formed through the incomplete combustion of fossil fuels, biofuel, and biomass, and is emitted in both anthropogenic and naturally occurring soot. BC warms the planet by absorbing heat in the atmosphere and by reducing albedo, the ability to reflect sunlight, when deposited on snow and ice. BC stays in the atmosphere from several days to weeks, whereas CO_2 has an atmospheric lifetime of more than 100 years.[12]

Given BC's relatively short lifespan, reducing BC emissions would reduce warming within weeks. Control of BC, "particularly from fossil-fuel sources, is very likely to be the fastest method of slowing global warming" in the immediate future, according to Dr. Mark Jacobson of Stanford University, and he believes that major cuts in BC emissions could slow the effects of climate change for a decade or two,[13] buying policymakers more time to reduce CO_2 emissions.[14] Reducing BC emissions could help keep the climate system from passing the tipping points for abrupt climate changes, including significant sea-level rise from the disintegration of the Greenland and/or Antarctic ice sheets.[15]

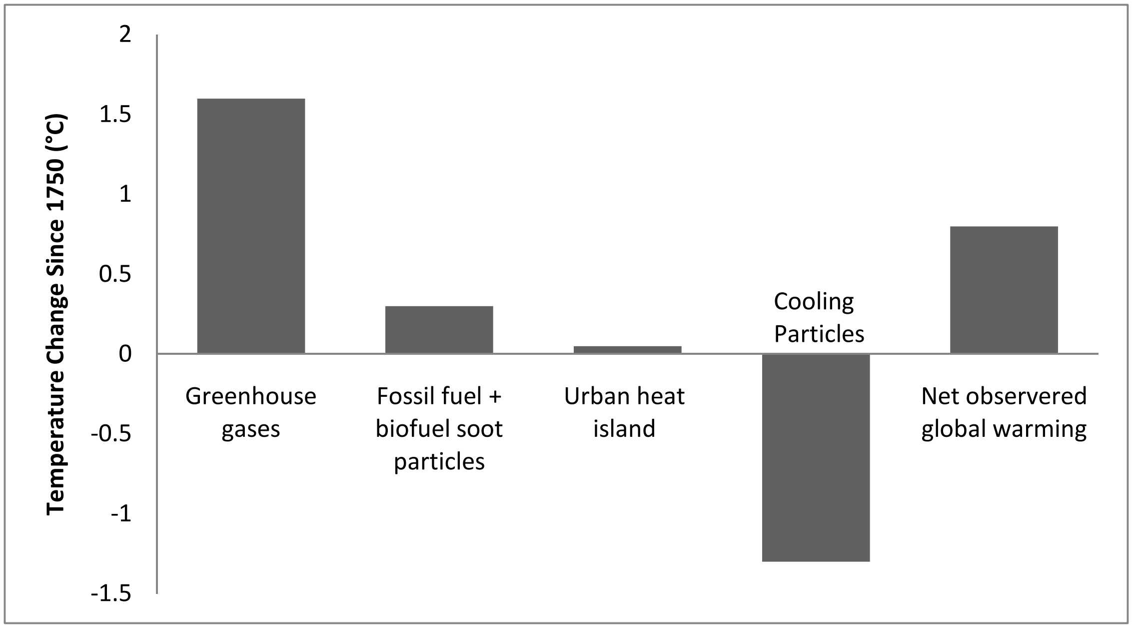
"[E]missions of black carbon are the second strongest contribution to current global warming, after carbon dioxide emissions," according to Dr. V. Ramanathan and Dr. G. Carmichael.[16] They calculate BC's combined climate forcing at 1.0 – 1.2 W/m^2, which "is as much as 55% of the CO_2 forcing and is larger than the forcing due to the other [GHGs] such as CH_4, CFCs, N_2O or tropospheric ozone."[17] Other scientists estimate the total magnitude of BC's forcing between + 0.2 to 1.1 W/m with varying ranges due to uncertainties.[2] (See Table 1.) This compares with the IPCC's climate forcing estimates of 1.66 W/m^2 for CO_2 and 0.48 W/m^2 for CH_4.[18] (See Table 2.) In addition, BC forcing is two to three times as effective in raising temperatures in the Northern Hemisphere and the Arctic than equivalent forcing values of CO_2.[19]

Jacobson calculates that reducing fossil fuel and biofuel soot particles would eliminate about 40% of the net observed global warming.[20] (See Figure 1.) In addition to BC, fossil fuel and biofuel soot contain aerosols and particulate matter that cool the planet by reflecting the sun's radiation away from the Earth.[21] When the aerosols and particulate matter are accounted for, fossil fuel and biofuel soot are increasing temperatures by about 0.35°C.[22]

BC alone is estimated to have a 20-year Global Warming Potential (GWP) of 4,470, and a 100-year GWP of 1,055-2,240.[23] Fossil fuel soot, as a result of mixing with cooling aerosols and particulate matter, has a lower 20-year GWP of 2,530, and a 100-year GWP of 840-1,280.[24]

Over the course of the century, however, the amount of these cooling aerosols in the atmosphere is expected to decrease, largely as a result of reductions in sulfur dioxide emissions. These reductions will unmask warming by other agents, such as BC, which these cooling aerosols currently help to offset. At the same time, under the IPCC A1B scenario, BC emissions are expected to double, further compounding their warming effect.[25] Thus, addressing BC is critical both to prevent additional warming by increased BC emissions and to keep pace with expected reductions in cooling aerosols that currently mask BC's present effects.[26]

Figure 1[27]



Primary contributions to observed global warming 1750 from the present from global model calculations. The fossil-fuel plus biofuel soot estimate takes into account the effect of soot on snow and ice albedo as well as cooling particles and particulate matter emitted with BC.

BC Is Accelerating Warming of Arctic Sea-Ice and Himalayan Glaciers

According to the IPCC, "the presence of BC over highly reflective surfaces, such as snow and ice, or clouds, may cause a significant positive radioactive forcing."[28] The IPCC also notes that emissions from biomass burning, which usually have a negative forcing,[29] have a positive forcing over snow fields in areas such as the Himalayas.[30]

BC is a significant contributor to Arctic ice-melt, and reducing such emissions may be "the most efficient way to mitigate Arctic warming that we know of," according to Dr. Charles Zender of the University of California, Irvine.[31] The "climate forcing due to snow/ice albedo change is of the order of 1.0 W/m^2 at middle- and high-latitude land areas in the Northern Hemisphere and over the Arctic Ocean."[32] The "soot effect on snow albedo may be responsible for a quarter of observed global warming."[33] "Soot deposition increases surface melt on ice masses, and the meltwater spurs multiple radiative and dynamical feedback processes that accelerate ice disintegration," according to NASA scientists Dr. James Hansen and Dr. Larissa Nazarenko.[34] As a result of this feedback process, "BC on snow warms the planet about three times more than an equal forcing of CO_2."[35] When BC concentrations in the Arctic increase during the winter and spring due to Arctic Haze, surface temperatures increase by 0.5°C.[36]

BC emissions from northern Eurasia, North America, and Asia have the greatest absolute impact on Arctic warming.[37] However, BC emissions actually occurring within the Arctic have a disproportionately larger impact per particle on Arctic warming than emissions originating elsewhere.[38] As Arctic ice melts and shipping activity increases, emissions originating within the Arctic are expected to rise.[39]

In some regions, such as the Himalayas, the impact of BC on melting snowpack and glaciers may be equal to that of CO_2.[40] Warmer air resulting from the presence of BC in South and East Asia over the Himalayas contributes to a warming of approximately 0.6°C. [41] An "analysis of temperature trends on the Tibetan side of the Himalayas reveals warming in excess of 1°C since the 1950s."[42] This large warming trend is the proposed causal factor for the accelerating retreat of Himalayan glaciers,[43] which threatens fresh water supplies and food security in China and India.[44]

Major Producers of BC

By Region: Developed countries were once the primary source of BC emissions, but this began to change in the 1950's with the adoption of pollution control technologies in those countries.[45] Whereas the U.S. emits about 21% of the world's CO_2, it emits 6.1% of the world's soot.[46] The Unites States and the European Union could further reduce their BC emissions by accelerating implementation of BC regulations that currently take effect in 2015 or 2020[47] and by supporting the adoption of pending International Maritime Organization (IMO) regulations.[48] Existing regulations also could be expanded to increase the use of clean diesel and clean coal technologies and to develop second-generation technologies.

Today, the majority of BC emissions are from developing countries[49] and this trend is expected to increase.[50] The largest sources of BC are Asia, Latin America, and Africa.[51] China and India account for 25-35% of global BC emissions.[52] BC emissions from China doubled from 2000 to 2006.[53] Existing and well-tested technologies used by developed countries, such as clean diesel and clean coal, could be transferred to developing countries to reduce their emissions.[54]

BC emissions "peak close to major source regions and give rise to regional hotspots of BC—induced atmospheric solar heating."[55] Such hotspots include, "the Indo-Gangetic plains in South Asia; eastern China; most of Southeast Asia including Indonesia; regions of Africa between sub-Sahara and South Africa; Mexico and Central America; and most of Brazil and Peru in South America."[56] Approximately three billion people live in these hotspots.[57]

By Source: Approximately 20% of BC is emitted from burning biofuels, 40% from fossil fuels, and 40% from open biomass burning, according to Ramanathan.[58] Similarly, Dr. Tami Bond of the University of Illinois, Urbana Champaign, estimates the sources of BC emissions as follows:[59]

42%	Open biomass burning (forest and savanna burning)
18%	Residential biofuel burned with traditional technologies
14%	Diesel engines for transportation
10%	Diesel engines for industrial use
10%	Industrial processes and power generation, usually from smaller boilers
6.0%	Residential coal burned with traditional technologies[60]

BC sources vary by region. For example, the majority of soot emissions in South Asia are due to biofuel cooking, whereas in East Asia, coal combustion for residential and industrial uses plays a larger role.

Fossil fuel and biofuel soot have significantly greater amounts of BC than climate-cooling aerosols and particulate matter, making reductions of these sources particularly powerful mitigation strategies. For example, emissions from the diesel engines and marine vessels contain higher levels of BC compared to other sources.[61] Regulating BC emissions from diesel engines and marine vessels therefore presents a significant opportunity to reduce BC's global warming impact.[62]

Biomass burning emits greater amounts of climate-cooling aerosols and particulate matter than BC, resulting in short-term cooling.[63] However, over the long-term, biomass burning may cause a net warming when CO_2 emissions and deforestation are considered.[64] Reducing biomass emissions would therefore reduce global warming in the long-term and provide co-benefits of reduced air pollution, CO_2 emissions, and deforestation. Johannes Lehmann of Cornell University estimates that by switching to slash-and-char from slash-and-burn agriculture, which turns biomass into ash using open fires that release BC[65] and GHGs,[66] 12% of anthropogenic carbon emissions caused by land use change could be reduced annually,[67] which is approximately 0.66 Gt CO_2-eq. per year, or 2% of all annual global CO_2-eq emissions.[68]

Technology for Reducing BC Is Available

Ramanathan notes that "developed nations have reduced their BC emissions from fossil fuel sources by a factor of 5 or more since 1950. Thus, the technology exists for a drastic reduction of fossil fuel related BC."[69]

Jacobson believes that "[g]iven proper conditions and incentives, [soot] polluting technologies can be quickly phased out. In some small-scale applications (such as domestic cooking in developing countries), health and convenience will drive such a transition when affordable, reliable alternatives are available. For other sources, such as vehicles or coal boilers, regulatory approaches may be required to nudge either the transition to existing technology or the development of new technology."[70]

Hansen states that "technology is within reach that could greatly reduce soot, restoring snow albedo to near pristine values, while having multiple other benefits for climate, human health, agricultural productivity, and environmental aesthetics. Already soot emissions from coal are decreasing in many regions with transition from small users to power plants with scrubbers."[71]

Jacobson suggests converting "[U.S.] vehicles from fossil fuel to electric, plug-in-hybrid, or hydrogen fuel cell vehicles, where the electricity or hydrogen is produced by a renewable energy source, such as wind, solar, geothermal, hydroelectric, wave, or tidal power. Such a conversion would eliminate 160 Gg/yr (24%) of U.S. (or 1.5% of world) fossil-fuel soot and about 26% of U.S. (or 5.5% of world) carbon dioxide."[72] According to Jacobson's estimates, this proposal would reduce soot and CO_2 emissions by 1.63 $GtCO_2$–eq. per year.[73] He notes, however, "that the elimination of hydrocarbons and nitrogen oxides would also eliminate some cooling particles, reducing the net benefit by at most, half, but improving human health," a substantial reduction for one policy in one country.[74]

For diesel vehicles in particular there are a several effective technologies available. Diesel oxidation catalysts have been in use for over 30 years, can be used on almost any diesel vehicle, and can eliminate 25-50% of black carbon emissions.[75] Newer, more efficient diesel particulate filters (DPFs), or traps, can eliminate over 90% of black carbon emissions,[76] but these devices require ultra low sulfur diesel fuel (ULSD). To ensure compliance with new particulate rules for new on-road and non-road vehicles in the U.S., the EPA first required a nationwide shift to ULSD, which allowed DPFs to be used in diesel vehicles in order to meet the standards. Because of recent EPA regulations, BC emissions from diesel vehicles are expected to decline about 70 percent from 2001 to 2020.[77] Overall, "BC emissions in the United States are projected to decline by 42 percent from 2001 to 2020."[78] By the time the full fleet is subject to these rules, EPA estimates that over 239,000 tons of particulate matter will be reduced annually.[79] Outside of the US diesel oxidation catalysts are often available and DPFs will become available as ULSD is more widely commercialized.

Another technology for reducing BC emissions from diesel engines is to shift fuels to compressed natural gas. In New Delhi, India, a court-ordered shift to compressed natural gas for all public transport vehicles, including buses, taxis, and rickshaws, resulted in a climate benefit, "largely because of the dramatic reduction of black carbon emissions from the diesel bus engines."[80] Overall, the fuel switch for the vehicles reduced black carbon emissions enough to produce a 10 percent net reduction in CO_2-eq., and perhaps as much as 30 percent.[81] The main gains were from diesel bus engines whose CO_2-eq. emissions were reduced 20 percent.[82] According to a study examining these emissions reductions, "there is a significant potential for emissions reductions through the [UNFCCC] Clean Development for such fuel switching projects."[83]

Technologies are also in development to reduce some of the 133,000 metric tons of particulate matter emitted each year from ships.[84] Ocean vessels use diesel engines, and particulate filters similar to those in use for land vehicles are now being tested on them. As with current particulate filters these too would require the ships to use ULSD, but if comparable emissions reductions are attainable, up to 120,000 metric tons of particulate emissions could be eliminated each year from international shipping.[85] Other efforts can reduce the amount of BC emissions from ships simply by decreasing the amount of fuel the ships use. By traveling at slower speeds or by using shore side electricity when at port instead of running the ship's diesel engines for electric power, ships can save fuel and reduce emissions.

Ramanathan estimates that "providing alternative energy-efficient and smoke-free cookers and introducing transferring technology for reducing soot emissions from coal combustion in small industries could have major impacts on the radiative forcing due to soot."[86] Specifically, the impact of replacing biofuel cooking with BC-free cookers (solar, bio, and natural gas) in South and East Asia is dramatic: over South Asia, a 70 to 80% reduction in BC heating; and in East Asia, a 20 to 40% reduction."[87]

Reduced BC Provides Strong Co-Benefits for Public Health and Food Security

Reducing BC emissions provides strong co-benefits for public health, with the potential to save up to three million lives a year that otherwise would be lost to air pollution (both indoor and outdoor).[88] It also provides significant co-benefits to agriculture, by reducing BC's damaging impact on plants, thereby improving crop productivity.[89]

New and Stronger Laws Are Needed to Address Black Carbon

New and stronger laws are needed to address Black Carbon, at all levels, from local to international. An initial list of options at the international and regional level includes:

- Developing a treaty under UNEP, UNDP, or WHO.
- Expanding the post-2012 UN climate treaty.
- Developing a regional arrangement under the Arctic Council.
- Establishing specially protected areas to restrict shipping in the Arctic and other areas sensitive to Black Carbon's change in albedo.

- Expanding and strengthening controls on shipping under the Int'l Maritime Organization.
- Expanding and strengthening controls on aviation under the Int'l Civil Aviation Organization
- Expanding and strengthening controls on stationary and mobile sources under the Convention on Long-range Transboundary Air Pollution.

Building on the existing national laws noted below in the discussion on compliance, there are many options at the national and local level to develop new and stronger laws to address Black Carbon. These laws can be pursued by parliamentarian groups such as GLOBE, as well as by national lawmaking bodies. In addition, there are other policy processes that can be used to address carbon immediately, including:

- Using World Bank Climate Investment Fund to help reduce Black Carbon.
- Emphasizing climate benefits and other synergies of reducing Black Carbon with the World Health Organization's efforts to reduce indoor air pollution and improve the health of women and children.
- Emphasizing importance of Black Carbon for achieving Millennium Development Goals.
- Pursuing and accounting for the benefits of Black Carbon in World Sustainable Development Summit's efforts to provide access for the poor to clean energy resources.

At the same time, efforts should be pursued to require the use of ultra-low sulfur diesel (ULSD) fuel in diesel vehicles and marine vessels. Such efforts would be similar to the effort to remove lead from gasoline and would allow the most effective particulate emissions control technologies to be used.

Improving Compliance and Enforcement with Existing Laws Will Reduce Black Carbon

Many countries have existing national laws that can be used to start regulating BC emissions, including laws that address particulate emissions. Some examples include:

- banning or regulating slash-and-burn clearing of forests and savannahs;
- requiring shore-based power/electrification of ships at port, regulating idling at terminals, and mandating fuel standards for ships seeking to dock at port;
- requiring regular vehicle emissions tests, retirement, or retrofitting (e.g. adding particulate traps[90]), including penalties for failing to meet air quality emissions standards, and heightened penalties for on-the-road "super-emitting" vehicles;
- banning or regulating the sale of certain fuels and/or requiring the use of cleaner fuels for certain uses;
- limiting the use of chimneys and other forms of biomass burning in urban and non-urban areas;
- requiring permits to operate industrial, power generating, and oil refining facilities and periodic permit renewal and/or modification of equipment; and
- requiring filtering technology and high-temperature combustion (e.g. super-critical coal) for existing power generation plants, and regulating annual emissions from power generation plants.

Enforcement of these and related existing national laws, along with appropriate compliance assistance, will promote near-term climate mitigation, as well as strong co-benefits. The International Network for Environmental Compliance & Enforcement recently issued a *Climate Compliance Alert on Black Carbon*.[91]

Table 1: Estimates of Black Carbon Climate (Radiative) Forcings by Effect

Source	Black Carbon Radiative Forcing (W/m^2)				
	Direct Forcing	**Semi-Direct Effect[92]**	**Dirty Clouds Effect[93]**	**Snow/Ice Albedo Effect**	**Total**
IPCC (2007)[94]	0.2 ± 0.15	-	-	0.1 ± 0.1	0.3 ± 0.25
Jacobson (2001, 2004, and 2006)	0.55[95]	-	0.03[96]	0.06[97]	0.64[98]
Hansen (2001, 2002, 2003, 2005, and 2007)	0.2 - 0.6[99]	0.3 ± 0.3[100]	0.1 ± 0.05[101]	0.2 ± 0.1[102]	0.8 ± 0.4 (2001) 1.0 ± 0.5 (2002) ≈0.7 ± 0.2 (2003) 0.8 (2005)[103]
Hansen & Nazarenko (2004)[104]	-	-	-	~ 0.3 globally 1.0[105] arctic	-
Ramanathan (2007)[106]	0.9	-	-	0.1 to 0.3	1.0 to 1.2

Table 2: Estimated Climate Forcings (W/m2)

Component	IPCC (2007)[107]	Hansen, *et al*. (2005)[108]
CO_2	1.66	1.50
BC	0.05-0.55	0.8
CH_4	0.48	0.55
Tropospheric Ozone	0.35	0.40
Halocarbons	0.34	0.30
N_2O	0.16	0.15

Endnotes

* Institute for Governance & Sustainable Development, http://www.igsd.org; International Network for Environmental Compliance & Enforcement, http://www.inece.org.

1 Abrupt climate change refers to the passing of a point beyond which no further inputs are required for the climate system to amplify itself irreversibly out of control on human time-scales. Timothy Lenton, Hermann Held, Elmar Kriegler, Jim

Hall, Wolfgang Lucht, Stefan Rahmstorf, and Hans Joachim Schellnhuber, *Tipping elements in the Earth's climate system*, 105 PROC. OF THE NAT'L ACAD. OF SCI. U.S.A. 6 (Feb. 12, 2008) (The palaeoclimate records show that past climate changes have included both steady linear changes, as well as abrupt non-linear changes where small increases in warming produced large and irreversible impacts once a tipping point was passed, including rapid loss of ice causing significant sea-level rise. Abrupt climate changes also are possible in the future. Tipping points for ice-melt in the Arctic and ice-melt and disintegration of the Greenland Ice Sheet are considered to be among the most sensitive. The tipping point for the loss of the West Antarctic Ice Sheet is considered less sensitive, though with large uncertainty. Other tipping points may apply to the Atlantic thermohaline circulation, the Amazon rainforest and boreal forests, the El Niño phenomenon, and the West African monsoon.) *See also* James Hansen, *Scientific reticence and sea level rise***,** Environ. Res. Lett. 2 (2007); James Hansen, *Climate Catastrophe*, NEW SCIENTIST (28 July 2007); Committee on Abrupt Climate Change, *Abrupt Climate Change: Inevitable Surprises*, National Academy Press, Washington, D.C., 2003 (the "available evidence suggests that abrupt climate changes are not only possible, but likely in the future, potentially with large impacts on ecosystems and societies"); *See also* Peter Schwartz & Doug Randall, *An Abrupt Climate Change Scenario and Its Implications for United States National Security* (2003) (warning that result of abrupt climate change without adequate preparation "could be a significant drop in the human carrying capacity of the Earth's environment", including shortages of food and fresh water, drought, and flooding, which could lead to geopolitical de-stabilization and "skirmishes, battles, and even war."), http://www.gbn.com/ArticleDisplayServlet.srv?aid=26231; and Chris Abbott, Paul Rogers, and John Slobada, *Global Responses to Global Threats: Sustainable Security for the 21st Century*, Oxford Research Group, June 2006, http://www.oxfordresearchgroup.org.uk/publications/briefing_papers/globalthreats.php.

[2] James Hansen recently estimated that the concentration beyond which the CO_2 level in the atmosphere is potentially catastrophic is 350ppm, a point which has already been passed. James Hansen, *Target Atmospheric CO2: Where Should Humanity Aim?*, at 11 (18 June 2008) ("Equilibrium sea level rise for today's 385 ppm CO2 is at least several meters, judging from paleoclimate history. Accelerating mass losses from Greenland and West Antarctica heighten concerns about ice sheet stability. An initial CO2 target of 350 ppm, to be reassessed as the effect on ice sheet mass balance is observed, is suggested.") (Internal citations omitted.)

[3] IPCC, *Changes in Atmospheric Constituents and in Radiative Forcing*, in CLIMATE CHANGE 2007: THE PHYSICAL SCIENCE BASIS. CONTRIBUTION OF WORKING GROUP I TO THE FOURTH ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE 129, 132 (2007), *available at* http://www.ipcc.ch/ipccreports/ar4-wg1.htm. (Magnitudes and uncertainties added together, as per standard uncertainty rules)

[4] V. Ramanathan and G. Carmichael, *Global and regional climate changes due to black carbon*, 1 NATURE GEOSCIENCE 221-22 (23 March 2008) ("The BC forcing of 0.9 W m–2 (with a range of 0.4 to 1.2 W m–2) … is as much as 55% of the CO_2 forcing and is larger than the forcing due to the other GHGs such as CH_4, CFCs, N_2O or tropospheric ozone.")

[5] *Id*. at 221 and 224.

[6] Charles Zender, Written Testimony for the Hearing on Black Carbon and Climate Change, U.S. House Committee on Oversight and Government Reform 1 (18 October 2007), *available at* http://oversight.house.gov/documents/20071018110919.pdf [hereinafter Zender Testimony].

[7] Zender Testimony, *Id*. at 6 ("Reducing Arctic BC concentrations sooner rather than later is the most efficient way to mitigate Arctic warming that we know of.").

[8] V. Ramanathan, Testimony for the Hearing on Black Carbon and Climate Change, U.S. House Committee on Oversight and Government Reform 4 (18 October 2007), *available at* http://oversight.house.gov/story.asp?ID=1550 [hereinafter Ramanathan Testimony] (The developed nations have reduced their BC emissions from fossil fuel sources by a factor of 5 or more since the 1950s. Thus the technology exists for a drastic reduction of fossil fuel related BC); *but compare* Bond, T. C., E. Bhardwaj, R. Dong, R. Jogani, S. Jung, C. Roden, D. G. Streets, and N. M. Trautmann *Historical emissions of black and organic carbon aerosol from energy-related combustion*, *1850–2000*, 21 Global Biogeochemical Cycles GB2018 (2007) (Previous work suggests a rapid rise in [global] BC emissions between 1950 and 2000; this work supports a more gradual, smooth increase between 1950 and 2000).

[9] See Bond, *supra* note 8.

[10] IPCC, *Changes in Atmospheric Constituents and in Radiative Forcing*, in CLIMATE CHANGE 2007: THE PHYSICAL SCIENCE BASIS. CONTRIBUTION OF WORKING GROUP I TO THE FOURTH ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE 129, 136, 163 (2007), *available at* http://www.ipcc.ch/ipccreports/ar4-wg1.htm.

[11] *See id*. at 164, 170, 174-76, 217-34 (citing studies by Ramanathan, Jacobson, Zender, Hansen, and Bond); *supra* notes 3-4 (Zender Testimony and Ramanathan Testimony); *infra* notes 9 and 42 (Jacobson Testimony and Bond Testimony).

[12] V. Ramanathan & G. Carmichael, *supra* note 4, at 226.

[13] Ramanathan Testimony, *supra* note 8, at 3 ("Thus a drastic reduction in BC has the potential of offsetting the CO_2 induced warming for a decade or two.").

[14] Mark Z. Jacobson, Testimony for the Hearing on Black Carbon and Climate Change, U.S. House Committee on Oversight and Government Reform 12 (18 October 2007), *available at*

http://oversight.house.gov/documents/20071018110606.pdf [hereinafter Jacobson Testimony]; V. Ramanathan and G. Carmichael, *supra* note 4, at 226 (Reducing future black carbon, or soot, emissions "offers an opportunity to mitigate the effects of global warming trends in the short term," according to Dr. V. Ramanathan of the Scripps Institution of Oceanography and Dr. G. Carmichael of the University of Iowa. Drastic climate mitigation results from BC's "significant contribution to global radiative forcing" and its "much shorter lifetime [estimated to be one week] compared with CO_2 [which has a lifetime of 100 years or more]").

[15] Timothy Lenton, Hermann Held, Elmar Kriegler, Jim Hall, Wolfgang Lucht, Stefan Rahmstorf, and Hans Joachim Schellnhuber, *Tipping elements in the Earth's climate system*, 105 PROC. OF THE NAT'L ACAD. OF SCI. 6 (12 February 2008) ("The greatest threats are tipping the Arctic sea-ice and the Greenland ice sheet. . ."); J. Hansen, *Climate Catastrophe*, NEW SCIENTIST (28 July 2007) (...the primary issue is whether global warming will reach a level such that ice sheets begin to disintegrate in a rapid, non-linear fashion on West Antarctica, Greenland or both.").

[16] V. Ramanathan and G. Carmichael, *supra* note 1, at 221 (". . . emissions of black carbon are the second strongest contribution to current global warming, after carbon dioxide emissions.") Numerous scientists also calculate that BC may be second only to CO_2 in its contribution to climate change, including Tami C. Bond & Haolin Sun, *Can Reducing Black Carbon Emissions Counteract Global Warming*, ENVIRON. SCI. TECHN. (2005), at 5921 ("BC is the second or third largest individual warming agent, following carbon dioxide and methane."); *and* J. Hansen, *A Brighter Future*, 53 CLIMATE CHANGE 435 (2002), *available at* http://pubs.giss.nasa.gov/docs/2002/2002_Hansen_1.pdf (calculating the climate forcing of BC at 1.0 +/- 0.5 W/m^2).

[17] V. Ramanathan and G. Carmichael, *supra* note 4, at 222.

[18] IPCC, *Technical Summary*, in CLIMATE CHANGE 2007: THE PHYSICAL SCIENCE BASIS. CONTRIBUTION OF WORKING GROUP I TO THE FOURTH ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, 21 (2007) *available at* http://www.ipcc.ch/ipccreports/ar4-wg1.htm.

[19] James Hansen & Larissa Nazarenko, *Soot Climate Forcing Via Snow and Ice Albedos*, 101 PROC. OF THE NAT'L ACAD. OF SCI. 423 (13 January 2004) ("The efficacy of this forcing is ≈2 (i.e. for a given forcing it is twice as effective as CO2 in altering global surface air temperature)"); *compare* Zender Testimony, *supra* note 7, at 4 (figure 3); *See* J. Hansen & L. Nazarenko, *supra* note 18, at 426. ("The efficacy for changes of Arctic sea ice albedo is >3. In additional runs not shown here, we found that the efficacy of albedo changes in Antarctica is also >3."); *See also* Flanner, M.G., C.S. Zender, J.T. Randerson, and P.J. Rasch, *Present-day climate forcing and response from black carbon in snow*, 112 J. GEOPHYS. RES. D11202 (2007) ("The forcing is maximum coincidentally with snowmelt onset, triggering strong snow-albedo feedback in local springtime. Consequently, the "efficacy" of BC/snow forcing is more than three times greater than forcing by CO_2.").

[20] Gross global warming should result in about 2°C temperature rise. However, observed global warming is only about .8°C because cooling particles off set much of the warming. Reducing fossil fuel and biofuel soot would reduce about 40% of the observed warming and about 16% of the gross warming. Jacobson Testimony, *supra* note 13, at 3. ("The figure also shows that fossil-fuel plus biofuel soot may contribute to about 16% of gross global warming (warming due to all greenhouse gases plus soot plus the heat island effect), but its control in isolation could reduce 40% of net global warming.").

[21] Jacobson Testimony, *id.* at 4.

[22] Jacobson Testimony, *id.*

[23] Jacobson Testimony, *id*. As an aerosol, there is not standardized formula for developing global warming potentials (GWP) for black carbon. However, attempts to derive GWP100 range from 190 – 2240 relative to CO2. Jacobson M Z 2005 Correction to `control of fossil-fuel particulate black carbon and organic matter, possibly the most effective method of slowing global warming' 110 J. Geophysical Res. D14105 (2005) (GWP BC – 190); Hansen, J., Mki. Sato, P. Kharecha, G. Russell, D.W. Lea, and M. Siddall, 2007: Climate change and trace gases. Phil. Trans. Royal. Soc. A, 365, 1925 (GWP BC – 500); Bond, T. and Haolin, Sun, "Can Reducing Black Carbon Emissions Counteract Global Warming?" Envtl. Sci. &Tech., 5921 (August 2005) (GWP BC – 680); Jacobson Testimony, *supra* note 9 at 4 (GWP BC – 2240)

[24] Jacobson Testimony, *supra* note 9, at 4.

[25] Levy, H. II, M.D., et. al., *Strong Sensitivity of late 21st century climate to projected change in short-lived air pollutants*, 113 J. GEOPHYS. RES. D06102, 2 (2008) (BC and OC emissions, which are scaled to carbon monoxide (CO) emissions,increase continuously and almost double by 2100.); *id.* ("These emissions are based on projections of technological change, economic and population growth, and regulatory action out to 2100.")

[26] *Id* at 1 ("However, by year 2100, the projected decrease in sulfate aerosol (driven by a 65% reduction in global sulfur dioxide emissions) and the projected increase in black carbon aerosol (driven by a 100% increase in its global emissions) contribute to a significant portion of the simulated A1B surface warming relative to the year 2000").

[27] Jacobson Testimony, *supra* note 13 at 3.

[28] IPCC, *Radiative Forcing of Climate Change*, in CLIMATE CHANGE 2001: THE SCIENTIFIC BASIS. CONTRIBUTION OF WORKING GROUP 1 TO THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE 351, 397. ("While the radiative forcing is generally negative, positive forcing occurs in areas with a very high surface reflectance such as desert regions in North

Africa, and the snow fields of the Himalayas."); J. Hansen & L. Nazarenko, *supra* note 18, at 425. (The brown haze over India, heavy with fossil fuel and biofuel soot, reaches to the Himalayas. If prevailing winds deposit even a fraction of this soot on glaciers, the snow BC content could be comparable to that in the Alps.").

[29] J. Hansen, *et al.*, *Efficacy of Climate Forcing*, 110 J. GEOPHYS. RES. D18104, 1 (2005), *available at* http://pubs.giss.nasa.gov/docs/2005/2005_Hansen_etal_2.pdf (Accounting for forcing efficacies and for indirect effects via snow albedo and cloud changes, we find that fossil fuel soot, defined as BC + OC (organic carbon), has a net positive forcing while biomass burning BC + OC has a negative forcing).

[30] IPCC, *supra* note 26, at 397.

[31] Zender Testimony, *supra* note 7, at 6.

[32] J. Hansen & L. Nazarenko, *supra* note 18, at 425.

[33] J. Hansen & L. Nazarenko, *id*. at 428.

[34] J. Hansen & L. Nazarenko, *id*. at 425.

[35] *See supra* note 18.

[36] P.K. Quinn, T.S. Bates, E. Baum, N. Doubleday, A.M. Fiore, M. Flanner, A. Fridlind, T.J. Garrett, D. Koch, S. Menon, D. Shindell, A. Stohl, and S.G. Warren. *Short-lived Pollutants in the Arctic: Their Climate Impact and Possible Mitigation Strategies*, 8 ATMOS. CHEM. PHYS. 1723, 1731 (2008); *See* David Shukman, *Vast Cracks Appear in Arctic Ice*, BBC NEWS (23 May 2008), *available at* http://news.bbc.co.uk/2/hi/science/nature/7417123.stm (A recent expedition study by Canada confirmed vast cracks stretching for more than 10 miles on Ward Hunt).

[37] P.K. Quinn, *supra* note 34, at 1732.

[38] P.K. Quinn, *id*.

[39] P.K. Quinn, *id*. at 1732; J. Hansen & M. Sato, *et al.*, *Dangerous Human-Made Interference with Climate: a GISS modelE Study* 7 ATMOS. CHEM. PHYS. DISCUSS. 2287, 2298, 2296 (2007)("We suggest that Arctic climate change has been driven as much by pollutants (O_3, its precursors CH_4 and soot) as by CO_2 . . . .Thus, in that case, reduction of some of the pollutants [including soot] may make it possible to keep further Arctic warming very small and thus probably avoid loss of all sea ice.").

[40] V. Ramanathan & G. Carmichael, *supra* note 4, at 221.

[41] V. Ramanathan & G. Carmichael, *supra* note 4, at 224.

[42] V. Ramanathan & G. Carmichael, *supra* note 4, at 224.

[43] V. Ramanathan & G. Carmichael, *supra* note 4, at 224.

[44] Lester R. Brown, *Melting Mountain Glaciers Will Shrink Grain Harvests in China and India*, PLAN B UPDATE, Earth Policy Institute (20 March 2008), *available at* http://www.earth-policy.org/Updates/2008/Update71.htm (Melting Himalayan glaciers will soon reduce water supply for major Chinese and Indian rivers (Ganges, Yellow River, Yangtze River) that irrigate rice and wheat crops that feed hundreds of millions and "could lead to politically unmanageable food shortages.").

[45] V. Ramanathan & G. Carmichael, *supra* note 4, at 221 ("Until about the 1950s, North America and Western Europe were the major sources of soot emissions, but now developing nations in the tropics and East Asia are the major source problem.").

[46] Jacobson Testimony, *supra* note 13, at 4.

[47] Clean Air Fine Particle Implementation Rule, 72 Fed. Reg. 20586, 20587 (April 25, 2007) (to be codified as 40 C.F.R. pt. 51), *available at* http://www.epa.gov/fedrgstr/EPA-AIR/2007/April/Day-25/a6347.pdf; Press Release, European Union, Environment: Commission welcomes final adoption of the air quality directive, (April 14, 2008), *available at* http://europa.eu/rapid/pressReleasesAction.do?reference=IP/08/570&format=HTML&aged=0&language=EN&guiLanguage=en.

[48] International Maritime Organization, Press Release, IMO Environment meeting Approves Revised Regulations on Ship Emissions, International Maritime Organization (4 April 2008), *available at* http://www.imo.org/About/mainframe.asp?topic_id=1709&doc_id=9123(The IMO has approved amendments to MARPOL Annex VI *Regulations for the Prevention of Air Pollution from Ships* which are now subject to adoption at an October 2008 meeting.).

[49] Tami Bond, Testimony for the Hearing on Black Carbon and Climate Change, U.S. House Committee on Oversight and Government Reform 2-3 (October 18, 2007), *available at* http://oversight.house.gov/documents/20071018110647.pdf [hereinafter Bond Testimony].

[50] Jacobson Testimony, *supra* note 13, at 5.

[51] Tami Bond, *Summary: Aerosols*, Air Pollution as a Climate Forcing: A Workshop, Honolulu, Hawaii, April 29-May 3, 2002, *available at* http://www.giss.nasa.gov/meetings/pollution2002.

[52] V. Ramanathan & G. Carmichael, *supra* note 4, at 226.

[53] V. Ramanathan & G. Carmichael, *supra* note 4, at 226.

[54] Ramanathan Testimony, *supra* note 8, at 4.

[55] V. Ramanathan & G. Carmichael, *supra* note 4, at 221.
[56] V. Ramanathan & G. Carmichael, *id.*
[57] V. Ramanathan & G. Carmichael, *id.*
[58] V. Ramanathan & G. Carmichael, *id.* at 224.
[59] *See* Bond Testimony, *supra* note 47, at 2 (figure 1).
[60] Bond Testimony, *id.* at 1-2.
[61] Jacobson Testimony, *supra* note 13, at 5-6 (showing that shipping emissions produce more than 3 times as much BC as POC, while off-road vehicles produce 40% more BC than POC, and on-road vehicles produce 25-60% more BC than POC).
[62] Although shipping only accounts for 1.7% of the global BC inventory, given the expected increase in shipping throughout regions especially sensitive to BC like the Arctic, it still represents a strong option for BC reductions. Lack, D., B. Lerner, C. Granier, T. Baynard, E. Lovejoy, P. Massoli, A. R. Ravishankara, and E. Williams, Light absorbing carbon emissions from commercial shipping, 35 Geophysical Res. Letters L13815 (2008).
[63] J. Hansen *et al.*, *Efficacy of Climate Forcing*, *supra* note 27.
[64] Mark. Z. Jacobson, *The Short-Term Cooling but Long-Term Global Warming Due to Biomass Burning*, 17 J. OF CLIMATE 2909, 2923 (". . . whereas aerosol particles emitted during burning may cause a short-term cooling of global climate, longer-lived greenhouse gases may cause warming (or cancel the cooling) after several decades. As such, reducing biomass burning may cause short-term warming but long-term cooling or no change in temperature. Although the eventual cooling may not appear for many years, its magnitude may be as large as 0.6 K after 100 yr.").
[65] Surabi Menon, James Hansen, Larissa Nazarenko, & Yunfeng Luo, *Climate Effects of Black Carbon*, 297 SCIENCE 2250, 2250 (27 September 2002) (Black Carbon emissions are "a product of incomplete combustion from coal, diesel engines, biofuels, and outdoor biomass burning . . .").
[66] *See* Lehmann, *et al*., *Bio-Char Sequestration in Terrestrial Ecosystems – A Review*, 11 MITIGATION AND ADAPTATION STRATEGIES FOR GLOBAL CHANGE 403, at 403-07, 418 (Springer 2006), *available at* http://www.css.cornell.edu/faculty/lehmann/publ/MitAdaptStratGlobChange%2011,%20403-427,%20Lehmann,%202006.pdf *; See id.* at 407 (Researchers estimate that between 38-84% of the biomass carbon in vegetation is released during the burn, whereas converting the biomass into bio-char by means of simple kiln techniques sequesters more than 50% of this carbon in bio-char).
[67] *Id.* at 407-08.
[68] *See* Raupach, Michael, *et al.*, *Global and Regional Drivers of Accelerating CO_2 Emissions*, 104 PROC. OF THE NAT'L ACAD. OF SCI. 24, (underlying data *available at*, http://www.pnas.org/cgi/content/full/0700609104/DC1) (indicating that between 2000-2005 land use emissions annually represented on average 1.5 GtC of the total 8.7 GtC global emissions or 5.5 Gt CO_2 eq. of 31.9 Gt CO_2 eq. of global emissions—17.25% of total. A reduction of 12% of land use emissions equals 0.66 Gt CO_2 eq., approximately 2% of annual global CO_2 eq. emissions. Lehmann's original estimates were based on a 0.2 GtC offset of the 1.7 GtC emissions from land use change estimated in 2001 by the IPCC). *See also* Lehmann, *et al.*, *supra* note 49, at 407-08. (Given the increase in fossil fuel emissions to 8.4 GtC, total anthropogenic emissions in 2006, including the estimated 1.5 GtC from land use change, were 9.9 GtC. Thus, despite an increase in overall CO_2 eq. emissions, using Lehmann's original 0.2 GtC reduction still results in an approximate 2% reduction in global CO_2 eq. emissions). *See* Global Carbon Budget Team, *Recent Carbon Trends and the Global Carbon Budget*, the Global Carbon Project, (15 November 2007), *available at* http://www.globalcarbonproject.org/global/pdf/GCP_CarbonCycleUpdate.pdf (giving 2006 global carbon emissions estimates).
[69] Ramanathan Testimony, *supra* note 8, at 4.
[70] Jacobson Testimony, *supra* note 13, at 5.
[71] J. Hansen & L. Nazarenko, *supra* note 18, at 428.
[72] Jacobson Testimony, *supra* note 13, at 9.
[73] Jacobson offers an estimate of total U.S. CO_2 emissions in 2005 of 6270 metric tonnes, 26% of which is 1630. *Id*.
[74] Jacobson Testimony, *supra* note 13, at 9.
[75] Manufacturers of Emission Controls Association (MECA), "Emission Control Technologies for Diesel-Powered Vehicles," 9 (December 2007) ("Diesel oxidation catalysts installed on a vehicle's exhaust system can reduce total PM typically by as much as 25 to over 50 percent by mass, under some conditions depending on the composition of the PM being emitted"), available at: http://www.meca.org/galleries/default-file/MECA%20Diesel%20White%20Paper%2012-07-07%20final.pdf.
[76] *Id*., ("DPFs can achieve up to, and in some cases, greater than a 90 percent reduction in PM. High efficiency filters are extremely effective in controlling the carbon fraction of the particulate, the portion of the particulate that some health experts believe may be the PM component of greatest concern").

[77] *Id*., at 5, ("Mobile source BC emissions are estimated at 234 Gg in 2001, representing 54 percent of the nationwide BC emissions of 436 Gg. Under Scenario F, mobile source emissions are projected to decline to 71 Gg, a reduction of 163 Gg."

[78] Bahner, Mark A., Weitz, Keith A., Zapata, Alexandra and DeAngelo, Benjamin, Use of Black Carbon and Organic Carbon Inventories for Projections and Mitigation Analysis," 1, (2007) available at: http://www.epa.gov/ttn/chief/conference/ei16/session3/k.weitz.pdf.

[79] EPA, Heavy-Duty Highway Diesel Program, available at: http://www.epa.gov/oms/highway-diesel/index.htm ("Once this action is fully implemented…Soot or particulate matter will be reduced by 110,000 tons a year"); EPA, Clean Air Nonroad Diesel Rule—Facts and Figures, available at: http://www.epa.gov/nonroad-diesel/2004fr/420f04037.htm ("Environmental Benefits When the Fleet of Older Nonroad Engines Has Fully Turned Over by 2030: Annual reductions of Fine PM (PM2.5): 129,000 tons").

[80] Conor C. O. Reynolds & Milind Kandlikar, *Climate Impacts of Air Quality Policy: Switching to a Natural Gas-Fueled Public Transportation System in New Delhi*, ENVIRON. SCI. TECHNOL. (forthcoming 2008) ("When aerosol emissions are included, the switch to CNG fueling results in a climate benefit, largely because of the dramatic reduction of black carbon emissions from the diesel bus engines"). The fuel switching policy was implemented with the aid of the Indian Supreme Court. *See* Urvashi Narain and Ruth Greenspan Bell, *Who Changed Delhi's Air? The Roles of the Court and the Executive in Environmental Policymaking*, Resources for the Future Discussion Paper 05-48 (December 2005) http://www.rff.org/rff/documents/rff-dp-05-48.pdf ("[T]he main role of the Supreme Court was to force the government to implement previously announced policies. … [T]he Delhi experience for instituting change has become a model for other Indian cities as well as neighboring countries.")

[81] Conor C. O. Reynolds & Milind Kandlikar, *Climate Impacts of Air Quality Policy: Switching to a Natural Gas-Fueled Public Transportation System in New Delhi*, ENVIRON. SCI. TECHNOL. (forthcoming 2008) ("However, when aerosol emissions are taken into account in our model, the net effect of the switch is estimated to be a 10% reduction in CO2(e), and there may be as much as a 30% reduction in CO_2(e)").

[82] *Id*., at Section 3.1 ("In total there is about a 10% reduction of net CO_2(e) emissions, and if buses are considered separately, net CO_2(e) emissions are reduced by about 20%").

[83] C. O. Reynolds & Milind Kandlikar, *Climate Impacts of Air Quality Policy: Switching to a Natural Gas-Fueled Public Transportation System in New Delhi*, 1, ENVIRON. SCI. TECHNOL. (forthcoming 2008).

[84] Lack, D., B. Lerner, C. Granier, T. Baynard, E. Lovejoy, P. Massoli, A. R. Ravishankara, and E. Williams, Light absorbing carbon emissions from commercial shipping, , 35 Geophysical Res. Letters L13815 (2008).

[85] That is, if particulate filters could be shown reduce BC emissions 90 percent from ships as they do for land vehicles, 120,000 metric tons of today's 133,000 metric tons of emissions would be prevented.

[86] V. Ramanathan & G. Carmichael, *supra* note 4, at 226.

[87] V. Ramanathan & G. Carmichael, *id.*

[88] Mark Jacobson, *Control of Fossil-Fuel Particulate Black Carbon and Organic Matter, Possibly the Most Effective Method of Slowing Global Warming*, 107 J. GEOPHYS. RES. D19 (2002) (*citing* C. A. Pope III and D. W. Dockery, *Epidemiology of particle effects*, in S. T. Holgate, *et al*., eds., AIR POLLUTION AND HEALTH 673– 705 (1999) and statistics from the World Health Organization).

[89] *See* Mike Bergin, *The Influence of Aerosols on Plant Growth*, Day 4 of Air Pollution as a Climate Forcing: A Workshop (2002), *available at* http://www.giss.nasa.gov/meetings/pollution2002/d4_bergin.html.

[90] O. Boucher and M.S. Reddy, *Climate trade-off between black carbon and carbon dioxide emissions*, 36 ENERGY POLICY 193, 196-198 (2007) (Particulate traps on diesel engines reduce BC emissions and associated climate forcing but are partially offset by an increase in fuel consumption and CO_2 emissions. Where the fuel penalty is 2-3%, BC reductions will produce positive benefits for the climate for the first 28-68 years, assuming reduction in BC emission is 0.15-0.30 g/mile, CO_2 emissions are 1500-2000 g/mile, and a 100-year GWP of 680 is used for BC. The net positive benefits for climate will continue for up to centuries in northern regions because of BC's effect on snow and ice albedo).

[91] *See* http://inece.org/climate/INECEClimateComplianceAlert_BlackCarbon.pdf.

[92] Mark Z. Jacobson, *Effects of Anthropogenic Aerosol Particles and Their Precursor Gases on California and South Coast Climate*, California Energy Commission, 6 (Nov. 2004), *available at* http://www.stanford.edu/group/efmh/jacobson/CEC-500-2005-003.PDF (BC's semi-direct effect occurs when "solar absorption by a low cloud increases stability below the cloud, reducing vertical mixing of moisture to the could base, thinning the cloud.").

[93] *Carbon's Other Warming Role*, GEOTIMES (May 2001), *available at* http://www.geotimes.org/mar01/warming.html (BC produces "dirty cloud droplets, causing an "indirect" impact that reduces a cloud's reflective properties.").

[94] IPCC, *supra* note 3 at 163-64, and 185 (2007) (estimating the direct radiative forcing of BC at 0.2 W/m^2 $\pm$ 0.15 and the indirect of effect of BC on snow and ice surface albedo at 0.1 W/m^2 $\pm$ 0.1).

[95] Mark Z. Jacobson, *Strong Radiative Heating Due to the Mixing State of Black Carbon in Atmospheric Aerosols*, NATURE, 409, 695-697 (2001) ("The final yearly averaged direct forcing due to BC in the external mixture, the multiple-distribution

coated-core, and the single internally-mixed, coated-core distribution cases from Fig. 3 were 0.31, 0.55 and 0.62 W m-2, respectively. The multiple-distribution BC direct forcing (0.55) falls between direct-forcing estimates for CH4 (0.47 W/m^2) and CO2 (1.56 W/m^2) from IPCC [2001].").

[96] Mark Z. Jacobson, *Climate response of fossil fuel and biofuel soot, accounting for soot's feedback to snow and sea ice albedo and emissivity*, 109 J. GEOPHYS. RES. D21201 (2004). (Dirty Clouds Effect of .03 W m-2)

[97] Mark Z. Jacobson, *Effects of Externally-Through-Internally-Mixed Soot Inclusions within Clouds and Precipitation on Global Climate*, 110 J. PHYS. CHEM. A. 6860-6873 (2006). (Snow/Ice Albedo Effect of .06 W m-2)

[98] This figure has been obtained by adding Jacobson's estimates for BC's direct and indirect forcings. *See supra*, notes 76-78 and accompanying text.

[99] James E. Hansen and Makiko Sato, Figure 1 in *Trends of Measures Climate Forcing Agents*, 98 PROC. OF THE NAT'L ACAD. OF SCI. 14778, 14779 (2001). (Hansen 2001 estimate – Direct Forcing – 0.6 W/m^2 Total forcing – 0.8 $\pm$ 0.4 W/m^2); J. Hansen, *supra* note 11, at 435 (Hansen 2002 estimate – "My present estimate for global climate forcings caused by BC is: (1) 0.4 $\pm$ 0.2 W/m^2 direct effect, (2) 0.3 $\pm$ 0.3 W/m^2 semi-direct effect (reduction of low level clouds due to BC heating; Hansen et al., 1997), (3) 0.1 $\pm$ 0.05 W/m^2 'dirty clouds' due to BC droplet nuclei, (4) 0.2 $\pm$ 0.1 W/m^2 snow and ice darkening due to BC deposition. … The uncertainty estimates are subjective. The net BC forcing implied is 1 + 0.5 W/m^2."); J. Hansen, *et al*., *Climate Change and Trace Gases*, 365 PHIL. TRANS. R. SOC. 1925, 1942 (2007) (Hansen 2007 estimate – "Soot from fossil fuel burning, i.e. highly absorbing aerosols that contain black carbon (BC) and organic carbon (OC), are estimated to cause a global climate forcing of 0.22 W m^{-2}. This is a conservative estimate for fossil fuel BC forcing . . . because it assumes a high OC/BC ratio for fossil fuel emissions. In addition, it assigns 50% of the aerosol indirect effect (which causes cooling) to soot (BC/OC).").

[100] J. Hansen, *supra* note 18, at 435.

[101] *Id*.

[102] *Id*.

[103] James E. Hansen and Makiko Sato, Figure 1 in *Trends of Measures Climate Forcing Agents*, 98 PROC. OF THE NAT'L ACAD. OF SCI. 14778, 14779 (2001). (Hansen 2001 estimate – Direct Forcing – 0.6 W m-2, Total forcing – 0.8 + 0.4 W m-2); J. Hansen, *supra* note 11, at 435 (Hansen 2002 estimate – "My present estimate for global climate forcings caused by BC is: (1) 0.4 $\pm$ 0.2 W/m^2 direct effect, (2) 0.3 $\pm$ 0.3 W/m^2 semi-direct effect (reduction of low level clouds due to BC heating; Hansen et al., 1997), (3) 0.1 $\pm$ 0.05 W/m^2 'dirty clouds' due to BC droplet nuclei, (4) 0.2 $\pm$ 0.1 W/m^2 snow and ice darkening due to BC deposition. … The uncertainty estimates are subjective. The net BC forcing implied is 1 + 0.5 W/m^2."); Makiko Sato, James Hansen, Dorthy Koch, Andrew Lacis, Reto Ruedy, Oleg Dubovik, Brent Holben, Mian Chin, and Tica Novakov, *Global Atmospheric Black Carbon Inferred from AERONET*, 100 PROC. OF THE NAT'L ACAD. OF SCI. 6319, at 6323 (2003) (… we estimate the anthropogenic BC forcing as $\approx$0.7 $\pm$ 0.2 W/m^2."); J. Hansen, *et al*., *Climate Change and Trace Gases*, 365 PHIL. TRANS. R. SOC. 1925, 1942 (2007) (Hansen 2007 estimate – "Soot from fossil fuel burning, i.e. highly absorbing aerosols that contain black carbon (BC) and organic carbon (OC), are estimated to cause a global climate forcing of 0.22 W m^{-2}. This is a conservative estimate for fossil fuel BC forcing . . . because it assumes a high OC/BC ratio for fossil fuel emissions. In addition, it assigns 50% of the aerosol indirect effect (which causes cooling) to soot (BC/OC).").

[104] J. Hansen & L. Nazarenko, *supra* note 18, 426 ("the effective forcing for the assigned snow albedo change in the most realistic cases 1 and 2 is F_e ~0.6 W/m^2 in the Northern Hemisphere or F_e ~0/3 W/m^2 globally.").

[105] *Id*., at 425 (The "climate forcing due to snow/ice albedo change is of the order of 1 W/m^2 at middle- and high-latitude land areas in the Northern Hemisphere and over the Arctic Ocean.").

[106] Ramanathan Testimony, *supra* note 8.

[107] IPCC, *supra* note 3.

[108] J. Hansen, *et al*., *Efficacy of Climate Forcing*, *supra* note 27.