Biomass sinks and biomass energy: key issues in using biomass to protect the global climate

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1. Introduction

There are two features of biomass that link it inextricably to the challenge of keeping carbon out of the atmosphere and preventing climate change. The first is that biomass, in the form of plants and the soils in which they grow, stores a huge amount of carbon. The second is that biomass can substitute for fossil fuel. It is not clear how these two features will be exploited in the global effort to address climate change, but it is clear that a tremendous amount of controversy surrounds biomass. In fact, at the Hague in November 2000, a primary reason for the breakdown of negotiations at the meeting of signatories to the Framework Convention on Climate Change was the argument over the role of biomass. This article aims to explain the main contentious issues surrounding the potential role of biomass in addressing the climate challenge.

2. Two roles for biomass: sinks and energy

Biomass serves as a so-called “carbon sink”, absorbing carbon from the atmosphere and storing it in the form of living plants, dead plant matter, and decomposed plant matter in soils. Vast amounts of carbon are continually being exchanged between this biospheric sink and the atmosphere. Through photosynthesis, plants absorb carbon from the atmosphere to make plant tissues (carbohydrates), and through respiration, plants release carbon as they metabolize stored carbohydrates. Dead plant matter also releases carbon dioxide to the atmosphere, as soil bacteria decompose it. Approximately 120 billion tonnes (i.e., gigatonnes) of carbon (GtC) is absorbed annually through photosynthesis, and a comparable amount is released through respiration and decomposition. This natural flux of carbon between the biosphere and the atmosphere is finely balanced, and has been so for millennia.

In the past century, however, we have perturbed this equilibrium enough to disrupt the climate system [IPCC, 2001]. Human activities, such as the clearing of land for agriculture and logging, currently release an additional 2 GtC to the atmosphere each year. In addition, roughly 6 GtC is released to the atmosphere annually from burning fossil fuels. Since the dawn of the industrial age, approximately 175 GtC of excess carbon has accumulated in the atmosphere due to human activity – enough to raise the concentration of carbon dioxide from 285 to 370 parts per million (ppm). (See Table 1.)

The amount of carbon held in the biosphere is vast – more than three times as much as is in the atmosphere. A relatively small change in the amount of carbon in the biosphere would cause a significant change in the greenhouse balance of the atmosphere. Indeed, the release of merely 7 % of the biospheric stock of carbon is enough to double the 175 billion tonnes (GtC) that human activities have so far added to the atmosphere. And releasing merely 0.3 % of the biospheric stock would double the 8 GtC emitted annually due to human activity. The biosphere’s critical place in the global carbon cycle has inspired many to consider the possibility of enlisting biospheric sinks in our efforts to avert climate change. Possible strategies include reducing deforestation, restoring degraded lands, improving land management practices, and shifting to land uses that increase the amount of carbon stored on the land.

There is a second set of strategies for enlisting the biosphere to help avert climate change. These are based on the fact that the biosphere contains not only a vast amount of carbon, but also a vast amount of energy. Biomass energy can be used to displace fossil energy. This will result in lower carbon emissions, *providing* that biomass is grown and harvested through a “carbon-neutral” cycle, wherein the carbon released when the biomass is consumed is offset by an equal amount of carbon absorbed when each successive crop of biomass is produced. The use of bioenergy might not be precisely carbon-neutral in totality, insofar as fossil fuels are used to grow, manage, fertilize, harvest, and process the biomass fuels. But, unlike fossil fuel cycles, well-designed biomass fuel cycles can be close to carbon-neutral. Bioenergy is likely to provide a crucial non-fossil energy source for a post-fossil fuel world.

3. Biomass sinks

From the standpoint of the greenhouse effect, both options – biomass sinks and biomass energy – are equivalent. It doesn’t matter whether you keep a tonne of carbon dioxide out of the atmosphere by preventing the clearing of some tropical forest in Brazil, or by substituting some coal with some biomass in a United States power plant. The two tonnes would have equally potent greenhouse impacts, and the atmosphere is mixed quickly enough that the location of the source is irrelevant. What, then, are the chief differences between the two biomass-based routes to reducing carbon emissions? To start, it is useful

Table 1. Terrestrial biomass contains huge amounts of carbon, hence considerable potential for climate change mitigation

Carbon stocks and fluxes	
Fluxes	
Annual natural exchange between biosphere and atmosphere (balance between photosynthesis and respiration/decomposition)	~120 GtC/yr
Annual excess releases from biosphere (due to human land-use activities)	+ 2 GtC/yr
Annual releases from fossil fuels (due to human energy activities)	+ 6 GtC/yr
Annual gross emissions to atmosphere due to human activity	**+ 8 GtC/yr**
Stocks	
Biospheric carbon	2500 GtC
of which : soils	2000 GtC
vegetation	500 GtC
Preindustrial atmosphere (285 ppm CO_2)	600 GtC
Today's atmosphere (370 ppm CO_2)	775 GtC
Net addition to atmosphere to date due to human activity	**+ 175 GtC**

Sources: Figures taken from IPCC [2000] and IPCC [2001].

to clarify the main features of sink-based approaches to mitigation, including the key contentious issues that arise.

3.1. Biomass sinks – reasons for enthusiasm

There are several compelling reasons for the enthusiastic pursuit of biospheric sinks. First, as Table 1 shows, human impacts on the biosphere result in approximately 2 GtC/yr of carbon emissions – roughly 25 % of total human emissions of carbon. In the long run, the climate cannot be stabilized unless *total* global emissions (fossil emissions plus land-use emissions) fall below this level, so, even if emissions from fossil fuels were completely halted, emissions from biospheric stocks must ultimately be reduced as well and, ideally, reversed.

Broadly, there are four means through which this can be done.

1. We can reduce the rate at which we destroy forests and other large reservoirs of carbon.
2. We can restore degraded ecosystems that have lost plant matter and soil carbon.
3. We can adopt new land-management practices that enable land to hold more carbon.
4. We can shift to entirely new land uses that store more carbon than current uses.

Table 2 illustrates the rough magnitude of emission benefits to be gained from a worldwide program to prevent deforestation (Group 1), restore land (Group 2), improve land management (Group 3), and change land uses (Group 4) [IPCC, 2000]. This very coarse estimate suggests a benefit of 1.9 GtC/yr by the year 2010 would be achievable if deforestation rates were halved relative to today's levels and further efforts were deployed across a considerable portion of other land categories. For reference, the Kyoto Protocol committed the industrialized countries to a collective emission ceiling that is approximately 0.5 GtC/yr below their projected level of emissions in the year 2010. Industrialized countries could in theory meet their commitments relying solely on a fraction of the sink-based activities listed in the table, with no need to resort to reducing fossil fuel consumption. Admittedly, this would entail an ambitious policy agenda with a level of success that dramatically exceeds efforts to date, yet it illustrates the magnitude of the opportunities available through sink-based mitigation activities.

It is difficult to estimate the cost of such measures, but many advocates of sink-based activities have claimed they will be inexpensive. In its efforts to address the climate problem, the global community has invested considerable effort in searching for the cheapest options for keeping CO_2 out of the atmosphere, often expressing the total cost in $/t of carbon. Based on an inventory of sink-based projects implemented to date, the cost of carbon reductions is typically in the range $ 1-15/t carbon [IPCC, 2000]. This is highly attractive to investors interested in carbon reductions. The above inventory of sink-based projects represents $ 160 million invested – *before* the Kyoto Protocol has entered into force. The World Bank has projected that the annual commerce in sink-based projects could reach $ 150 *billion* per year in 2020 [Lohmann, 1999].

The emission of carbon from biospheric sinks is usually a sign of deeper problems, so steps to preserve or enhance those sinks can yield tremendous ancillary benefits. Indeed, carbon is kept out of the atmosphere, but arguably the *primary* gain would derive from stopping deforestation, restoring wastelands, preventing soil erosion, preserving wetlands, protecting watersheds, and making agriculture more sustainable. One might argue that climate change is a less immediate problem than declining biodiversity, deteriorating freshwater resources, or agricultural pollution. Directing climate change efforts toward sinks could provide a financial incentive to resolve crises for which resources are now sorely lacking.

Sink-based options might be the only emission mitigation activities that direct resources toward the world's rural poor. Activities aimed at reducing fossil fuel emissions will flow toward those who use (generally large quantities of) fossil fuels. The estimated two billion people who have neither electricity nor refined cooking fuels will remain irrlevant to the billions of dollars invested in such activities. In contrast, resources aimed at preserving biospheric carbon might naturally flow toward the

Table 2. Illustrative potential for reducing emissions using biospheric reservoirs

	Total global area (Mha)	Percentage targeted in 2010	Annual change in carbon stock (tC/ha/yr)	Estimated change in carbon in 2010 (MtC/yr)
1. Halting deforestation				
Temperate forests current annual rate:	2	50%	60	60
Tropical forests current annual rate:	14	50%	120	840
2. Restoring degraded ecosystems				
Wetland restoration	230	5%	0.4	4
Restoring severely degraded land	280	5%	0.3	3
3. Improving land management				
Forest management	4,050	10%	0.4	170
Cropland management	1,300	30%	0.3	125
Grazing land management	3,400	10%	0.7	240
Agroforestry	400	20%	0.3	26
Rice paddies	150	50%	0.1	7
Urban land management	100	5%	0.3	2
4. Changing land uses				
Agroforestry on unproductive lands	630	20%	3.1	390
Cropland conversion from grassland	1,500	3%	0.8	38
Emission reduction potential				1,900

Source: Adapted from IPCC [2000]. Section 1 adapted from Table 3, Sections 2-4 adapted from Table 4.

rural poor. Subsistence farmers might eagerly collaborate in agroforestry programs, indigenous communities might welcome efforts that help them protect their native forests, and landless poor could be the prime beneficiaries of the restoration of the degraded lands on which their livelihoods rely.

3.2. Biomass sinks – reasons for caution

For the above reasons, the enthusiasm for sink-based projects is great, among investors as well as some environment and development NGOs. However, serious problems also arise, which have led to a strong resistance to their unrestricted deployment within the international climate regime.

First, although sink-related emissions are important, fossil fuel-related emissions are by far inflicting more harm on the climate. They account for three-quarters of global emissions and are increasing more rapidly. To resolve the climate problem, it is indisputably necessary for fossil fuel emissions to be cut radically. The longer this is postponed, the longer the delay in developing and deploying low-carbon technologies, and the greater the investments sunk in fossil fuel-intensive capital and infrastructure. Long-lived capital, such as vehicles, buildings, and factories, is a long-term commitment to emit, which cannot be broken without considerable cost. Seemingly inexpensive sink-based options might prove to be a false economy in the longer term.

Second, crediting sink-based mitigation is problematic. The science of biospheric carbon is extremely complex, introducing considerable uncertainty into quantifying the carbon benefits of any given activity. Measuring the carbon contained on a parcel of land is a fairly imprecise exercise. The proportional change in carbon induced by some sink-based activities (especially those related to soil carbon) can be very small, and the natural variability – both spatial and temporal – can be much greater. Accurate measurements can therefore be difficult and costly. It might therefore be prudent to postpone the formal crediting of sink-based activities until the science and monitoring technology is more advanced [WBGU, 1998].

Third, the benefits of sink-based activities are difficult to credit not only because of technical uncertainties, but because of social uncertainties as well. A particular parcel of forest can certainly be protected from deforestation, but unless the underlying cause is addressed, it is likely that the offending logging or land-clearing will simply “leak” to a nearby parcel of forest outside of the formal boundaries of the project. Sink-based activities that aim to protect ecosystems, therefore, cannot be effective unless they are focused primarily on the demand – rather than supply – side of the equation. Arguably, projects aimed at recycling wood products and reducing (land-intensive)

Table 3. Approximate full fuel cycle carbon dioxide emissions from sample biomass and fossil technologies

Fuel and technology	Generation efficiency	Grams of CO_2 per kWh
Small diesel generator	20 %	1320
Coal steam cycle power plant	33 %	1000
Natural gas combined cycle power plant	45 %	410
Biogas digester with diesel generator (with 15% diesel pilot fuel)	18 %	220
Biomass steam cycle power plant	22 %	100
Biomass gasifier/gas turbine power plant	35 %	60

Source: adapted from Kartha and Larson [2000]

meat consumption would more effectively reduce deforestation than projects aimed at fencing and guarding plots of land.

Fourth, the net result of a sink-based project is the enhancement of a biospheric stock of carbon – either by augmenting an existing stock or preventing its release. This is an impermanent result that can be undone at any time, through human activities or natural events. A forest, though it may be protected for some indefinite meantime, remains a potential target for logging or land-clearing and remains vulnerable to being consumed by fire, ravaged by pests, or devastated by storms. Most dangerously, a warming climate could itself degrade forests and other ecosystems, releasing carbon that further accelerates warming in a positive feedback of unpredictable magnitude [IPCC, 2000]. This reflects the fact that a vast flow of carbon rapidly cycles between the biospheric and atmospheric reservoirs via processes over which humankind has little control. In contrast, fossil carbon rests in a secure underground reservoir that is not vulnerable to unintentional releases to the atmosphere. This distinction is critical. It underlies the potential hazard in rationalizing the continued release of fossil carbon by "offsetting" it with carbon sequestered in a much more labile biospheric reservoir.

Finally, sink-based activities hold out the promise of channeling resources towards activities that deliver a host of environmental and social benefits. This is, perhaps, the most compelling reason for undertaking such activities. However, these benefits do not automatically materialize as carbon is stored on the land. It must appear as the result of well-designed activities that explicitly allocate resources toward environmentally and socially sustainable results, with carbon storage as a component but not the driving element in the effort. If an international climate agreement such as the Kyoto Protocol confers an economic value on carbon, then investors' sink-based activities will respond to that incentive with projects that maximize the storage of carbon. It is not difficult to imagine sink-based activities that very effectively sequester carbon, *without* delivering environmental or social benefits, and perhaps delivering detrimental impacts. For instance, some intensive monoculture plantations have replaced native grasslands that were more biodiverse; and some forests have been "protected" by displacing native communities; and some degraded common lands have been restored by excluding communities whose livelihoods had relied on that land [Lohmann, 1999; Ford Foundation, 1998].

4. Biomass energy

Bioenergy-based options for reducing carbon emissions address most, but not all, of these concerns. Each of the five concerns cited above is discussed here. First, bioenergy reduces fossil carbon emissions, and offers a set of technological options that are likely to prove critical to the long-term transition away from a fossil economy. (See, for example, the other papers in this issue and in *Energy for Sustainable Development* Vol 4 No 3, Special Issue on Modernized Biomass Energy.) It cannot be assumed that the timely development and deployment of the needed technologies will occur spontaneously. The over-reliance on biomass-based sinks to satisfy obligations under the Kyoto Protocol would dilute the incentive to develop such alternative technologies.

Table 3 gives an approximate comparison of the carbon dioxide emissions from selected fossil fuel and biomass electricity generation technologies. The emissions from each fuel/technology combination depend on the efficiency of the generation technology and the carbon content of the fuel. In the case of biomass, it is assumed that the biomass feedstock is grown sustainably, leading to no long-term reduction in carbon on the land, only the cyclical variations as the land passes through periodic stages of growth and harvest. (For example, it is assumed that biomass fuel is not obtained by clearing virgin land.) It is also assumed that the production, harvesting and delivery of biomass consume fossil fuels that amount to approximately 1/12 of the energy of the delivered biomass [Turhollow and Perlack, 1991]. The carbon benefit of a given bioenergy technology will depend on the fossil technology it displaces. For example, approximately 85% reduction in carbon emissions would result from displacing diesel oil with biogas in a diesel generator. A comparable benefit would result from displacing natural gas with gasified biomass in a gas turbine. In the long term, low-carbon technological options such as these will need to provide the basis for the global energy system.

Second, compared with sink-based activities, mitigation projects based on bioenergy are less subject to measurement uncertainty. These problems do exist, but they are less severe. One can straightforwardly measure the energy produced at a bioenergy facility. The greater challenge is to determine what fossil fuel-based energy has been displaced. This so-called "baseline" is not amenable to direct measurement, but reflects a counterfactual situation that must be conjectured on the basis of projections and observations of the surrounding energy sector context. This is likely to be a vexing exercise for both bioenergy projects and sink-based projects. While quantifying the benefits of *individual* bioenergy projects will be difficult, there is no doubt that dramatic carbon benefits would result from a transition to an energy strategy that relies more on bioenergy and less on fossil energy.

Third, the "leakage" of emissions outside of the bioenergy project boundary is largely irrelevant. A bioenergy project satisfies a specific demand for energy services with biomass fuels instead of fossil fuels. This avoids carbon emissions from fossil fuels that would have otherwise occurred, and fundamentally differs from simply shifting demand to another location – which provides no carbon benefits.

Leakage might occur, however, if the decreased demand for a fossil fuel triggers a decrease in its market price, causing demand to increase elsewhere. A careful calculation of carbon benefits would attempt to account for this effect. Under conditions of scarcity (such as a power sector with chronic under-capacity) a bioenergy facility might not be displacing any fossil facilities – existing or planned – but merely supplementing them. In such cases, it is necessary to take leakage into account.

Fourth, emission reductions earned through bioenergy activities do not suffer from the problem of impermanence. Once a biomass fuel has displaced a fossil fuel over some period of time in a specific application, it has irreversibly satisfied some specific energy demand. Certainly, the biomass fuel might at some future time be given up in favor of the fossil fuel, but this would not undo the carbon benefits that had been previously gained. This differs from the storage of carbon in biomass sinks, the gains of which are undone once the activity is reversed.

Finally, it is comparably difficult to ensure the environmental and social benefits of bioenergy activities and biomass sink activities. Both are land-intensive undertakings that strongly affect the ecosystems and livelihoods. Over time, bioenergy options are more land-efficient than biomass sink options [IPCC, 2000]. The carbon-absorbing capacity of the latter is eventually saturated over time, requiring that progressively more land be allocated to storing carbon if a constant storage rate is to be sustained. The options listed in Table 2, for example, saturate over a period of 20-40 years [IPCC, 2000]. Even bioenergy strategies, however, can exert pressure on valuable land resources, especially if they require highly productive land in order to be economically attractive [Azar and Larson, 2000].

5. Conclusions and recommendations

If activities based on either bioenergy or biomass sinks are to play important roles in addressing the climate change problem, they will need to be conducted in ways that not only reduce carbon emissions, but are environmentally and socially sustainable. Parties to the Framework Convention on Climate Change and the Kyoto Protocol can adopt -- although they have not done so yet – specific provisions to ensure that the climate agreements motivate only biomass-related projects that are sustainable. Such provisions can ensure that adequate effort is directed at fostering the timely transition away from fossil-intensive technologies, in light of the long-term need for technology development and the replacement of long-lived capital stock. They can recognize only those carbon reductions that are rigorously verifiable, permanent (or scrupulously risk-managed), and without unaccounted leakage. They can require that biomass activities are consistent with other environmental agreements, such as the Convention on Biodiversity, and principles of environmental integrity. And they can insist on an effective impact assessment process that incorporates participatory approaches and positively affects local livelihoods.

Instituting such precautions can help resolve some of the controversy surrounding biomass, and allow it to fulfill its promise as part of the solution to climate change and, more generally, sustainable development. ■

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