Reducing Black Carbon, or Soot, May Be Fastest Strategy for Slowing Climate Change

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Summary

Emissions from black carbon (BC), or soot, are the second largest contributor to global warming after carbon dioxide (CO_2) emissions, and reducing these emissions is the fastest strategy for slowing climate change. The most recent estimate of BC forcing, 0.9 watts per square meter (W/m^2) (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."[1] In some regions, such as the Himalayas, the impact of BC on melting snowpacks and glaciers may be equal to that of CO_2.[2] BC emissions also significantly contribute to Arctic ice-melt, and reducing such emissions may be "the most efficient way to mitigate Arctic warming that we know of."[3] Since 1950, developed countries have successfully reduced BC emissions by a factor of five, primarily to improve public health, and "technology exists for a drastic reduction of fossil fuel related BC" in the rest of the world.[4] Many existing laws address black carbon emissions, and improving compliance and enforcement with such laws will provide immediate and significant climate mitigation.

Reducing Black Carbon May Be Fastest Way to Slow Global Warming

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 at Stanford University; major cuts in soot emissions could slow the effects of climate change for a decade or two,[5] buying policymakers more time to address CO_2 emissions.[6] This also would help keep the climate system from passing the tipping points for abrupt climate changes, including serious sea-level rise from the disintegration of the Greenland and/or Antarctic ice sheets.[7]

"[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.[8] The climate forcing of BC is 0.9 W/m^2; this "is as much as 55% of the CO_2 forcing and is larger than the forcing due to the other [greenhouse gases] such as CH_4, CFCs, N_2O or tropospheric ozone."[9] The large magnitude of BC forcing has been confirmed by many scientists, with estimates ranging from 0.4 W/m^2 to 1.2 W/m^2.[10]

Jacobson states that BC from fossil-fuel and 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 [i.e. reducing BC emissions from fossil-fuel and biofuel while ignoring BC from biomass burning, which has a net cooling effect, at least in the short run] could reduce 40% of net global warming [i.e. warming from all positive radiative forcings (e.g. GHGs and BC) minus cooling from all negative radiative forcings (e.g. sulfates)]."[11]

BC Is Primarily a Problem in Developing Countries

Today, the overwhelming majority of BC emissions are from developing countries[12] and this trend is expected to increase.[13] The largest sources of BC are Asia, Latin America, and Africa.[14] China and

India alone account for 25-35% of global BC emissions.[15] BC emissions from China doubled from 2000 to 2006.[16]

BC emissions "peak close to major source regions and give rise to regional hotspots of BC- induced atmospheric solar heating."[17] 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."[18] Approximately three billion people live in these hotspots.[19]

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.[20] Whereas the U.S. emits about 21% of the world's CO_2, it emits 6.1% of the world's soot.[21]

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

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.[22] 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."[23] The "soot effect on snow albedo may be responsible for a quarter of observed global warming."[24] "Soot deposition increases surface melt on ice masses, and the meltwater spurs multiple radiative and dynamical feedback processes that accelerate ice disintegration," according to Dr. James Hansen and Dr. Larissa Nazarenko.[25]

In some regions, such as the Himalayas, the impact of BC on melting snowpacks and glaciers may be equal to that of CO_2.[26] 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. [27] An "analysis of temperature trends on the Tibetan side of the Himalayas reveals warming in excess of 1°C since the 1950s."[28] This large warming trend is the proposed causal factor for the accelerating retreat of Himalayan glaciers,[29] which threatens fresh water supplies and food security in China and India.[30]

Major Sources of BC

Approximately 20% of BC is emitted from burning biofuels, 40% from fossil fuels, and 40% from open biomass burning, according to Ramanathan.[31] Dr. Tami Bond of the University of Illinois, Urbana Champaign, estimates the sources of BC emissions as follows:[32]

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[33]

BC emissions vary by region. For example, the "majority of soot emission in South Asia is due to biofuel cooking, whereas in East Asia, coal combustion for residential and industrial uses plays a larger role."[34]

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."[35]

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."[36]

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."[37]

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 sources, 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."[38] According to Jacobson's estimates, this proposal would reduce soot and CO_2 emissions equivalent to 1.63 $GtCO_2$ per year.[39] 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," though this is still a substantial reduction for one policy in one country.[40]

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."[41] Specifically, the impact of replacing biofuel cooking with BC-free cookers (solar and bio and natural gas) in South and East Asia … are dramatic: over South Asia, a 70 to 80% reduction in BC heating; and in East Asia, a 20 to 40% reduction."[42]

Improving Compliance and Enforcement with Existing Laws Will Reduce Black Carbon

Many countries have existing national laws and measures regulating black carbon emissions, including, for example:

- laws banning or regulating slash-and-burn clearing of forests and savannahs.
- laws requiring shore-based power/electrification of ships at port, regulating idling at terminals, and mandating fuel standards for ships seeking to dock at port;
- laws requiring regular vehicle emissions tests, retirement, or retrofitting (e.g. adding particulate traps), including penalties for failing to meet air quality emissions standards, and penalties for on-the-road "super-emitting" vehicles.

- laws banning or regulating sale of certain fuels and/or requiring the use of cleaner fuels for certain uses;
- laws limiting the use of chimneys and other forms of biomass burning in urban and non-urban areas.
- laws requiring permits to operate industrial, power generating, and oil refining facilities and periodic permit renewal and/or modification of equipment;
- laws requiring installation of scrubbers and other filtering technology for existing power generation plants, and regulating annual emissions from power generation plants.

Enforcement of these and related existing domestic measures, along with appropriate compliance assistance, will promote near-term climate mitigation, as well as strong co-benefits.

Increasing Compliance and Enforcement to Reduce BC Will Provide Strong Co-Benefits for Public Health

Reducing BC emissions would provide 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).[43] It also would provide significant co-benefits to agriculture, by reducing the pollutions damaging impact on plants, thereby improving crop productivity.[44]

Endnotes

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

[1] V. Ramanathan and G. Carmichael, *Global and regional climate changes due to black carbon*, NATURE GEOSCIENCE 222 (23 March 2008).

[2] *Id*. at 221.

[3] Chales Zender, Written Testimony for the Hearing on Black Carbon and Climate Change, U.S. House Committee on Oversight and Government Reform 6 (October 18, 2007) *available at* http://oversight.house.gov/documents/20071018110919.pdf [hereinafter Zender Testimony] ("Reducing Arctic BC concentrations sooner rather than later is the most efficient way to mitigate Arctic warming that we know of.").

[4] V. Ramanathan, Testimony for the Hearing on Black Carbon and Climate Change, U.S. House Committee on Oversight and Government Reform 4 (October 18, 2007) *available at* http://oversight.house.gov/story.asp?ID=1550 [hereinafter Ramanathan Testimony].

[5] Ramanathan, Testimony, *supra* note 4 at 3 ("Thus a drastic reduction in BC has the potential of offsetting the CO_2 induced warming for a decade or two.").

[6] Mark Z. Jacobson, Testimony for the Hearing on Black Carbon and Climate Change, U.S. House Committee on Oversight and Government Reform 12 (October 18, 2007) *available at* http://oversight.house.gov/documents/20071018110606.pdf [hereinafter Jacobson Testimony]; V. Ramanathan and G. Carmichael, *supra* note 1, 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)."

[7] 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 (Feb. 12, 2008) ("The greatest threats are tipping the Arctic sea-ice and the Greenland ice sheet. . ."); James 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.").

[8] 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. TECHNOLOGY (2005), at 5921 ("BC is the second or third largest individual warming agent, following carbon dioxide and methane."); *and* James Hansen, *A Brighter Future*, 53 CLIMATE CHANGE 435 (2002) *available at* http://pubs.giss.nasa.gov/docs/2002/2002_Hansen_1.pdf.

[9] V. Ramanathan and G. Carmichael, *supra* note 1, at 222.

[10] Dr. Hansen calculates the climate forcing of BC at 1.0 +/- 0.5 W/m^2, Hansen, *A Brighter Future*, *supra* note 8. Dr. V. Ramanathan of the Scripps Institution of Oceanography calculates it to be 1.0-1.2 W/m^2, Ramanathan, Testimony, *supra* note 4, at 7. This compares with the IPCC's estimates of 1.66 W/m^2 for CO_2 and 0.48 W/m^2 for CH_4, 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 29 (2007) available at http://www.ipcc.ch/ipccreports/ar4-wg1.htm.

[11] Jacobson Testimony, *supra* note 6, at 3.

[12] 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].

[13] Jacobson Testimony, *supra* note 6, at 5.

[14] Tami Bond, *Summary C. 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.

[15] V. Ramanathan and G. Carmichael, *supra* note 1, at 226.

[16] V. Ramanathan and G. Carmichael, *supra* note 1, at 226.

[17] V. Ramanathan and G. Carmichael, *supra* note 1, at 221.

[18] V. Ramanathan and G. Carmichael, *supra* note 1, at 221.

[19] V. Ramanathan and G. Carmichael, *supra* note 1, at 221.

[20] V. Ramanathan and G. Carmichael, *supra* note 1, 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.").

[21] V. Ramanathan and G. Carmichael, *supra* note 1, at 4.

[22] Zender Testimony, *supra* note 3, at 6.

[23] James Hansen & Larissa Nazarenko, *Soot Climate Forcing Via Snow and Ice Albedos*, PROC. OF THE NAT'L ACAD. OF SCI. (13 January 2004), at 425.

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

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

[26] V. Ramanathan and G. Carmichael, *supra* note 1, at 221.

[27] V. Ramanathan and G. Carmichael, *supra* note 1, at 224.

[28] V. Ramanathan and G. Carmichael, *supra* note 1, at 224.

[29] V. Ramanathan and G. Carmichael, *supra* note 1, at 224.

[30] Brown, Lester R., *Melting Mountain Glaciers Will Shrink Grain Harvests in China and India*, PLAN B UPDATE, Earth Policy Institute (20 March 2008) (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.") *available at* http://www.earth-policy.org/Updates/2008/Update71.htm

[31] V. Ramanathan and G. Carmichael, *supra* note 1, at 224.

[32] *See* Bond Testimony, *supra* note 12, at 2 (figure 1).

[33] Bond Testimony, *supra* note 12, at 1-2.

[34] V. Ramanathan and G. Carmichael, *supra* note 1, at 226.

[35] Ramanathan Testimony, *supra* note 4, at 4.

[36] Jacobson Testimony, *supra* note 6, at 5.

[37] J. Hansen and L. Nazarenko, *supra* note 23, at 428.

[38] Jacobson Testimony, *supra* note 6, at 9.

[39] Jacobson offers an estimate of total U.S. CO_2 emissions in 2005 of 6270 metric tonnes, 26% of which is 1630. *Id*.

[40] Jacobson Testimony, *supra* note 6, at 9.

[41] V. Ramanathan and G. Carmichael, *supra* note 1, at 226.

[42] V. Ramanathan and G. Carmichael, *supra* note 1, at 226.

[43] Mark Jacobson, *Control of Fossil-Fuel Particulate Black Carbon and Organic Matter, Possibly the Most Effective Method of Slowing Global Warming,* 107 J. GEOPHYSICAL RESEARCH No. D19 19 (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).

[44] *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.