BURY, BURN OR BOTH: A TWO-FOR-ONE DEAL ON BIOMASS CARBON AND ENERGY

Reply to R. A. Metzger, G. Benford, and M. I. Hoffert

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Once harvested, there are three general ways in which biomass may be used to manage carbon. It may be used as an almost CO_2-neutral substitute for fossil fuels, it may be sequestered away from the atmosphere by burial, or finally, it may be used as a substitute for fossil fuels with capture and sequestration of the resulting CO_2 (Keith, 2001b; Obersteiner et al., 2001); for example, we may use biomass to make hydrogen and sequester the resulting CO_2 in geologic formations.

In 'To Bury or Burn . . . ' Metzger et al. (2002) dismiss attempts to assess the cost of managing carbon, and focus instead on assessing the efficiency of reducing net emissions per unit biomass. They argue that it is better to bury a unit of biomass and burn methane than to substitute biomass for methane as an energy source because the former results in more carbon-free energy per unit of biomass. Consider the use of a unit of biomass, to be specific, assume a unit of biomass containing exactly 1 ton carbon (1 tC) which has a mass of $\sim$2.3 t and contains $\sim$35 GJ of energy (here, and throughout numerical values have been adjusted to match the assumptions in Metzger and Benford, 2001 and/or 'To Bury or Burn . . . '). As presented in 'To Bury or Burn . . . ', there are two options for using the biomass: (1) bury the biomass and use 1 tC worth of methane producing 66 GJ of primary energy with zero net CO_2 emissions; or (2) burn the 1 tC of biomass producing 35 GJ of primary energy with zero net CO_2 emissions.

If these were the only two choices – and if there were an infinite supply of methane – then Metzger et al. would be correct in asserting that burial always trumps bioenergy. Indeed, they understate their case because the efficiency of converting biomass to carbon free energy (electricity or hydrogen) is less than the efficiency of converting methane, so that more than one GJ of biomass is required to substitute for one GJ of methane.

These are not, however, the only two choices, there is a third: burn the biomass producing $\sim$35 GJ of primary energy and sequester the resulting CO_2, spending some fraction, in practice about a third, of the 35 GJ of energy released to sequester the CO_2. Such a system still generates a carbon sink of exactly 1 tC (assuming 100% CO_2 capture) and so still allows the combustion of 1 tC of methane producing 66 GJ of primary energy with zero net CO_2 emissions. But it produces about 25 GJ of additional carbon free energy from the biomass generating a total

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Table I

Summary of primary energy (in GJ) derived from the use of one ton-carbon of biomass with zero net atmospheric carbon emissions.

Energy source	Bury	Burn	Both
Biomass	0	33	25
Methane	66	0	66
Total	66	33	~90

of about 90 GJ of net carbon-free energy (Table I). Ignoring cost and focusing on the efficiency of biomass in producing carbon free energy, this last option always trumps the first two. We therefore cannot agree with the conclusions of 'To Bury or Burn ...'.

In the real world, the costs of managing carbon do matter and the choice between these and other options will be strongly determined by economics. As illustration, consider the economics of carbon mitigation in the electric sector as displayed schematically in Figure 1 in which the cost of electricity is shown as a function of the carbon price. Such a price might emerge either from a tax, a cap-and-trade system, or some hybrid. The burial of biomass generates carbon credits to offset emissions at fixed marginal price of 125 $/tC (accepting the assumptions in Metzger and Benford, 2001). Assuming that this carbon credit is only used to offset emissions from conventional fossil fuel generation (option 1, above), the price of electricity from fossil fuels rises with the carbon price until it reaches 125 $/tC, beyond which a generator would buy emissions credits in preference to paying the carbon tax. Electricity from bioenergy (option 2) is carbon neutral so its price is independent of carbon price. Finally, (option 3) the price of electricity using bioenergy with sequestration declines monotonically with carbon price, due to the internal generation of carbon credits, until at a sufficiently high carbon price emissions-free electricity is generated as a free byproduct of pumping biomass derived carbon underground as CO_2.

Which is best: bury, burn or both? The extraordinary heterogeneity of the energy system makes it unlikely that any single solution will triumph everywhere. In practice, there will be no absolute dominance of any one strategy over another, and each may well succeed in some niche. In general, however, because of the effectiveness of biomass with sequestration in reducing emissions per unit biomass, 'both' will tend to triumph over the other biomass options as constraints on carbon grow stronger.

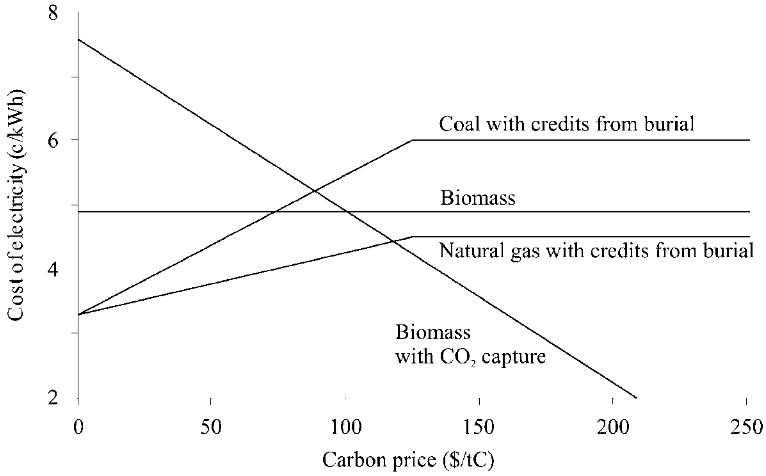

Figure 1. The cost of electricity as a function of carbon price. The cost and performance of these technologies is necessarily uncertain, so no strong conclusions can be drawn from the specific values shown here. The robust result, however, is that the cost of electricity from biomass with capture declines with increasing carbon price. Therefore, at very high prices – corresponding to very stringent emissions controls – it will tend to dominate other options. Similar graphs can be made for the production of hydrogen or liquid fuels. The following assumptions were used to derive the costs. For coal, natural gas, biomass, and biomass with capture, capital costs in $/kW were respectively 1000, 500, 1200, and 2000; marginal operating costs were 0.8, 0.3, 1.0 and 1.0 c/kWhr; efficiencies were 40%, 50%, 37%, and 30% on an HHV basis. The cost of biomass is low, 1.9 $/GJ, reflecting the assumptions of (Metzger and Benford, 2001). The costs of coal and natural gas are 0.9 and 3 $/GJ respectively. To simplify the graph the values were deliberately adjusted to make the cost of electricity from coal and natural gas exactly equal at a carbon price of zero. Finally, the capture efficiency of the biomass with capture system was set at 100%. Such zero-emissions performance could in general be achieved either via pre-combustion decarbonization in which fuel gasification is followed by the water-gas shift reaction to make hydrogen, or via the oxy-fuel route in which the combustion takes place in pure oxygen (Keith, 2001a).

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