complement prior studies that highlight the importance of short- and medium-lived pollutants (14–17).

The top 10 pollutant-generating activities contributing to net RF (positive RF minus negative RF) in year 20 are shown in the bottom chart, page 526, which takes into account the emission of multiple pollutants from each source activity (18). The seven sources that appear only on the left side (purple bars) would be overlooked by mitigation strategies focusing exclusively on long-lived pollutants.

The distinctly different sources of near-term and long-term RF lend themselves to the aforementioned two-pronged mitigation approach. This decoupling is convenient for policy design and implementation; whereas this perception of urgency of near-term mitigation will evolve with our knowledge of the climate system. Additionally, optimal near-term mitigation strategies will reflect decadal oscillations (19), seasonal and regional variations (20, 21), and evolving knowledge of aerosol-climate effects (22, 23) and methane-atmosphere interactions (22)—considerations unique to the near-term 

Thus, short- and medium-lived sources (black carbon, tropospheric ozone, and methane) must be regulated separately and dynamically. The long-term mitigation treaty should focus exclusively on steady reduction of long-lived pollutants. A separate treaty for short- and medium-lived sources should include standards that evolve based on periodic recommendations of an independent international scientific panel. The framework of “best available control technology” (strict) and “lowest achievable emissions rate” (stricter) from the U.S. Clean Air Act (24) can be used as a model.

Such a two-pronged institutional framework would reflect the evolving scientific understanding of near-term climate change, the scientific certainty around long-term climate change, and the opportunity to separately adjust the pace of near-term and long-term mitigation efforts.

References and Notes
2. The e-folding time (required to decrease to 37% of original airborne amount) is on the order of days to weeks for short-lived pollutants (e.g., black and organic carbon, tropospheric ozone, and sulfur dioxide), a decade for medium-lived (e.g., methane and some halocarbons), and a century for long-lived (e.g., nitrous oxide, some halocarbons). CO₂ takes roughly a century to reach 37% then decays more slowly over millennia.
4. S. Solomon et al., Climate Change 2007: The Physical

11. RF is a property of the climate at a point in time. Increases in RF create planetary energy imbalance, with more incoming solar radiation than outgoing infrared radiation and a warming effect on the system.

CLIMATE CHANGE

Fixing a Critical Climate Accounting Error

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Rules for applying the Kyoto Protocol and national cap-and-trade laws contain a major, but fixable, carbon accounting flaw in assessing bioenergy.

The accounting now used for assessing compliance with carbon limits in the Kyoto Protocol and in climate legislation contains a far-reaching but fixable flaw that will severely undermine greenhouse gas reduction goals (1). It does not count CO₂ emitted from tailpipes and smokestacks when bioenergy is being used, but it also does not count changes in emissions from land use when biomass for energy is harvested or grown. This accounting erroneously treats all bioenergy as carbon neutral regardless of the source of the biomass, which may cause large differences in net emissions. For example, the clearing of long-established forests to burn wood or to grow energy crops is counted as a 100% reduction in energy emissions despite causing large releases of carbon.

Several recent studies estimate that this error, applied globally, would create strong incentives to clear land as carbon caps tighten. One study (2) estimated that a global CO₂ target of 450 ppm under this accounting would cause bioenergy crops to expand to displace virtually all the world’s natural forests and savannahs by 2065, releasing up to 37 gigatons (Gt) of CO₂ per year (compa-
The potential of bioenergy to reduce greenhouse gas emissions inherently depends on the source of the biomass and its net land-use effects. Replacing fossil fuels with bioenergy does not by itself reduce carbon use effects. Replacing fossil fuels with bioenergy inherently depends (4) on the carbon neutral, economics favor large-scale land conversion for bioenergy regardless of the actual net emissions (4).

The Kyoto Protocol caps the energy emissions of developed countries. But the protocol applies no limits to land use or any other emissions from developing countries, and special crediting rules for “forest management” allow developed countries to cancel out their own land-use emissions as well (1, 10). Thus, maintaining the exemption for CO\textsubscript{2} emitted by bioenergy use under the protocol (11) wrongly treats bioenergy from all biomass sources as carbon neutral, even if the source involves clearing forests for electricity in Europe or converting them to biodiesel crops in Asia.

This accounting error has carried over into the European Union’s cap-and-trade law and the climate bill passed by the U.S. House of Representatives (1, 12, 13). Both regulate emissions from energy but not land use and then erroneously exempt CO\textsubscript{2} emitted from bioenergy use. In theory, the accounting system would work if caps covered all land-use emissions and sinks. However, this approach is both technically and politically challenging as it is extremely hard to measure all land-use emissions or to distinguish human and natural causes of many emissions (e.g., fires).

The Intergovernmental Panel on Climate Change (IPCC) has long realized that bioenergy’s greenhouse effects vary by source of biomass and land-use effects. It also recognizes that when forests or other plants are harvested for bioenergy, the resulting carbon release must be counted either as land-use emissions or energy emissions but not both. To avoid double-counting, the IPCC assigns the CO\textsubscript{2} to the land-use accounts and exempts bioenergy emissions from energy accounts (5). Yet it warns, because “fossil fuel substitution is already ‘rewarded’” by this exemption, “to avoid underreporting . . . any changes in biomass stocks on lands . . . resulting from the production of biofuels would need to be included in the accounts” (9).

This symmetrical approach works for the reporting under the United Nations Framework Convention on Climate Change (UNFCCC) because virtually all countries report emissions from both land and energy use. For example, if forests are cleared in Southeast Asia to produce palm biodiesel burned in Europe, Europe can exclude the tailpipe emissions as Asia reports the large net carbon release as land-use emissions.

However, exemption from bioenergy use is improper for greenhouse gas regulations if land-use emissions are not included. The Kyoto Protocol caps the energy emissions of developed countries. But the protocol applies no limits to land use or any other emissions from developing countries, and special crediting rules for “forest management” allow developed countries to cancel out their own land-use emissions as well (1, 10). Thus, maintaining the exemption for CO\textsubscript{2} emitted by bioenergy use under the protocol (11) wrongly treats bioenergy from all biomass sources as carbon neutral, even if the source involves clearing forests for electricity in Europe or converting them to biodiesel crops in Asia.

Reference and Notes
1. Additional references supporting the themes of this Policy Forum can be found in the supporting online material.


11. UNFCCC, Updated UNFCCC reporting guidelines on annual inventories following incorporation of the provisions of decision 1/CP.11 (FCCC/Subsidiary Body for Scientific and Technological Advice (SBSTA/2006/9, Geneva, 2006), p. 23.


15. The authors express thanks for the support of the German Marshall Fund of the United States.

Supporting Online Material
www.sciencemag.org/cgi/content/full/326/5952/527/DC1