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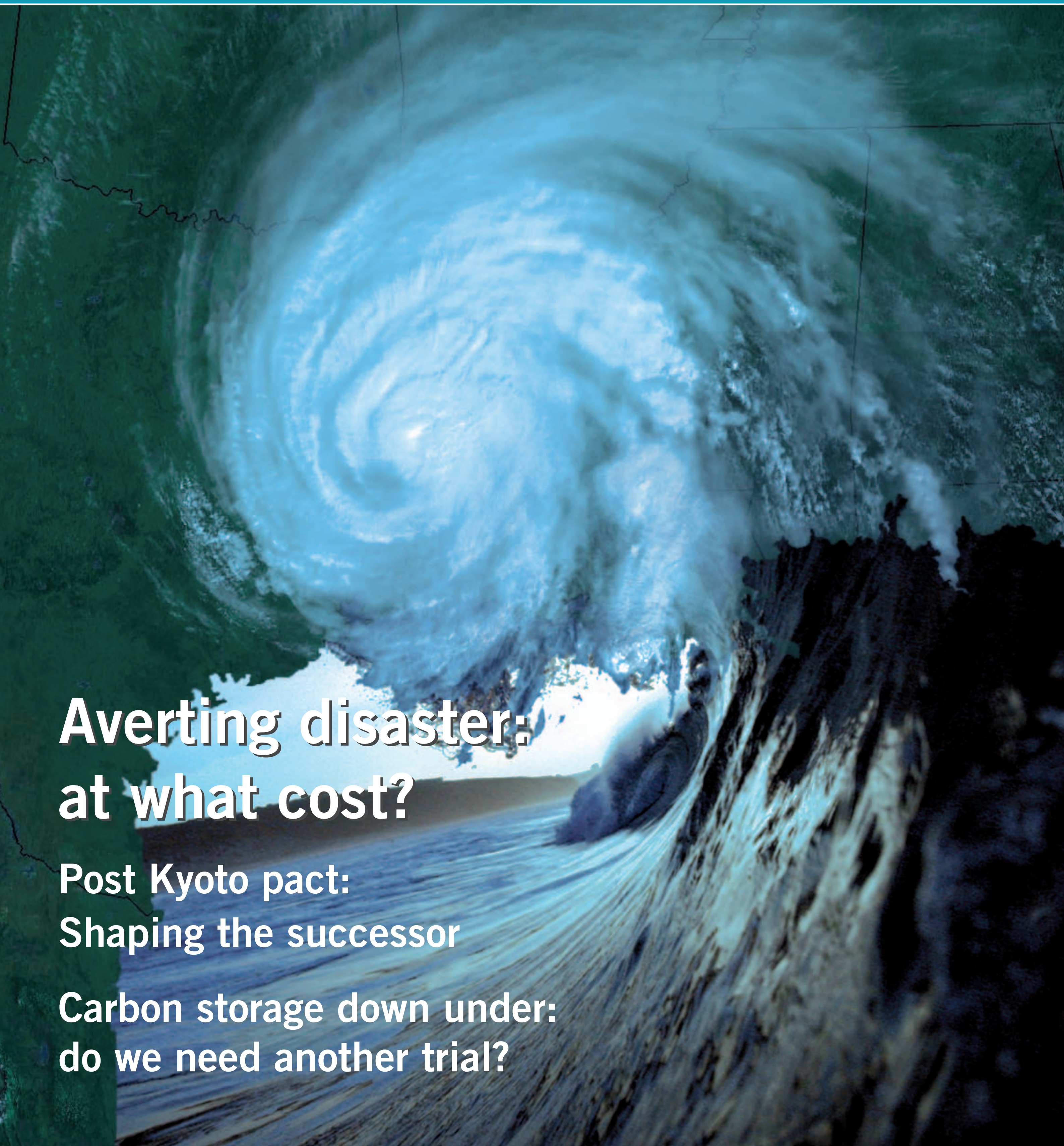

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AN END TO HOT AIR

Climate change is the most far reaching of the great challenges of the twenty-first century. It affects not only all people on the planet, it will also govern the future of the rest of the biosphere. Because so much, and so many, are at stake, the question of how to minimize and deal with climate change remains hugely controversial.

Making good choices on how we deal with such change requires accurate information and open discussion. It is now firmly established that human activity is largely responsible for the climatic future, but there is still much to say, and to learn, about the extent and the timing of the changes to come. Yet, despite a 20-fold increase in coverage of climate change in the UK since the 1980s (and a fivefold increase in the US over the same period), the facts of climate change remain a low priority for the mainstream media. Readers are often left out in the cold when it comes to separating issues of consensus from debate, fact from opinion and even fact from fiction.

In light of the need for greater discussion and understanding and easier access to information, *Nature* has launched a new online resource to extend its reporting of the issue. *Nature Reports: Climate Change* is freely accessible and is updated weekly with unique news, comment, analysis, reviews, features and more. Every month, the content is collated into a downloadable digital edition, of which this is the first issue. Each issue can be cited and archived just like a magazine —but without the carbon footprint that goes with ink on paper. If you prefer, you can get some of the material in audio form through our monthly podcasts coming shortly.

Aside from providing authoritative coverage of climate science and its wider implications, *Nature Reports: Climate Change* is an interactive hub, with opportunities for readers to contribute by commenting on our *Climate Feedback* blog and by voting on recent papers in our Journal Club.

The website complements *Nature*'s existing coverage of climate change, both in print and online. Together with sister sites on Avian Flu and Stem Cells, *Nature Reports* represent a new venture for *Nature*, providing site-specific online coverage of highly topical and controversial issues of interest to the world at large. We hope you enjoy reading and joining our discussions.

OLIVE HEFFERNAN, NEWS EDITOR

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MITIGATION

Barking up the wrong tree?

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Proc. Natl Acad. Sci. **104**, 6550–6555 (2007)

It is often assumed that global warming can be reduced by planting trees, which soak up carbon dioxide from the atmosphere. However, trees also change the planet's surface albedo, or its ability to reflect sunshine.

Govindasamy Bala of the Lawrence Livermore National Laboratory in California and co-workers compared a deforested world with a standard world using an integrated global carbon cycle and climate model. A treeless world would be 0.3 K cooler by 2100, they claim. Although this world would have higher carbon dioxide in the atmosphere and oceans, it would reflect more sunlight, lowering the temperature.

Deforestation does not have the same cooling effect everywhere. In the tropics, clouds forming above rainforests also reflect sunlight. Their loss would cancel out any cooling effect from increased land reflectivity as a result of logging. Compared with the standard world in 2100, a world devoid of tropical forests only would be 0.7 K warmer, mainly from CO_2-induced warming, whereas a world lacking only high-latitude trees would be 0.8 K cooler than the standard world.

The scientists advise against deforestation to mitigate global warming because of forests' many economic and environmental values.

Samia Mantoura

BIODIVERSITY AND ECOLOGY

Fruiting fungi

© A. C. GANGE

Science **316**, 71 (2007)

The fruiting season for fungi in southern England has more than doubled in the last half century owing to the region's warmer summers and wetter autumns. Many species are now also fruiting twice a season. This is an unprecedented change in reproductive behaviour attributable to the planet's warming.

Alan Gange of the University of London and colleagues found that the period from first to last fruiting for autumn-fruiting species has increased from around 33 days in the 1950s to almost 75 days in the current decade. The fruiting season expansion correlates to higher temperatures in the region since 1975. The researchers also found that 140 of the 315 species studied now fruit twice a year.

The study of more than 52,000 records of fruiting dates expands the body of data on the effects of climate change on living organisms. Previous studies have focused on springtime changes to growth and migration patterns of birds, insects and plants. Fungi play a key role in forest ecosystems, breaking down leaf litter and returning nutrients to trees via their roots. The expanded fruiting season implies a major increase in nutrients available to trees and thus increased tree growth.

Eric Smalley

OCEAN SCIENCE

Twilight zone transport

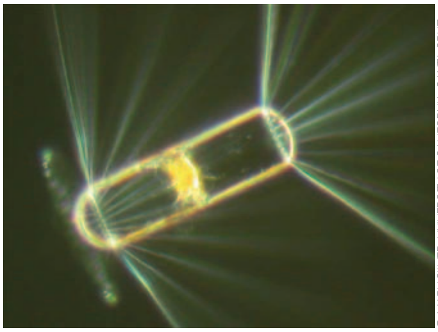
Science **316**, 567–570 (2007)

Carbon that reaches the deep ocean is stored and does not re-enter the atmosphere for centuries, mitigating its short-term contribution to global warming. Microorganisms inhabiting the mesopelagic or 'twilight zone' between about 100 and 1,000 metres consume carbon as it sinks, however, making it available as a greenhouse gas.

Now, an international team led by Ken Buesseler of Woods Hole Oceanographic Institute has discovered that the efficiency of carbon transport to the deep sea depends critically on the type of microorganisms in the murky mesopelagic. Using a newly designed sediment trap that hovers at specific depths, they measured the transfer through the twilight zone of sinking carbon-containing particles in Hawaiian subtropical and Northwest Pacific subarctic waters.

In the Northwestern Pacific, where diatoms thrive on the nutrient-rich waters, carbon reached the deep ocean with an efficiency of 46 to 55%. In nutrient-poor Hawaiian waters, dominated by smaller, shell-less phytoplankton, the transport efficiency was only 20%. Extrapolated globally, the difference in carbon sequestration between the nutrient-rich and nutrient-poor waters is equivalent to nearly half of all human-generated carbon emissions. As the oceans warm, nutrient supply is expected to decrease, which will favour smaller phytoplankton and less carbon storage in the deep sea.

Eric Smalley



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EXTREME EVENTS

Rainfall rules

Geophys. Res. Lett. **34**, L07711 (2007)

Checking Mediterranean rain gauges in winter may provide clues for predicting Europe's next deadly heat wave. Robert Vautard of France's Institut Pierre-Simon Laplace and colleagues have now discovered that a deficit of winter rainfall in southern Europe is a good indicator of high summertime temperatures and drought farther north.

Using meteorological data from over 100 sites in Europe, Vautard's team analysed the ten hottest European summers between 1948 and 2005, including 2003 when some 35,000 people died. All were preceded by southern

European winters of below average rainfall. The water reservoir in Mediterranean soils plays a crucial role in maintaining this link, the researchers say.

During dry southern winters, soils release little moisture to the atmosphere. As a result, southerly winds blow warm dry air northward, reducing cloud cover and warming the air. Northern soils also dry faster, causing further warming from below. Scientists expect southern Europe to become increasingly dry, triggering more frequent heat waves and drought, as a result of climate change. Authorities can better prepare for extreme summer heat by studying rainfall patterns in the Mediterranean each winter.

Harvey Leifert

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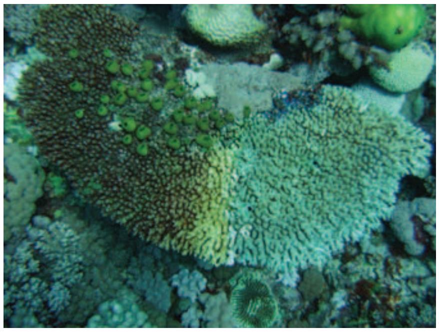
Biodiversity and Ecology

Healthiest corals hit hardest

PLoS Biol. **5** (6), e124 (2007)

White syndrome is a disease fatal to Pacific reef-building corals. Although the disease has been linked to an increase in ocean temperature, it has a complex epidemiology and predicting its spread has proven difficult. John Bruno of the University of North Carolina in the USA and colleagues have now found the first conclusive evidence of a link between the frequency of warm years and the severity of the disease on corals along Australia's Great Barrier Reef.

Combining high-resolution satellite observations of ocean temperature with annual on-site epidemiological inspections, the researchers tracked white syndrome along 48 reefs over six years. They found that warmer ocean temperature was a necessary, but not sufficient, condition for the spread of the disease. When temperatures increased by at least 1 °C in 1 to 6 months, healthy reefs



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with a minimum of 50 % living coral cover suffered more severe outbreaks than reefs with less living coral.

The greater concentration of fish and other species on healthy reefs may assist the spread of white syndrome, the researchers say. Weaker reefs attract far fewer fish and paradoxically escape such epidemics. Rising sea temperatures resulting from climate change could see diseases like white syndrome destroying reefs.

Harvey Leifert

Atmospheric science

Winds of change

Geophys. Res. Lett. **34,** L08702 (2007)

An increase in the intensity of Atlantic hurricanes over the past decade has been attributed to climate change. Now, a new study suggests that global warming could induce atmospheric changes that will tear apart Atlantic hurricanes during this century.

Using 18 of the latest global climate models, Gabriel Vecchi at the National Oceanic and Atmospheric Administration in Princeton, New Jersey and Brian J. Soden from the University of Miami in Florida predicted the number and intensity of tropical Atlantic storms for early and late twenty-first century. Wind shear, caused by differences in the speed or direction of wind with altitude, is likely to strengthen in the region, they found. This effect is linked to weakening of the Pacific Walker circulation, a wind system that influences global climate and slows during El Niño events when fewer hurricanes form.

The study represents the first evidence that changes in wind shear could be large enough to counteract the increase in hurricane activity associated with higher sea surface temperatures. In the tropical Atlantic and East Pacific, the effect of wind shear on hurricanes could overpower that of ocean warming. Most other areas, however, will experience more frequent and intense storms.

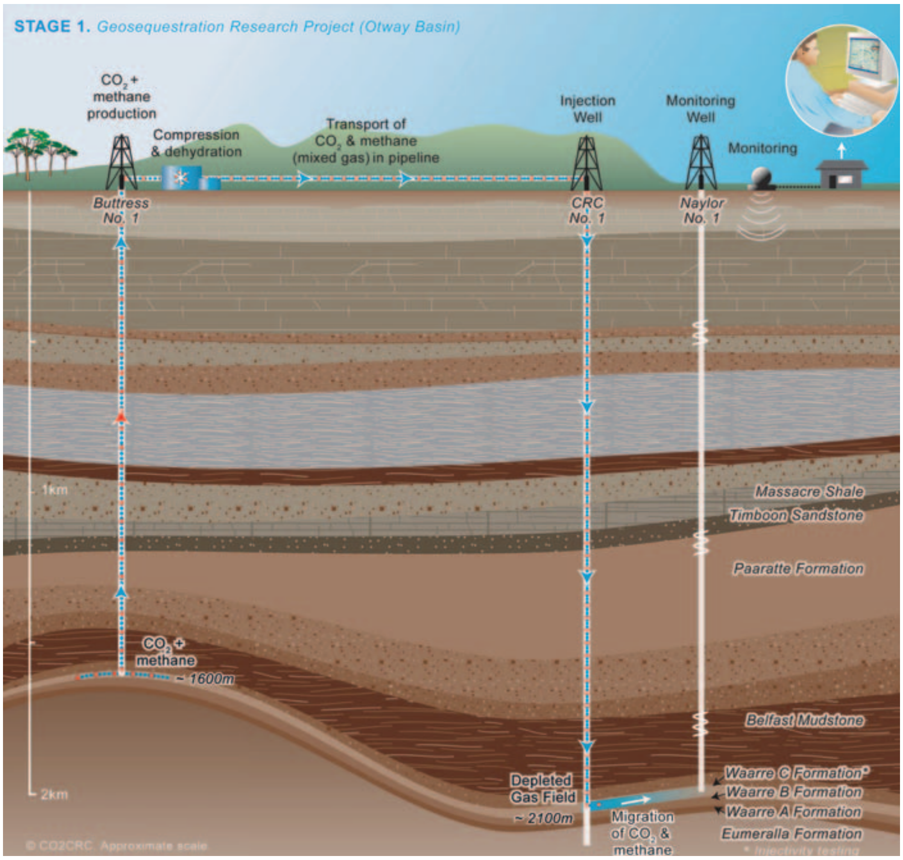
Samia Mantoura

Carbon storage deep down under

As the world's largest trial carbon storage project gets underway, some are questioning its necessity. Hannah Hoag reports from Australia

Perched on the southern edge of Australia, the Otway Basin spreads offshore from Cape Jaffa in South Australia, through Victoria, to the northwest coast of Tasmania. For nearly 100 years, gas wells have been drilled into the onshore portion of the basin that was formed when Antarctica broke free of Australia. Now researchers are probing the basin for its capacity to store carbon dioxide generated from Australia's coal-burning power plants. But some are asking if the world needs another demonstration project.

The Otway Basin Pilot Project, Australia's first carbon sequestration demonstration project — and perhaps the most intensely monitored — kicked off in February when the drilling of a 2,100-metre well began near the small town of Warrnambool, about 250 kilometres from Melbourne. Peter Cook, head of the Canberra-based Cooperative Research Centre for Greenhouse Gas Technologies (CO2CRC) that runs the project, says they plan to begin injecting gas into the new well in July. By the end of the year, up to 100,000 tonnes of supercritical carbon dioxide will have been injected into the natural reservoir.



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Concept for the Otway Basin pilot project

PROMISING PROSPECTS

Consisting of porous sandstone overlain with an impermeable mudstone, the Otway Basin has been identified as Victoria's most suitable onshore carbon storage site. After the carbon dioxide is injected, researchers expect it to disperse through the porous rock, but remain locked below the mudstone seal. Geologists say rock samples from the site show that both the sandstone layer and the cap-rock above it have the correct features to safely inject and store the carbon dioxide.

If the gas does leak, it will be detected by an extensive monitoring system sniffing the surrounding soil, water and air. Tracers will distinguish the injected carbon dioxide from that produced by vegetation or other natural sources. "Because of the risk assessment and all our geological knowledge of the site, we don't expect any carbon dioxide to leak, but there could be some force that we cannot see," says Kevin Dobbs, at CSIRO Petroleum in Perth and CO2CRC.

> "These are important experiments in terms of bringing down the costs of carbon sequestration"
> Peter Cook

WORLD FIRSTS

The reservoir holds promise for the state's future efforts to curb its greenhouse gas emissions. According to a study by the Australian Petroleum Cooperative Research Centre, Australia could currently store 25–30% of its carbon dioxide emissions using such sites. And Cook says that as more suitable sites are found and as power plants are built closer to storage facilities, the capacity to capture carbon dioxide will grow. Well-chosen and maintained sites should be able to retain 99% of buried carbon for over 1,000 years.

Although it is the world's largest carbon burial demonstration site, Otway Basin is smaller than the world's biggest commercial carbon burial project at Sleipner in the North Sea. There, the injected carbon dioxide enhances oil recovery, enabling Statoil to recover some of the costs of carbon storage

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Black and brown coal produces 85% of Australia's electric power generation

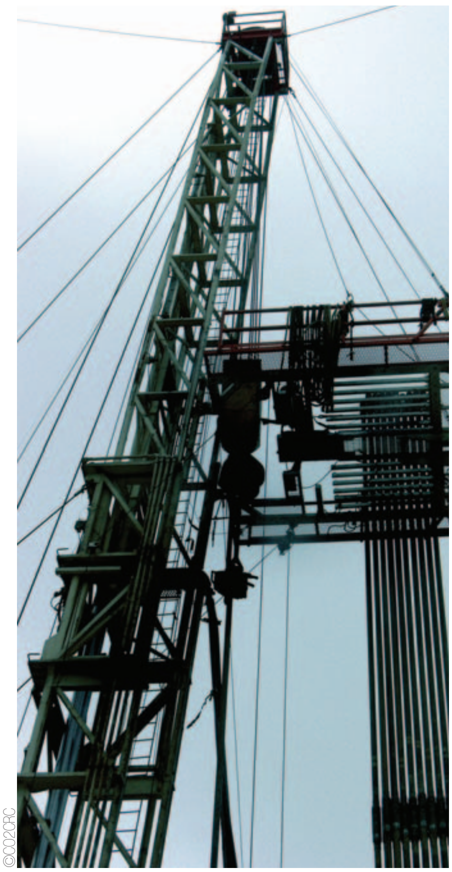
and save carbon taxes. The Otway project will help determine which injection and monitoring methods are most cost-effective for underground burial. "These are important experiments in terms of bringing down the costs of carbon sequestration," says Cook.

CHALLENGING CONSENSUS

Many environmental groups are not enthusiastic about burying carbon, saying that scientific efforts and financial investments should focus on cutting emissions rather than the subterranean storage of greenhouse gases. "The current commitment of public funds by the Australian, Queensland and Victorian governments toward R&D of coal capture and storage [is] about A$800 million," says Ian Lowe, president of the Australian Conservation Foundation, and emeritus professor at Griffith University. "By comparison, we have spent less than A$100 million on all forms of renewable energy supply and about A$10 million on efficiency improvements."

But it is unlikely that coal is on its way out in Australia. Black coal and the dirtier brown coal are abundant and account for producing 85% of the country's electric power generation. In 2003, Australia was the world's leading coal exporter, supplying 238 million tonnes of coal to the international market. Globally, 25% percent of the world's energy demand is met by coal, and the International Energy Agency only expects coal use to rise – nearly 1,400 gigawatts of new coal-fired power generation capacity may be built globally between now and 2030, compared with the current global capacity of 1,100 gigawatts.

Others are asking whether we are wasting time we don't have by building small-scale carbon capture and storage facilities. "Every step we delay, more power will come on the grid without this technology and it will become more and more entrenched," says Dobbs. How much more additional research is needed before we start to deploy carbon capture and storage technology? David Hawkins, the director of the climate change centre at the Natural Resources Defense Council, a US non-profit, recommends the carbon dioxide emissions from all new plants be captured and stored. "We know enough about the geologic storage mechanisms to do this safely and effectively," he says.



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Drilling at the Otway Basin test site

> "Every step we delay, more power will come on the grid without this technology and it will become more and more entrenched"
>
> Kevin Dobbs

RISK ASSESSMENT

Hawkins and Stefan Bachu, a senior geosciences advisor at the Alberta Energy and Utilities Board, Canada, presented a paper at the 8th International Conference on Greenhouse Gases in Norway last year evaluating the risks posed by proceeding with large-scale carbon capture and storage compared with delaying implementation. The pair found that if the technology was up and running by 2012 — even with "unrealistically high assumed leakage from the sites" — net carbon dioxide emissions to the atmosphere from these plants would be far less than if their construction were delayed for the data analysis from additional demonstration projects. "We aren't arguing that we go out and drill a hole anywhere and start pumping carbon dioxide into it — there need to be site surveys," he says. "But rather than a ten year research program, if there is a coal-powered plant being built it should have its carbon dioxide captured."

Either the cost of carbon capture and storage will have to drop or the cost of carbon emissions will have to rise before these plants are built. In their recent report, *The Future of Coal*, researchers at the Massachusetts Institute of Technology found that the technology would not be adopted until carbon emissions cost $30 per tonne. Until then, it will always be cheaper to float the carbon dioxide into the air than to bury it into the ground. □

Hannah Hoag is a freelance science writer.

Averting disaster: at what cost?

JEFFREY D. SACHS

Avoiding dangerous climate change will require considerable global efforts to reduce greenhouse gas emissions. A daunting challenge, but one that is practically and economically achievable, argues Jeffrey D. Sachs.

The basic economics of climate change have been explained clearly in the Stern Review[1]. The global business-as-usual (BAU) path, in which fossil fuel use continues unabated without reducing carbon emissions or capturing and sequestering them, will raise atmospheric concentrations of greenhouse gases during the coming decades to dangerous levels. The higher the greenhouse gas concentrations the greater the societal costs will be, in terms of more frequent and extreme droughts and storms, loss of biodiversity, declining crop yields, rising sea levels and much more[2]. Emissions can be averted, and thereby greenhouse gas concentrations can be reduced below the BAU path, at an extra cost to society. As long as the resulting social benefits exceed this abatement cost, then it should be adopted. The optimum pace and intensity of emissions reduction are found by balancing the additional costs of aggressive greenhouse gas stabilization against the incremental benefits of reduced climate change.

THE BARGAINING GAME

So far, so good. But the translation of these ideas into practice is extremely challenging, both conceptually and practically. The costs of reducing emissions are unknown, because their control will depend on a myriad of technologies that are potentially effective but not yet proved. The societal costs of climate change are known with even less precision. Moreover, both societal and abatement costs will vary widely across geographical space and across generations. At a conceptual level, there is an enormous bargaining game, marked by potential winners and losers, high uncertainty, potential side payments, tendencies towards free riding, and future generations who are not even at the bargaining table. The current generation plays its own hand, as well as that of future generations. Some might say the game is rigged.

For many concerned observers, the situation appears to be well nigh hopeless, simply too complex to reach an accord that bridges the diverse interests of rich and poor countries, and current and future generations. Moreover, implementation will depend on literally billions of individual decisions in the present and future, and these of course will be exceedingly difficult to align, even if the world can agree on a desirable path of emissions control. The prospects, for example, would seem to compare very poorly with the control of ozone depletion. In that case, the central challenge centred on phasing out the use of a single class of industrial compounds — chlorofluorocarbons (CFCs) — in the context of a limited number of industrial producers and users, and with good technical substitutes at hand.

HIGH-IMPACT APPROACH

Yet a closer look at this daunting challenge of climate change gives several important reasons to believe that a global agreement and implementation plan are much closer than they initially seem. First, perhaps two-thirds or more of the fossil-fuel-based emissions of carbon dioxide — the main greenhouse gas — depend on a small number of industries. Electricity generation and automobiles account for roughly half of the total emissions. Other high-emission industries include steel, petrochemicals, refineries and cement. A large proportion of non-fossil-fuel-based carbon emissions arise from tropical deforestation.

The highly concentrated nature of carbon emission sources suggests that the preponderance of abatement efforts could be addressed using a focused strategy, including:

- emissions reduction at power plants through a shift to non-carbon energy sources (such as wind, solar and nuclear) and through carbon capture and sequestration (CCS) for fossil-fuel-burning plants;
- high-mileage automobiles — of 100 miles per gallon (42 km per litre) or more —which use plug-in hybrids, light-weight materials and other technologies;
- high-impact energy efficiency by replacing incandescent bulbs with compact fluorescent bulbs, improving building insulation and using 'smart' motors and appliances that economize on electricity;
- emissions control in cement, petrochemicals and steel through CCS, improved boilers, stationary fuel cells, improved heat management and other technologies;
- direct 'air capture' of carbon dioxide and subsequent sequestration — a variant of CCS;
- reduced tropical deforestation through incentives to preserve the forest margin.

By focusing on selected high-impact sectors, the number of relevant decision makers can be reduced by several orders of magnitude. Rather than facing billions of individual decision points, the control efforts are focused on a few thousand power plants, a dozen or so global automobile manufacturers, and a few thousand large industrial units.

Smart incentives can be tailored to each sector, using a combination of industrial codes and standards, tradable permits, carbon taxes and other regulatory tools. Emissions limits can be phased in to achieve predictability while avoiding costly shocks to global economies. Public policies can be set to ensure that the incentives across key sectors are at least roughly comparable, so as to equate the marginal abatement costs across transport, industry and buildings, and across countries.

This sort of targeted approach can avoid an unwieldy global emissions permit system that aims to cover millions of enterprises around the world, in a naïve extrapolation of the European Emissions Trading System. Such a system would be virtually impossible to negotiate and even harder to police. It would probably open the way for massive, arbitrary and politicized wealth transfers resulting from the allocations of carbon permits across countries and enterprises.

CONTROLLABLE COSTS

There is another crucial reason why success may prove to be easier than is now feared. With enough lead-time and policy consistency, the annual global costs of emissions abatement are likely to be relatively modest, on the order of 1% of the world's income, or perhaps less. If true, the inevitable wrangling across countries and generations can be muted, even solved, as the amounts at stake will be manageable on both financial and political scales. Rich countries will be able to afford both their own emissions control as well as co-financing of control in poorer countries as part of equitable cost sharing.

Of course, the absolute costs of global emissions abatement are likely to be significant. The world gross national product by mid-century could be $200 trillion or more (measured in today's dollars), compared with around $50 trillion today. An annual emissions abatement cost of 1% would therefore be $2 trillion, not a trifling sum, but one that would be manageable within a much larger and richer world economy. In fact, there are reasons to hope that the control costs could be held far below 1% of the gross national product, but the precise costs will of course depend on technologies that are still highly uncertain and on the decades-long trajectory of emissions control. The longer the world waits to begin serious emissions abatement, the more rapid — and more costly — the transition to a low-emissions global regime will be.

Given the crucial role of new, and yet-to-be proved technologies, one of the key goals for policy is public funding for research, development and diffusion of low-emissions technologies. An early focus, for example, should be on carbon-capture and sequestration, and plug-in hybrid automobiles. Market forces, left on their own, will under-invest in basic science, and a sole reliance on patents as the incentive for R&D will slow down the diffusion of successful technologies by granting their owners a temporary monopoly. These considerations, well known in public economics, suggest a central role for public financing of R&D.

A WORKABLE SYSTEM

If these reflections are roughly correct, they suggest three guidelines for global negotiations over emissions control. First, the world need not aim for comprehensive sector-by-sector control of carbon emissions, but for a focus on key sectors. Second, the world should not argue endlessly about perfect efficiency and perfect justice as the ultimate costs of emissions control are likely to be fairly modest, whereas the costs of delay could be extremely high. We should aim for a workable system, not a perfect system. Third, we should give an urgent focus on the development and diffusion of new technologies.

"The world should not argue endlessly about perfect efficiency and perfect justice as the ultimate costs of emissions control are likely to be fairly modest, whereas the costs of delay could be extremely high."

Complex as this agenda will be, mitigating greenhouse gas emissions will be only part of the story. Climate change is already upon us and will intensify considerably even if we succeed in stabilizing and then reducing global emissions in the coming decades. Sensible policies must therefore not only mitigate climate change, but adapt to it as well, learning as best as possible how to live with the inevitable increases of water stress, crop failures, extreme storms, and other shocks that are on the way. The challenge of adaptation requires a separate and thorough strategy, and the global work on that has hardly begun.

Jeffrey D. Sachs is Director of the Earth Institute at Columbia University and Quetelet Professor of Sustainable Development

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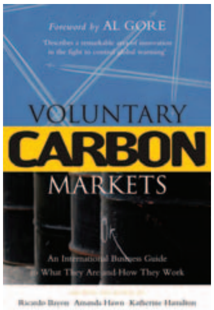
Optional offsetting



Matthew Lockwood

Will voluntary carbon markets genuinely tackle climate change or could they encourage further emissions?

VOLUNTARY CARBON MARKETS: AN INTERNATIONAL BUSINESS GUIDE TO WHAT AND HOW THEY WORK

Edited by Ricardo Bayon, Amanda Hawn and Katherine Hamilton

Earthscan: 2007. 164 pp. £24.95

The origins of the voluntary carbon market lie in the growing trend amongst companies over the last twenty years to demonstrate their corporate social and environmental responsibility. Through financing projects that (claim to) reduce greenhouse gas emissions, companies or individuals can offset their own emissions in an attempt to go 'carbon neutral'. The first recorded offset deal took place in 1989, when an American electricity company, AES Corporation, invested in a tree-planting project in Guatemala. Since then, offsetting has become increasingly mainstream. An example discussed in some detail in this book is the commitment by international bank HSBC from late 2005 to buy carbon offsets of about 600,000 tonnes a year. From small beginnings, total trading in voluntary carbon markets has grown in volume to 3–5 million tonnes of carbon in 2004 and to an estimated 100 million tonnes this year. This short book is the first of its kind — a practical and comprehensive guide to these rapidly growing markets for voluntary carbon offsets.

The authors cover the basic theory of emissions trading and provide a useful overview of the official (here called 'compliance') markets established through the Kyoto Protocol. They include the Clean Development Mechanism (CDM) offset markets, whereby parties to the Protocol can buy part of their emissions reduction effort through projects in developing countries, such as renewable energy investments or methane and other greenhouse gas capture projects. Some CDM credits are also permitted in the world's largest official market, the EU emissions trading scheme. Shifting the focus to the voluntary market, the authors provide a clear and quite detailed explanation from product creation, to verification, distribution and consumption.

Written largely from a US perspective, a central portion of the book describes the growing links between the national voluntary carbon market and renewable energy certificates (RECs). Like Renewable Obligation Certificates in the UK, RECs are designed to incentivize investment in renewable power generation. Market makers in the US are increasingly offering RECs as a product for other companies and individuals wishing to purchase offsets. They effectively retire the RECs, thereby helping to maintain scarcity in the market and keeping the price up. Sales of RECs in the American voluntary market more than doubled between 2003 and 2005 alone.

Despite a diversity of contributors (in addition to the main authors, thirteen, including carbon traders, project developers and NGO experts on voluntary markets), most of them make the same two points. The first is that the voluntary market will remain secondary to, and will probably eventually be swallowed up by, official markets. Official carbon markets are established in the EU, Japan and parts of Australia, and are due in California and the North Eastern American states very shortly. Likewise, in the UK, a new mandatory carbon cap-and-trade scheme — the Energy Performance Commitment — will draw many large retail and service organizations into a compliance market. There are many questions about how the voluntary market will interact with these official markets, and a global official market (as argued for in the Stern Review) is now an increasingly likely reality.

The second point is that although the voluntary system offers flexibility and innovation not seen in the official

Voluntary markets offset emissions through projects such as afforestation, gas capture and renewable energy projects.

markets, the down side of this is the common problem of ensuring standards in a new and unregulated market. This is not an insignificant problem given that the efficacy of some Clean Development Mechanism projects within the Kyoto Protocol is under question. As HSBC found when it entered the market as a particularly large buyer, finding credible offset projects is still not an easy task. This book acknowledges the lack of uniformity in voluntary markets — which offset emissions through a range of projects from afforestation in central America, to landfill gas capture initiatives, through to large-scale renewable energy projects in the USA — as well as the lack of transparency in some projects.

The authors raise the major pitfalls of emissions offsetting, ranging from how a company buying credit knows whether the emission reduction would have happened anyway (so-called 'additionality') to ensuring it is reasonably permanent. Trees planted to offset emissions might die, for example. These credibility issues are not probed in any great depth, however. With the subtitle: "An international business guide to what they are and how they work", this book is not a critical theoretical treatment. What the authors do provide is quite comprehensive information on how the market itself has attempted to respond to its shortcomings, for example by developing major international standards. One problem with a book like this is that it can very quickly become dated, nowhere more so than in such a fast-developing area.

The biggest question overhanging offset markets — both official CDM projects and voluntary market projects — is whether they actually help tackle climate change, or, through giving a false sense of security, actually encourage further emissions. At the end of the book the authors describe the voluntary carbon market as "an interesting public relations and risk-management option for companies", which "at the same time helps involve and educate consumers about the importance of combating climate change". PR and risk management are not bad objectives, but they do not equate with genuinely offsetting emissions. The latter can only be guaranteed if this effectively self-regulating market improves standards across the board, to ensure that all credits reflect genuinely additional and lasting emissions reductions — a very challenging task. With its acknowledgement of the challenges, this handbook is a useful and practical contribution to helping address the shortcomings of the voluntary markets. However, the optimistic prediction that they will develop into an important part of efforts to stem climate change, providing a broad spectrum of 'gourmet carbon' products, needs to be taken with a pinch of salt. □

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OCEAN SCIENCES

Iron findings

Philip W. Boyd

A huge phytoplankton bloom in the Southern Ocean yields estimates of how a continuous supply of iron affects oceanic carbon sequestration. But iron is not the only factor — nutrient supply is crucial too.

The ocean is a daunting place to study, where investigations must contend with a wide range of scales — from intracellular to ocean basins, from nanoseconds to seasons[1]. The difficulties are evident in the variety of approaches used to study the ecological productivity of its microscopic algae, or phytoplankton. Small-scale perturbation experiments, for example incubating seawater samples in small bottles with added elements such as iron, provide useful information on phytoplankton physiology and other intrinsic processes. They cannot, however, represent processes occurring across entire ecosystems, as the sampled phytoplankton are enclosed and isolated. In contrast, 'mesoscale' *in situ* studies, which perturb patches of ocean on the scale of hundreds of square kilometres, can address ecosystem-scale questions[2]. But even month-long experiments at this scale have flaws, such as pronounced mixing of the enriched patch with surrounding waters, altering its properties.

In a recent paper in *Nature*, Blain *et al.* (page 1070, Vol 466, 2007)[3] overcame these scaling issues by investigating a naturally occurring phytoplankton bloom covering an area of 45,000 km^2. Such large blooms photosynthetically convert so much carbon into an organic form that they have a marked effect on the atmospheric carbon dioxide concentration, and hence the global climate: a significant proportion of the carbon thus 'fixed', known as particulate organic carbon, is sequestered in the ocean depths. Iron is now recognized to be of equal importance to nutrients such as nitrate[4] in stimulating the development of these blooms. A larger supply of iron to the surface ocean — from dust deposition, for instance, as recorded from the geological past[5] — can increase phytoplankton productivity and thus carbon sequestration and CO_2 drawdown[6].

Blain and colleagues[3] used satellite images to pinpoint an annually recurring bloom near Kerguelen, an island archipelago in the Southern Ocean south of, and at a longitude about equidistant from, South Africa and Australia. This 'natural laboratory' was sustained for months through constant iron and nutrient enrichment from below (Fig. 1, overleaf). The larger spatial and temporal scales of the bloom permitted Blain and colleagues to address questions inconclusively covered by previous mesoscale iron-enrichment studies in polar regions (see ref. 2 for a review). Chief among these was how much of the carbon fixed by the bloom was sequestered into the ocean depths.

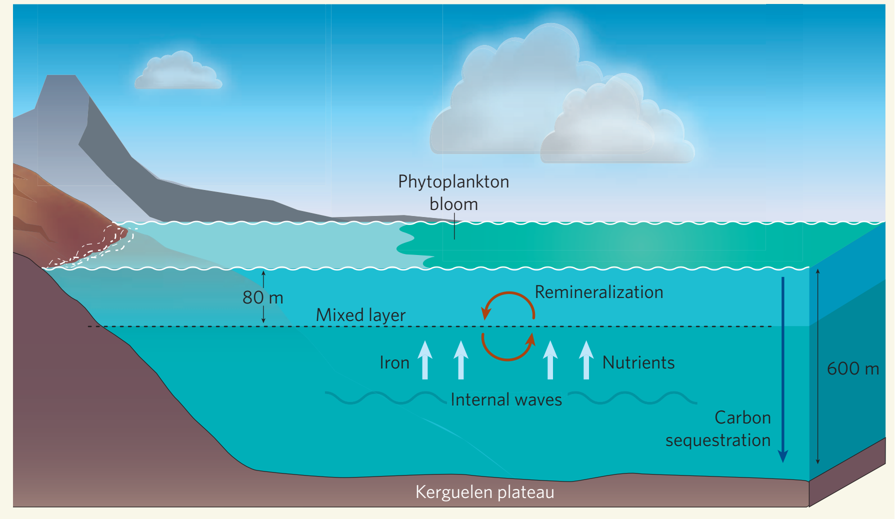

Figure 1 | Kerguelen blooming. The Kerguelen plateau is about 600 m under the ocean surface; in this region, internal waves enhance the vertical mixing of the deep waters above the plateau, which have higher iron and nutrient concentrations, with those in the 80-m-thick surface mixed layer. Up to half of the particulate iron and other nutrient elements were broken down (remineralized) to dissolved forms in the upper ocean. Both of these processes supplied continual nourishment to the phytoplankton studied by Blain *et al.*[3], which — through photosynthesis and the subsequent sinking of organic carbon into the deep ocean over several months — contribute to higher than previously reported[2] sequestration of atmospheric CO_2 per unit iron supplied.

The determinant of whether iron enrichment can alter global climate is the magnitude of carbon sequestration per unit of iron added. During their 30-day study, Blain *et al.* report 10 to 100 times more carbon export per unit of iron supplied than was estimated during the previous studies. These higher ratios are particularly significant, because they indicate that the higher iron supply evident during glaciation maxima[5] had a greater impact on atmospheric CO_2 drawdown than has generally been assumed. The contribution of iron enrichment to the total glacial–interglacial shift of 80 parts per million (p.p.m.) in atmospheric CO_2 might therefore approach the upper bound of 24 p.p.m. cited recently[6].

What are the reasons for this discrepancy[2,3]? Blain *et al.*[3] provide two explanations. First, the polar mesoscale iron-enrichment measurements[2] underestimated carbon export, because they were too short-term (lasting just weeks) to observe its full extent. Second, they overestimated iron supply: pulses of extra iron into the surface ocean are prone to rapid removal, for example by sticking to sinking particles.

The ratios of carbon export to iron supply estimated by Blain *et al.* for particles sinking from the Kerguelen bloom are very similar to carbon–iron ratios in phytoplankton in high-iron laboratory cultures[7], pointing to little biological modification of these ratios between photosynthesis and subsequent sequestration. The similarity of the ratios is difficult to reconcile with recent reports that the organic carbon on sinking particles is broken down into dissolved forms, or remineralized, more rapidly than is iron[8]. The authors also report high stocks of zooplankton grazing on the Kerguelen blooms that would be absent from the laboratory cultures. The presence of zooplankton aids the remineralization of both iron and carbon, and thus reduces carbon export while resupplying iron to the phytoplankton.

The phytoplankton bloom at Kerguelen, fuelled by a sustained supply of iron and nutrients, was of exceptional duration, lasting some months. Although it used up virtually all of the iron and silicic acid in surface waters, it did not deplete its nitrate stock. Under high-iron conditions, a bloom should use equal amounts of nitrate and silicic acid[9]. The implication is that, despite the continuous vertical supply of nutrients characteristic of the Kerguelen site, the growth rate of the resident bloom is probably suboptimal owing to insufficient iron.

Together with other measurements[2], Blain and colleagues' results provide a powerful tool for modellers investigating the effects of the mode of iron supply on ocean biogeochemistry. The main modes, in the geological past, have been episodic iron enrichment of the uppermost ocean through dust deposition and/or sustained enrichment of overlying waters through the upwelling of deep waters. The sustained iron and nutrient supply through internal wave activity at Kerguelen means that the intensity — and, more importantly, the ratio of its iron and nutrient supplies — may differ from those of polar upwellings. A quantification of the effects of upwelling and internal waves on this ratio is needed to determine whether the Kerguelen data are a proxy for the polar ocean during the glacial maxima.

But does Blain and colleagues' evidence[3] of more carbon export per unit iron supply mean that iron enrichment is a viable short-term climate-mitigation strategy? The authors say no: the enhanced export resulted from bloom longevity that was driven not just by sustained iron enrichment, but also by continuous nutrient enrichment. Moreover, the ratio of carbon export to iron supply is notoriously difficult to measure, and only a fifth of the phytoplankton's requirements were accounted for in the study's iron budget.

Nevertheless, the work is a novel and valuable addition to the library of phytoplankton-biogeochemistry studies. A final testament to the challenges of marine research, and the technical difficulties in assessing the efficacy of iron enrichment as a climate-mitigation strategy, is given by the story of Blain and colleagues' sediment traps, particle interceptors used to measure carbon sequestration at great depth. These could not in the first instance be recovered, but have just finally been salvaged — one year on. □

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Article originally published in *Nature* (989-991, Vol 446, 26 April 2007) Please refer to this for citation purposes.

Post-Kyoto pact: shaping the successor

As discussions get underway over a global agreement to slash CO2 emissions beyond 2012, Amanda Leigh Haag looks at how the Kyoto Protocol has fared and the issues that will shape its successor.

Last November, as nearly 6,000 participants gathered at the United Nations climate talks in Nairobi, Kenya, a sea change was taking place in American politics on the other side of the Atlantic. Many at the conference walked away disappointed in the lack of momentum on discussions about post-2012, when the Kyoto Protocol expires. But the shifting leadership in the US House and Senate injected the climate community with hope. To some, the Democratic takeover in Congress holds the key to adoption of domestic policies that could bring the US — and ultimately developing country powerhouses like China and India — into serious policy actions on curbing greenhouse-gas emissions in time for a commitment beyond Kyoto.

The Protocol was adopted unanimously in 1997 in Kyoto, Japan and entered into force in February 2005, after Russia's ratification brought it into acceptance by industrialized countries representing 55% of the world's greenhouse-gas emissions. Developed, 'Annex I', nations that ratify are legally bound to mandatory emissions reductions that vary from country to country, with a goal towards bringing all nations' combined global emissions to at least 5% below 1990 levels during the first commitment period. Developing nations that are party to the Protocol have no obligations to reduce emissions and instead can benefit from hosting clean-energy projects financed by industrialized nations hoping to offset their own emissions. Under the terms of Kyoto, significant progress towards a mandate beyond the first commitment period of 2008–2012 is overdue. Many countries within the international community are edging for a finalized agreement to be put in place by 2009, or at the latest by 2010, in order to ensure a smooth transition into even bolder actions in the next phase.


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Some nations are falling far short of their commitments to reduce their greenhouse gas emissions.

TROUBLED TARGETS

Although most climate experts have long acknowledged that Kyoto's first round of emission cuts would make only a small dent in the build-up of greenhouse gases, it was viewed as a significant first step towards long-term stabilization of the world's climate. A prominent failure of the agreement thus far is that some nations are falling far short of their commitments. Emissions targets that were perceived as modest first attempts have, in some cases, proven too ambitious. Canada recently announced that it will not meet its Kyoto commitment, prompting concerns that other countries may follow suit. "One can argue forever about the realism of the targets," says Michael Oppenheimer, a geoscientist and climate-policy expert at Princeton University in New Jersey. "But given that the timelines were relatively short, I think it's no surprise that some countries had difficulty. And given especially that the US decided not to play at all, it's remarkable that any countries are doing anything serious."

The Bush administration backed out in early 2001, taking a strong stance against the fact that Kyoto does not limit emissions from developing countries like China and India and claiming it would put undue pressure on the US economy. The US is responsible for a quarter of the world's greenhouse-gas emissions, but China is close behind and stands to outpace the US by later this year or 2008. China's newly built coal-fired plants alone have the capacity to nullify the global carbon dioxide emissions that would be achieved by Kyoto reductions during the next five years. Most agree that without the participation of both the US and the leading developing countries in a post-Kyoto agreement, the aim to stabilize greenhouse-gas emissions below dangerous levels may be a dead end.

POLITICAL PULL

To many who believe that the US holdout has been both a symbolic and effectual linchpin in the Kyoto process, its future leadership will be crucial in reaching a workable successor. In addition to being the world's largest greenhouse-gas emitter, the US is also the world's only economic superpower, with more resources than any other country to invest in clean technologies and development. It has also been a historical leader in environmental circles, including drafting of the Kyoto Protocol in the 1990s. And economically, countries like China and India have no incentive to take on emissions targets if their biggest trade competitor — the US — is not leading the way. "It's absolutely critical, if you're going to get any interest from major developing countries, for them to see that things can happen on the ground here, and that it's not hurting the economy," says John Drexhage, director of climate change and energy programs at the International Institute for Sustainable Development in Ontario, Canada.

Canada, experts say, highlights the crippling effect that the US has had on other countries' lack of progress under Kyoto. "The absence of the US from the process is the single most important reason why the whole system didn't do as well as it should," says Rob Bradley, director of international climate policy at the World Resources Institute, in Washington DC. "Canada does 85% of its trade with the US. When you've got that elephant just across the border that suddenly decided not to play, that becomes a political uphill struggle." Although it will not meet Kyoto targets, Canada hopes to cut its emissions by 20% of current levels by 2020. This target falls well below their Kyoto goals, but as the second commitment period has not been negotiated, it is unclear what penalties they will face.

A GLOBAL AFFAIR

Some EU countries, such as Austria, Spain and Ireland, face challenges similar to Canada's. However, under the umbrella of the European Union, which has stated that it will reach its emissions targets unilaterally, nations will not endure penalties if they don't meet their individual targets. Countries that are on track, such as Germany, Britain and Sweden, have been adopting aggressive energy policies for years. The ramping-up time is one reason why future commitments must be negotiated so far in advance of 2012, especially if countries are to eventually take on steeper reductions.

There are signs that Australia, which has not ratified the Protocol, could be brought back into Kyoto talks even before the US. Their Labour Party, which supports Kyoto, has a substantial lead in the polls prior to a general election to be held late this year. The government is currently considering a national carbon-trading scheme that could kick-start in 2010. Australia leads the world in per capita emissions, owing in large part to its dependence on coal-fired electricity, but it contributes less than 2% of global greenhouse-gas emissions. If Australia doesn't beat the US — its political ally — to it, experts agree that it would almost certainly come onboard the treaty if the US led the way.

In the meantime, lobbyists are pushing for the US to enact a strong domestic policy under the new Democratic congress, which they believe will trigger cooperation from developing nations. This includes adoption of a domestic cap-and-trade system and a nation-wide carbon market by 2007 or 2008, so that the US can begin trading in other flourishing markets and tap innovation in favour of clean-energy technologies. Although it has encountered some obstacles, the European Trading System has proved highly successful overall and, according to Oppenheimer, is "the single greatest achievement of Kyoto". Policy-makers envision linking individual markets into a global carbon market that could get underway in 2013, when a new climate pact is launched. In the meantime, as individual markets take shape, experts say they can be designed to provide incentives for recalcitrant nations to come onboard.

> The European Trading System *"is the single greatest achievement of Kyoto."*
> Michael Oppenheimer

SOFT SOLUTIONS

Discussion abounds about how to woo countries like China, India and Brazil into taking bold steps to reduce emissions when Kyoto expires, without hindering their development. A mosaic of policies could constitute developing-country commitments, with hopes of bringing those nations into firm emissions caps in the future. Such policies might be aimed at immediate needs, such as reducing air pollution and improving public health, with the dual effect of assisting with climate-change mitigation. China already has some aggressive domestic policies in place, including higher vehicle fuel-efficiency standards than the US and a pledge to meet 15% of its electrical demands with renewable energy by 2020. "In the US, we have a one-dimensional view of the term 'commitment,'" says Elliot Diringer, director of international strategies for the Pew Center on Global Climate Change, based in Arlington, Virginia. Now, Diringer says, there is a growing recognition that emissions targets aren't going to work for everybody, "so we need to broaden our concept of commitment and allow for other possibilities". Roger Pielke Jr, a climate-policy expert at the University of Colorado, Boulder, believes that future policies should involve actions that are "justified on their own merits in the short term". For instance, if nations like China emphasize reducing air pollution from dirty coal in order to improve public health, it will be much more motivating than simply focusing on the idea of reducing greenhouse gases in 50 to 100 years, he says.

For an arrangement of 'soft' commitments to proceed, it will need to be very clear that countries like China are wholly committed to making a meaningful contribution to the fight against climate change, in whatever

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China already has some aggressive domestic policies in place, including higher vehicle fuel-efficiency standards than the US.

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Regions such as the Amazon are being rapidly deforested. Negotiations are underway on how to reduce deforestation to stem further growth in emissions.

form it takes. The China of 1997, when the Kyoto treaty was first established, and the China of 2007 are two entirely different worlds, Drexhage notes. "When it comes to competitiveness, particularly in resource-based industries and manufacturing, they're every bit as much our peer, and in some cases very much superior than was the case before," Drexhage says. Unless it is apparent that China is ratcheting down its greenhouse-gas emissions substantially, what will result is an "incredibly massive and gross leakage to developing countries on dirty and energy-intensive industries that gets us absolutely nowhere". At this stage, India's participation in reducing its emissions has been primarily through acting as a host nation for some 233 clean-energy projects sponsored by Annex I countries. Such investments will allow poorer nations to leapfrog over fossil fuel-intensive technologies, avoiding the mistakes that industrialized nations have made.

"When it comes to competitiveness, particularly in resource-based industries and manufacturing, [China is] every bit as much our peer, and in some cases very much superior than was the case before."

John Drexhage

FURTHER CONSIDERATIONS

Brazil has asserted itself as a progressive leader in the transportation sector by converting the majority of its passenger-car fleet to run on sugar-cane ethanol. It stands to play a key role in cutting emissions in the next commitment period through market incentives to reduce deforestation. As the world's fourth largest contributor to greenhouse gases, 70% of Brazil's emissions are from deforestation.

Negotiators are now hoping to move quickly on the issue of avoided deforestation to stem even further growth in emissions. Within the Kyoto framework, industrialized parties must account for their land-use activities, including deforestation and replanting projects, as forests represent enormous potential carbon 'sinks' to soak up carbon. Developing parties do not currently pay a penalty for deforestation, yet the yearly greenhouse-gas emissions from destruction of the world's rainforests closely rival total annual US emissions. A handful of Brazilian non-profits and US-based organizations have proposed 'compensated reduction' as a means to offer incentives for nations to avoid deforestation. Nations that curb their emissions by reducing deforestation below a baseline level would be compensated through credits that could then be sold to governments or private investors via the carbon market. Hopes are high for an agreement at the next UN climate conference in Bali, Indonesia, that would send a strong market signal to governments to begin reducing deforestation immediately.

The issue of adaptation will take on much greater prominence in the post-Kyoto framework. Discussions on how to assist countries like Africa, small island states and other 'least developed countries' in adapting to the effects of climate change are very preliminary. Some experts say that Kyoto focused to such a large degree on mitigation of climate change and reduction of greenhouse-gas emissions that it largely neglected the looming need for adaptation. "We can't lose sight of the broader context," says Pielke. "Whatever we do on mitigation and whatever successes we have, we're going to have to adapt no matter what."

Under the Kyoto Protocol, an adaptation fund would help nations that are most vulnerable and least equipped to cope with the impacts of climate change. Proceeds for the fund are generated by a 2% levy on CDM transactions and currently amount to some $9^million dollars, although the fund is not yet operational. The World Bank estimates that between $10^billion and $40^billion will eventually be needed to assist countries in adaptation efforts for new infrastructure alone. Proposals for how to generate substantial sums are sure to be on the table for post-2012 discussions. Polluting activities such as commercial airline flights could eventually be eligible for the levy. "We need to have a vehicle that taxes the bad, taxes pollution, taxes emissions, and puts it into a fund for adaptation," says Saleemul Huq of the London-based International Institute for Environment and Development. "There's no way that the aid channel is going to be sufficient for adaptation." How the funds would be allocated to various nations and which forms of adaptation should be addressed first will have to be negotiated. Efforts might include providing crops that would thrive in more arid conditions, introducing new irrigation practices or relocating whole coastal communities threatened by rising seas.

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Any post-Kyoto pact will have to address how to adapt to climate change impacts such as increased flooding in countries like Bangladesh.

BRIDGING THE GAP

As post-Kyoto talks begin in earnest, one thing is clear: a large gulf exists between the global emissions trajectory of today and that which is needed to stabilize emissions in the long term. There is wide agreement that warming should be held at a level below 2^°C over pre-industrial levels in order to avert 'dangerous climate change.' This would require that greenhouse gases be stabilized at between 450 and 550 parts per million (p.p.m.) of CO_2 equivalent, which could be achieved by halving today's greenhouse-gas emissions by 2050. Current levels are at roughly 430^p.p.m. CO_2 equivalent and are rising at an average of 2^p.p.m. per year. Opening talks on post-Kyoto were kicked off in May at a two-week UN climate meeting held in Bonn, Germany. Long-awaited discussions at the G8 Summit in Heiligendamm, Germany this week will look to set a timeline for post-Kyoto negotiations. Prior to the current round of talks, the US reportedly worked to remove portions of the draft that call for emissions caps and establishment of a global carbon market. The US has also said it is unlikely to participate in further negotiations on a global agreement to cut CO2 emissions at the end of this year.

But many see the next commitment period beyond Kyoto as a narrowing window of time in which to slash emissions growth. Britain recently pledged cuts of 60% by 2050 and the European Union has pledged to reduce its emissions by 20% of 1990 levels by 2020 if other nations make comparable efforts. It is likely that negotiators will agree to a longer commitment period for the second round, perhaps an eight or ten-year period rather than Kyoto's five-year timeframe. This week, world leaders plan to rally for global negotiations on the framework to be launched in Bali in December and to be concluded by 2009. In the meantime, the world is poised to see whether domestic policies will take shape on the US home front, and whether the US and China will be willing to come to the table with policy measures they are open to negotiating. "That's the kind of dialogue that is really essential in order to be able to see anything moving forward," says Bradley of the World Resources Institute. "I don't think it's impossible, but I think there's still a mountain to climb."☐

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Commercial airline flights could be eligible for a levy in a post-Kyoto pact.

Amanda Leigh Haag is a freelance science writer.

Washington Watch

KEVIN VRANES

This month, Kevin Vranes at the Center for Science and Technology Policy Research in Boulder, Colorado, reviews recent climate legislation passing through US Congress.

Legislation addressing climate change and energy issues is starting to move through the Senate and House of Representatives. More than 20 bills have been introduced in both chambers, committees have been busy holding hearings, and three new bills on power plant emissions are expected to be introduced in the Senate soon.

The Senate Committee on Energy and Natural Resources passed a four-bill package on 2 May to address biofuels, energy efficiency, and carbon capture, sequestration and storage (CSS). Although the bills passed committee on a 20–3 vote, partisan wrangling over a proposed mandate for coal-derived liquefied fuels (also called 'synfuels') hinted that passing broad legislation to address climate and energy issues will be politically difficult. The measures now await action by the full Senate.

The Senate Committee on Environment and Public Works has held six climate-related hearings since the session began in January, including an appearance by former Vice President Al Gore on 21 March. Gore gave legislators a list of ten immediate steps to be taken to address global warming, including instituting a carbon tax and creating a federally-backed mortgage instrument used for energy efficiency improvements in residential homes.

House Majority Leader Nancy Pelosi created an *ad hoc* select Committee on Energy Independence and Global Warming in January, and has made frequent statements that the House will introduce a broad climate bill by July 4. The White House has continued to insist on voluntary measures to address greenhouse gases, but lost a major Supreme Court decision on 2 April. In Massachusetts *et al.* versus the Environmental Protection Agency (EPA) *et al.*, the EPA argued that it had no authority under the Clean Air Act to regulate carbon dioxide emissions. The justices rejected the EPA's arguments, finding that, "EPA's steadfast refusal to regulate greenhouse gas emissions presents a risk of harm to Massachusetts that is both 'actual' and 'imminent'".

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