

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.

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Supporting Online Material

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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-

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nable to total human CO₂ 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 CO₂ 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 CO₂ 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 CO₂ 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 CO₂ 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 CO₂ 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-CO₂ 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.

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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-CO₂ 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 . . . CO₂ 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).

Forest management credits under Kyoto Protocol: 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.

Use of forests for electricity on additional carbon: 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-CO₂ 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.

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LETTERS

edited by Jennifer Sills

Stop Listening to Scientists?

AS A CLIMATE SCIENTIST AND A CONTRIBUTING AUTHOR TO THE INTERGOVERNMENTAL PANEL on Climate Change, my heart always warms when I hear policy-makers refer to doing what “the science dictates,” as President Obama did in his remarks toward the end of the U.N. Climate Change Treaty negotiations in Copenhagen, Denmark. However, after the first-hand experience of the rapid crash of the Copenhagen meeting, I have changed my thinking: World leaders, please stop listening to us! I don’t say this because I have lost faith in the verity of scientific results or the projected warming and subsequent global damages. I say this because international policy-makers are adhering too rigidly and too literally to recommended concentration thresholds and emissions targets, and it is crippling the international policy process.

By demanding nothing less than rigid recipes, we have lost valuable momentum. To combat this trend, I offer the following recommendations.

Leave aside the near-obsessive need to benchmark everything against the 2°C target. Science has done a commendable job outlining the boundaries of the climate change problem, and those boundaries are well-considered, rigorous guideposts, but don’t use science recommendations as a litmus test for policy success or failure.

Don’t let the perfect be the enemy of the good. Accept any binding commitment as long as it demonstrates effort beyond Kyoto or “business as usual” (whichever requires the greater effort). This can be tightened in the future—you can’t amend something you don’t have.

Lower the rhetoric. Climate politics has evolved to a point where if one side thinks the other side isn’t listening, they shout louder and invoke phrases like “genocide” and “murder.” Overblown rhetoric inevitably leads to the well-known “donor fatigue.”

Other than commitments to slow deforestation and forest degradation, leave forestry complications out of a current agreement. It has generated confusion, raced ahead of science, opened mitigation loopholes, and consumed far too much negotiating oxygen.

To the developing world: Approach funding offers as a starting point to get a funding system flowing. You can’t attract new revenue, or extend or add funds, to financing that doesn’t exist.

Agree to even loose commitments on monitoring, reporting, and verification (MRV), a key sticking point in the Copenhagen talks. Science can solve this problem, but can’t get started without a clear signal and research commitment from all large emitting countries.

Prioritize country commitments to mobilize domestic and international energy research support. In addition to technology transfer opportunities, effort can be directed toward MRV.

In short, we need agreement, even an imperfect agreement, to show a consistent and committed forward momentum. What were general scientific guideposts have become ossified deal-breakers. Instead, we need a sufficient signal to unleash the private and public resources to begin decarbonization. With that, we will start walking in the direction of our goal but leave ourselves open to shortcuts we can’t see at the outset.

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Carbon Calculations to Consider

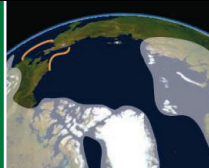
T. SEARCHINGER *ET AL.* (“FIXING A CRITICAL climate accounting error,” Policy Forum, 23 October 2009, p. 527) suggest that it would be more scholarly to account for all carbon assimilation and release as function of time rather than just consider biomass as carbon neutral. However, they do not distinguish between felling mature forest to get wood for burning and doing so to grow energy crops. What matters is what is done with the wood from clearing. If combusted, this is a one-time, negative impact on the carbon balance. If the wood is used for house construction or furniture, the immediate climate impact is zero. There will be a negative impact only if these items are later burned.

Some of the same authors recently attacked “second-generation” biofuels (*1*), making the prediction that biofuels will soon be derived entirely from cellulosic material grown on marginal land. This is at variance with another definition of second-generation biofuels: vehicle fuels derived entirely from residues from already-existing biomass cultivation. These are evidently carbon neutral, and no energy inputs are changed. The soil-nutrient balance can be improved because residues from fuel production can be returned to the fields, where they are less likely to foul waterways than are chemical fertilizers. One should remember that most agri- and silvicultural residues are



Letters to the Editor

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Explaining
ice age cycles

790



Where chromosomes
cross over

791

already used today without recycling nutrients, primarily for power and heat plant combustion. The most sustainable option available to us is to use second-generation biofuels along with recycling.

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Response

OUR POLICY FORUM POINTED OUT A MAJOR flaw when treaties and laws treat all bioenergy as carbon neutral regardless of the source of the biomass. Sørensen's main point appears to be that when mature forests are cleared to plant bioenergy crops, any use of harvested wood to add to the stocks of long-lived wood products preserves some of the carbon and therefore reduces the scope of emissions. We agree. This statement supports our central point that proper accounting of biomass must reflect its effects on carbon stocks and flows.

Unfortunately, using harvested wood for long-lived furniture or housing does not by

itself make biomass carbon neutral. When forests are cleared and planted with energy crops or plantation forests, much carbon is lost to the atmosphere from unharvested branches, roots and soils. In addition, many mature forests continue to sequester carbon if left standing (1), and the loss of this ongoing carbon sequestration counts as another carbon cost of clearing the forest. Forest regrowth or the displacement of fossil fuels through energy crops provides carbon savings, but analyses that count the amount of harvested wood incorporated into furniture and houses still find that energy crops can take more than 100 years to repay the carbon debt from clearing forests (2). Given the urgency of reducing greenhouse gas emissions (3), policy should focus on the net effect on emissions over a few decades at most. Over these periods, forest clearing for energy will rarely, if ever, approach carbon neutral outcomes—i.e., cause a 100% reduction in carbon emissions compared to use of fossil fuels. In practice, carbon emissions will often increase (4).

Rather than attacking second-generation biofuels, we have distinguished biofuels in both our recent and previous papers based

on the feedstock. The key distinction is whether biofuels merely shift carbon from one use to another, which does not reduce greenhouse gases, or instead result in “additional” carbon uptake in plants or reduced biomass decomposition, both of which can reduce greenhouse gases. Whether crop and timber residues are better used for liquid biofuels or electricity and power is a separate question. Many studies have found that using biomass to replace fossil fuels for electricity or power saves more carbon than using biomass for liquid fuels (5, 6). One reason is that much of the energy in biomass is lost in the process of transforming it into a liquid fuel (7). Sørensen is correct that such comparisons need to consider the potential benefits of by-products that can displace synthetic fertilizers. Most biofuels do not, and probably will not, produce such by-products. The potentially expanded use of biomass for a wide range of industrial applications highlights the importance of correct accounting.

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CORRECTIONS AND CLARIFICATIONS

Reports: “Plumage color patterns of an extinct dinosaur” by Q. Li *et al.* (published online 4 February in *Science Express*; 10.1126/science.1186290). In the abstract view, Long Miao was mistakenly included as an author. The author list on the PDF file is correct.

Reports: “Elevated CO₂ reduces losses of plant diversity caused by nitrogen deposition” by P. B. Reich (4 December 2009, p. 1399). The 0.70 and 0.65 values and corresponding <0.0001 values in the first row of Tables 1 and 2, respectively, are the R² values and significance values for the whole models (and should not have been placed in the columns labeled “F value” and “P > F,” respectively).

Research Articles: “The pelvis and femur of *Ardipithecus ramidus*: The emergence of upright walking” by C. O. Lovejoy *et al.* (2 October 2009, p. 71; full text online only at <http://dx.doi.org/10.1126/science.1175831>). The first sentence of the Fig. 4 caption should read, “Fig. 4. Lateral (A) and posterior (B) CT scan surface renders of (Left) MAK-VP-1/1 (*Au. afarensis*, cast) and (Right) ARA-VP-1/701 (*Ar. ramidus*, original).”

Research Articles: “Reexamining human origins in light of *Ardipithecus ramidus*” by C. O. Lovejoy *et al.* (Special Section on *Ardipithecus ramidus*, 2 October 2009, p. 74; full text online only at <http://dx.doi.org/10.1126/science.1175834>). The article notes that daily sperm production per gram of testes in humans is <0.06 × 10⁶. The correct figure is <6 × 10⁶.

Reports: “Reversible reactions of ethylene with distannynes under ambient conditions” by Y. Peng *et al.* (25 September 2009, p. 1668). The Figure 2 legend incorrectly stated that average bond angles were measured in degrees Celsius. The bond angles were actually measured in degrees.

Reports: “Allelopathy and exotic plant invasion: From molecules and genes to species interactions” by H. P. Bais *et al.* (5 September 2003, p. 1377). The authors have had difficulty replicating the high and consistent levels of catechin found in soils surrounding *Centaurea maculosa* plants as originally reported (see Fig. 1A). For the most part, catechin seems to be present in low concentrations or not detectable in soils surrounding *C. maculosa* in the field, with the exception of one sampling period during which it was found at concentrations similar to those in the Report [see L. G. Perry, *J. Chem. Ecol.* **33**, 2337 (2007)]. Furthermore, in vitro exudation of catechin by *C. maculosa* roots has not been reproducible by the Vivanco laboratory, and therefore the origin of catechin in the field is unclear. However, the authors have reconfirmed that catechin has the signaling and phytotoxic activities indicated in the Report.

Finding more beauty than terror

1202



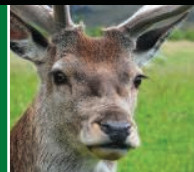
Earth's magnetic shield for life

1206



Up close and personal

1207



LETTERS | BOOKS | POLICY FORUM | EDUCATION FORUM | PERSPECTIVES

LETTERS

edited by Jennifer Sills

A Greener Future for China's Cities

IN THEIR PERSPECTIVE "CLEAN AIR FOR MEGACITIES" (30 OCTOBER 2009, P. 674), D. D. Parrish and T. Zhu highlighted the opportunities and challenges that exist for megacities to address air quality and climate change issues. In China, only 60.5% of the 287 large cities monitored in 2007 had air quality that met the standard of the Ministry of Environmental Protection of China (1). However, there is encouraging evidence that China is striving to build more low-carbon cities. In early 2008, the World Wildlife Fund collaborated on pilot programs with Shanghai and Baoding, focusing on how to implement low-carbon development in China's urban areas (2).



Shanghai

Afterward, Beijing, Shanghai, Tianjin, Shenyang, Wuhan, Hangzhou, and Shenzhen all laid out their respective low-carbon road maps (3–6).

The World Exposition Expo to be held in May 2010 will offer a glimpse of a greener future for Shanghai. During the construction of the Shanghai Expo Park, energy use efficiency and low greenhouse gas emissions were prioritized in activities such as planning, building, and transportation. For example, 4.5 MW integrated solar systems will be used to power buildings in the Expo Park. The use of this clean power is expected to save an estimated 4100 tons of carbon dioxide emissions annually, compared with coal-fired electric power (7).

Addressing air pollutants and climate-forcing agents in Chinese cities will require strategic urban planning, large-scale inputs of finances and technology, new regulations, and

lifestyle changes. The carbon emissions during the development of low-carbon cities (mostly existing district-level and larger cities) must also be taken into account. New regulations (8) have recently been issued in China to eradicate the corrupt inflation in statistics (9) associated with the development of low-carbon cities. If these are carefully implemented, we have every reason to look forward to more low-carbon cities in China.

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Bioenergy: Counting on Incentives

THE SUGGESTION BY T. D. SEARCHINGER *et al.* ("Fixing a critical climate accounting error," Policy Forum, 23 October 2009, p. 527) to account for CO₂ by "tracing the actual flows of carbon" appears to promote an approach to carbon accounting in which emissions and removals from a forest are determined on the basis of gross atmospheric fluxes between the forest, or forest products, and the atmosphere. This contrasts with the current "stock-change" approach, in which the annual removals or emissions from a country's forest are assumed to be equal to the net change in carbon stocks in biomass and soils of the forest estate.

We share the concern of the authors that a "critical climate accounting error" exists within the Kyoto protocol and could undermine greenhouse gas (GHG) reduction goals. However, we feel that their solution would create new, unintended disincentives for the sustainable use of biomass.

The practical problem in the current accounting framework is that some countries do not have commitments under the Kyoto Protocol, and they are therefore not obliged to account for emissions from loss of terrestrial carbon. Furthermore, some countries with commitments choose not to account for some sources of emissions (for example, conversion of natural to managed forest, conversion of grassland to cropland). Therefore, loss of carbon stock associated with the supply of biomass for bioenergy may not be accounted for.

Applying the atmospheric-flow accounting approach would not solve this problem. The importing country would account only for the carbon contained in the biomass used for bioenergy, even though the carbon stock losses in the cleared forest, especially if growing on peatland, could be many times greater than the quantity of carbon contained in the imported biomass (1). Replacing the current stock-change accounting approach with the proposed atmospheric-flow-based accounting approach would also lead to unintended incentives. For instance, combustion of biomass may appear in national GHG accounting with higher CO₂ emissions than coal combustion (because the energy content per unit of carbon is higher for coal than for biomass), even if biomass is harvested on a sustainable basis without reducing the biological carbon stock. This would make all imported bioenergy uncompetitive with fossil fuels. The negative impacts of the atmospheric-flow approach have been discussed in depth (2–5); the conclusions favoring a stock-change-based approach, which is applied in the existing GHG accounting framework, remain valid. Rather than abandoning the current approach and implementing the atmospheric-flow-based strategy that they advocate, we suggest retaining the existing stock-change-based accounting framework for biomass while extending the end-user's responsibility to include the terrestrial carbon stocks.

The "end-user country" would be required to take full or partial responsibility for changes in the terrestrial carbon stocks in the "producer country." Quantifying the change in carbon stocks attributable to bioenergy is difficult, especially given that bioenergy is not the only driver of land-use change. (For example, the food industry is also a rapidly growing market for vegetable oils.) Development of feasible accounting rules is thus a challenging task. However, it is critical that policy measures do not create disincentives for bioenergy from sustainable sources.

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Response

PINGOUD *ET AL.* AGREE WITH US THAT A carbon accounting error underestimates greenhouse gas emissions from bioenergy. Our Policy Forum offers a narrower solution than their Letter because we focus on a narrower source of the problem.

Pingoud *et al.* focus on the Kyoto Protocol decision not to limit most land-based emissions, which is equally true of many European and U.S. laws. Just as this decision leaves out most emissions from agriculture and forestry, it also means that emissions from the produc-

tion and use of bioenergy could potentially exceed those saved from fossil fuels, particularly over decades. This deliberate omission reflects measurement challenges, resistance by landowners, and the difficulty of distinguishing human from natural causes of many land-based emissions. We agree that some increased accountability for land-based emissions would be desirable, but worldwide enforceable limits are unlikely to come into effect soon. Incentives are likely to remain the main tool for reducing land-based emissions.

The decision to exempt most land-use emissions does not require the separate decision to exempt CO₂ emitted by using bioenergy from limits that are applied to energy emissions. Our Policy Forum focuses on the undercounting of net greenhouse gas emissions created by this exemption. Land use is affected because this energy rule incorrectly rewards activities that cut down forests or otherwise reduce carbon stocks to make bioenergy.

CORRECTIONS AND CLARIFICATIONS



News: "Armed and dangerous" by E. Pennisi (Special Section on Food Security, 12 February, p. 804). The potato blight leaf photo showed early blight, not late blight. Late blight is shown here. The image has been corrected in the HTML version online.

Random Samples: "Loading springs" (29 January, p. 507). The term "radioisotopes" should have been "environmental isotopes." Also, K. Shivanna is an isotope hydrologist.

Reports: "²³⁸U/²³⁵U variations in meteorites: Extant ²⁴⁷Cm and implications for Pb-Pb dating" by G. A. Brennecke *et al.* (22 January, p. 449). There was an error in the numerator of the expression on the left-hand side of Eq. 1. The correct expression is here. $\frac{^{207}\text{Pb}^*}{^{206}\text{Pb}^*}$

News Focus: "From medfly to moth: Raising a buzz of dissent" by I. Chen (8 January, p. 134). Light brown apple moth larvae have been observed feeding on only around 265 species, not more than 2000 plant species, as the story and photograph caption stated. The higher number is the agriculture agencies' estimate of all potential plant hosts for the pest, including relatives (such as cypress trees) in the same genera as those 265 species. Critics say that the larger figure is unsubstantiated.

TECHNICAL COMMENT ABSTRACTS

COMMENT ON "Movement Intention After Parietal Cortex Stimulation in Humans"

Hans-Otto Karnath, Svenja Borchers, Marc Himmelbach

Desmurget *et al.* (Reports, 8 May 2009, p. 811) applied direct electrical stimulation (DES) to the human cortex to study the origin of movement intention. Their interpretation assumed that DES causes cortical activation, whereas it is possible that it actually evokes deactivation. The lack of certain knowledge about the true effects of DES limits its use for validation of cognitive models.

Full text at www.sciencemag.org/cgi/content/full/327/5970/1200-c

RESPONSE TO COMMENT ON "Movement Intention After Parietal Cortex Stimulation in Humans"

Angela Sirigu, Carmine Mottolise, Michel Desmurget

Karnath *et al.* argue that the behavioral effects observed in our study after direct parietal and premotor electrical stimulation (DES) could reflect a decrease of local cortical activity. If so, intention and awareness would not reflect the activity of the stimulated area but the recruitment of remote regions. Although tenable, this view does not seem to be the most plausible.

Full text at www.sciencemag.org/cgi/content/full/327/5970/1200-d

Our solution is to count the CO₂ from all energy use but then to reward bioenergy to the extent it results from “additional” biomass—i.e., carbon that would not otherwise be stored in plants or soils. This approach does not treat liquid and solid biofuels as automatically equivalent to coal but credits them to the extent they truly offset energy emissions. This solution would not control land-based emissions spurred by economic factors or policies, as Pingoud *et al.* would wish, but it would properly count energy emissions and avoid creating inaccurate incentives to clear land and release carbon through the laws aimed at reducing global warming.

Letters to the Editor

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Our proposal does not imply using carbon fluxes instead of stock changes to measure carbon or otherwise change the accounting used in the U.N. Framework Convention on Climate Change (UNFCCC). Under that approach, emissions from land-use change are counted in the countries where they occur for international reporting purposes, not where timber or crops are consumed. By definition, the “carbon stock” approach can work only in a legal regime like the UNFCCC that counts changes in carbon stock—i.e., land-use emissions. The problem we identified is found in laws and treaties that do not legally “count” land-use emissions.

Our modest fix does not require “end-user responsibility” for land-use emissions, as suggested by Pingoud *et al.*, or any other direct or indirect regulation of those emissions. Instead, our approach is about accurately counting energy emissions and offsetting sinks. It treats bioenergy in the same way that the Kyoto Protocol and many other climate laws already treat agricultural and forestry activities. Although most of their land-use emissions are unregulated, land-use activities can only receive credits for off-

setting energy emissions when net effects are counted; thus, only “additional carbon” receives credits. The same approach should apply whether the offset involves sequestering carbon in forests or generating biomass for energy.

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