Carbon Accounting and Biomass Energy

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The Kyoto Protocol – Article 3.3

"The net changes in greenhouse gas emissions by sources and removals by sinks resulting from direct human-induced land-use change and forestry activities, limited to afforestation, reforestation and deforestation since 1990, measured as verifiable changes in stocks in each commitment period, shall be used to meet the commitments…"

Article 3.4 "…which, additional human-induced activities…shall be added to…"

It is often assumed that the regrowth of the crop following harvest of biomass will offset all of the carbon released from the harvesting and use of the biomass. This might be true if there was no loss of soil carbon and if the regrown biomass contained the same amount of carbon as the harvested biomass…In any case, there will be a time interval between when the biomass emissions are incurred and when CO_2 is taken up by growth. This interval may be a matter of months for annual crops, years for short-rotation woody crops, or decades if the biomass is from traditional harvesting of trees.

Kheshgi, Prince and Marland, Annu. Rev Energy Environment, 2000.

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

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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 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-

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Goodbye to carbon neutral: Getting biomass footprints right

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ABSTRACT

Most guidance for carbon footprinting, and most published carbon footprints or LCAs, presume that biomass heating fuels are carbon neutral. However, it is recognised increasingly that this is incorrect: biomass fuels are not always carbon neutral. Indeed, they can in some cases be far more carbon positive than fossil fuels. This flaw in carbon footprinting guidance and practice can be remedied. In carbon footprints (not just of biomass or heating fuels, but all carbon footprints), rather than applying sequestration credits and combustion debits, a 'carbon-stock change' line item could be applied instead. Not only would this make carbon footprints more accurate, it would make them consistent with UNFCCC reporting requirements and national reporting practice.

There is a strong precedent for this change. This same flaw has already been recognised and partly remedied in standards for and studies of liquid biofuels (e.g. biodiesel and bioethanol), which now account for land-use change, i.e. deforestation. But it is partially or completely missing from other studies and from standards for footprinting and LCA of solid fuels.

Carbon-stock changes can be estimated from currently available data. Accuracy of estimates will increase as Kyoto compliant countries report more land use, land use change and forestry (LULUCF) data.

1. Carbon footprints of biomass fuels: current guidance and practice

Prominent guidance for carbon footprinting (Table 1) presumes that biomass is inherently carbon neutral. Carbon dioxide emitted in biomass combustion is automatically excluded from carbon footprints.

Guidance from the World Business Council for Sustainable Development and the World Resources Institute (WBCSD, 2004; WRI, 2006; WRI, 2007) recognises that presuming carbon-neutrality is problematic, but it still excludes biomass carbon-combustion emissions from its footprint definitions.

Most published footprint or life-cycle assessment studies take the same approach; they automatically exclude carbon dioxide emitted in the combustion of biomass. This has been reported by Rabl et al. (2007), and it has been confirmed by the author. In an early 2008 survey of over 100 publications by 56 researchers about solid biomass fuels, 25 researchers were identified who had estimated footprints of wood fuel (in log, pellet or chip form). Of those 25 researchers, only Börjesson and Gustavsson (2000) did not presume wood to be carbon neutral.

Published studies presume carbon neutrality of biofuels in either of two approaches: *implicit* sequestration credit or *explicit* sequestration credit. Most studies apply the former approach, simply ignoring the CO_2 flux within a biofuel (Rabl et al., 2007), presuming that 'CO_2 in equals CO_2 out', so using a net flux of zero. Others, such as EcoInvent (2003), use the latter approach, offsetting biomass-combustion CO_2 emissions with a sequestration credit that is nearly equal to the combustion emission. Either way, the biomass combustion footprint is zero or close to it, i.e. carbon neutral.

Disaggregated carbon footprints, using both of these approaches to carbon neutrality, are shown below (Tables 2 and 3), using figures from EcoInvent (2003) for forested logs used as heating fuel. In both cases, for reference to a fossil fuel[1] they are compared to natural gas in residential heating, again using figures from EcoInvent.

2. Problems with current guidance and practice

Current guidance and practice are problematic for three reasons. It defies common sense, contravenes UNFCCC rules and ISO standards and ignores a large body of existing research.

2.1. It defies common sense

If a tree is harvested for fuel, this reduces carbon stocks. However, current approaches to carbon footprinting – by presuming carbon neutrality – do not recognise this.

This is problematic, because first, as Rabl et al. (2003) point out, this can lead to absurd conclusions: for example, if carbon neutrality is presumed, it makes no difference to a carbon footprint if a forest is standing or if it has been chopped down for fuel wood.[2] Second,

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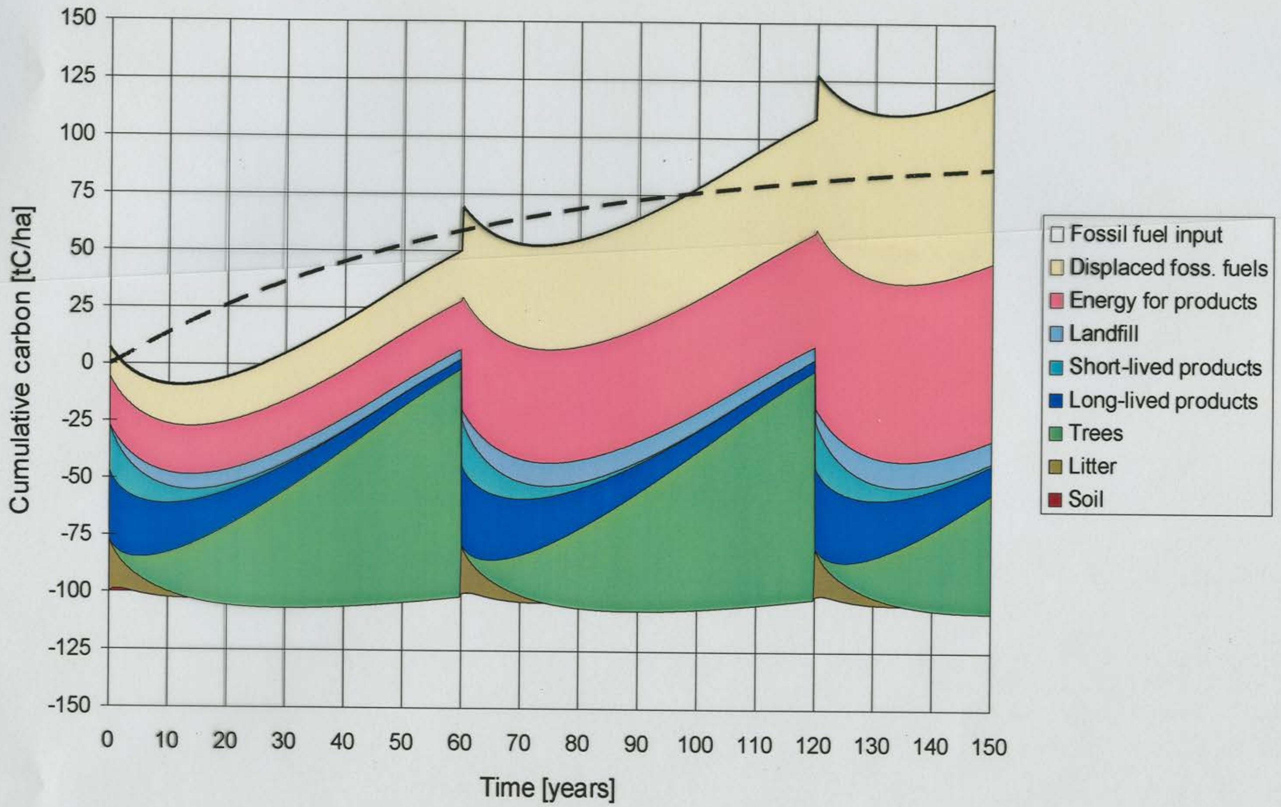
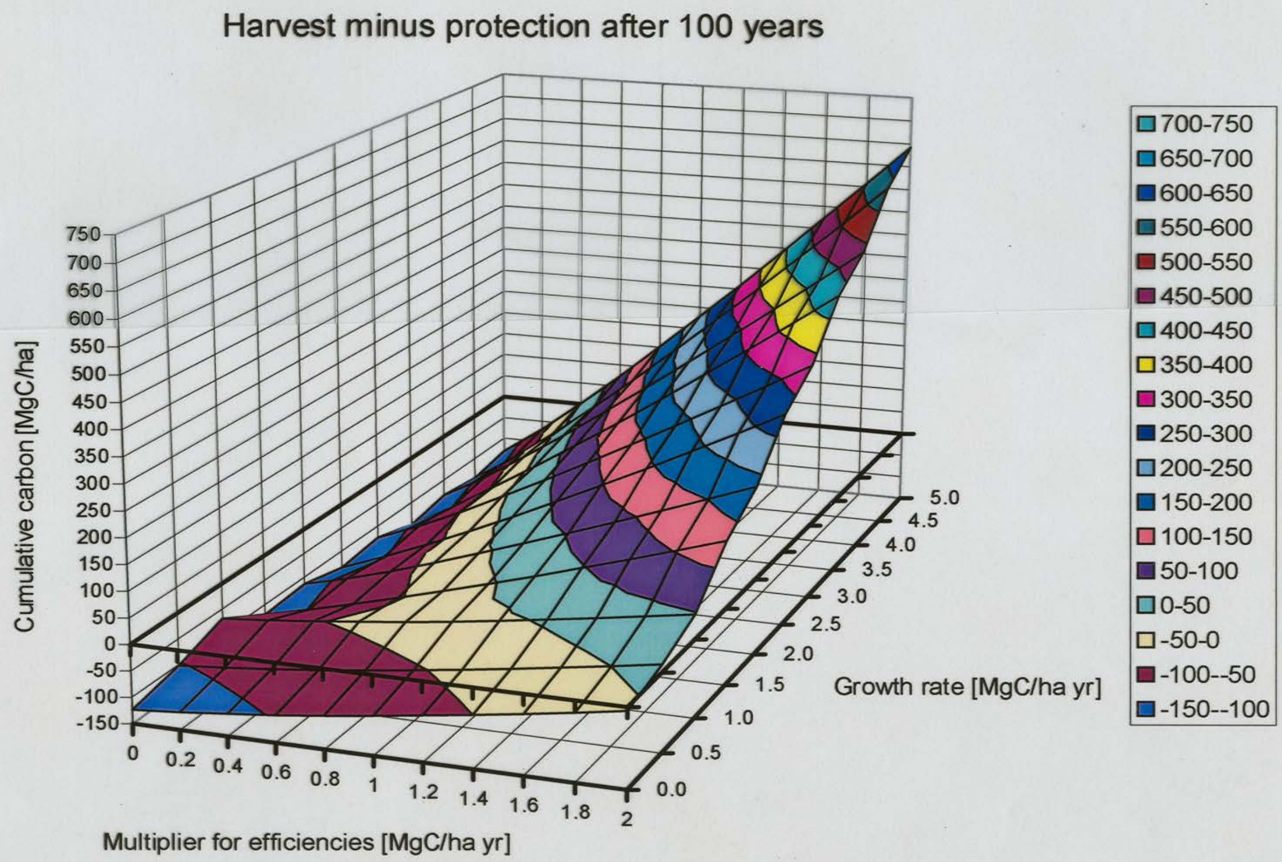
[1] Fossil fuels do not receive sequestration credits, either implicit or explicit, in current guidance and practice.

[2] As long as the land use has not been changed, i.e. the forest is allowed to regrow.



150
125
100
75
50
25
0
-25
-50
-75
-100
-125
-150
Cumulative carbon [tC/ha]
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
Time [years]
Fossil fuel input
Displaced foss. fuels
Energy for products
Landfill
Short-lived products
Long-lived products
Trees
Litter
Soil


Harvest minus protection after 100 years
Cumulative carbon [MgC/ha]
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
-50
-100
-150
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Multiplier for efficiencies [MgC/ha yr]
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Growth rate [MgC/ha yr]
700-750
650-700
600-650
550-600
500-550
450-500
400-450
350-400
300-350
250-300
200-250
150-200
100-150
50-100
0-50
-50-0
-100--50
-150--100

- “the most effective strategy for using forest land to minimize increases in atmospheric CO_2 will depend on the current status of the land, the productivity that can be expected, the efficiency with which the forest harvest is used to substitute for fossil fuels, and the time perspective of the analysis.”

G. Marland and S. Marland, 1992

SCOPE

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Bioenergy & Sustainability: bridging the gaps

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Climate Connections

BY GLOBAL JUSTICE ECOLOGY PROJECT | DECEMBER 2, 2013 · 10:41 AM

Important letter to the EPA by 41 scientists questioning biomass

November 26, 2013

Mr. Joe Goffman Senior Counsel, Office of Air and Radiation, U.S. Environmental Protection Agency1200 Pennsylvania Avenue, N.W. Mail Code: 6101A Washington, DC 20460

Dear Mr. Goffman:

We, the undersigned scientists, believe regulations governing how stationary sources account for biogenic carbon emissions must be based on sound science and ensure adequate protections for forests and the climate. We applaud the EPA for setting a high standard in making policy on this important issue by seeking expert scientific input from the Science Advisory Board (SAB). We now urge the agency to follow through on that process and embrace the central scientific principles underscored by the SAB as you finalize these accounting rules. Doing otherwise at this juncture will fail the test of rigorous, science- based policy making and could result in regulations that distort the marketplace towards greater use of unsustainable sources of biomass, with significant risks to our climate, forests and the valuable ecosystem services they provide and we rely on.

In 2011, EPA initiated a science-driven process to develop a methodology for properly quantifying biogenic carbon emissions from stationary sources under the Clean Air Act. As part of this process, the agency rightly solicited scientific input by submitting a draft "Accounting Framework for Biogenic CO_2 Emissions from Stationary Sources" to the SAB for review by an assembled Biogenic Carbon Emissions Panel. As now EPA finalizes its biogenic carbon accounting rules, it must follow through on that process and adopt the science panel's key recommendations: 1) moving beyond the flawed assumption that bioenergy is inherently carbon neutral; 2) rejecting the regional accounting method originally proposed in the draft Accounting Framework; and 3) ensuring a scientifically-sound methodology for determining the carbon emissions impact to the atmosphere from burning long-recovery biomass feedstocks—most notably, whole trees.

First, the carbon dioxide (CO_2) emitted by biomass-fired stationary sources has often been ignored in regulatory contexts, usually on the assumption that biomass regrowth would quickly reabsorb the CO_2 emitted by the facilities. As the EPA has itself determined, that assumption is misguided. The SAB issued a clear rejection of an a priori assumption of carbon neutrality as it applies to bioenergy. This includes repeated reference in the panel's report to the considerable heterogeneity in biomass feedstock types, sources, and bioenergy production methods and thus net biogenic carbon emissions impacts, and insistence on the need to define carbon outcomes based on "what the atm

Follow

The SAB's findings are both informed by and echo recent advances in science and accounting for CO_2 emissions

February 9, 2015

Sent via First Class Mail and E-mail

Gina McCarthy
Administrator, US Environmental Protection Agency
1200 Pennsylvania Avenue, NW
Washington, DC 20460

Dear Administrator McCarthy,

As the Environmental Protection Agency strives to limit greenhouse gas (GHG) emissions, it is critical for the carbon accounting rules to be correct. Rules that improperly credit activities for reducing emissions when they actually increase them create powerful perverse incentives. We write to raise strong concerns about the November 19th, 2014 memo from Acting Assistant Administrator for the Office of Air and Radiation Janet McCabe (McCabe memo), which would credit use of woody biomass for energy with reducing emissions, when it actually increases them. Because EPA can expect its accounting rule to be applied globally, it is likely to lead to the additional harvest or conversion to agriculture of large areas of the world's forests.

Burning biomass instead of fossil fuels does not reduce the carbon emitted by power plants. In fact, as EPA itself acknowledges, burning biomass degrades facility efficiency and increases day-to-day emissions over emissions when fossil fuels are burned alone. Growth of additional biomass beyond business-as-usual or recovered from waste can help to offset those emissions, but peer-reviewed science indicates this process takes several years to several decades. This conclusion was the basis of a report issued by EPA's Science Advisory Board (SAB) in 2012, which criticized EPA's 2010 Draft Framework for Biogenic CO_2 Accounting (the Framework) because it would have claimed carbon savings for harvests of wood that diminished the growth of forest stocks in the US and much of the world. By itself, diverting biomass from existing uses in food, paper and timber cannot reduce GHG emissions (except at the cost of food, paper and timber). At the same time, burning biomass, such as trees, that would otherwise continue to absorb and store carbon comes at the expense of reduced carbon storage.

The McCabe memo proposes to treat as "carbon-free" all woody or agricultural feedstocks so long as they are derived "from sustainable forest or agricultural practices." At maximum, "sustainability" implies that forest harvesting does not exceed growth, which is a necessary, but not sufficient condition for carbon neutrality, as found by the SAB. At minimum, sustainability practices can help reduce soil erosion and other environmental impacts of forestry or agricultural production. But such practices have little-to-no bearing on the carbon implications of biomass use. Including such exemptions for broad categories of biomass fuels in a final rule would not only encourage large-scale harvesting of wood to replace coal and other fossil fuels but also place no limits on the diversion of the world's agricultural land to energy use, requiring conversions of forests and grasslands to meet food needs.

The potential implications of these exemptions are large because even small quantities of bioenergy require large quantities of wood. For example, the US Energy Information Agency estimates that treating woody biomass as carbon free with modest carbon restrictions would result in an additional 4% of present US electricity from wood by 2035. That would require an increase of wood equivalent to 70% of the US timber harvest, which for perspective would be far greater than if we were to abolish all paper and cardboard recycling in the US. The International Energy Agency estimates that treating bioenergy as carbon free globally, coupled the Y chromosome in a single fly strain (ensuring an otherwise common genetic background). They then screened a nearly genome-wide set of genes and looked for differences in gene expression in response to the substituted Y chromosome. Because of high statistical error rates when thousands of genes are scored simultaneously, it is difficult to estimate the exact number of affected genes, but the estimates are surprisingly high, ranging from around 100 up to about 1000 (*D. melanogaster* is estimated to have ~13,000 genes).

Lemos *et al.* also detected several coherent patterns among the Y-regulated genes. The Y chromosome influences the expression of genes that are more strongly expressed in males. Genes regulated by the Y chromosome are also more strongly influenced by environmental stress (heat shock), and many are associated with sperm development. Genes that influence the mitochondria are also overrepresented in the pool of genes regulated by the Y chromosome. In addition, affected genes are more evolutionarily dynamic in terms of polymorphisms for gene expression within the species, and more diverged from a closely related congener (*Drosophila simulans*).

It is now well established that a large proportion of the genome is expressed at different levels in males and females in many organisms (*3*), and the patterns found by Lemos *et al.* fit well with what would be expected for Y-linked regulatory genes. Whereas the Y chromosome spends every generation in males, the X chromosome and autosomes alternate between the sexes across generations. A mutation favoring males that is located on the X chromosome or autosomes can therefore only accumulate when selection in females is concordant, absent, or not too strongly discordant (*4*). However, this restriction is removed for Y-linked mutations because there can be no counterselection in females. Even when a mutation results in a phenotype that is exclusive to males, it will have an advantage if Y-linked because, unlike the X chromosome and autosomes, the Y chromosome is expressed (and hence selected) in males every generation (see the figure). The Y chromosome therefore represents a favorable platform for mutations that improve male gene expression.

As many Y-linked genes have degenerated, should we expect the Y chromosome to inevitably be lost altogether? Not necessarily. As the number of functional genes on the Y chromosome declines, the efficacy of natural selection increases on the remaining genes. Decay of the Y chromosome therefore slows down over time and can ultimately stop altogether. The fitness advantage of a highly degenerated Y chromosome is illustrated by *Drosophila afinis* in which the Y chromosome is not required for fertility. In this species, males with no Y chromosome (XO) sire 25 to 38% fewer offspring when competing with XY males (*5*). The study by Lemos *et al.* provides a mechanism for the large fitness advantage of XY males, even when vital fertility factors are absent on the Y chromosome: The Y chromosome has evolved to become a major regulator of gene expression in males.

If the Y chromosome is such a strong regulator of genes in males, then why have past studies found so few Y-linked traits in humans and flies? The Y chromosome may have evolved to modulate rather than turn on or turn off gene expression. Its effects may therefore be continuous rather than discrete and thus more difficult to detect than the more distinct phenotypes associated with loss-of-function mutations. As the power of quantitative trait locus analysis increases, the phenotypic manifestations of the genes regulated by the Y chromosome discovered by Lemos *et al.* may become more apparent.

The next stage in understanding the newly discovered regulatory powers of the *Drosophila* Y chromosome will be to characterize the genetic mechanism(s) underlying their influence. It will also be interesting to see, in flies and other species, whether genomic components that are only transmitted through the matriline (mitochondria and cytoplasmic endosymbionts) have evolved to strongly influence gene expression in females. The study by Lemos *et al.* further suggests that it will be important to test whether the human Y chromosome also has evolved to become a regulatory giant.

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ENVIRONMENTAL SCIENCE

How Green Are Biofuels?

Jörn P. W. Scharlemann and William F. Laurance

Many biofuels are associated with lower greenhouse-gas emissions but have greater aggregate environmental costs than gasoline.

Global warming and escalating petroleum costs are creating an urgent need to find ecologically friendly fuels. Biofuels—such as ethanol from corn (maize) and sugarcane—have been increasingly heralded as a possible savior (*1*, *2*). But others have argued that biofuels will consume vast swaths of farmland and native habitats, drive up food prices, and result in little reduction in greenhouse-gas emissions (*3*–*5*). An innovative study by Zah *et al.* (*6*), commissioned by the Swiss government, could help to resolve this debate by providing a detailed assessment of the environmental costs and benefits of different transport biofuels.

To date, most efforts to evaluate different biofuel crops have focused on their merits for reducing greenhouse-gas emissions or fossil fuel use. Some studies suggest that corn-derived ethanol in the United States (*7*) and Europe (*8*) consumes more energy than it produces; others suggest a modest net benefit (*2*). Relative to petroleum, nearly all biofuels diminish greenhouse-gas emissions, although crops such as switchgrass easily outperform corn and soy (*9*). Such comparisons are sensitive to assumptions about local growing conditions and crop by-products, but even more important, their focus on greenhouse gases and energy use is too narrow.

The arguments that support one biofuel crop over another can easily change when one considers their full environmental effects. A key factor affecting biofuel efficacy is whether native ecosystems are destroyed to produce the biofuels. For example, regardless of how effective sugarcane is for producing ethanol, its benefits quickly diminish if carbon-rich tropical forests are being razed to make the sugarcane fields, thereby causing vast greenhouse-gas emission increases (*4*). Such comparisons become even more lopsided if the full environmental benefits of tropical forests—for example, for biodiversity

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Donald Kennedy is the Editor-in-Chief of *Science*.

The Biofuels Conundrum

THIS STORY BEGINS WITH GOOD NEWS, FOLLOWED BY A PROBLEM. MANY GOVERNMENTS around the world, and even some states within the United States, are finding ways to reduce greenhouse gas emissions. A major step is the almost completed buyout of the giant Texas electric utility TXU by an improbable concatenation of big investors, environmental organizations, and bankers. This promising deal would kill 8 of 11 projected coal-fired power plants and require the others to meet environmental performance standards. That's like a 15th seed making the final four or Watford winning the FA Cup. Meanwhile, there is hopeful talk in Silicon Valley about "clean tech," and "biofuels" is the new entrepreneurial mantra there. But the problem is that limiting carbon emissions with biofuels like ethanol is complex terrain, and most proposals turn out to carry external costs.

Let's start with the explosive growth of a corn ethanol industry in the tallgrass prairies of America's West. This boon for those rural economies succeeds a long history of dual-purpose farm legislation, in which production objectives are mixed with rural welfare goals. Refineries now number well over 100 with more being added rapidly, as farmers expand cultivation into lands formerly set aside for conservation and drop soybeans to make room for corn. Even if corn could yield 30% of the equivalent energy of gasoline (the goal set by the Secretary of Energy), that would create a whole array of collateral distortions. One would be its environmental impact in the United States. Another would be distortion of the price structure of an important grain commodity that is traded in world markets and used in livestock production. Will that make maize or meat more affordable to poor countries that must import it, or to the poor people who need to buy it? Not likely.

Ethanol derived from sugar cane is better: Growing the plant is energetically less costly, and extraction and fermentation are more efficient. That's what must have interested President Bush during his "Chavez shadow tour" of South America in March. Of course, U.S. companies would love to import this valuable product, which now accounts for a quarter of the ground-transportation fuel in Brazil. Despite such hopes, some senators supporting alcohol-from-corn have helped lay a heavy U.S. protective tariff on Brazilian alcohol derived from sugar. If we got rid of that, it would reduce total carbon emissions, though only if Brazil could expand its production substantially. Is there some deal in progress? Alas, nothing's up.

Sugar alcohol is better than corn alcohol, but palm oil is even better in your tank (though not in your martini). Its relatively high energy efficiency per unit volume makes it a good biodiesel fuel. Trucks can run entirely on palm oil, although it is usually mixed with conventional fossil fuels. A large-scale effort is under way to convert lands in Indonesia to palm oil plantation agriculture, with plans to double current production in a few years. But again, the effort has a downside. Not only will the needed rainforest destruction (by burning) partly cancel any energy advantage supplied by the palm oil, but the conversion will also threaten orangutans and other endangered species.

The best course is to abandon this cluttered arena and invest seriously in a direct approach. As Chris Somerville pointed out in this space,* the conversion of cellulosic biomass (corn stover, wood chips) has a far higher potential for fuel production than any of the above biofuels. The challenge is biochemical: Plant lignins occlude the cellulose cell walls; they must be removed, and then the enzymology of cellulose conversion needs to be worked out. The technology is complex.† No commercial reactor has yet been built, though six are funded. Some hope has been raised by new commitments, like the $500 million joint project between British Petroleum and the Universities of California and Illinois. Nevertheless, as Somerville notes, the sobering reality is that what the U.S. government spends on all of plant physiology is only one-hundredth of the research budget of the National Institutes of Health. That's far too little for a venture this important.

–Donald Kennedy

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*C. Somerville, *Science* **312**, 1277 (2006). †R. F. Service, *Science* **315**, 1488 (2007).

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EDITORIAL

Large-scale biomass for energy, with considerations and cautions: an editorial comment

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A decade ago, Vitousek et al. (1997) wrote of "the human domination of Earth's Ecosystems" (see also Vitousek et al. 1986). They noted that "most aspects of the structure and functioning of Earth's ecosystems cannot be understood without accounting for the strong, often dominant influence of humanity", and they estimated that one-third to one-half of the Earth's land surface had already been transformed by human action. Most recently Haberl et al. (2007) have estimated that humans are "appropriating" 24% of potential, global, terrestrial net primary productivity (NPP). That is, of the plant cover that would exist on Earth in the absence of human intervention, humans, through harvest or productivity changes, have affected NPP by 24%. Cassman et al. (2005) estimated that 27% of the global land area (not counting Greenland and Antarctica) is now covered with cultivated systems. Of course, humans impact the terrestrial biosphere even more broadly through indirect impacts like nitrogen deposition (see, for example, Magnani et al. 2007).

Humans have altered the land surface to provide food, fiber, a place to live, a place to work, and a place to play; and for the extraction of resources from below the surface, and for some modest amounts of energy. With the prospect that our principal current source of energy (fossil fuel) is leading to an unacceptable impact on the Earth's climate system, we now ask whether it is possible for the terrestrial biosphere to supply carbon-based fuels for both our bodies and our machines? Read (2008, this issue) describes a vision in which management of the biosphere would provide enough fuel to avoid the continuing and growing use of fossil fuels. But it is not now clear if his vision is a dream or a nightmare.

The dream, of course, is the possibility of fueling industrial society without the risk of what Read characterizes as "abrupt climate change"—that is without encountering "a threshold or tipping point for some kind of non-linear, possibly catastrophic climate event". The nightmare is the possibility that the ecological and social consequences of enlarging

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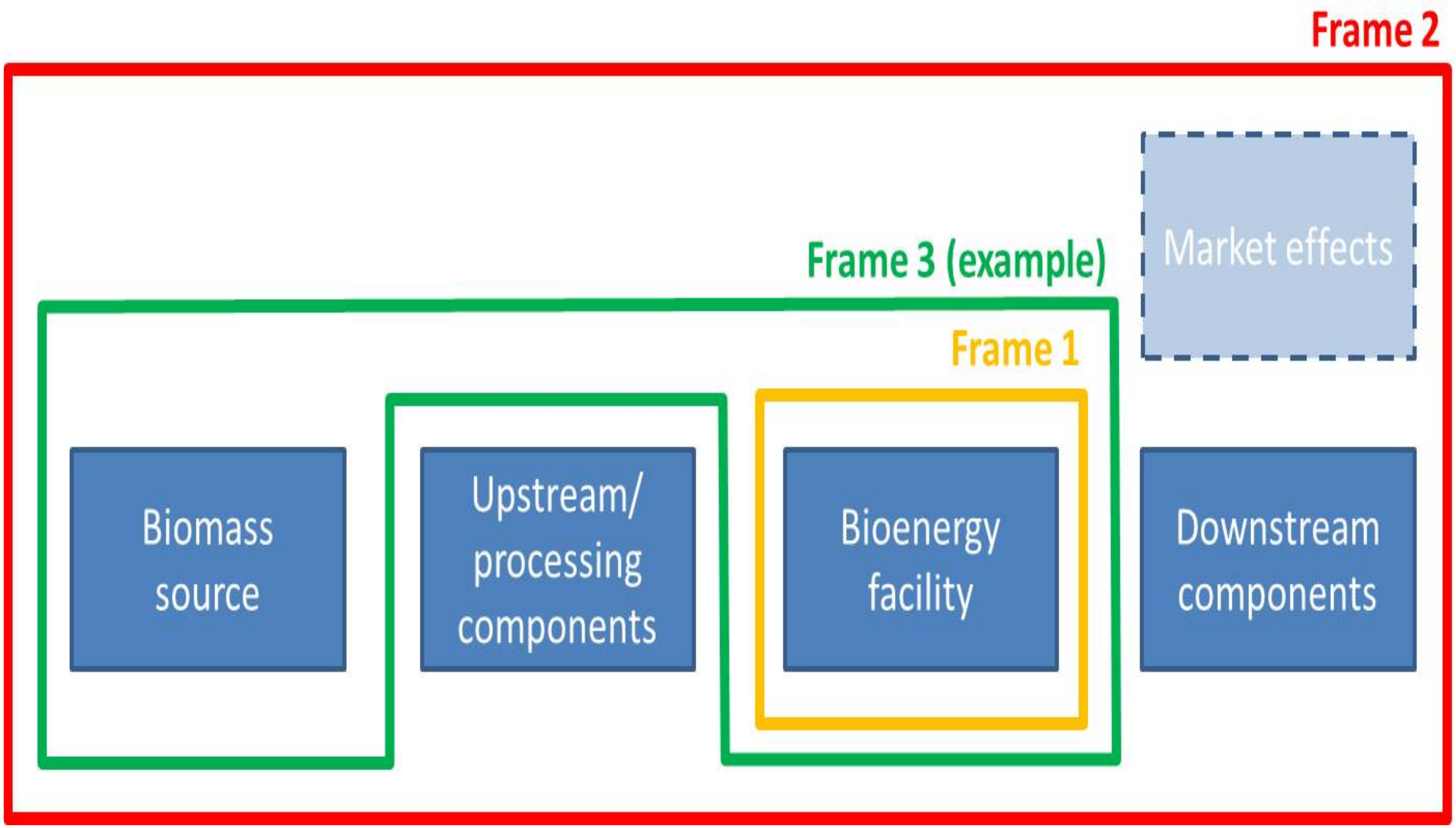
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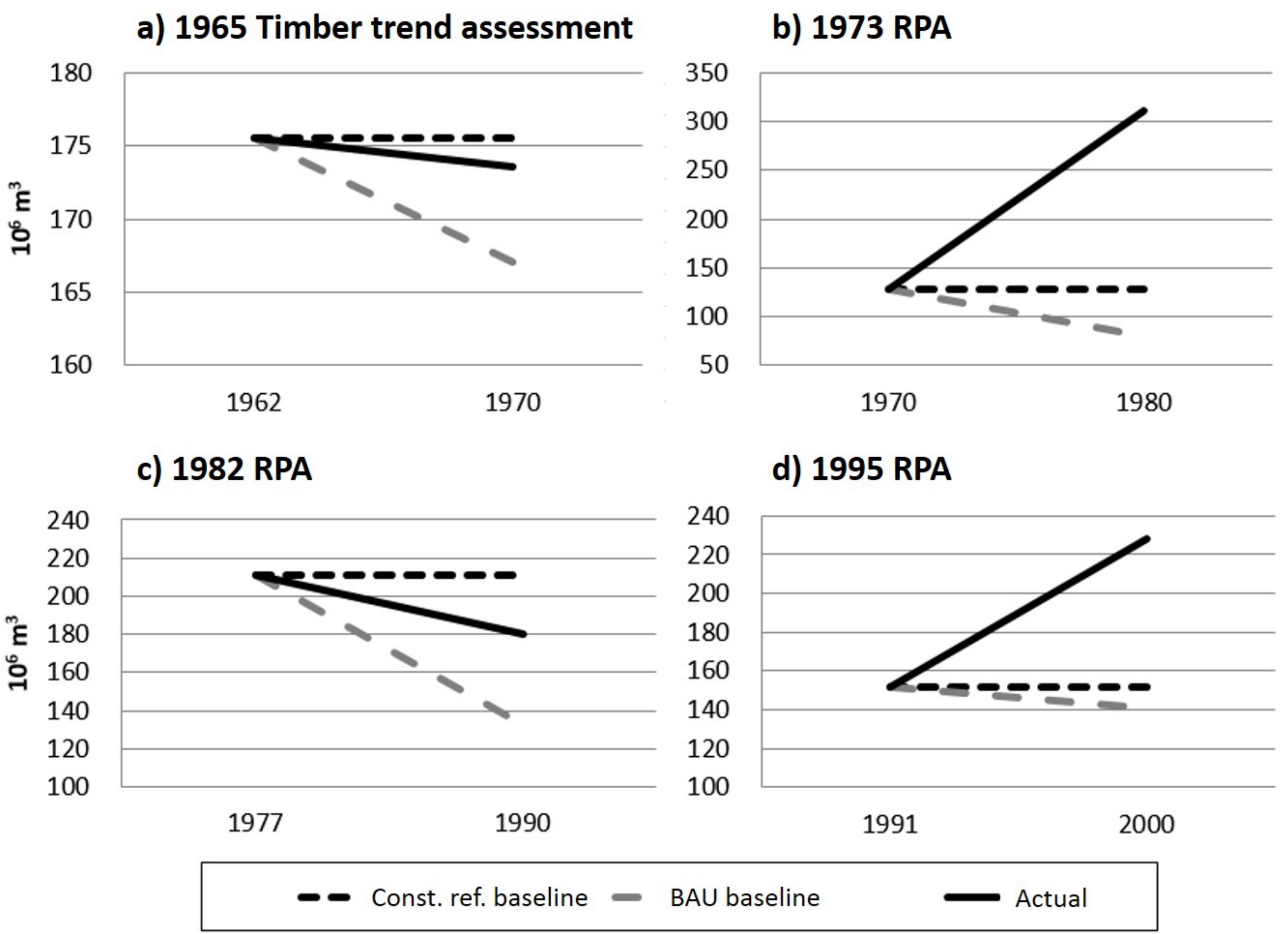
Frame 3 (example)
Frame 1
Biomass source
Upstream/ processing components
Bioenergy facility
Downstream components



A constant reference baseline approach assuming constant levels of annual growth and removals would have been closer to observed actual data for every assessment since

It has been argued (by some) that a project that stores carbon temporarily has no value.

But how about a portfolio of these projects. Would there be no value to the program as a whole, which is not temporary?