

A black-carbon mitigation wedge

Andrew P. Grieshop, Conor C. O. Reynolds, Milind Kandlikar and Hadi Dowlatabadi

Comprehensive abatement strategies will be needed to limit global warming. A drastic reduction of black-carbon emissions could provide near-immediate relief with important co-benefits.

Light-absorbing black carbon, emitted through incomplete combustion, warms the atmosphere at regional and global scales¹. Furthermore, black-carbon particulate matter is damaging to human health: it is estimated that in developing countries over 1.8 million people die every year from exposure to black carbon and other emissions from indoor fires². Bringing black-carbon emissions into the next round of climate negotiations would take advantage of the natural alignment of the interest of developing countries in cleaner air with those of developed nations in climate mitigation.

Pacala and Socolow³ identified 15 evocative mitigation ‘wedges’ that define carbon emission reduction targets to stabilize atmospheric carbon dioxide concentrations and limit climate warming using strategies that rely on existing technologies. Each of their wedges represents 25 billion tons of carbon (25 Gt C) avoided over a 50-year period. Examples include doubling the efficiency of two billion cars, building two million windmills that each produce 1 MW of power and establishing 3,500 large-scale carbon sequestration sites. We propose that a drastic reduction of black-carbon aerosols should be considered as a sixteenth wedge. Steadily eliminating all present-day emissions of black carbon globally over the next 50 years would have an approximately equivalent climate mitigation effect to removing 25 Gt C from the atmosphere over the same period: according to conservative estimates, one ton of black carbon causes about 600 times the warming of one ton of carbon dioxide over a period of 100 years^{4,5}.

A black-carbon ‘wedge’ is admittedly a coarse representation of the complex climate impacts of black carbon, which are fundamentally different from the effects of greenhouse gases. Furthermore, uncertainties in quantifying radiative forcing from black carbon are unlikely to be fully resolved in the near future. One complication of the basic calculation above arises from the mix of aerosols that

originate from some sources. Specifically, elimination of black-carbon emissions would also reduce co-emitted organic carbon compounds and sulphate that tend to have a cooling effect by means of direct light scattering and interactions with clouds¹. The relative contribution of black-carbon compounds from combustion sources varies considerably with source type⁶. Therefore sources dominated by black carbon, such as residential combustion of solid fuels and high-emitting diesel engines, have a stronger warming effect than others such as biomass burning, which is generally dominated by organic carbon⁶.

However, the presence of uncertainty should not deter action towards mitigation of black carbon^{4,7}. From a climate perspective, decisions to reduce black-carbon emissions will be of significant benefit, regardless of their exact warming potential relative to carbon dioxide. This is particularly true for emissions where black carbon is dominant relative to other aerosol components^{4,5,8}. Moreover the short atmospheric lifetime of black carbon, on the order of days to weeks, presents a potentially valuable opportunity for mitigation with a very short delay between action and effect^{1,7,9}.

At the same time, the health impacts from black-carbon sources are substantial (see Fig. 1a). Products of incomplete combustion, such as black-carbon-containing soot, are among the largest contributors to ambient air pollution and personal exposure levels. Health detriments are especially widespread in developing nations, where extensive indoor use of solid fuel makes exposure to particulate matter and other products of incomplete combustion the fourth largest contributor to the total burden of disease after malnutrition, unsafe sex and poor sanitation¹⁰. Outdoors, older vehicles, dirty industries and an array of other black-carbon sources contribute to urban levels of particulate air pollution that are ten or more times higher than those in the cities of developed nations¹¹.

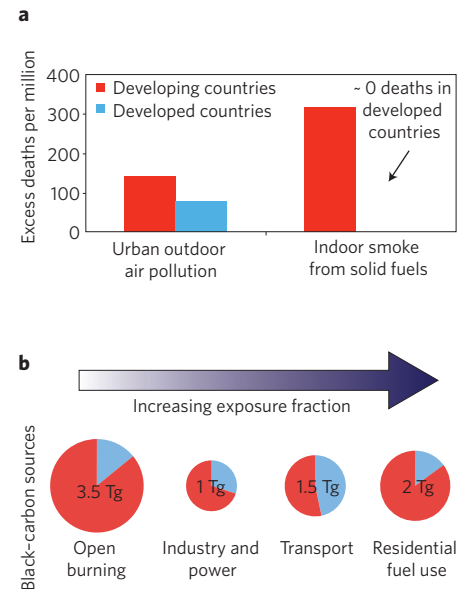


Figure 1 | Health impacts and source strengths of black carbon. **a**, The population-normalized mortality rate in developing countries from both indoor and outdoor exposure is substantially higher than for developed nations. All values from ref. 10. **b**, Central estimates of annual black-carbon emissions from four different source categories (taken from ref. 4) are much higher in developing (red) than in developed (blue) countries, in particular for indoor combustion sources — emissions of which are most damaging to health because a relatively large fraction is inhaled by people.

Technologies to reduce black-carbon emissions already exist: newer combustion techniques and after-treatments often reduce particle emissions by several orders of magnitude in provision of the same service⁴. Globally, overall emissions are far lower in developed countries (Fig. 1b). In developing parts of the world, black-carbon emissions tend to be dominated by biomass burning in open fires and in ‘contained’ combustion for the provision of household energy, as well as the ‘dirty’ combustion of coal. In contrast, emissions in the developed parts of the world are dominated

by transportation sources such as heavy-duty diesel trucks. The population in developing countries is roughly five times that in developed ones, so although overall emissions in developing nations are much higher, per-capita emission levels are fairly uniform across both sets of countries, differing by less than a factor of two⁷.

Simply replacing solid fuels in home cooking stoves in developing countries with cleaner fuels and combustion technologies can lead to dramatic improvements in health¹² and is eminently feasible¹³. Tough emission reduction measures have been (and continue to be) undertaken in developed countries as part of regional air pollution control, but many current and future opportunities remain in both developed and rapidly developing countries^{4,7,9}. Eliminating black-carbon emissions from contained combustion, approximately 60% of the total⁶, and severely limiting those from open burning could plausibly amount to a full 50-year emission reduction wedge. Although the simultaneous reduction of co-emitted species will reduce the overall

impact of such an intervention, using time frames shorter than the 'standard' 100-year period and accounting for the high warming 'efficacy' of black carbon¹ could counterbalance at least some of these complicating factors.

Eliminating black-carbon emissions from contained combustion and severely limiting those from open burning could plausibly amount to a full 50-year emission reduction wedge.

The upcoming Conference of the Parties to the United Nations Framework Convention on Climate Change (COP 15) in December 2009 provides an ideal forum for integrating the control of black-carbon emissions into global climate policy. Taking bold action to make the reduction of black-carbon aerosol levels an international priority may be a rapid way

forward on the pressing issues of climate change and health. □

Andrew P. Grieshop¹, Conor C. O. Reynolds¹, Milind Kandlikar² and Hadi Dowlatabadi¹ are at the ¹Institute for Resources, Environment and Sustainability and the ²Liu Institute for Global Issues, University of British Columbia, Vancouver, British Columbia V6T 1Z4, Canada. e-mail: andy.grieshop@ires.ubc.ca

References

1. Ramanathan, V. & Carmichael, G. *Nature Geosci.* **1**, 221–227 (2008).
2. Ezzati, M. *et al.* in *Global Burden of Disease and Risk Factors* (eds Lopez, A. D., Mathers, C. D., Ezzati, M., Jamison, D. T. & Murray, C. J. L.) 241–268 (Oxford Univ. Press, 2006).
3. Pacala, S. & Socolow, R. *Science* **305**, 968–972 (2004).
4. Bond, T. C. & Sun, H. L. *Environ. Sci. Technol.* **39**, 5921–5926 (2005).
5. Reynolds, C. & Kandlikar, M. *Environ. Sci. Technol.* **42**, 5860–5865 (2008).
6. Bond, T. C. *et al.* *J. Geophys. Res.* **109**, D14203 (2004).
7. Bond, T. C. *Environ. Res. Lett.* **2**, 045030 (2007).
8. Shindell, D. & Faluvegi, G. *Nature Geosci.* **2**, 294–300 (2009).
9. Jacobson, M. Z. *J. Geophys. Res.* **107**, 4410 (2002).
10. Ezzati, M., Lopez, A. D., Rodgers, A., Vander Hoorn, S. & Murray, C. J. *Lancet* **360**, 1347–1360 (2002).
11. Molina, M. & Molina, L. J. *Air Waste Manage.* **54**, 644–680 (2004).
12. Smith, K. R. & Haigler, E. *Annu. Rev. Publ. Health.* **29**, 11–25 (2008).
13. Smith, K. R., Shuhua, G., Kun, H. & Daxiong, Q. *World Dev.* **21**, 941–961 (1993).