Natural solutions to climate change

Greenhouse gases, high-energy crops and the future of the world

Fifty years ago, humans harboured the hubristic idea that they could alter the weather and climate to their advantage, perhaps to prevent future ice ages or to induce rainfall in drought-stricken regions. These high-flying hopes were eventually doused by reality; today, we have the more humble objective of merely keeping the climate stable—in particular, mitigating the impact of greenhouse gases (GHGs). But this is an equally daunting task and one that necessitates political action and widespread cultural change, as well as scientific progress. Although progress on the political front is stalling—US President George W. Bush announced in April 2008 that he would postpone any measures to reduce the release of CO₂ into the atmosphere until 2025 (Stolberg, 2008)—there is some optimism about using nature itself to achieve this goal.

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The challenge is twofold: to stabilize and reduce emissions, and to mop up excess GHGs released from the burning of fossil fuels. The aim is to return to the pre-industrial—pre-late-eighteenth century—levels of the main anthropogenic GHGs: CO₂, methane, nitrous oxide, ozone and chlorofluorocarbons (CFCs). However, this does not mean completely removing them from the atmosphere. In the absence of any GHGs, the mean global surface temperature would be about –18°C, instead of the current 15°C. In fact, natural GHGs make a considerable contribution to keeping the earth warm enough for life, with water vapour being responsible for around 50% of this extra warmth—although estimates

vary from 35% to 66%. As human industrial and agricultural activities have a negligible impact on the levels of atmospheric water vapour, debates about how to mitigate climate change concentrate on the components that we can influence: CO₂, which is responsible for around 37% of the remaining warming component; methane, responsible for 5%; nitrous oxide for 6%; and the rest, including ozone and CFCs, for 2%.

More significantly, however, the increase in the levels of these gases since the industrial revolution has led to a radiative-forcing effect—the trapping of outgoing heat radiation from the Earth—which is thought to be raising global temperatures further. The increase in CO₂ accounts for 55% of this effect, compared with 16% for methane, 5% for nitrous oxide, 12% for ozone and 12% for CFCs (Blasing & Smith, 2006). It is these figures that define the GHG mitigation strategies, and the strongest focus so far has been on geological mechanisms to store CO₂. At a quick glance, this is an appealing strategy: pumping CO₂ into now-empty oil and gas fields or disused coal mines would effectively lock the carbon in place of that which was originally extracted. However, this is not a sustainable strategy as it does nothing to curb emissions and is unlikely to be able to mop up all anthropogenic CO₂—it also does not address the other GHGs. Consequently, there has been increasing interest in biological methods of sequestering GHGs, especially because these techniques have the potential to produce large amounts of carbon-neutral fuel. The CO₂ released through the combustion of such fuels would be equal to the amount of the gas previously absorbed from the atmosphere during the growth of the energy crop.

At least, that is the theory. In reality, however, growing plants and turning them into fuel requires fossil fuels in the first place, and the crops now used for biofuels are not ideal for the purpose because

they were developed for food (Ruth, 2008). Furthermore, displacing food crop production with crops for biofuels has contributed to the recent two-year doubling of the price of staple commodities (FAO, 2008). Robert Zoellick, President of the World Bank (Washington, DC, USA), has already warned about the humanitarian and political consequences of rising food prices, caused by turning food crops into fuel for consumers in richer nations, among other factors (BBC, 2008).

The main focus of short- to medium-term research is therefore on processes that both stabilize current GHG emissions and reduce atmospheric levels of GHGs—notably by addressing their agricultural production. Although agriculture makes little or no contribution to ozone and CFC levels, it accounts for nearly half the anthropogenic global emissions of methane and nitrous oxide, and about 15% of CO_2 (FAO, 2007); however, there are considerable uncertainties.

In the case of CO_2 , crops themselves are neutral, but the change in land use associated with them leads to net emissions. Deforestation, for example, releases the carbon that was previously locked in the trees. In addition, more CO_2 is produced by the microbial decay of organic debris, or by burning plant litter and soil organic matter (Smith, 2004). There is much scope for reducing these CO_2 emissions through improved management practices—for example, by avoiding the net clearance of trees, replanting certain areas, crop rotation, and more efficient processing or recycling of organic waste.

In the case of methane and nitrous oxide, there is even more potential for reducing emissions. Although these gases are released in small volumes compared with CO_2 , they trap more outgoing terrestrial radiation per unit mass and are therefore more potent GHGs—together

accounting for 21% of anthropogenic radiative forcing in total. As agriculture accounts for half of the total production of these gases, changes in agricultural practices could eliminate about 10% of human-caused climate change.

Methane is produced by the anaerobic decomposition of organic matter. The main agricultural source of methane is ruminant livestock—particularly cattle and sheep as they digest food in the absence of oxygen—along with saturated rice fields and manure. Nitrous oxide is produced naturally in the soil by microbial nitrification and denitrification. Current agricultural practices—especially the use of both synthetic and organic nitrate-containing fertilizers, as well as the planting of nitrogen-fixing crops—increase these levels. Indeed, natural and organic farming practices can stimulate the emission

of as much nitrous oxide as intensive farming methods. Overall, the increased use of nitrogenous fertilizers and proliferating ruminant populations led to a 17% increase in the anthropogenic emission of both nitrous oxide and methane between 1990 and 2005 (Smith *et al.*, 2007).

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Agricultural emissions of both methane and nitrous oxide could be reduced substantially through improved soil management, according to Pete Smith, Professor of Soils and Global Change at the University of Aberdeen, Scotland. Smith and colleagues have already catalogued potential methane reduction measures, which include the regular draining of waterlogged rice fields during the growing season and replacing foliage feed in the diet of ruminants with concentrates that contain high levels of oils (Smith *et al.*, 2008). Emissions of nitrous oxide can also be reduced, Smith says, by more judicious use of nitrogenous fertilizers to meet the precise levels needed by crops and by adopting slow-release products, perhaps with nitrification inhibitors. This would reduce the availability of surplus nitrogen in the soil for microbes to convert into nitrous oxide.

Inevitably, such measures can only reduce—rather than eliminate—agricultural emissions of these two GHGs. Yet, there is also progress in dealing with another main source of methane: landfill rubbish sites in which the organic matter decays in the absence of oxygen. Landfills are potentially easier to deal with than rice fields and ruminants because the methane produced can, in principle, be contained, collected and used for energy. In fact, given the mountains of rubbish produced in densely populated areas, the challenge for landfill sites is to increase the rate of waste decomposition and, consequently, methane production.

Therefore, landfill reactor projects began many years ago. The longest running one—situated in Yolo County in California, USA—began in 1989 and has been operating on a large scale since 1995. The success of this and other projects can be measured against

the twin objectives of decomposing waste more quickly and capturing the resulting methane more efficiently, compared with conventional landfill sites. Typically, it takes several decades for waste to decompose entirely to methane in landfill sites, with much or all of the gas ultimately escaping to the atmosphere where it contributes to anthropogenic climate change.

“We developed strategies to decompose waste to methane several-fold faster, and capture the resultant methane with high 90% plus efficiency,” said Paul Imhoff, Professor of Civil and Environmental Engineering at the University of Delaware (Newark, DE, USA) and a senior member of the California landfill reactor project. The team is also developing methanotrophic covers to consume any methane that is not immediately captured as it reaches the landfill surface. Water processing plants are also switching to the anaerobic decomposition of organic waste in order to produce methane that could, for example, be used to generate electricity and heat (Parker, 2002). Combustion of the methane captured from these processes is thus relatively carbon-neutral, as the CO₂ released was only locked into the organic waste by photosynthesis a relatively short time ago.

Measures such as these have the potential to significantly curb the emissions from agriculture and food production—but there is still the greater problem of how to sequester the GHGs produced from burning fossil fuels. At first glance, the world’s oceans would seem to be the most promising route for removing CO₂ from the atmosphere, as they already soak up around one-third of anthropogenic carbon emissions—twice as much as the land. There are various strategies to improve the oceanic carbon sink—notably, feeding iron fertilizer into the water to stimulate the growth of phytoplankton, thus boosting the rate at which they take up CO₂ through photosynthesis. Several small-scale experiments in the southern Pacific ocean have shown that this strategy works over a limited geographical range and on a short time scale, and have yielded valuable information about how to apply the fertilizer most effectively—for example, by intermittent application in harmony with natural plankton-bloom cycles.

But, such projects are environmentally controversial, with little evidence so far that they are sustainable in the long term.

Indeed, pressure from environmentalists and some scientists ultimately forced the California-based firm Planktos (Foster City, CA, USA) to cancel an ambitious plan for an ongoing oceanic fertilization scheme. One objection to the scheme was that the phytoplankton blooms triggered by the fertilization would, in turn, expand bacterial populations, thereby increasing the production of nitrous oxide and offsetting the benefits of carbon sequestration. Whatever the case, there are definite risks linked to attempting to increase the rate of oceanic CO₂ take-up. For example, one result might be a rise in oceanic pH levels with damaging consequences for corals and organisms that produce shells or exoskeletons from carbonates (Hunter, 2007).

The possible risks from land-based sequestration efforts are smaller, although not without their own ecological impacts. “Most carbon sink strategies during the next few decades should be focused at maintaining the terrestrial carbon sinks—soils and vegetation—by changing land use practice,” commented Dave Reay, a marine biologist at Edinburgh University, Scotland, who now focuses on all aspects of GHG emissions. Still, there is a definite limit to absorbing anthropogenic carbon emissions. A forest, for example, can only be a net sink for CO₂ while it is expanding in size and, therefore, increasing its capacity year on year. As Smith noted: “Yes, we can manage natural habitats to absorb more CO₂, and yes, this will be for a limited duration due to sink saturation [...] but, over time, space will run out.” He insisted, however, that biological sequestration, coupled with a genuine reduction of emissions, could have a large role in stabilizing GHG levels in the short to medium term.

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One promising candidate for long-term storage of carbon is biochar, which is made through the pyrolysis—heating in the absence of oxygen—of organic matter, just as charcoal is made by the pyrolysis of wood. Such organic matter would decay and release carbon over time anyway, but biochar persists for much longer—up to thousands of years. Biochar could therefore become a reliable way of sequestering carbon that would

instantly appeal to farmers and conservationists alike as it also greatly increases the soil's fertility, water retention capability, microbial activity and the rate of mineral delivery to plant roots. "The most obvious angle for CCS [carbon capture and storage] in this context is the use of biochar to increase soil carbon stocks and longevity, while at the same time increasing soil quality/nutrient retention and yields," Reay noted. Biochar has the potential not only to sequester carbon directly, but also to stimulate plant growth by restoring the fertility of impoverished land. This makes it easier to persuade farmers, landowners and governments to adopt biochar as it provides immediate benefits, rather than just the nebulous promise of future climate stability for the planet.

In any case, stabilizing the climate in the long term inevitably requires developing alternatives to fossil fuels. However, the current crop of renewable energies—including wind and tidal power—can only provide part of the solution, while nuclear options remain controversial in some countries. Dedicated energy crops hold great promise and some recent studies suggest that the current pessimism over the future of biofuels is misplaced. New technologies for both agriculture and energy crops could reduce the amount of land needed for food production, thus freeing up enough space to meet a large proportion of the world's energy needs (Smeets *et al*, 2007). In fact, the authors of the study estimate that energy crops could deliver 800 EJ per year without jeopardizing global food supply (1 EJ = 1×10^{18} J). This is considerably more energy than is now consumed globally—consumption was 500 EJ in 2006, according to the US Department of Energy (Washington, DC, USA). Of this 500 EJ, 86.5% came from fossil fuels, and the rest

came mainly from renewable and carbon-neutral energy sources. The International Energy Agency (Paris, France) predicts that global energy consumption will increase by 50% to around 750 EJ by 2030, and renewable energy sources will make a greater contribution to meeting this demand. If the prediction of Smeets and co-authors is correct, energy crops could thus meet virtually all of the world's energy requirements and eliminate our reliance on fossil fuels.

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More realistically, energy crops will be part of a mix of various energy sources as researchers explore other biological and sustainable means of producing energy. An important goal of synthetic biology, for example, is to engineer micro-organisms that produce hydrogen through photosynthesis instead of carbohydrates—some bacteria do this anyway, so scientists are quite confident that it is achievable. In fact, hydrogen has been touted as the energy source of the future because it burns cleanly, yields only water and liberates large amounts of energy per unit weight. But, although the automobile manufacturing and energy industries have already made considerable investments into hydrogen-based technology, the volatility and flammability of the gas is still a serious problem for building an efficient system of storage and distribution.

In the meantime, biofuels are poised to replace the use of some fossil fuels. However, sophisticated genetic engineering is almost certainly required to make them perfect for

the task to avoid costly processing and to increase the energy yield per hectare. In this regard, the public might eventually have to accept genetically engineered crops not only to help to feed the planet at a reasonable cost, but also to keep it cool.

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Philip Hunter

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