COMMENTARY

A handful of carbon

Locking carbon up in soil makes more sense than storing it in plants and trees that eventually decompose, argues **Johannes Lehmann**. Can this idea work on a large scale?

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Sequestering 'biochar' in soil, which makes soil darker in colour, is a robust way to store carbon.

To meet the challenges of global climate change, greenhouse-gas emissions must be reduced. Emissions from fossil fuels are the largest contributor to the anthropogenic greenhouse effect, so a reduction in fossil-energy use is a clear priority[1]. Yet, because some emissions will be unavoidable, a responsible strategy also means actively withdrawing carbon dioxide from the atmosphere[2]. Such carbon sequestration faces multi-faceted challenges: the net withdrawal of carbon dioxide must be long term and substantial, the process must be accountable and must have a low risk of rapid or large-scale leakage. One near-term technology that can meet these requirements is biochar sequestration. When combined with bioenergy production, it is a clean energy technology that reduces emissions as well as sequesters carbon[3]. In my view, it is therefore an attractive target for energy subsidies and for inclusion in the global carbon market.

An existing approach to removing carbon from the atmosphere is to grow plants that sequester carbon dioxide in their biomass or in soil organic matter[2] (see graphic, overleaf). Indeed, methods for sequestering carbon dioxide through afforestation have already been accepted as tradable 'carbon offsets' under the Kyoto Protocol. But this sequestration can be taken a step further by heating the plant biomass without oxygen (a process known as low-temperature pyrolysis). Pyrolysis converts trees, grasses or crop residues into biochar, with twofold higher carbon content than ordinary biomass. Moreover, biochar locks up rapidly decomposing carbon in plant biomass in a much more durable form[4].

No limits

The precise duration of biochar's storage time is under debate, with opinions ranging from millennial (as some dating of naturally occurring biochar suggests) to centennial timescales (as indicated by some field and laboratory trials)[5]. Whether biochar remains in soils for hundreds or thousands of years, it would be considered a long-term sink for the purposes of reducing carbon dioxide emissions. Moreover, the storage capacity of biochar is not limited in the same way as biomass sequestration through afforestation, conversion to grassland or no-tillage agriculture[2]. Agricultural lands converted to no-tillage, for example, may cease to capture additional carbon after 15–20 years, and even forests eventually mature over decadal and centennial timescales and start to release as much carbon dioxide as they take up.

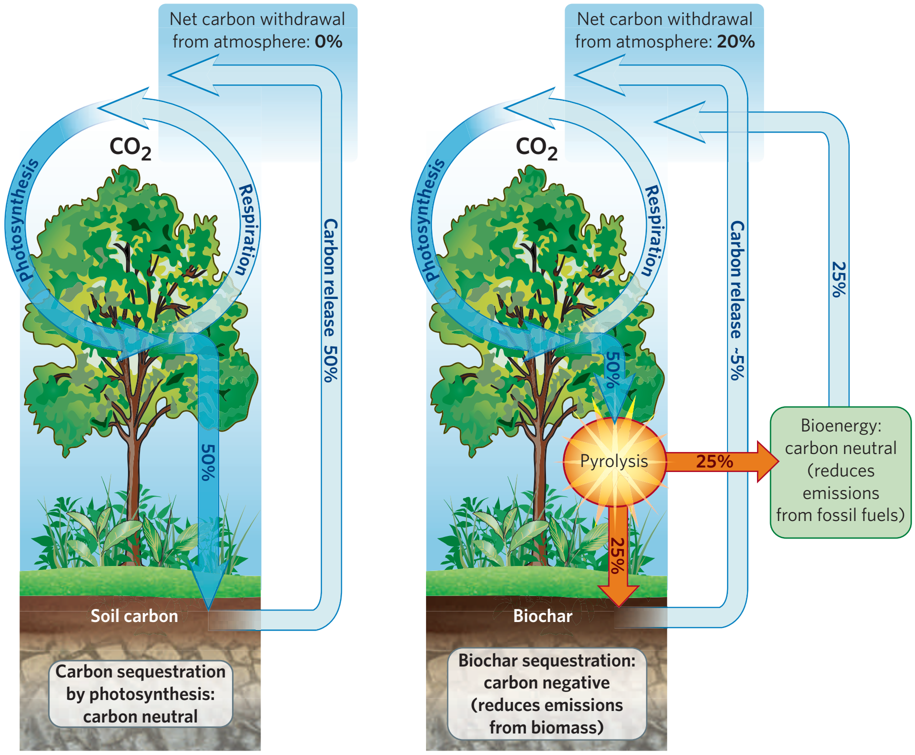
> "Biochar offers the chance to turn bioenergy into a carbon-negative industry."

Biochar is a lower-risk strategy than other sequestration options, in which stored carbon can be released, say, by forest fires, by converting no-tillage back to conventional tillage, or by leaks from geological carbon storage. Once biochar is incorporated into soil, it is difficult to imagine any incident or change in practice that would cause a sudden loss of stored carbon.

The bottom line is that plant biomass decomposes in a relatively short period of time, whereas biochar is orders of magnitudes more stable. So given a certain amount of carbon that cycles annually through plants, half of it can be taken out of its natural cycle and sequestered in a much slower biochar cycle (see graphic). By withdrawing organic carbon from the cycle of photosynthesis and decomposition, biochar sequestration directly removes carbon dioxide from the atmosphere. Pyrolysis does have costs associated with the machinery and heating (around US$4 per gigajoule) and is dependent on a supply of cheap biomass. But the bigger question is whether this approach can be scaled up to national and regional, or even global, scales.

At the local or field scale, biochar can usefully enhance existing sequestration approaches. It can be mixed with manures or fertilizers and included in no-tillage methods, without the need for additional equipment. Biochar has been shown to improve the structure and fertility of soils, thereby improving biomass production[3]. Biochar not only enhances the retention[6] and therefore efficiency of fertilizers but may, by the same mechanism, also decrease fertilizer run-off.

For biochar sequestration to work on a much larger scale, an important factor is combining low-temperature pyrolysis with simultaneous capture of the exhaust gases and converting



them to energy as heat, electricity, biofuel or hydrogen[3]. Depending on the feedstock used and bioenergy produced, low-temperature pyrolysis with gas capture (but no sequestration) can be a carbon-neutral energy source. Most companies that generate bioenergy in this way view biochar merely as a byproduct that can itself be burned to offset fossil-fuel use and reduce costs. But our calculations suggest that emissions reductions can be 12–84% greater if biochar is put back into the soil instead of being burned to offset fossil-fuel use[7]. Biochar sequestration offers the chance to turn bioenergy into a carbon-negative industry.

The million-dollar question is: can biochar sequestration and the associated bioenergy production make a real difference to national and global carbon budgets?

Promising approaches

I have calculated emissions reductions for three separate biochar approaches that can each sequester about 10% of the annual US fossil-fuel emissions (1.6 billion tonnes of carbon in 2005)[8]. First, pyrolysis of forest residues (assuming 3.5 tonnes biomass per hectare per year) from 200 million hectares of US forests that are used for timber production; second, pyrolysis of fast-growing vegetation (20 tonnes biomass per hectare per year) grown on 30 million hectares of idle US cropland for this purpose; third, pyrolysis of crop residues (5.5 tonnes biomass per hectare per year) for 120 million hectares of harvested US cropland. In each case, the biochar generated by pyrolysis is returned to the soil and not burned to offset fossil-fuel use[5]. Even greater emissions reductions are possible if pyrolysis gases are captured for bioenergy production.

Similar calculations for carbon sequestration by photosynthesis suggest that converting all US cropland to Conservation Reserve Programs — in which farmers are paid to plant their land with native grasses — or to no-tillage would sequester 3.6% of US emissions per year during the first few decades after conversion[9]; that is, just a third of what one of the above biochar approaches can theoretically achieve. Although these calculations highlight the potential of biochar, realistic projections will require rigorous economic and environmental analyses[10].

> “Would returning biochar to the soil make more financial sense than burning it?”

Most, if not all, approaches to bioenergy, including corn ethanol production, are costly. Pyrolysis plants that use biochar to offset fossil-fuel consumption are financially viable only when inexpensive feedstock is continuously available in sufficient quantities, for example animal wastes, clean municipal wastes or forest residues collected for fire prevention. But would returning biochar to the soil make more financial sense than burning it? There are some potential savings to be made by reduced fertilizer use and through possible gains in agricultural productivity, but the answer to this question depends largely on the value that carbon markets assign to emissions reductions.

At present, the Chicago Climate Exchange is trading carbon dioxide at US$4 per tonne. These prices are expected to rise over the coming years to decades to US$25–85 per tonne, assuming that societies accept the social costs of climate change[11]. We calculate that biochar sequestration in conjunction with bioenergy from pyrolysis becomes economically attractive[7], under one specific scenario, when the value of avoided carbon dioxide emissions reaches $37 per tonne.

This calculation does not consider the indirect benefits associated with biochar — which do not currently have a dollar value — from reduced pollution of surface or groundwaters. Subsidies to support biochar sequestration, in conjunction with bioenergy production, would be sufficient to jump-start this technology. US Senator Ken Salazar is working on comprehensive legislation, as part of the 2007 Farm Bill, that would provide significant support for biochar research and development.

Easy to monitor

When it comes to including biochar in emissions-trading schemes, accountability is more straightforward than with other soil sequestration methods. Both the conversion of biomass into biochar and its application to soil are readily monitored, without additional costs. No complex predictive models or analytical tools are required, as is the case with other soil sequestration approaches. The source of biochar additions can easily be identified by soil analyses, if desired for verification under carbon-trading schemes. Tracing the source of carbon in soil back to a change in agricultural practice, or other photosynthetic source, is much more difficult, and therefore currently not accepted under the Kyoto Protocol. Because these barriers do not exist for biochar sequestration, in my opinion there is no reason why the associated emission reductions should not be allowed into trading markets under current agreements.

The consequences of climate change are already being felt[1] and there is an urgency not only to identify but also to implement solutions. Biochar sequestration does not require a fundamental scientific advance and the underlying production technology is robust and simple, making it appropriate for many regions of the world. It does, however, require studies to optimize biochar properties and to evaluate the economic costs and benefits of large-scale deployment. ■

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1. IPCC *Climate Change 2007: The Physical Science Basis* www.ipcc.ch/SPM2feb07.pdf (2007).
2. Lackner, K. S. *Science* **300,** 1677–1678 (2003).
3. Lehmann, J. *Frontiers in Ecology and the Environment* (in the press).
4. Baldock, J. A. & Smernik, R. J. *Org. Geochem.* **33,** 1093–1109 (2002).
5. Lehmann, J., Gaunt, J. & Rondon, M. *Mitigation Adapt. Strateg. Glob. Change* **11,** 403–427 (2006).
6. Liang, B. *et al. Soil Sci. Soc. Am. J.* **70,** 1719–1730 (2006).
7. Gaunt, J. & Lehmann, J. Presentation at Power-Gen Renewable Energy and Fuels *From Plant to Power Plant* (Las Vegas, 6 March 2007).
8. EIA *Emissions of Greenhouse Gases in the United States 2005* report number DOE/EIA-0573 (2006).
9. Jackson, R. B. & Schlesinger, W. H. *Proc. Natl Acad. Sci. USA* **45,** 15827–15829 (2004).
10. McCarl, B. A. & Schneider, U. A. *Science* **294,** 2481–2482 (2001).
11. Stern, N. *The Economics of Climate Change: The Stern Review* (Cambridge Univ. Press, Cambridge, 2007).