Science&Technology

Getting Rid of Black Carbon

A Neglected but Effective Near-Term Climate Mitigation Avenue

Dennis Clare, Kristina Pistone, and Veerabhadran Ramanathan

The signatories to the December 2009 Copenhagen Accord, which included both Group of 8 (G8) and Group of 77 (G77) countries, agreed that "climate change is one of the greatest challenges of our time."[1] They also cited a need to keep total global warming below 3.7 degrees Fahrenheit. To achieve this goal, policymakers focus largely on reducing carbon dioxide (CO_2) emissions over the long-term.[2] Although a long-term, CO_2-centered approach to climate change is unquestionably necessary, it is not sufficient. An appropriately comprehensive climate policy must also address the variety of non-CO_2 pollutants that cause warming and aim to minimize warming trends in the near-term so that we do not commit the climate system to irreversible and potentially catastrophic changes long before CO_2 emissions can be stabilized and reduced. Fortunately, by addressing non-CO_2 warming pollutants, such as black carbon, we can achieve some of the short-term results we urgently need and perhaps also buy time for our critical long-term efforts.

Proponents of strong climate action correctly assert that we must reduce CO_2 emissions between 50 percent and 80 percent this century.[3] The climate system has already warmed by 1.4 degrees Fahrenheit, and the blanket of gases

Dennis Clare is an experienced researcher and advocate for domestic and international climate change policy.

Kristina Pistone is a graduate student in the Scripps Institution of Oceanography, University of California at San Diego.

Veerabhadran Ramanathan is distinguished professor of climate and atmospheric sciences at the Scripps Institution of Oceanography, University of California at San Diego.

that surrounds the planet is already thick enough to warm the system by as much as 3 degrees Fahrenheit.[4] Meanwhile, about thirty-five billion additional tons of CO_2 are emitted into the atmosphere annually. At this rate, we may commit the planet to yet another 3 degrees of warming this century.[5] CO_2 emissions are particularly problematic because they can remain in the atmosphere and continue to cause warming for hundreds to thousands of years thereafter.[6] Therefore, we must urgently reduce CO_2 in order to prevent the future warming caused by our emissions from worsening.

According to one study, black carbon has caused roughly half of the observed warming in the Arctic region during the twentieth century alone.

To achieve more rapid, short-term climate mitigation, however, we need to reduce emissions of shorter-lived warming agents that remain in the atmosphere anywhere from a couple of weeks to about a decade. To date, pollutants such as black carbon, methane, ozone, and halocarbons have contributed as much warming to the climate system as CO_2.[7] Reducing emissions of these short-lived pollutants can help achieve important short-term goals, including alleviating present warming trends; reducing already occurring impacts; and forestalling the worst potential outcomes, such as abrupt climate change.

Black carbon is largely ignored in the ongoing policy discussions, yet reductions in black carbon emissions are likely the fastest known method to mitigate warming. Technologies are already available to drastically reduce these emissions, and because the lifetime of black carbon is only a few days to weeks, its warming effects will be diminished almost immediately after emissions are reduced. Between now and the mid twenty-first century, removing one ton of black carbon can have the same effect as removing more than one thousand tons of CO_2 from the atmosphere.[8] Although many countries regulate particulate pollution in general, none presently regulates black carbon specifically. However, as we learn more about black carbon's negative climate and health impacts, narrower regulations may be necessary.

A Potent Climate Warmer.

Black carbon is not a greenhouse gas. Rather, it is one of several types of fine particles emitted from incomplete combustion of fossil fuels, cooking with biomass fuels, and burning of open vegetation. Black carbon particles are what give the dark color to smoke from diesel engines, crop burning, and wood and coal fires. Long infamous for its public health and air quality impacts, black carbon is now also acknowledged as the second or third strongest warming pollutant, contributing from 25 percent to 60 percent as much warming as CO_2.[9]

Black carbon causes warming in two ways. First, while in the atmosphere, black carbon absorbs sunlight, thus directly warming the surrounding air. Second, when it washes out of the atmosphere, usually after only a few days or weeks aloft, black carbon can land on snow and ice, darkening these surfaces. This increases solar absorption by snow and ice and accelerates melting. The melting can lead to even further warming if the bright snow or ice surface melts away and reveals a darker, more absorbing land or sea surface beneath it. Black carbon can therefore contribute to the dangerous warming feedbacks that threaten mountain glaciers and Arctic sea ice.

According to one study, black carbon has caused roughly half of the observed warming in the Arctic region during the twentieth century alone.[10] Emissions from increased shipping activity in and around the Arctic only threaten to exacerbate this impact. Similarly, in the Himalayan-Tibetan region, studies have estimated that warming due to black carbon may have contributed as much to the large temperature increase in these elevated regions as has warming from greenhouse gases.[11] Furthermore, atmospheric warming by black carbon can disrupt rainfall patterns, especially in the monsoon regions of China and India.[12] Reducing emissions of black carbon provides a promising means of protecting threatened areas that play a vital role in limiting global warming because of the massive amounts of sunlight they reflect. Indeed, any suite of measures aimed at rapid climate mitigation should prioritize efforts to protect the planet's natural climate defense systems, such as glaciers and sea ice.

Sources and Solutions. The good news is that there are many presently available technologies that can be used to substantially reduce black carbon emissions from primary sources. These sources include on- and off-road diesel engines, traditional cooking and heating stoves, small industrial sources, and open burning of biomass, generally from agricultural waste and deforestation. However, black carbon is not the only substance emitted from these sources. Some of the other pollutants emitted along with black carbon, though they are also harmful to human health, can cause cooling because they are light in color and reflect sunlight back into space. Thus, when addressing total emissions from various combustion sources, reductions of warming can be maximized by targeting sources that emit a high ratio of warming pollutants to cooling pollutants.

Fossil fuel combustion and cooking with biomass emit account for about 60 percent of black carbon emissions globally. Diesel vehicle emissions, which account for more than 17 percent of black carbon emissions globally, have a particularly high ratio of warming to cooling pollutants and should therefore top the agenda for immediate action.[13] The most effective way to reduce emissions from diesel vehicles is to install a diesel particulate filter (DPF), which can eliminate over 90 percent of black carbon emissions.[14]

In the United States, European Union (EU), and Japan, DPFs are required on new diesel vehicles. One study estimates that the United States's new vehicle standards will reduce total domestic black carbon emissions by 42 percent from 2001 to 2020.[15] The

rules will reduce black carbon from the U.S. transportation sector by 70 percent. The U.S. Environmental Protection Agency (EPA) claims that, by the time the full vehicle fleet is replaced in 2030, 110,000 tons of particulate matter will have been eliminated annually from heavy duty highway emissions; 27,000 tons from locomotive and marine engines; and another 120,000 tons from non-road vehicles.[16] The EPA also aims to reduce the emissions of 11 million vehicles in the legacy fleet by 2014, but its programs to address these in-use vehicles are voluntary and now underfunded. On the whole, standards such as those in effect in the United States, EU, and Japan are very positive steps forward, but the health and climate benefits from addressing diesel emissions could be increased and accelerated if vehicles already in use were also required to use DPFs. In New Delhi, a court-mandated switch from diesel to natural gas for municipal transportation vehicles reduced the overall warming effect due to vehicular emissions from 10 percent to 30 percent, largely because of reductions in black carbon emissions.[17]

A second major opportunity to reduce black carbon emissions in a manner which yields both cost-effective health and climate benefits is by replacing kerosene lamps and traditional stoves used for cooking and heating with more efficient, less emissive alternatives. More than 3 billion people in the developing world depend on traditional solid-fuel stoves for cooking and heating.[18] These stoves typically burn wood, coal, dung, or crop residue. Emissions from these stoves, including significant amounts of black carbon, organic carbon, and other particles, are the primary source of an indoor air pollution that kills over 1.6 million people annually, most of whom are women and children under the age of five.[19] This pollution is one of the major health risks in poor developing countries. In addition to premature death, other negative health impacts from indoor pollution include respiratory illness, aggravated asthma, and chronic bronchitis.[20]

In South Asia, cooking with biofuels accounts for two-thirds or more of total black carbon emissions.[21] Although cooking stoves emit a more even balance of particle emissions than diesel engines, the heating effect from black carbon still dominates the cooling effect from lighter, more reflective particles.[22] Thus, reducing this warming and directly improving human health are principal motives for improving these stoves. In locations where biofuel use overlaps with deforestation, such as Central and South America, Africa, and Southeast Asia, reduced deforestation from decreased demand for biomass fuel could be yet another benefit of using more efficient stoves. And in regions where particulate emissions from stoves can contribute to the formation of heat trapping clouds, or where black carbon particles from stoves can be deposited onto snow and ice surfaces, the warming impact of stoves increases, so the win-win of health and climate co-benefits from replacing these stoves is strengthened.

There is still scientific work to be done analyzing stove emissions and determining the most effective means of reducing them. Standards still need to be

established to weigh the various factors, such as the cost of the stove, the amount of fuel consumption reduced, and the amounts of the various species of pollutants reduced. For example, some efforts to improve cooking stoves have been successful in reducing net emissions but have still not managed to reduce particulate emissions to safe levels.[23] By carefully measuring and comparing stoves in the field for their impacts on health and climate, efficiency, and other benefits, positive results can be maximized. Project Surya is one example of a pilot project reaching toward this goal, and has been initiated in the Indo-Gangetic Plains region of India.

Improving traditional cooking and heating stoves is fundamentally a development issue. It touches not only on climate and health but on access to energy and even education, because when children spend less time collecting firewood, they have more time to attend school. Therefore, stove improvement programs should be a larger part of overall development efforts, and should be candidates for funding from international financial institutions and development organizations focusing on such issues as women's health, girls' education, access to clean energy, and climate mitigation.

In South Asia, cooking with biofuels accounts for two-thirds or more of total black carbon emissions.

Policy Strategies. In addition to identifying the primary sources of black carbon emissions and the leading technologies to reduce them, fashioning an effective policy response will require choosing the most competent form of governance to catalyze the on-the-ground work that needs to be done. Any reductions would likely result from national plans of action, which could involve funding, technology development, and partnerships between government, non-governmental organizations, and industry. However, how and whether to integrate national efforts into regional or global mitigation efforts remains to be determined, as there are various potential strengths and weaknesses of national, regional, and larger multilateral coordination or governance frameworks.

An obvious benefit of any national or regional regime is that, because black carbon is short-lived and not well-mixed in its spread through the atmosphere, it tends to have more localized effects. This means that the benefits of emissions reductions mostly accrue in the areas near the source of emissions. Emitters in close proximity may tend to cooperate if they will benefit directly when nearby emitters reduce pollution. States that share borders or threatened resources, for example, may have extra incentives to cooperate in reducing emissions.

A disadvantage of black carbon's spatial concentrations for cooperative regional governance, however, is that

if a large emitter in a region is not involved in the coordinated regional effort, other states' reductions may be unable to meet their air quality goals. Another potential disadvantage of solely regional coordination is that a particular state or region might stand to benefit greatly from black carbon reductions but lacks the resources to bring them about. Conversely, an advantage of broader international approaches may be linking funds, expertise, and technologies from one state to another in need. On the other hand, distant states' interests in sharing a particular region's local reduction burden may not correspond as well as they do within that region.

To maximize total reductions in near-term global black carbon emissions, a more tailored approach may be ideal: a quadrilateral partnership between the United States, the European Union, China, and India. Together these parties represent more than half of the world's black carbon emissions from contained combustion sources, such as diesel and stoves.[24] The United States and EU have made great strides in reducing black carbon emissions and have developed valuable technologies, but the United States still has high per capita black carbon emissions, at a rate comparable to that in China. These per capita emissions must be reduced. China is the largest emitter of black carbon, and India's emissions are lower but growing.[25] Consequently, China, India, and other developing nations have the most to gain from reductions. Moreover, these parties are connected because some EU emissions end up in South and East Asia and some Chinese emissions are transported to the United States.[26]

Such a quadrilateral partnership could evolve from initial bilateral cooperation between the EU and China or India and between the United States and China or India. The partnership might even have a larger overall focus—starting with black carbon, for example—as part of a broader partnership on reducing pollution for sustainable development. The United States, EU, China, and India could then effectively cooperate to address other short-lived pollutants, such as tropospheric ozone. Developing tailored programs to address specific emissions by source or sector might also illustrate a more disaggregated, bottom-up approach that could serve as an example for other climate mitigation efforts.

For small developing states interested in reducing black carbon, entering into bilateral, resource-sharing agreements with other states could be a promising option. These agreements could privilege the provision of resources for development programs through cross-cutting benefits. Existing bilateral arrangements, such as those that provide diesel fuel in order to power electric generators, might be altered to favor renewable energy, such as solar power for nations in the middle latitudes where incident solar radiation is greatest. Whether through bilateral, regional, or global arrangements, the strategies for development projects should include an examination of where there are potential, multiple benefits.[27] Programs with numerous co-benefits, such as stove replacement programs, should be given priority and should also be eligible for funds directed toward a variety of separate purposes, including development, health, climate mitiga-

tion, poverty reduction, girls' education, and improving access to clean energy.

Conclusion. To address climate change, the nations of the world must act now, and they must address the multitude of pollutants that cause warming—not just CO2. There are three powerful and compelling rationales for reducing non-CO2 pollutants, particularly black carbon. First, these pollutants have proven negative effects on health, agriculture, and regional air quality. Second, because of their short atmospheric lifetimes, the expected results will come quickly. Local policymakers will see the positive effects of their actions while still in office, and the public will see the positive effects on air quality within the communities where such actions are taken. International policymakers, too, will have a golden opportunity to verify predictions that black carbon reductions will slow both the rapid retreat of Arctic sea ice and the warming trends over elevated regions of the Himalayan-Tibetan glacier region. Finally, diesel filters, stoves, and other technologies for cleaning up the air are already available, so mitigation actions can start immediately. As the time to address global warming grows short, an immediate start on reducing black carbon emissions will bring some of the near-term results we need and will build momentum for further rapid climate mitigation.

NOTES

1 UNFCCC 15th Congress of the Parties, "Copenhagen Accord 2009," Internet, http://unfccc.int/files/meetings/cop_15/application/pdf/cop15_cph_auv.pdf (date accessed: 7 April 2010).

2 Malte Meinshausen et al., "Greenhouse-gas emission targets for limiting global warming to 2 degrees C," *Nature* 458, no. 7242 (April 2009):1158-1162.

3 Members of the German Advisory Council on Global Change (WBGU), "Special Report: Solving the climate dilemma: The budget approach," Internet, http://www.wbgu.de/wbgu_sn2009_en.pdf (date accessed: 7 April 2010).

4 Kevin E. Trenberth et al., "Observations: Surface and Atmospheric Climate Change," 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* (Cambridge: Cambridge University Press, 2007), 237; V. Ramanathan and Y. Feng, "On avoiding dangerous anthropogenic interference with the climate system: formidable challenges ahead," *Proceedings of the National Academy of Sciences of the United States of America* 105, no. 38 (September 2008): 14245-14250.

5 Malte Meinshausen et al., "Greenhouse-gas emission targets for limiting global warming to 2 degrees C," *Nature* 458, no. 7242 (April 2009):1158-1162.

6 Susan Solomon, "Irreversible climate change due to carbon dioxide emissions," *Proceedings of the National Academy of Sciences of the United States of America* 106, no. 6 (February 2009): 1704-1709.

7 Piers Forster et al., "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* (Cambridge: Cambridge University Press, 2007), 205-207; V. Ramanathan and G. Carmichael, "Global and regional climate changes due to black carbon," *Nature Geoscience* 1 (2008): 221-227.

8 Mark Z. Jacobson, "Climate response of fossil fuel and biofuel soot, accounting for soot's feedback to snow and sea ice albedo and emissivity," *Journal of Geophysical Research* 109, no. D21 (November 2004): D21201.

9 For low-end estimate, see the estimate of 0.44 W/m2 of BC forcing in Piers Forster et al., "Changes in Atmospheric Constituents and in Radiative Forcing"; high-end estimate of 0.95 W/m2 is from V. Ramanathan and G. Carmichael, "Global and regional climate changes due to black carbon," both including albedo effects. This is compared to the forcing of CO2 to be 1.56 W/m2, given by Piers Forster et al., "Changes in Atmospheric Constituents and in Radiative Forcing."

10 Drew Shindell and Greg Faluvegi, "Climate response to regional radiative forcing during the twentieth century," *Nature Geoscience* 2, no. 4 (April 2009): 294-300.

11 V. Ramanathan and G. Carmichael, "Global and regional climate changes due to black carbon," 221-227; Veerabhadran Ramanathan et al., "Warm-

ing trends in Asia amplified by brown cloud solar absorption," *Nature* 448, no. 7153 (August 2007): 575-578; M.G. Flanner et al., "Springtime warming and reduced snow cover from carbonaceous particles," *Atmospheric Chemistry and Physics* 9, no. 7 (April 2009): 2481-2497.

12 V. Ramanathan and G. Carmichael, "Global and regional climate changes due to black carbon," 221-227.

13 Tami C. Bond et al., "A technology-based global inventory of black and organic carbon emissions from combustion," *Journal of Geophysical Research* 109 (2004): D14203.

14 United States Environmental Protection Agency, Office of Transportation and Air Quality, "Technical Highlights: Questions and Answers on Using a Diesel Particulate Matter Filter in Heavy-Duty Trucks and Buses," Internet, http://www.epa.gov/cleandiesel/documents/420f03017.pdf (date accessed: 7 April 2010).

15 Mark A. Bahner et al., "Use of Black Carbon and Organic Carbon Inventories for Projections and Mitigation Analysis" (paper presented at the 16th Annual International Emission Inventory Conference, Raleigh, NC, 14-17 May 2007).

16 United States Environmental Protection Agency, Office of Transportation and Air Quality, "National Clean Diesel Campaign," Internet, http://www.epa.gov/cleandiesel (date accessed: 7 April 2010).

17 Conor C. O. Reynolds and Milind Kandlikar, "Climate Impacts of Air Quality Policy: Switching to a Natural Gas-Fueled Public Transportation System in New Delhi," *Environmental Science and Technology* 42, no. 16 (August 2008): 5860-5865.

18 World Health Organization, "Indoor Air Pollution," Internet, http://www.who.int/indoorair/en/ (date accessed: 7 April 2010).

19 World Health Organization, "Global estimates of burden of disease caused by the environment and occupational risks," Internet, http://www.who.int/quantifying_ehimpacts/global/globalair/en/index.html (date accessed: 7 April 2010).

20 World Health Organization, "Health effects," Internet, http://www.who.int/indoorair/health_impacts/disease/en/index.html (date accessed: 7 April 2010).

21 Tami C. Bond et al., "A technology-based global inventory of black and organic carbon emissions from combustion," D14203.

22 Nadine Unger et al., "Attribution of climate forcing to economic sectors," *Proceedings of the National Academy of Sciences of the United States of America* 107, no. 8 (February 2010): 3382-3387.

23 R. D. Edwards et al., "Household CO and PM measured as part of a review of China's National Improved Stove Program," *Indoor Air* 17, no. 3 (June 2007): 189-203.

24 Tami C. Bond et al., "A technology-based global inventory of black and organic carbon emissions from combustion," D14203.

25 V. Ramanathan and Y. Feng, "Air pollution, greenhouse gases, and climate change: global and regional perspectives," *Atmospheric Environment* 43, no. 1 (January 2009): 37-50.

26 Baiqing Xu et al., "Black soot and the survival of Tibetan glaciers," *Proceedings of the National Academy of Sciences of the United States of America* 106, no. 52 (December 2009): 22114-22118; O. L. Hadley et al., "Trans-Pacific transport of black carbon and fine aerosols (D<2.5μm) into North America," *Journal of Geophysical Research* 112, No. D5 (March 2007): D05309.

27 Mario Molina et al., "Reducing abrupt climate change risk using the Montreal Protocol and other regulatory actions to complement cuts in CO2 emissions," *Proceedings of the National Academy of Sciences of the United States of America* 106 (2009): 20616-20621.