to each patient this necessary information.

Clinicians are ethically free to filter incidental findings that have so little clinical significance that they would not actively seek them as secondary findings. Here, too, in keeping with shared decision-making, clinicians live up to their highest calling when they discuss how they will handle incidental findings with their patients.

References and Notes

1. S. Hilgenberg, "Recipient of a finding incidental to research," Incidental Findings in Research, presentation to the Presidential Commission for the Study of Bioethical Issues, 30 April 2013; http://bioethics.gov/node/1617.
2. Presidential Commission for the Study of Bioethical Issues, *Anticipate and Communicate: Ethical Management of Incidental and Secondary Findings in the Clinical, Research, and Direct-to-Consumer Contexts* (Presidential Commission for the Study of Bioethical Issues, Washington, DC, 2013).
3. U.S. Preventive Services Task Force Screening for Lung Cancer, Draft Recommendation Statement (AHRQ Publication No. 13-05196-EF-3, USPSTF, Rockville, MD, 2013); www.uspreventiveservicestaskforce.org/uspstf13/lungcan/lungcandraftrec.htm.
4. L. J. Esserman, I. M. Thompson, Jr, B. Reid, *JAMA* **310**, 797 (2013).
5. R. C. Green *et al*., *Genet. Med.* **15**, 565 (2013).
6. ACMG *Genet. Med.* **15**, 664 (2013).

10.1126/science.1248764

CLIMATE CHANGE

What Role for Short-Lived Climate Pollutants in Mitigation Policy?

Parallel strategies must focus on long- and short-lived pollutants, but not at the cost of reducing pressure for action on CO_2.

J. K. Shoemaker,[1] D. P. Schrag,[1]* M. J. Molina,[2] V. Ramanathan[3,4]

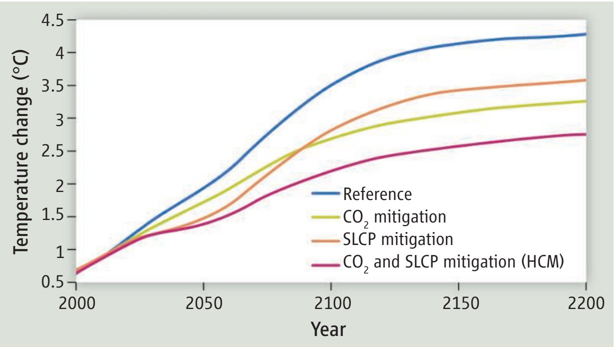
Short-lived climate pollutants (SLCPs) include methane (CH_4), black carbon (BC), tropospheric ozone, and hydrofluorocarbons (HFCs). They are important contributors to anthropogenic climate change, responsible for as much as one-third of the current total greenhouse forcing (*1*). An emerging strategy, which we refer to as hybrid climate mitigation (HCM), emphasizes reducing SLCPs in parallel with long-lived carbon dioxide (CO_2) so as to achieve climate goals, as well as health and food security benefits, associated with some of the SLCPs. Proponents of HCM argue that we should focus substantial effort on reducing SLCPs now, as we wait for sufficient political will to reduce CO_2 emissions (*2*–*4*). But others (*5*) worry that any strategy involving SLCPs risks delaying efforts to reduce CO_2, the main greenhouse gas most important for long-term warming if emissions continue as projected.

We attempt to clarify this emerging HCM strategy. Reducing emissions of SLCPs is an essential component of any comprehensive climate action plan for addressing both near-term and long-term climate change impacts (*1*, *3*). There are real opportunities to reduce emissions of SLCPs without distracting from other mitigation efforts focused on CO_2. But the dangers of delaying efforts to reduce CO_2 emissions are serious and must be articulated clearly to the policy community. We believe that such a delay can be prevented with appropriate policies, and that both short (decades) and long (century or longer) time scales must be considered.

Direct comparisons of the climate influence of SLCPs and CO_2 require making a judgment about the relative importance of short and long time scales. SLCPs have a powerful impact on climate, but they persist in the atmosphere for only a short time—days to weeks for BC, a decade for CH_4, and about 15 years for some HFCs. Thus, immediate reductions in SLCPs will result in relatively immediate climate benefits, as the effects on climate depend largely on the emission rate, or flow, of SLCPs to the atmosphere. In contrast, CO_2 has a very long atmospheric lifetime; more than 20% will remain for thousands to tens of thousands of years (*6*). Thus, climate effects from CO_2 depend on the cumulative emissions, or stock, of CO_2 in the atmosphere (*7*).

In the next year, monthly mean CO_2 concentrations will reach 400 parts per million (ppm); annual mean CO_2 concentrations have been rising more than 2 ppm per year because of emissions from fossil fuel use, and this will continue for at least the next several decades because of the dominance of fossil fuels in our world energy system. Because it is the most dominant greenhouse gas, near-complete reduction in CO_2 emissions is the only way to limit the rise of global temperatures and to avoid the risk of catastrophic impacts. But a partial reduction in CO_2 emissions over the next few decades will produce minimal relief from climate impacts until mid-century because of the long time scales of CO_2 in the atmosphere and the momentum of climate change due to the CO_2 already emitted.

One way to diminish climate impacts in the next few decades is to also reduce emissions of



Climate temperature response to reductions in emissions of CO_2, SLCPs, or both. Based on scenarios detailed in the supplemental material. Temperature change is shown relative to a pre-industrial baseline. In the Reference scenario, annual CO_2 emissions peak in 2080, after which they decline rapidly, while SLCP (CH_4, BC) emissions remain at or above current levels. In the "SLCP mitigation" scenario, deep cuts in BC (80%) and CH_4 (40%) emissions, relative to 2010 levels, are implemented linearly from 2010 to 2050. In the "CO_2 mitigation" scenario, CO_2 emissions are reduced by 20% relative to the reference scenario by 2050, followed by slowly decreasing emissions that intercept the reference scenario emissions at 2150. In this scenario, emissions of both BC and CH_4 are partially decreased relative to the reference scenario owing to those sources associated with fossil fuel consumption. The "HCM" scenario includes simultaneous mitigation of CO_2, CH_4, and BC, as described above. For simplicity, we ignore HFCs as well as different sulfate aerosol trajectories. Including these would slightly change the shape of the curves, but not the relative time scales between them.

[1]Department of Earth and Planetary Sciences, Harvard University, Cambridge, MA 02138, USA. [2]Division of Physical Chemistry, University of California, San Diego, La Jolla, CA 92093, USA. [3]Scripps Institution of Oceanography. University of California San Diego, La Jolla, CA, 92093, USA. [4]UNESCO Professor, TERI University, New Delhi, DL 110070, India. *Corresponding author: schrag@eps.harvard.edu

Published by AAAS

SLCPs. Some have argued that mitigating SLCPs to the maximum extent possible by using available technologies can reduce the projected warming by about a half, and sea level rise by about 25%, during this century, relative to a scenario in which only CO_2 emissions are reduced (*8*). Others have argued that the benefits would be smaller, because of the possibility that measures to mitigate CO_2 emissions will also mitigate emissions of SLCPs (*9*).

A key point is that the development of new, low-carbon technologies is driven by policies aimed at reducing CO_2 emissions. Removing political and economic pressure for their development can result in slower innovation, and lead to continued emissions and a warmer climate. In contrast, no new technological innovation is required for many cuts in SLCPs, such as sealing natural gas leaks or reducing biomass burning. Thus, if one delays societal pressure to reduce CO_2 emissions, one will end up with higher cumulative emissions and higher peak and long-term warming.

It is easy to understand why focusing on SLCPs is attractive. Reducing SLCPs achieves climate benefits on generational time scales. In contrast, a substantial reduction of CO_2 emissions requires a deep transformation of the world's fossil energy dependence. Some have argued that reducing emissions of SLCPs will help to avoid "tipping points" in the climate system, irreversible thresholds with drastic consequences. Exactly how to define a tipping point and when we might cross one remain controversial (*10*), but if such thresholds do exist, it is clear that reducing SLCPs alone can only delay by a few decades our reaching them (*1*, *11*), as long as the concentration of atmospheric CO_2 continues to rise.

Another proposal is that an initial focus on SLCPs will slow the rate of warming by as much as 50% by 2050, allowing for easier adaptation by both human society and natural ecosystems (*12*), while we wait for political will to address CO_2 emissions. But if the focus on SLCPs inhibits actions to slow the growth of fossil CO_2 emissions, it will result in a higher peak temperature overall, and we will trade a slower rate of warming in the first half of this century for a steeper rise in temperature imposed thereafter (see the graph).

It is also important to recognize that CO_2 and SLCP emissions are not independent. Some of the steps to reduce CO_2 emissions will drive down emissions of SLCPs, as some of the largest sources of BC and methane are associated with fossil fuel production and combustion. There is also the complicated case of sulfur emissions, which produce sulfate aerosols that are short-lived, like BC, but reflect sunlight and cool the climate, partially compensating for greenhouse warming. Reducing some types of fossil fuel use, especially sulfur-rich coal and ship fuel, will also reduce the concentration of sulfate aerosols, which may amplify warming in the near-term, but reduce the peak warming over the long term.

A common metric for valuation of different greenhouse gases, the 100-year global warming potential (GWP) (*13*, *14*), compares the average radiative forcing of a greenhouse gas relative to CO_2 over the next 100 years. Some have argued that the 100-year GWP undervalues SLCPs, as the formulation includes no discount rate to prioritize near-term impacts. Others have argued that the 100-year GWP overvalues SLCPs as the formulation completely ignores any impacts beyond 100 years. Efforts to improve the GWP metric have encountered criticism from both perspectives (*15*). Our view is that there is no scientifically correct answer, as it requires trading near-term benefits for avoidance of substantial costs passed down to future generations, essentially in perpetuity.

Policy discussions about SLCPs are happening now. For example, the U.S. State Department, along with five other countries, unveiled in early 2012 an initiative for reducing emissions of BC, HFCs, and CH_4, and many other nations have now joined the initiative. If successful, such an initiative could lead to important health, agriculture, and climate benefits in the near-term. At the same time, there is legitimate concern that this initiative could be used to shield some countries from international pressure to reduce CO_2 emissions. It is imperative that this does not happen. The only way to permanently slow warming is through lowering emissions of CO_2. The only way to minimize the peak warming this century is to reduce emissions of CO_2 and SLCPs.

We suggest that the best way to prevent the slowing of CO_2 mitigation efforts is to emphasize parallel strategies for reducing SLCP and CO_2 emissions. For example, efforts to reduce BC emissions can be undertaken through air pollution measures whose main focus is on public health, such as regulations on diesel exhaust or the promotion of cleaner cooking technologies. HFCs can be regulated through the Montreal protocol. Such strategies have already proven to be effective. In California, for example, new regulations of particle emissions from diesel exhaust resulted in a reduction in ambient BC over all of the state by 50% within the last 25 years (*16*). Another example is the recent agreement at the G-20 Summit in St. Petersburg to reduce use of HFCs.

An implication of our proposal is that trading between CO_2 and SLCP emissions, CH_4 in particular, should be discouraged. If efforts to reduce greenhouse gas emissions, both SLCPs and CO_2, were at a mature state with a well-developed market, we would embrace a broader discussion of the time scales of climate change and encourage society to reach a consensus on how to value short-term and long-term climate change. But we do not believe that real decisions about health policies and climate policies are made through an interconnected market, so parallel efforts are essential. We recognize that compromises may be required to achieve political goals; in particular, giving developing countries some form of "credit" for reductions in SLCPs may be important to broaden participation in international climate agreements. But more widespread trading between different greenhouse gases, especially when it may affect markets for low-carbon technologies, risks committing our children and grandchildren to even greater climate impacts in the more distant future.

References and Notes

1. V. Ramanathan, Y. Xu, *Proc. Natl. Acad. Sci. U.S.A.* **107**, 8055 (2010).
2. J. S. Wallack, V. Ramanathan, *Foreign Aff.* **88**, 105 (2009).
3. M. Molina *et al*., *Proc. Natl. Acad. Sci. U.S.A.* **106**, 20616 (2009).
4. D. Shindell *et al*., *Science* **335**, 183 (2012).
5. R. Pierrehumbert, RealClimate.org (2010); www.realclimate.org/index.php/archives/2010/12/losing-time-not-buying-time/.
6. D. Archer, V. Brovkin, *Clim. Change* **90**, 283 (2008).
7. M. R. Allen *et al*., *Nature* **458**, 1163 (2009).
8. A. Hu, Y. Xu *et al*., *Nat. Clim. Change* **3**, 730 (2013).
9. S. J. Smith, A. Mizrahi, *Proc. Natl. Acad. Sci. U.S.A.* **110**, 14202 (2013).
10. E. Kriegler *et al*., *Proc. Natl. Acad. Sci. U.S.A.* **106**, 5041 (2009).
11. United Nations Environment Programme and World Meteorological Organization, "Integrated assessment of black carbon and tropospheric ozone" (UNEP, Nairobi, 2011).
12. D. Shindell, *Milken Inst. Rev.* **2013**, 36 (2013).
13. D. A. Lashof, D. R. Ahuja, *Nature* **344**, 529 (1990).
14. P. Forster *et al*., 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*, S. Solomon *et al*., Eds. (Cambridge Univ. Press, New York, 2007), pp. 131–234.
15. J. S. Fuglestvedt *et al*., *Clim. Change* **58**, 267 (2003).
16. V. Ramanathan *et al*., "Black carbon and the regional climate of California" (for the California Air Resources Board, Univ. of California, San Diego, 2013); www.arb.ca.gov/research/rsc/3-8-13/item8dfr08-323.pdf.

Supplementary Materials

www.sciencemag.org/content/342/6164/1323/suppl/DC1

10.1126/science.1240162