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 the importance of long-term climate stabilization is clear, the perceived 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

1. D. Archer *et al*., *Annu. Rev. Earth Planet. Sci.* **37**, 117 (2009).
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). CO_2 takes roughly a century to reach 37%, then decays more slowly over millennia.
3. C. P. McMullen, J. Jabbour, Eds., *Climate Change Science Compendium 2009* (U.N. Environment Programme, Nairobi, EarthPrint, 2009); www.unep.org/compendium2009/.
4. S. Solomon *et al*., *Climate Change 2007: The Physical Science Basis: Contribution of Working Group I to the Fourth Assessment Report of the IPCC* (Cambridge Univ. Press, New York, 2007).
5. S. Rahmstorf *et al*., *Science* **316**, 709 (2007).
6. J. B. Smith *et al*., *Proc. Natl. Acad. Sci. U.S.A.* **106**, 4133 (2009).
7. A. Sokolov *et al*., *J. Clim.* **22**, 5175 (2009).
8. T. Stocker, *Quat. Sci. Rev.* **19**, 301 (2000).
9. T. M. Lenton *et al*., *Proc. Natl. Acad. Sci. U.S.A.* **105**, 1786 (2008).
10. J. Hansen *et al*., *Open Atmos. Sci. J.* **2**, 217 (2008).
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.
12. T. F. Stocker, A. Schmittner, *Nature* **388**, 862 (1997).
13. R. B. Alley *et al*., *Science* **299**, 2005 (2003).
14. J. Hansen *et al*., *Philos. Trans. R. Soc. London Ser. A* **365**, 1925 (2007).
15. P. K. Quinn *et al*., *Atmos. Chem. Phys.* **8**, 1723 (2008).
16. M. Z. Jacobson, *J. Geophys. Res. Atmos.* **107**, 4410 (2002).
17. F. C. Moore, M. C. MacCracken, *Intl. J. Strategic Change Mgmt.* **1**, 42 (2009).
18. D. Koch, T. C. Bond, D. Streets, N. Unger, *Geophys. Res. Lett.* **34**, L05821 (2007).
19. K. Trenberth *et al.*, in (*4*), pp. 235–336.
20. D. Koch, T. Bond, D. Streets, N. Unger, G. van der Werf, *J. Geophys. Res.* **112**, D02205 (2007).
21. A. Stohl, *J. Geophys. Res.* **111**, D11306 (2006).
22. P. Forster *et al.*, in (*4*), pp. 129–234.
23. V. Ramanathan, G. Carmichael, *Nat. Geosci.* **1**, 221 (2008).
24. U.S. Clean Air Act, www.epa.gov/oar/caa/.
25. The same analysis applied to the IPCC's SRES marker scenarios (A1, A2, B1, and B2) (*26*) produces results that fall largely within the bounds of these two scenarios (fig. S1).
26. N. Nakićenović, R. Swart, Eds., *Special Report on Emissions Scenarios* (IPCC, Cambridge Univ. Press, Cambridge, 2000).
27. Data for year 2000 RF are based on (*14*), emissions are from (*28*), decay rates are based on the lifetimes on p. 212 in (*22*) and historical CO_2 decay is calculated according to p. 824 in (*29*). Growth rates are from (*28*) and (*30*). Zero growth of emissions assumed for BC, OC, SO_2, and halocarbons Each year's RF for short-lived pollutants (BC, OC, O_3, SO_2) is due only to emissions in that year; thus, the RF does not accumulate from one year to the next. The contributions of black carbon and ozone are conservative, as they do not reflect recent near-double estimates of black carbon's RF (*23*) nor recent estimates of ozone's indirect land sink effect (*31*).
28. EDGAR 3.2 (www.mnp.nl/edgar/model/).
29. G. Meehl *et al.*, in (*4*), pp. 747–845.
30. Climate Analysis Indicators Tool v6.0 (http://cait.wri.org).
31. S. Sitch, P. M. Cox, W. J. Collins, C. Huntingford, *Nature* **448**, 791 (2007).
32. T. C. Bond *et al.*, *Global Biogeochem. Cycles* **21**, GB2018 (2007).

33. The author thanks J. Harte for providing encouragement and critique.

Supporting Online Material
www.sciencemag.org/cgi/content/full/326/5952/526/DC1

10.1126/science.1177042

CLIMATE CHANGE

Fixing a Critical Climate Accounting Error

Timothy D. Searchinger,[1]* Steven P. Hamburg,[2]* Jerry Melillo,[3] William Chameides,[4] Petr Havlik,[5] Daniel M. Kammen,[6] Gene E. Likens,[7] Ruben N. Lubowski,[2] Michael Obersteiner,[5] Michael Oppenheimer,[1] G. Philip Robertson,[8] William H. Schlesinger,[7] G. David Tilman[9]

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 CO_2 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 CO_2 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 CO_2 per year (compa-

[1]Princeton University, Princeton, NJ 08544, USA. [2]Environmental Defense Fund, Boston, MA 02108, and Washington, DC 20009, USA. [3]Marine Biological Laboratory, Woods Hole, MA 02543, USA. [4]Duke University, Durham, NC 27708, USA. [5]International Institute for Applied Systems Analysis, Laxenburg 2361, Austria. [6]University of California at Berkeley, Berkeley, CA 94720, USA. [7]Cary Institute of Ecosystem Studies, Millbrook, NY 12545, USA. [8]Michigan State University, Hickory Corners, MI 49060, USA. [9]University of Minnesota, St. Paul, MN 55108, USA.

*Authors for correspondence. E-mail: shamburg@edf.org (S.P.H.); tsearchi@princeton.edu (T.D.S.).

Published by AAAS

rable to total human CO_2 emissions today). Another study predicts that, based solely on economic considerations, bioenergy could displace 59% of the world's natural forest cover and release an additional 9 Gt of CO_2 per year to achieve a 50% "cut" in greenhouse gases by 2050 (*3*). The reason: When bioenergy from any biomass is counted as carbon neutral, economics favor large-scale land conversion for bioenergy regardless of the actual net emissions (*4*).

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 emissions, because the CO_2 released by tailpipes and smokestacks is roughly the same per unit of energy regardless of the source (*1*, *5*). Emissions from producing and/or refining biofuels also typically exceed those for petroleum (*1*, *6*). Bioenergy therefore reduces greenhouse emissions only if the growth and harvesting of the biomass for energy captures carbon above and beyond what would be sequestered anyway and thereby offsets emissions from energy use. This additional carbon may result from land management changes that increase plant uptake or from the use of biomass that would otherwise decompose rapidly. Assessing such carbon gains requires the same accounting principles used to assign credits for other land-based carbon offsets.

For example, if unproductive land supports fast-growing grasses for bioenergy, or if forestry improvements increase tree growth rates, the additional carbon absorbed offsets emissions when burned for energy. Energy use of manure or crop and timber residues may also capture "additional" carbon. However, harvesting existing forests for electricity adds net carbon to the air. That remains true even if limited harvest rates leave the carbon stocks of regrowing forests unchanged, because those stocks would otherwise increase and contribute to the terrestrial carbon sink (*1*). If bioenergy crops displace forest or grassland, the carbon released from soils and vegetation, plus lost future sequestration, generates carbon debt, which counts against the carbon the crops absorb (*7*, *8*).

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_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, exempting emissions 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_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_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 straightforward solution is to fix the accounting of bioenergy. That means tracing the actual flows of carbon and counting emissions from tailpipes and smokestacks whether from fossil energy or bioenergy. Instead of an assumption that all biomass offsets energy emissions, biomass should receive credit to the extent that its use results in additional carbon from enhanced plant growth or from the use of residues or biowastes. Under any crediting system, credits must reflect net changes in carbon stocks, emissions of non-CO_2 greenhouse gases, and leakage emissions resulting from changes in land-use activities to replace crops or timber diverted to bioenergy (*1*).

Separately, Europe and the United States have established legal requirements for minimum use of biofuels, which assess greenhouse gas consequences based on life-cycle analyses that reflect some land-use effects (*1*, *14*). Such assessments vary widely in comprehensiveness, but none considers biofuels free from land-based emissions. Yet the carbon cap accounting ignores land-use emissions altogether, creating its own large, perverse incentives.

Bioenergy can provide much energy and help meet greenhouse caps, but correct accounting must provide the right incentives.

References and Notes

1. Additional references supporting the themes of this Policy Forum can be found in the supporting online material.
2. M. Wise *et al.*, *Science* **324**, 1183 (2009).
3. J. M. Melillo *et al.*, *Unintended Environmental Consequences of a Global Biofuel Program* (MIT Joint Program Report Series, Massachusetts Institute of Technology, Cambridge, MA, 2009).
4. International Energy Agency, *Energy Technology Perspectives: In Support of the G8 Plan of Action: Scenarios and Strategies to 2050* [Organization for Economic Cooperation and Development (OECD)/IEA, Paris, 2008].
5. IPCC, *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, prepared by the National Greenhouse Gas Inventories Programme [Institute for Global Environmental Strategies (IGES), Tokyo, Japan, 2007].
6. E. Manichetti, M. Otto, in *Biofuels: Environmental Consequences and Interactions with Changing Land Use: Proceedings of the Scientific Committee on Problems of the Environment*, R. W. Howarth, and S. Bringezu, Eds. (Cornell Univ. Press, Ithaca, NY, 2009), pp. 81–109.
7. T. Searchinger *et al.*, *Science* **319**, 1238 (2008).
8. J. Fargione, J. Hill, D. Tilman, S. Polasky, P. Hawthorne, *Science* **319**, 1235 (2008).
9. R. Watson *et al.*, Eds., *Land Use, Land-Use Change, and Forestry* (IPCC, Cambridge Univ. Press, Cambridge, 2000).
10. UNFCCC, *Report of the Conference of the Parties on Its Seventh Session: Action taken by the COP* (FCCC/CP/20001/13/Add.1, UNFCCC, Geneva, 2002), Addendum, part 2.
11. UNFCCC, *Updated UNFCCC reporting guidelines on annual inventories following incorporation of the provisions of decision 14/CP.11* [FCCC/Subsidiary Body for Scientific and Technological Advice (SBSTA)/2006/9, Geneva, 2006], p. 23.
12. European Commission, *Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003*, Official Journal of the European Union L 275, 25.10.2003.
13. The American Clean Energy and Security Act of 2009, H.R. 2454, 111th Cong., 1st Sess. (as passed by U.S. House of Representatives July 2009).
14. T. D. Searchinger, in *Biofuels: Environmental Consequences and Interactions with Changing Land Use: Proceedings of the Scientific Committee on Problems of the Environment,* R. W. Howarth and S. Bringezu, Eds. (Cornell Univ. Press, Ithaca, NY, 2009), pp. 37–52.

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

10.1126/science.1178797

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

Supporting Online Material for

Fixing a Critical Climate Accounting Error

Timothy D. Searchinger,* Steven P. Hamburg,* Jerry Melillo, William Chameides, Petr Havlik, Daniel M. Kammen, Gene E. Likens, Ruben N. Lubowski, Michael Obersteiner, Michael Oppenheimer, G. Philip Robertson, William H. Schlesinger, G. David Tilman

*To whom correspondence should be addressed. E-mail: shamburg@edf.org (S.P.H.); tsearchi@princeton.edu (T.D.S.)

Published 23 October 2009, *Science* **326**, 527 (2009)
DOI: 10.1126/science.1178797

This PDF file includes

SOM Text
References

SUPPORTING ONLINE MATERIAL

SOM Text

Combustion emissions per unit of energy: The Intergovernmental Panel on Climate Change provides default factors for greenhouse gas emissions per unit of energy from stationary installations using different forms of energy. Emissions rates from some biomass sources, such as wood and wood waste, are modestly higher than those for coal, oil or natural gas[p. 217 in (*S1*)]. Nearly all life-cycle assessments either explicitly or implicitly treat the emissions from combustion of ethanol and biodiesel as the same for gasoline and fossil diesel per unit of energy (*S2*, *S3*). Many do so in practice by assuming that there are no emissions from the combustion of the biofuels on the theory that they are necessarily canceled out by the carbon absorbed through the growth of the plants that become the biofuel.

Higher production/refining emissions typically found for biofuels: The production/refining emissions for gasoline and diesel consist of the emissions involved in mining the crude oil, refining it into gasoline or diesel and the associated transportation. The production emissions for biofuels are those from the growing of the biofuel feedstock (not counting land use effects or carbon uptake), the refining process and the associated transportation. The average production emissions for gasoline or diesel are typically estimated at roughly 20% of total emissions from their use (*S2*, *S3*). For this reason, this 20% represents the maximum potential savings from any biofuel with a more efficient production/refining process not counting the effects of land use change.

Nearly all life-cycle analyses of the greenhouse gas emissions from biofuels count only these “production emissions” while assuming that the tailpipe emissions from consuming the biofuel in the vehicle are fully offset by the carbon absorbed by the plant feedstocks. In such a comparison, if the production emissions for the biofuel and petroleum based fuels were the same, the greenhouse gas emissions from biofuels would be estimated at 80% lower than those for petroleum. In fact a summary of 27 life-cycle analyses of ethanol from different starch sources and 25 analyses of biodiesel from different vegetable oils found that nearly all estimated less than 80% savings and therefore that these production emissions are higher for biofuels than for the petroleum products they replace [Tables 5.1 & 5.2 in (*S4*)]. Farrell et al (*S5*) [supporting materials, Table S3 in (*S5*)], came to the same conclusion in evaluating several studies of corn-based ethanol.

Some life-cycle analyses of ethanol from cellulose or Brazilian sugarcane emissions estimate savings relative to petroleum greater than 80% and even more than 100% in some cases, but even these studies do not truly estimate lower production/refining emissions [Tables 5.1 & 5.3 in (*S4*)]. These higher savings occur because much of the energy that fuels the refining process comes from the sugarcane or cellulose, and often this biomass also provides an electricity energy co-product. The analyses assume that the emissions from this biomass energy use, just like the emissions from the ultimate consumption of the fuel, are cancelled out by the carbon absorbed with the growth of the biomass. As our paper discusses, that offset only occurs if this carbon derives from biomass that is "additional," in that it would not otherwise remain or become sequestered in plants or soils. In other words, these calculations do not alter the result that the actual emissions from the production process are still higher. Instead, they calculate implicitly that these production/refining emissions may themselves be cancelled out by additional carbon in the biomass feedstock that is used to energize the production process, or to generate energy co-products.

Exclusion of emissions from consumption of biomass for energy in Kyoto Protocol and European Union and U.S. climate legislation: The original reporting under the IPCC revised 1996 guidelines (*S6*), recommends that countries report emissions for the United Nations Framework Convention on Climate Change from the consumption of biomass for information purposes only and not as national totals although non-CO_2 emissions from this consumption, such as methane or nitrous oxide, do count toward national totals. The accounting rules for Annex I countries under the Kyoto Protocol (*S7*), which in large part reference these IPCC guidelines, state on page 23: "Consistent with the Revised 1996 IPCC Guidelines . . . CO_2 emissions from biomass and emissions from multilateral operations, should be reported in the appropriate tables, but not included in the national totals."

The principal climate legislation in the European Union, the Emissions Trading Scheme, caps greenhouse gas emissions from major energy and industrial facilities and allows trading of emissions. But as specified in Annex I, it does not cover emissions from agriculture or land use change (*S9*). Annex IV then provides, "The emission factor for biomass shall be zero."

As passed by the U.S. House of Representatives in July, 2009, the American Clean Energy and Security Act of 2009 (*S10*), Sections 721-728, establishes a cap for greenhouse gas emissions from energy use. Factories and power plants are responsible for holding allowances to match their emissions from energy use. Sellers of transportation fuels must also hold allowances for the emissions their fuels will cause when consumed. The level of allowances declines over time and will require large reductions in emissions by 2050 by these various "covered" entities. Section 722 specifies which emissions are covered, and in the case of all liquid transportation fuels, applies only to those from fossil origin and therefore not biofuels. For electricity generation or industrial power, emissions from use of "renewable biomass" do not count. The definition of renewable biomass (§ 126) places some restrictions on harvesting material from special value, publicly owned lands in the United States but allows the use of virtually any private forest material or the harvesting of any planted bioenergy crop regardless of the private area planted.

The bioenergy provisions of the bill were the subject of negotiations between the bill's lead sponsor, Congressman Henry Waxman, and the Chairman of the Agriculture Committee, Collin Peterson. When they released the language that resulted from their negotiations, they sent a letter to the Speaker of the House, Congresswoman Nancy Pelosi, showing awareness of an accounting problem. The letter stated, "we also agree on the need to account for the carbon footprint of biofuels and biomass used for electricity and power generation through the carbon accounting system in the global warming pollution program or an equally effective mechanism" (*S11*).

<u>Forest management credits under Kyoto Protocol</u>: Nearly all developed countries have abundant re-growing forests that were harvested prior to 1990 and are sequestering carbon (*S12*). Because these re-growing forests primarily result from human activities prior to 1990, they would not normally be entitled to carbon credits as human-induced sinks (*S12*, *S13*). However, under the "Marrakesh Accords" for implementing the Kyoto Protocol, developed (*Annex I*) countries subject to commitments to reduce emissions under the Protocol may take credit for this re-growing carbon, at least during the first commitment period of 2008-12, as "forest management," but only up to levels set at 15% of the estimated annual carbon re-growth (*S14*). This percentage was explicitly based on the theory that 15% of the forest growth could be attributable to ongoing forest management efforts (*S11*, *S13*). By itself, this credit does not alter the consequences of causing emissions from further land use activities. However, countries may take additional credits for this carbon gain from "forest management" to the extent needed to offset their emissions from land use change and forestry (the emissions covered by Article 3, paragraph 3 of the Kyoto Protocol) up to 9 megatons per year [¶ 6, 10, 11 (*S14*)]. As a result, even if the production of bioenergy in these developed countries increases emissions from land use change or forestry, most developed countries are likely to be able to offset them with additional, otherwise unused, forest management credits. As a practical matter, at least during the first commitment period, this system means that emissions from land use change effectively do not count against compliance with the national emissions targets because each new ton of emissions entitles a country to use an additional ton of carbon credits.

<u>Use of forests for electricity on additional carbon</u>: Roughly a quarter of anthropogenic emissions of carbon dioxide are removed from the atmosphere by the terrestrial carbon sink, of which the re-growth of forests cut in previous decades plays a major role (*S15*, *S16*). Any gain in carbon stored in regenerating forests contributes to the sink, so activities that keep otherwise regenerating forests to constant levels of carbon reduces that sink relative to what would have occurred without those activities.

The net effect of harvesting wood for bioenergy is complicated and requires more analysis. Each ton of wood consumed in a boiler instead of coal does not significantly alter combustion emissions. However, some of the wood in standing timber is typically not utilized and is left to decay in the forest or nearby, causing additional emissions. Much of the carbon in roots will also decompose. Replanting may accelerate release of carbon from forest soils. As the forest regenerates following cutting, it may sequester carbon faster or slower than would have occurred in the absence of the harvesting, depending on the previous forest's age, site quality and forest type. Over long periods, the carbon stocks of the forests with and without the harvest for biofuels may be equal. For this reason, how different emissions are valued over time plays an important role in estimating the net carbon effects of harvesting wood for use as a bioenergy. [For one discussion of the time issues, see (*S17*)].

Calculations of greenhouse gas emissions for liquid biofuel mandates: Both the European Union (EU) and the United States, along with many other countries, have instituted blending requirements for transportation fuel distributors that require a minimum percentage of biofuels (*S18*). For biofuels to meet this blending requirement in both the EU and United States, they must reduce greenhouse gas emissions by specified levels by comparison with gasoline or diesel--levels that vary by year and type of biofuel. These emissions are based on life-cycle analyses. In the United States this life-cycle analysis includes a broad array of potential emissions from land use, including nitrous oxide emissions generated by growing a bioenergy crop, and emissions from land use change. As the Environmental Protection Agency has proposed to implement this requirement, these emissions from land use change do not distinguish between direct land use change and indirect land use change, i.e., they do not differ depending on where the bioenergy crop is grown, but represent the EPA's estimate of the emissions from the incremental land-use changes that will occur as a result of producing the required levels of biofuels of a particular feedstock (*S19*).

Crediting biomass for energy use versus life-cycle analysis: The life-cycle analyses for biofuels proposed for use by the U.S. Environmental Protection Agency (*S19*) and adopted by the California Air Resources Board (*S20*) attempt to calculate the total change in life-cycle emissions that results from a switch between petroleum fuel and the particular biofuel. That kind of analysis includes emissions from the energy used in the production process. For purposes of determining if the use of biomass for energy should receive a carbon credit, as we recommend, emissions that are otherwise regulated under a cap should not be counted again. For example, the tractor fuel used to produce a biofuel crop in the United States, or the natural gas or coal used to refine it, creates emissions that would also be subject to a cap under the climate change bill passed by the U.S. House of Representatives (*S10*). Because these emissions require compensating reductions elsewhere in energy use to meet the cap, they do not need to be included in the calculation of the carbon effects of the biomass generation and use. Put another way, the cap puts a price on these regulated emissions, so there is no false incentive to switch to bioenergy to avoid legal responsibility for them.

For regulatory programs that do not limit or cap emissions from land use, however, the net land use consequences of biomass for energy have to be assessed to determine the extent of any greenhouse gas credit for the use of this biomass. As we propose, this crediting should focus on the extent to which the generation of the biomass in “additional carbon,” i.e., a net gain in carbon that would not otherwise be stored in terrestrial ecosystems anyway. This analysis should credit the carbon absorbed by the plant that becomes the fuel (or that helps to fuel the refining process if the emissions from that refining process are under the cap) and also credit any increase in ongoing carbon sequestration. But the calculation must deduct any loss in carbon stocks, and any loss in ongoing carbon sequestration. If the generation of the biomass uses land that otherwise supported carbon uptake in the form of food (whether crops or livestock forage) or timber products, this carbon would not be sequestered, but the calculation must then estimate the “leakage.” The leakage involves the change in emissions from land use (and other unregulated emissions) elsewhere, such as the loss of carbon involved in conversion of forest or grassland to crops, that will occur to replace the product elsewhere. In this analysis, non-CO_2 emissions need to be included, such as nitrous oxide from fertilizer use, to the extent they are non-regulated emissions. These additionality and leakage considerations are now a conventional part of the crediting of land-based emissions reductions under the Clean Development Mechanism established by the Kyoto Protocol and by other proposed methods for crediting land-based offsets. When bioenergy products are generated abroad, the biomass has to be evaluated in the same way.

References

S1. IPCC, *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, prepared by the National Greenhouse Gas Inventories Programme [Institute for Global Environmental Strategies (IGES), Tokyo, Japan, 2007].

S2. U.K. Renewable Fuels Agency, *Carbon and Sustainability Reporting Within the Renewable Transport Fuel Obligation Technical Guidance Part Two Carbon Reporting –Default Values and Fuel Chains* (Publisher?, London, March 2008).

S3. Argonne National Laboratory, *Greenhouse gases, regulated emissions, and energy use in transportation (*GREET*) computer model* (ANL, Argonne, Illinois, 2007).

S4. E. Menichetti, M. Otto, in *Biofuels: Environmental Consequences and Interactions with Changing Land Use. Proceedings of the Scientific Committee on Problems of the Environment*, R.W. Howarth. S. Bingezu, Eds. (Cornell Univ. Press, Ithaca, NY, 2009), pp. 81-109.

S5. A.E. Farrell *et al*., *Science* **311**, 506-508 (2006)

S6. European Commission, *Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading with the Community and amending Council Directive 96/61/EC*, Official Journal of the European Union L275, 25.10.2003.

S7. IPCC, "2006 IPCC Guidelines for National Greenhouse Gas Inventories," prepared by the National Greenhouse Gas Inventories Programme [Institute for Global Environmental Strategies (IGES), Tokyo, Japan, 2007].

S8. UNFCCC, *Updated UNFCCC reporting guidelines on annual inventories following incorporation of the provisions of decision 14/CP.11* [FCCC/Subsidiary Body for Scientific and Technological Advice (SBSTA)/2006/9, Geneva, 2006].

S9. European Commission, *Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003*, Official Journal of the European Union L 275, 25.10.2003.

S10. The American Clean Energy and Security Act of 2009, H.R. 2454, 111th Cong., 1st Session (as passed by the House of Representatives July 2009).

S11. Letter from Henry A. Waxman and Collin C. Peterson to Nancy Pelosi (June 24, 2009).

S12. B. Schlamadinger et al., *Environ. Sci. Policy* ***10***, 271-82 (2007).

S13. J. G. Canadell et al., *Environ. Sci. Policy* **10**, 370-384 (2007).

S14. UNFCCC, *Report of the Conference of the Parties on Its Seventh Session: Action Taken by the COP*, (FCCC/CP/20001/13/Add.1, UNFCCC, Geneva, 2002), Addendum, part 2.

S15. T. Barker et. al., in *Climate Change 2007: Mitigation: Contribution of Working Group III to the Fourth Assessment Report of the IPCC* (Cambridge Univ. Press, Cambridge, UK 2007).

S16. G. J. Nabuurs, et al., in *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the IPCC* (Cambridge Univ. Press, Cambridge, UK 2007)

S17. M. O'Hare et al., *Environ. Res. Lett*. 4, 024001 (2009)

S18. T. Searchinger, in *Biofuels: Environmental Consequences and Interactions with Changing Land Use: Proceedings of the Scientific Committee on Problems of the Environment* (Cornell Univ. Press, Ithaca, NY, 2009), pp. 37–52.

S19. U.S. EPA, "Notice of Proposed Rulemaking: Regulation of Fuels and Fuel Additives: Changes to Renewable Fuel Standards Program," *Federal Register* **74**, 249004-25143 (26 May 2009).

S20. California Air Resources Board, *Proposed Regulation to Implement the Low Carbon Fuel Standard*, *Vol. 1, Staff Report: Statement of Reasons* (CARB, Sacramento, CA, 2009).