nature REPORTS climate change
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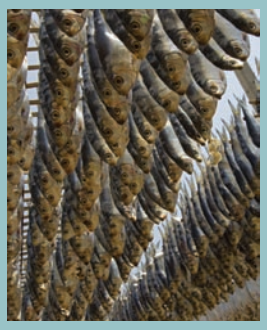
BIOMASS INTO BIOCHAR
Nature's cure?

CLIMATE CHANGE AND HEALTH
What's in store?

Fisheries and climate policy
A place at the table



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BEST PRACTICE FOR BIOCHAR

With just six months left to go, all sectors are vying for a place at the table in Copenhagen, where negotiators will begin sketching what should eventually become an all-embracing climate deal. While some players are seeking assistance in adapting to the impacts of climate change (page 68), others are hoping to stake a claim in the emerging green economy (page 72). The prospects of the latter are bright for those involved in the nascent biochar industry, which plans to sequester vast quantities of carbon in soil using an ancient Amazonian agricultural practice and to sell the latent emissions as credits on a global carbon market.

The concept is simple: if *terra preta* — or charcoal-enriched soil — was re-created globally, as much as 6 billion tonnes of CO_2 could be prevented from entering the atmosphere annually, a substantial fraction of the 8–10 billion tonnes emitted each year by humans. Proponents, who include no small number of world-class climate scientists, say that burying biochar not only would slow the rate of warming, it would enhance soil fertility — and the charcoal-making process could produce sustainable biofuels to boot.

In late May, the United Nations released its draft negotiating text for Copenhagen (UNFCCC document FCCC/AWGLCA/2009/8; http://tiny.cc/GnvBQ), which specified that biochar should be considered eligible as an advanced mitigation option under a post-Kyoto treaty. Should negotiators — who will discuss the document over the coming weeks in Bonn and again in Copenhagen — find the suggestion favourable, the biochar industry will unavoidably become a legitimate source of tradable carbon credits. And why not? Burying biochar could be the closest contender yet for a silver-bullet solution to climate change (*Guardian* 13 March 2009; http://tiny.cc/ETEHv), in which case its deployment can't come quickly enough.

But despite its astounding potential, caution is warranted in implementing biochar on any sizeable scale. Though re-creating *terra preta* sounds simple, recent research suggests that modern-day soils may respond less well to the treatment and that the carbon may escape sooner than anticipated. On these questions alone, all of the evidence is not in. Yet we clearly don't have the luxury of time to answer them definitively.

The recent exuberance over biochar is reminiscent of the earlier fervour over biofuels, as critics have been eager to highlight (*Guardian* 24 March 2009; http://tiny.cc/EfOSs). But both face some of the same problems — most controversially, the need for land should carbon credits command a high enough price — suggesting there is scope here to learn from previous errors.

What's now needed is an international code of best practice for biochar that evolves as knowledge comes in. For a start, this would clearly define acceptable land-use policy for plantations, as well as a lower limit on carbon sequestered from those claiming certification. Inclusion in a global climate deal will certainly speed the adoption of biochar, but it can also help ensure that this solution is applied responsibly.

OLIVE HEFFERNAN, EDITOR

Published online: 2 June 2009

doi:10.1038/climate.2009.53

RESEARCH HIGHLIGHTS

COMMENTARY

BOOKS & ARTS

FEATURE

Q&A

BIODIVERSITY AND ECOLOGY

Impeccable timing

S. SOUTHERLAND

Science **324,** 791–793 (2009)
The northern shrimp — a small, sweet-tasting crustacean — times its reproduction so that hatchlings can feed on the local spring algal bloom. A new study, which used a decade of satellite-derived data from the North Atlantic Ocean, suggests that although this local adaptation is highly effective, it is also extremely vulnerable to climate-related changes.

Peter Koeller of the Bedford Institute of Oceanography in Dartmouth, Nova Scotia, and colleagues found that, although an increase in sea surface temperature is thought to kick-start the spring bloom, egg development and hatching times for the northern shrimp are governed by local bottom water temperatures throughout the North Atlantic. At its southernmost limit in the Gulf of Maine, where bottom temperatures are the warmest in the shrimp's range, egg-bearing females adopt an additional strategy — overwintering in nearby cold waters — to ensure that egg hatching coincides with the plankton bloom.

The authors deduce that the ability of this species to time its reproduction carefully could be threatened by climate change if surface and bottom waters were to respond differently. Given that the species comprises more than 70 per cent of the 500,000 tons of coldwater shrimp harvested annually worldwide, such impacts could have commercial implications.

Olive Heffernan

ADAPTATION

Risky response

CDC / JAMES GATHANY

PLoS Negl. Trop. Dis. **3,** e429 (2009)
In an effort to combat warming-induced drought, Australians may be clearing the way for the spread of dengue fever. A recent move by the government to encourage households to install rainwater storage tanks may provide a breeding ground for the insect that transmits the disease, raising the risk of future outbreaks, finds new research.

In an ecological modelling study, Nigel Beebe of the University of Queensland and colleagues found that the mosquito that transmits dengue fever, *Aedes aegypti*, could potentially occupy a range that includes most major cities in Australia. It is currently found only in northern Queensland, however, because its distribution is limited by the availability of suitable breeding sites. On its own, further warming up to 2050 is unlikely to cause the mosquito to spread more widely — but the government-subsidized water tanks, which over one-fifth of Australian households have already installed, could allow it to gain a foothold outside Queensland.

Once infected mosquitoes have arrived, say the authors, dengue transmission could be aided by rising temperatures, which may lengthen the warm season in which the virus can pass to humans.

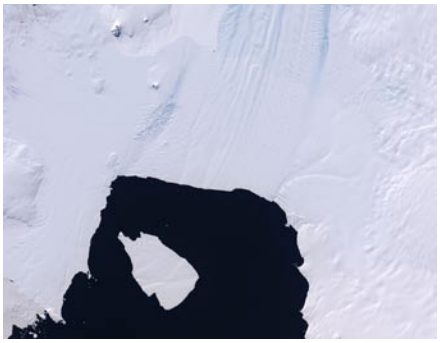
Alicia Newton

CRYOSPHERE

Cautionary collapse

Science **324,** 901–903 (2009)
Small shifts in climate could lead to a rapid disintegration of the West Antarctic Ice Sheet. But new research suggests that the effect of such a collapse on sea level rise has been significantly overestimated.

Jonathan Bamber of the University of Bristol, UK, and colleagues used an ice-sheet model, combined with recent studies of seabed topography and ice-sheet elevation,



NASA / JESSE ALLEN / US GEOLOGICAL SURVEY

to examine how sea levels across the globe would change with a sudden collapse of the underwater portion of the West Antarctic Ice Sheet. They show that the volume of ice lost would be smaller than previously anticipated and estimate that sea levels would rise by no more than 3.3 meters on average — considerably less than the 5 to 6 meters usually quoted. However, marked regional variations mean that the impact on coastal areas could still be devastating. Sea level rise along the eastern and western coasts of the United States, for example, is expected to be 25 per cent greater than the global mean.

Importantly, the regional pattern of sea level rise is insensitive to how much of the ice collapses or how fast. Thus, US coastal cities should prepare for the worst.

Anna Armstrong

ENERGY

Biofuel boost

© ISTOCKPHOTO / GEORGE CLERK

J. Am. Chem. Soc. **131,** 6508–6515 (2009)
Biofuels release less carbon dioxide than their petroleum-based counterparts, but the intensive agriculture and processing needed to convert biomass into common fuel drives up their overall carbon footprint. Genetically engineered microbes may change the equation, however, allowing biofuel to be produced in a way that is both efficient and sustainable, according to scientists.

Christopher Voigt and colleagues at the University of California, San Francisco used a unique approach to manufacture microbes that could transform biomass into methyl halides, a precursor to products ranging from polymers to gasoline, in quantities with

near-commercial potential. Methyl halides are produced naturally by plants, fungi and bacteria at low levels. The researchers chemically recreated all 89 genes that allow these organisms to produce the molecules and inserted them into a common form of yeast. From there it was a team effort: bacteria were fed a variety of agricultural waste products, including the leaves and stalks of corn and the fibrous residue of sugar cane. As they were eating, the bacteria released acetate, which the yeast consumed. Instead of the customary alcohols, the engineered yeast began churning out methyl halides.

Though industrial-scale facilities to convert methyl halides to fuel may be a way off, the group says that this approach could eventually enable biofuels to be created with low energy consumption and without diverting land away from food production.

Alicia Newton

ATMOSPHERIC SCIENCE

Secondary sources

© ISTOCKPHOTO / KLASS LINGBEEK-VAN KRANEN

Proc. Natl. Acad. Sci. USA
doi:10.1073/pnas.0904128106 (2009)

The climate-cooling haze that covers the southeastern United States in summer comes largely from an underappreciated source, new research shows. Large numbers of aerosol particles are forming, say scientists, when organic gases released mainly by trees react with pollution released by human activity.

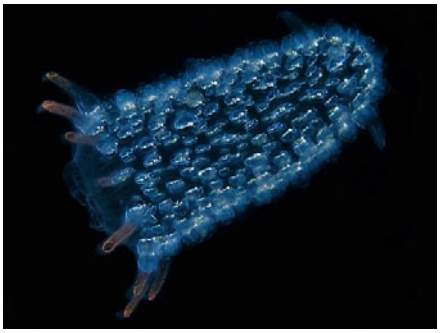
Allen Goldstein and colleagues at the University of California, Berkeley used satellite and ground-based measurements to examine concentrations of aerosols in the atmosphere over the entire United States. They found that in the southeastern US the observed patterns could not be explained solely by manmade aerosols — previously thought to be the main source. Concentrations in the region were considerably higher in summer than in winter, especially over forests that release more organic gases as temperatures climb. Warmer individual days also increased both the forest emissions and the overall aerosol levels, suggesting that most of the summertime haze is created when natural and anthropogenic emissions react, forming a secondary aerosol layer.

Further warming could result in an even denser cooling haze over the region, putting a brake on increasing summertime temperatures — unless reactive pollutants emitted from tailpipes and smokestacks are reduced.

Anna Barnett

BIODIVERSITY AND ECOLOGY

Pyrosome pump



NICK HOBGOOD

Limnol. Oceanogr. **54,** 1197–1209 (2009)

Common jelly-like creatures known as pyrosomes transport vast amounts of carbon to the sea floor, finds a new study. The research by Mario Lebrato and Daniel Jones of the National Oceanography Centre at the University of Southampton, UK, provides new evidence of the importance of gelatinous zooplankton in the marine carbon cycle.

Lebrato and Jones used a remotely operated vehicle equipped with underwater video cameras to survey the sea floor off the Ivory Coast of west Africa after the mass deposition of thousands of pyrosome carcasses between February and March 2006. The creatures piled up on the sea bed, in some regions exceeding 4,000 per 100 square metres. The researchers found that carbon constituted a third of the body mass of sampled carcasses, exceeding previously recorded levels in any gelatinous creature. They estimate that the pyrosomes contributed more than 5 grams of carbon per square metre — and in some cases as much as 22 grams per square metre — to the seabed in the studied area, which covers over 13,000 square metres.

Eight types of animal, together with bacteria, were found feeding on the carcasses, suggesting that gelatinous carbon is a key — and previously unappreciated — component of the marine food web off the Ivory Coast. The authors say that pyrosome carcasses probably have an important role in transporting carbon from the sea surface to the sea floor across the globe.

Anna Armstrong

A place at the table?

NICHOLAS DULVY AND EDWARD ALLISON

An oft-forgotten source of food security and livelihoods, fisheries must be included in ongoing discussions of how the world's most vulnerable can adapt to climate change.

It is well recognized that the world's most vulnerable nations will bear the brunt of escalating greenhouse gas emissions, primarily through reduced food and water availability. But while agriculture and freshwater resources have been central in climate policy discussions, the effects of climate change on fisheries resources — and the implications for health and livelihoods in the developing world — have been largely ignored. Whatever the details of a global climate treaty, it must aid adaptation to climate change as well as minimize its impacts. Here we ask that aquatic production systems and the people dependent on them are appropriately included in climate adaptation measures considered for coastal zones, water resources management, agriculture, food security and rural development. We put forward a series of policy and research priorities that will enable the fisheries sector to adapt to change as well as contribute to mitigation measures.

INCREASING UNCERTAINTY

Currently, one-third of the world's 6 billion people rely on fish and other aquatic products for at least one-fifth of their annual protein intake, and catches by subsistence and artisanal fisheries make up more than half of the essential protein and mineral intake for over 400 million people in the poorest countries in Africa and south Asia[1]. Fisheries and aquaculture directly employ over 36 million people worldwide, 98 per cent of whom are in developing countries. Taking into account ancillary occupations and their dependents, there are approximately 520 million fisheries-dependent people. Fisheries and aquaculture also support global trade worth over 78 billion dollars in 2008 (ref. 1).

The physical, biological and ecological impacts of climate change in aquatic ecosystems are becoming increasingly apparent. Coral reefs are bleaching and their associated fisheries collapsing rapidly. Commercially exploited fishes are moving northward and into deeper waters at rapid rates, invading polar seas, and withdrawing from subpolar seas, semi-enclosed seas and the tropics[2]. Climate change may affect fisheries, and their contribution to local livelihoods, national economies and global trade-flows, through both direct and indirect pathways. Always an unpredictable way to make a living, fishing may increasingly become a lottery as fish migration routes and spawning and feeding grounds change from those that fishers have learnt to harvest. In addition, the growing frequency and severity of extreme events such as floods and hurricanes will increase the vulnerability of fishing communities through disasters that damage infrastructure and threaten human health[3]. The future consequences for global fisheries are uncertain, however, and subject to ongoing analysis. But what is certain is that there will be winners and losers, and we can bet the losers will be those who don't have much already.

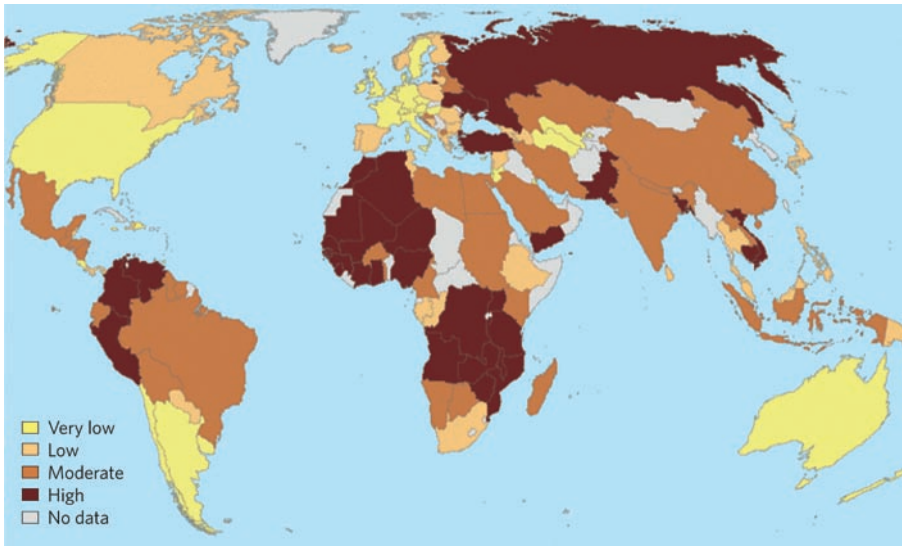


Figure 1 Unequal vulnerability. The vulnerability of national economies to potential climate change impacts on fisheries was calculated on the basis of exposure, sensitivity and adaptive capacity, assuming slowly increasing global emissions (scenario B2 of the Intergovernmental Panel on Climate Change). Colours represent quartiles, with dark brown for the upper quartile (highest vulnerability), yellow for the lowest quartile and grey where no data were available. Originally published in ref. 3.

DOUBLE JEOPARDY

In a recent analysis[3], we, together with collaborators, demonstrated that African and southeast Asian countries are the most economically vulnerable to climate change impacts on their fisheries and aquaculture sectors (Fig. 1). This vulnerability arises from a relatively high reliance on fisheries combined with low levels of societal capacity to adapt to anticipated temperature increases. Of the 33 nations identified as being most vulnerable to climate impacts on

their fisheries sectors, 19 are among the world's least developed countries, whose inhabitants are twice as reliant on fish and fisheries for food as those of more developed nations. Not only are the most vulnerable countries highly dependent on fish for protein, they also rely on fish and fisheries products as a source of income, producing around 20 per cent of the total tonnage of global fish exports, a fraction worth about US$6.2 billion.

African and southeast Asian nations face the double jeopardy of high vulnerability to climate effects on both their fisheries and agriculture sectors. By 2050, the global yield of rain-fed maize is forecast to decline by 17 per cent and the yield of irrigated rice by a fifth as a result of climate change, with sub-Saharan Africa and south Asia being the worst hit[4]. Three countries in particular have both the highest national vulnerability to climate impacts on fisheries and 'extremely alarming' global hunger indices: Sierra Leone, Niger and the Democratic Republic of the Congo[5]. Clearly these nations deserve the greatest support for adaptation and development to face off against these challenges.

DEDI ADHURI, WORLDFISH CENTER

African and southeast Asian countries are the most economically vulnerable to climate change impacts on fisheries resources.

POLICY PROGRESS

Until now, the fisheries sector has been rather slow to get involved with both climate change and development issues — one of the reasons why fisheries and aquaculture are often left out of global policy processes. This is changing: partnership and collective action are *mots du jour*. One example is a collaborative effort of the UN Food and Agriculture Organization, the World Bank's PROFISH programme — an initiative to tackle unsustainable fishing practices — and international non-profit research group the WorldFish Center in Penang, Malaysia. This coalition aims to share the task of achieving representation for the sector in high-level climate policy dialogues by joining forces with other agencies such as the UN Environment Programme, regional intergovernmental organizations such as the Secretariat of the Pacific Community, and representatives of fisherfolk's organizations worldwide. Such alliances can be used to highlight vulnerability, adaptation needs and mitigation opportunities in the aquatic sector.

Here we identify four key areas where policy responses and associated research are needed, and we call upon delegates and decision-makers participating in the UN Framework Convention on Climate Change process to take these on board in considering how best to involve the fisheries sector in mitigation and adaptation efforts[6–8].

African and southeast Asian nations face the double jeopardy of high vulnerability to climate effects on both their fisheries and agriculture sectors.

First, consideration should be given to the ability of aquatic production systems to reduce emissions of CO_2 and other greenhouse gases. Fisheries currently account for about 1.2 per cent of global oil consumption; this is comparable to the fuel consumption of the Netherlands — the eighteenth most fuel-intensive economy. Despite this apparent appetite for energy, the fisheries sector is relatively fuel-efficient compared to other protein production systems. The energy content of captured fish is around ten per cent of the fuel used to catch it[9]. Though the sector cannot make a major contribution to global emissions reductions, options should be pursued wherever there are synergies between mitigation, adaptation and sound environmental management. With substantial overcapacity in the global fishing fleet, emissions reductions could be achieved by taking excess capacity out of commission — that is, by reducing fleet size. This could aid efforts towards sustainable fisheries management, and countries could even gain carbon credits for doing so if this could be demonstrated as a legitimate offsetting activity.

Second, it is important to increase the fisheries sector's socio-ecological resilience and ability to respond to the opportunities and challenges of climate change. This can be done by maintaining larger stock sizes, achieved in part by reducing subsidies that artificially sustain the profitability of dangerously depleted fisheries. While reducing capacity is essential, over-regulation of the activities of the remaining fishers is counter-productive. Management measures should be supported that still allow fishing fleets to be mobile and flexible in what they catch so that they can adapt to anticipated changes in stock distribution and catch composition. Promoting less capital-intensive fisheries enterprises and providing opportunities for fishers to diversify into supplementary or alternative activities are key factors in building capacity to adapt to climate change; they reduce the risk of livelihood failure by spreading risk across more than one income source.

INTEGRATED EFFORTS

Third, there is a need for adaptation approaches that involve managing an integrated portfolio of natural resource sectors such as water resources, forestry, farming, aquaculture and capture

fisheries. The poorest people often rely on two or more such sectors to sustain their livelihood. One novel cross-sectoral scheme in the Solomon Islands, funded by the Australian government, is assessing the potential for carbon sequestration by mangrove forests — ecosystems threatened by unsustainable aquaculture — which could then be eligible as a source of carbon credits under the UN programme Reducing Emissions from Degradation and Deforestation, or REDD. Researchers are examining how such an approach might be used to promote conservation, mitigate climate change and help alleviate poverty among people dependent on the mangroves and adjacent marine ecosystems.

Finally, thought should be given to mainstreaming fisheries in wider development processes. Climate change is not the only stress facing fishing and fish-farming communities. Many fishing communities are poorly served by infrastructure, markets and social services, and are thus economically, socially and politically marginalized. Building adaptive capacity to address these multiple stressors will require cross-sectoral approaches implemented through newly decentralized governance approaches. The world's least developed countries are among those eligible for UN funding to engage in long-term adaptation planning through the National Adaptation Programmes of Action. In countries where fisheries are important, sector-specific adaptation needs should be planned and budgeted for in this process. All sectors will be vying for a place at the climate change negotiating table in Copenhagen. The agencies representing the fisheries sector are calling, above all, for fisheries to be remembered when, as is hoped, commitments to funding adaptation are agreed this December.

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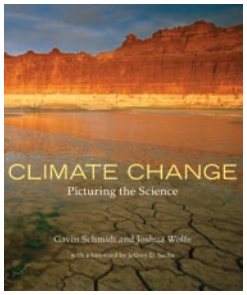
The big picture



CLIMATE CHANGE: PICTURING THE SCIENCE

Edited by Gavin Schmidt and Joshua Wolfe

W. W. Norton and Company: 2009. 320pp. £17.99

Words matter as much as images in communicating climate change.

As the world struggles with the stunningly complex politics of averting a climate catastrophe and building sustainability, policymakers and the public must fortify themselves with reliable information. Here, the epic work of scientists is critical. Science is, after all, "the most reliable and self-correcting method ever devised by humans for finding empirical truths about the real world," note the editors of a new book on climate change. A collaboration between NASA climate modeller Gavin Schmidt, who founded the *RealClimate* blog, and photographer Joshua Wolfe, *Climate Change: Picturing the Science* is the latest of various efforts to convey the seriousness of the climate situation through imagery as well as words.

In this regard, it follows from *Earth Under Fire* by Gary Braasch and *Dire Predictions,* released last year by Schmidt's fellow *RealClimate* contributor Michael Mann and climatologist Lee Kump. *Picturing the Science* mostly features the photography of Wolfe, Braasch and Peter Essick, but it also includes a smattering of pictures by other photographers and scientists, resulting in a broad diversity of images that are, in many cases, truly arresting.

The graphics nicely achieve the editors' objective of illustrating the science, but the book's real strength is in the essays. Schmidt and Wolfe bring together an impressive array of contributors to provide lucid, informative discussions of the key issues in climate science and policy. Highlights include physicist Tim Hall's cogent and direct explanation of why anthropogenic global warming is scientifically correct, and journalist Elizabeth Kolbert's brief but characteristically forceful essay on reporting climate change. In enabling the average reader to grasp some reasonably difficult concepts, *Picturing the Science* measures up well to Kolbert's *Field Notes from a Catastrophe* — for my money, the single most important contribution to the literature on climate change.

The numerous "Cool, I didn't know that!" moments are an enjoyable aspect of *Picturing the Science*. The threat of sea level rise is, of course, common knowledge at this stage, but how many people knew that thermal expansion of water from rising temperatures and the melting of ice and snow contribute in just about equal measure? And unless you're a paleoscientist of some ilk, it's unlikely you've appreciated that the average lifetime of a species on Earth, from origin to extinction, is 4.5 million years.

Although the book covers a lot of good ground from science through to technology and policy, on certain topics more detailed coverage would have been welcome. For example, the book could have benefited from more discussion of two warming agents that, although not regulated under the Kyoto Protocol, have powerful impacts: black carbon (or soot) and ozone. Similarly, some of the more obvious impacts of climate change, such as those on human health and agriculture, barely get a mention.

In the section on mitigation, farming again seems orphaned. Though engineer Frank Zeman informs us that "genetic solutions may reduce emissions" of methane and nitrous oxide from agriculture, we are not apprised of other potentially powerful options such as biochar, no-till and organic farming, and, as Nobel laureate Rajendra Pachauri has implored, eating less meat.

On the subject of solutions, nuclear power is covered, however briefly, with all of its warts. Geoengineering is similarly — and accurately — depicted as having all manner of drawbacks. The discussion of carbon capture and storage, in my opinion a red herring, doesn't shy away from the many factors that make it a highly questionable bet. We simply need to stop using coal, not only because of the immense danger to our climate system, but also because of the attendant ills of devastating the land and water with mining, not to mention the associated pollution and debilitating human health impacts. The pursuit of carbon capture and storage is a considerable distraction as we seek to make the transition to a zero-carbon, sustainable world economy.

What we do need is a laser-like focus on producing clean energy. The book claims that "the transition to an emissions-free electricity sector has yet to begin", but I beg to differ. Diverse renewable technologies — including power from wind, geothermal, and marine sources such as tides and waves, and solar technologies such as photovoltaics — are burgeoning. And quantum leaps in energy efficiency, green building, distributed generation and smart-grid technology are producing huge gains now and promise much more in the future.

On the issue of policy, the book holds up well. There is a particularly clear and concise discussion of cap and trade and other mechanisms. The authors are perfectly correct in their assessment that there has been "a remarkable shift in attitudes" in the last few years. This bodes well, certainly, but the consensus for action needs to be deepened and broadened. That is this book's *raison d'etre*, and to that end it will be an important contribution.

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William F. Hewitt

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The bright prospect of biochar

Enthusiasts say that biochar could go a long way towards mitigating climate change and bring with it a host of ancillary benefits. But others fear it could do more harm than good. **Kurt Kleiner** reports.

Jim Fournier wants to help save the planet, though in a most unlikely way: by burning biomass. At the forefront of a carbon-sequestration technology that proponents say offers a rare 'win-win-win' environmental opportunity, Fournier's company Biochar Engineering in Golden, Colorado, manufactures machines that turn biomass into charcoal, or biochar.

Spread on soil, biochar can keep CO_2 out of the atmosphere while improving soil fertility and boosting productivity. In addition, gases released in the charcoal-making process can be used to make biofuels that are more sustainable than those currently on the market. "Char happens to be the one thing that represents a solution to all of these factors together. It's a unique opportunity," Fournier says.

But while enthusiasts are pushing to have biochar recognized as an official means of offsetting greenhouse gas emissions, others remain cautious. At best we know too little, say critics, and at worst using biochar to sequester carbon could ultimately lead to unintended consequences, including the destruction of virgin forests to make way for plantations.

"Biochar certainly has potential," says David Wardle, a soil scientist at the Swedish University of Agricultural Sciences in Uppsala. "But it's premature to be already including it in carbon accounting. Maybe it really is an answer. But we don't know that yet."

> "Biochar certainly has potential. Maybe it really is an answer. But we don't know that yet."
> David Wardle

Though the idea of using biochar for climate change mitigation is relatively new, its origins extend back to the pre-Columbian era, when humans first made *terra preta* — in Portuguese, dark earth — soils in the central Amazon basin. According to archaeologists, the rich, black and fertile *terra preta* was created by adding a mixture of bone, manure and charcoal to the otherwise relatively infertile soil over many years. The charcoal — believed to be the key ingredient — is 70 times more concentrated in *terra preta* than in surrounding soils and is formed by heating biomass in an oxygen-poor or oxygen-free environment. Some of the charcoal in Amazon *terra preta* soils has persisted for thousands of years, back to when people first started this practice. Its persistence has attracted the attention of research scientists who think that it could be used to lock away carbon for a similarly long time in the future, keeping it out of the atmosphere as a greenhouse gas.

"You can get charcoals that are tens of thousands of years old, or even older," says Chris Turney, a geographer at the University of Exeter and director of the start-up Carbonscape. With headquarters in Blenheim, New Zealand, Carbonscape is developing a unique approach to producing biochar. The company is soon to launch in the United Kingdom. "If you want a very simple method of fixing carbon in a relatively stable form for potentially tens of thousands of years, charcoal is a good way of doing it," Turney says.

TONNES TUCKED AWAY

The recent surge of interest in biochar as both a commercial venture and an academic challenge was evident at a one-day workshop held last month at the University of Edinburgh and sponsored by the UK Biochar Research Centre. "When I wrote the grant proposal to fund this, I could find only about four or five people in the UK who were interested," says Stuart Haszeldine, the geologist and biochar researcher who organized the event. "Now last week we were turning people away. We had 80 people attend, and we could have had 150."

As a solution to escalating emissions, biochar is certainly promising. Every year, human activity results in the release of somewhere between 8 and 10 billion tonnes of carbon dioxide. Of that, several billion tonnes are soaked up by the oceans and land, leaving around 4.1 billion tonnes in the atmosphere.

That number is dwarfed by the 60.6 billion tonnes of carbon that terrestrial

ROBERT FLANAGAN

Tilling charcoal into the soil can promote lush plant growth as well as sequestering carbon, say biochar enthusiasts.

plants absorb during photosynthesis every year. A similar amount goes back into the atmosphere through plant respiration. But if a fraction of that carbon could be stored in the soil, it would mitigate climate change to some degree. "Any organic matter that is taken out of the rapid cycle of photosynthesis ... and put instead into a much slower biochar cycle is an effective withdrawal of carbon dioxide from the atmosphere," says Johannes Lehmann, a soil scientist at Cornell University in Ithaca, New York, who has spent years studying *terra preta* and biochar.

Lehmann and colleagues think that the potential benefits could be huge. Of the more than 60 billion tonnes of carbon taken up annually by photosynthesis, around ten per cent eventually becomes available as agricultural residue such as corn and rice stalks, or forestry residue such as branch and leaf litter, as well as animal waste. If all 6 billion tonnes were put through pyrolysis — the heating process that turns biomass into charcoal — 3 billion tonnes of biochar would be produced every year, reducing atmospheric carbon emissions by the same amount[1]. That would offset a substantial proportion of the 4.1 billion tonnes of excess carbon dioxide that accumulates annually in the atmosphere.

And since biochar manufacture has the added benefit of creating liquid fuel as a useful by-product, there's even greater potential for mitigating climate change than from sequestering CO_2 alone. According to Lehmann's calculations, a third of a tonne of biofuel could be produced for every tonne of biomass used. If those biofuels replaced fossil fuels — in transport, for example — it would reduce carbon emissions by an additional 1.8 billion tonnes per year.

Tim Lenton, professor of Earth-system science at the University of East Anglia, UK, recently rated biochar as one of the best technological fixes for cooling the planet. According to Lenton's analysis of 17 geoengineering options[2], biochar has the potential to sequester almost 400 billion tonnes of carbon by 2100 and to lower atmospheric carbon dioxide concentrations by 37 parts per million. Advoctaes, including Lehmann, admit that the real numbers will probably be much smaller. Haszeldine, for instance, says that 1 billion tonnes of carbon sequestered per year by 2030 is a reasonably conservative estimate of biochar's potential. "Even if it's only 500 tonnes of carbon a year, it's useful," says Haszeldine. "If it's a million or a billion tonnes a year, that's significant."

BURNT OFFERING

Most biochar-making technologies use heat produced by the biomass itself to form the charcoal. But Turney, the Exeter professor and Carbonscape director, is backing a slightly different approach, one that uses industrial-scale microwaves. He says the idea was inspired by a cooking accident in his teenage years, when he put a potato in the microwave for 40 minutes and it turned into charcoal. Although using microwave technology has the disadvantage of requiring electricity, the process will result in twice as much carbon being stored in the soil as is emitted as greenhouse gas.

JASON KOSKI, CORNELL UNIVERSITY PHOTOGRAPHY

Soil scientist Johannes Lehmann with biochar made from forestry waste.

> "The whole point is to suck up carbon, not to start pillaging native vegetation."
> Chris Turney

A much lower-tech approach is to promote the use of charcoal-making cook-stoves to the roughly 2 billion people who rely on wood for fuel. The cook-stoves, produced by a number of companies, use wood or other organic materials as fuel and burn only the gases and oils, leaving charcoal behind. The result is a cleaner-burning flame that gives off less smoke, and the leftover biochar can potentially be applied to soil.

Fournier of Biochar Engineering says that he became involved in biochar because of its mitigation potential. But he thinks its value as an addition to the soil will ultimately drive its production. Right now his company manufactures relatively small biochar units for researchers, capable of making 50 kilograms of biochar per hour. He says, however, that the real market will probably be in medium-sized units that can produce 250 to 300 kilograms per hour but are still small enough to be packed into a standard cargo container and shipped anywhere in the world. Fournier expects individual farmers or local entrepreneurs to begin buying the units and using them to make biochar for agricultural purposes, with co-production of energy a secondary benefit. These small operators might decide to forego biofuel production altogether, says Fournier, and concentrate on making biochar. The extra heat generated by the char-making process could be used for warming a building or for industrial processes, however, and possibly for producing electricity.

While charcoal for agricultural use is now selling for about US$500 per tonne, that same tonne of charcoal, at current prices, is worth only about US$50 if sold for offsetting emissions. Even if the price of carbon offsets rose to US$100 per tonne of CO_2, that tonne of biochar would still be worth only US$350 in offsets, says Fournier. In fact, he says, the economics of biochar will be determined by a combination of its value as a soil additive, as a carbon offset measure and as an energy source.

PRESSURE TO PLANT

But some worry that once production becomes profitable, pressure will mount to use land specifically for biochar plantations. "The level at which they are promoting this could result in enormous land-use change issues," says Rachel Smolker, a biologist and anti-biochar activist who helped organize a petition in April signed by 143 non-

profit groups protesting what they called a "charred earth policy". The petition came as a reaction to an effort by 11 African countries and biochar proponents to have the United Nations consider biochar's eligibility as an official means for nations and companies to offset their emissions under international regulations.

"It would require huge areas of land to be turned into plantations," warns Smolker. Carbonscape, for one, has suggested that forests might be planted, harvested for charcoal, and then replanted. For instance, the company says, if the 200 million hectares of forest in the United States that are harvested for timber were instead used for biochar, replanted, and harvested again, each rotation would reduce atmospheric carbon dioxide levels by ten parts per million. Others, such as Lehmann, have proposed replacing winter wheat crops with switchgrass that would be turned into biochar.

Smolker and Almuth Ernsting, who works with Biofuelwatch, a UK environmental organization, are specifically concerned that a market for biochar would encourage the destruction of tropical forests, much as a market for biofuel has encouraged forest destruction for palm-oil plantations. Ernsting estimates that sequestering even a relatively modest 1 billion tonnes of carbon a year would require that 500 million hectares of land be devoted to biochar plantations[3]. By comparison, there are an estimated 1.5 billion hectares of tropical forest remaining in the world.

But demand for biochar plantations needn't lead to the destruction of forests, argues Turney. Although he believes it would make the most economic sense to use agricultural and forest waste for biochar, he says that if plantations were needed they could be situated on land that has already been deforested. In fact, he says, biochar production might actually provide an incentive to reforest the estimated 900 million hectares of degraded land worldwide. "The whole point is to suck up carbon, not to start pillaging native vegetation that's already out there," says Turney. Fournier also agrees that destroying forests for biochar plantations would be a perverse effect, but he thinks that international agreements and certification could prevent that from happening.

That isn't Smolker's only concern, though. The hope is that once the carbon is stored in the soil, it will stay there for many thousands of years. But although *terra preta* shows that's possible, it is not known whether all soils will benefit from biochar application, or even how long

CARBONSCAPE

New Zealand start-up Carbonscape is using industrial-scale microwaves to turn biomass into biochar.

modern manufactured char will persist. "You can't assume that modern biochar behaves like *terra preta*," says Smolker. Soil scientist David Wardle reported in *Science* last year that, in Swedish forests at least, charcoal may cause carbon to disappear from the soil much more quickly than expected[4]. Wardle and his team left mesh bags containing either humus, charcoal or a mixture of both on the forest floor and recorded how much mass was lost from each over a ten-year period. They found that the mixtures of humus and charcoal lost more mass than the controls of humus and charcoal alone. Wardle thinks that the charcoal promoted microbial breakdown of the humus, accelerating the release of CO_2 back into the atmosphere. It's also possible that some microbes could degrade biochar directly. Although the black carbon that makes up the bulk of biochar is thought to be biologically unavailable to most microbes, research suggests that some microbes might be able to metabolize it. If so, it would be less stable in soil than currently thought[5].

Another outstanding issue is to what extent modern-day biochar application will fulfil the promise of *terra preta* in improving soil fertility. Research by Lehmann[6] suggests that in most cases the addition of charcoal improves soil productivity, and although the reasons for the increased fertility still aren't entirely understood, several things seem to be going on. First, the biochar itself contains some nutrients such as phosphorus, potassium and zinc. But the biochar also seems to help the soil retain some nutrients that would otherwise leach out, as well as helping it to retain water. In addition, biochar might encourage soil microbes that increase crop productivity. And the productivity gains seem to continue to increase even when very high levels of carbon have been added to the soil — up to 140 tonnes per hectare in sandy, weathered soils, and up to about 50 tonnes per hectare on average.

PROCEED WITH CAUTION

But without more research, says Smolker, it's wrong to assume biochar can be safely applied to soil on a large scale. "I think there's potential that this could backfire and worsen the climate situation," she says. Alan Robock, a climate scientist at Rutgers University, also worries that methods to sequester carbon, including biochar production, could distract attention from the need to reduce emissions. "The people who created the problem like the idea. They can keep using the atmosphere as a sewer and let other people clean up the mess," he says.

Most biochar researchers agree that the technology needs more study and that the most important thing is to reduce emissions in the first place. "Biochar is not a silver bullet for sequestration," Lehmann says. "We cannot continue the emissions that we generate today and anticipate that any technology or combination of technologies could compensate." Nevertheless, it's possible that biochar could help mitigate those emissions, he says.

"Part of what our group will be trying to do is to contribute to that work, and monitor and review where all this has got to," Haszeldine says. "We want to make sure we're not making a giant mistake."

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Interview: Anthony Costello

Climate change represents the biggest health threat of the twenty-first century, according to a new report published 16 May in *The Lancet*. **Olive Heffernan** talks to lead investigator Anthony Costello, director of the Institute for Global Health at University College London.

How did this study come about?
Just over a year ago, *The Lancet* challenged us to do this study. Back then, climate change was not one of my top priorities. I would have said that dealing with malnutrition and HIV and having a better health service were more important issues in health. But I've changed my perspective now, partly because I'm beginning to notice the effect that rising temperatures are having in certain parts of the globe.

What climate-related health issues can we expect this century?
In a very broad sense, there will be changing patterns of infection. Insect-borne diseases like dengue fever, tick-borne encephalitis and malaria will spread. We're already seeing blue tongue virus in livestock moving up from southern Europe, for example. But I don't think that infectious disease will be the major health effect of climate change, unless new viruses emerge, which is a great unknown.

The biggest health effect that will emerge in the next 20 years will be related to food and water security.

Heat is a silent killer. Certainly as average temperatures rise we're going to get many more heat waves and people outside of their coping range. When you get above a certain temperature level, the question is how well can people adapt.

But the biggest health effect that will emerge in the next 20 years will be related to food and water security. There could be quite serious shortages and large rises in food prices, which will penalize the poorest. Currently malnutrition is quite a significant factor in about 60 per cent of childhood deaths. This can result in low birth weight and predisposition to infectious diseases, such as measles, tuberculosis and pneumonia.

What can health professionals do?
Firstly, we have to add the voice of the health community to the argument to reduce greenhouse gas emissions. We must campaign urgently on emissions and reforestation. Climate change is going to affect the health of our children and grandchildren, and getting that message across does focus minds. Secondly, we need a framework for tackling this problem.

What exactly would that framework involve?
We need more information. I was shocked to find that there are no health impact assessments on the impacts of climate change in Africa. Not one. The World Health Organization has the tools to do this, but there are very few resources. So we need to start by having country-level health impact assessments for climate change. There's a deficit of data on climate impacts in Africa, but the situation isn't much better in Asia. Beyond that, we need to get down to localities. It's quite important to do participatory work with communities on their risks, and we're interested in launching an initiative to get people to collect their own data.

There are also lots of technological improvements we can make, whether they relate to food production or water storage and conservation. Another aspect will involve northern industrialized countries cutting their luxury emissions rather than their survival emissions. We've got to slash our emissions to get ours down to the level of a country like India. This is going to be a formidable challenge, but we have to highlight the benefits. If we could persuade everyone to take more exercise and cycle to work, for example, then there would be health benefits as well as environmental benefits. And another thing is eating less meat, of course, which would reduce methane emissions from livestock.

CHRIS CLUNN

Anthony Costello of University College London.

How optimistic are you that we can tackle this?
I think we might not get there with technology on a global scale — to clean up the globe is a lot to ask. And have we got enough time to do it? I am fearful of tipping points. There's also an absolute deficit of funding to make this work — the funding for adaptation is pitiful. So this has to become our number-one issue now. But I think there's been a tipping point in public opinion, and if we had a practical, rational action plan then there would be a lot of public support for it.

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Olive Heffernan is editor of Nature Reports Climate Change.

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