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The Business of Climate Change

Challenges and Opportunities

John Llewellyn

LEHMAN BROTHERS

FOREWORD

The past year has seen a significant shift in the debate on climate change. No longer the preserve of scientists and political activists, it has started to occupy the mainstream of everyday discussion.

In the world of business and finance, climate change has developed from being a fringe concern, focusing on the company's brand and its Corporate and Social Responsibility, to an increasingly central topic for strategic deliberation and decision-making by executives and investors around the globe.

Driving all this is an emerging consensus on three broad points: that Earth is warming; that this is the result in large part of mankind's emission of greenhouse gases; and that there will be significant consequences for Earth's environment.

It is in this context that Lehman Brothers decided to take a hard look at global warming, starting with the scientific and climatological evidence, then proceeding to the economic consequences and implications for policy; and finally – with significant help from the Firm's equity analysts – considering potential impacts on major business sectors.

The result is this publication: *The Business of Climate Change: Challenges and opportunities*. It reaches a number of broad conclusions. Global warming, we judge, is likely to prove one of those tectonic forces that – like globalization or the ageing of populations – gradually but powerfully changes the economic landscape in which our clients operate, and one that causes periodic sharp movements in asset prices. And, as the title indicates, we consider that climate change poses many challenges but also presents many business opportunities.

Firms that recognise the challenge early, and respond imaginatively and constructively, will create opportunities for themselves and thereby prosper. Others, slower to realise what is going on or electing to ignore it, will likely do markedly less well.

This study is far from the last word: indeed, we see it as just the starting point for a dialogue with our investing and corporate clients. As the discussions with our clients and policy experts progress, we will take this work further.

Dr John Llewellyn
Senior Economic Policy Advisor
Lehman Brothers

ACKNOWLEDGEMENTS

Particular appreciation is due to Camille Chaix and Julia Giese, my co-authors, for their substantial contributions throughout. Getting to grips, as they did, with subject areas as complex and diverse as the science of global warming, the modelling of climate change, the implications for economies, the prospects for policy, and potential consequences for business, was no small feat. Both applied themselves with diligence, competence, and thoroughness, all the while with unwavering good humour.

Jeremy Isaacs made it possible for this work to be undertaken, supporting it firmly from the outset. Peter Sherratt, Piers le Marchant, and Theodore Roosevelt IV provided important encouragement throughout, as did Christopher Tugendhat, who also offered astute comments on various of the key parts. Michael Dicks, Michael Hume, Alan Castle, and Phyllis Papadavid commented helpfully on the first full draft of the study; and in turn Andrew Hyde and Jeremy Apfel made substantive comments on the penultimate version.

Andrew Gowers provided invaluable impetus and assistance in a variety of ways, not least in emphasising the need for, and in turn helping to obtain, numerous examples of immediate business relevance. In addition to our equity analysts, who wrote the fascinating sectoral pieces, David Buchan brought his breadth of experience to bear on a range of issues, especially, but not limited to, the sections on business implications. Alastair Newton provided stalwart support, as well as help and guidance on a range of political and policy issues. And John Wilson and Rufus Grantham provided much-appreciated assistance in helping to marshal and guide our considerable research resources in the production of the sectoral essays.

Outside Lehman Brothers, Sir Nicholas Stern, through the course of a long lunch, provided a brilliant overview of the principal climate change issues as he had come to see them; and William Nordhaus, also in a much appreciated lunch, took me on a veritable *tour de force* of all the climate change issues as he sees them, and updated me on his latest thinking. Tom Burke and Nick Mabey clarified my mind on a range of scientific and other technical issues, while John Ashton talked me through a range of international policy issues.

Many members of Lehman Brothers Research made written contributions, and generally these are attributed in the text. Specific mention should also be made of particularly helpful discussions with Vicki Arroyo, Sir Samuel Brittan, Sir Colin Budd, Nick Butler, Beverley Darkin, Peter Davies, Martin Donnelly, Roger Harrabin, David Henderson, Cameron Hepburn, Christopher Huhne, Saleemul Huq, Rod Janssen, Cornelia Meyer, Max Mosley, Baroness O’Cathain, Joel Smith, Don Verry, and David Ward.

All that said, no study, let alone one such as this, can be immune from errors, and for those I alone am responsible.

The cut off date for information in this study is 15 January 2007.

EXECUTIVE SUMMARY

John Llewellyn
+44 20 710 22272
jllewell@lehman.com

Camille Chaix
+44 20 710 29616
cachaix@lehman.com

Julia Giese
+44 20 710 23969
jgiese@lehman.com

Science: Evidence, mechanisms, and scenarios of climate change

Earth warmed by more than 0.6 degrees Celsius (ºC) over the 20th century.

Past fluctuations in naturally-occurring atmospheric greenhouse gas concentrations have caused Earth to warm and to cool, in cycles of around 100,000 years, with the timing of these cycles largely determined by a repeating pattern in the Earth's solar orbit.

However, the most recent warming trend results largely from human activities. Atmospheric CO_2 concentration, approximately 280 parts per million by volume (ppmv) before the Industrial Revolution, has increased to about 380ppmv today.

Each doubling of greenhouse gas concentration raises Earth's equilibrium temperature by about 3ºC. But there is considerable systemic inertia: even were emissions to cease today, Earth's temperature would continue to increase, by more than 1ºC.

Greenhouse gas emissions will not cease, however: 'business as usual' trends imply concentration rising above 500ppmv by 2050. In turn, a base case scenario suggests that Earth's temperature will likely increase by 2-5ºC by 2100.

Emerging evidence on positive feedbacks raises the possibility that the temperature rise will be significantly greater.

Climatology: Global and regional scenarios

Rising temperatures have already altered Earth's climate, with consequences for: hydrology and water resources; agriculture and food security; terrestrial and freshwater ecosystems; coastal zones and marine ecosystems; and human health.

Predictions of climate change are uncertain: they involve making projections outside the range of recorded experience. The scope and scale of effects will depend on the degree and speed of adaptation of countries, economies, and people; and will differ by region.

Climatologists broadly agree however that likely effects include: melting of glaciers and ice caps; higher sea levels (up to 1m by 2100 in the base case, and ultimately by 4-7m should half of Greenland and the West Antarctic Ice Sheet melt); and more frequent and violent weather events.

Economics: Costs, abatement, and adaptation

The economic costs of climate change are a second major uncertainty. Conservative estimates suggest a cost of between 0 and 3% of global GDP annually by the time that Earth's temperature has risen by 2-3ºC, with poor countries affected disproportionately.

Were greenhouse gas concentration to rise beyond 550ppmv, temperature to increase by more than 3ºC, and the ecological impact to be more abrupt, the economic cost could be much higher.

The free market fails to limit climate-damaging emissions sufficiently, because polluters do not have to pay for the damage they cause. A basic role of policy in such cases is to 'internalise' such costs into emitters' cost structures – the 'polluter pays' principle.

Estimates of the cost of limiting emissions sufficiently to keep greenhouse gas concentration below 550ppmv range between -2% (net gains) and +5% (net losses) of global GDP.

A policy to maximise the gains (i.e. damage avoided) relative to the costs of abatement requires determining and setting either an emissions volume (through emission targets, or regulation) or a 'social' price for carbon (e.g. via an emissions tax).

Under a base-case scenario, the 'social' price of carbon rises progressively, from perhaps $20 per tonne today to over $80 by 2050. Some estimates are significantly higher.

Additionally, society might wish to pay more than the 'social' price of carbon, out of a desire for: a cleaner environment in its own right; and/or insurance against the risks from taking temperatures higher than they have been for at least many hundreds of years.

Policies: Design, implementation, and international cooperation

It is important that the cost of abatement be as close as reasonably possible to the value of the damage thereby avoided, even if that value is uncertain. The price mechanism should therefore be a central component of policies to reduce emissions.

However, other policies – volume targets, technology, and regulation – all have important roles, particularly in inducing development and implementation of new technologies.

Climate change being a global issue, it also requires that national policies be mutually consistent; but some of the biggest emitting countries are not yet engaged in international agreements.

However, political positions are evolving, and we see a greater than 50% likelihood that some sort of global emissions trading system will be in place within five years.

Business: Challenges and opportunities for sectors and firms

While governments arguably should focus – as they do with the risk of nuclear or terrorist attacks – on minimising the likelihood of extreme and catastrophic events, businesses should in general plan on the basis of more likely, central, estimates.

For firms, climate change, like globalization, technical change, and population ageing, is likely to be another powerful force that inexorably shapes the economic environment.

While climate change may well be a slow-moving force, asset prices will on occasion move sharply, when new evidence reaches the market, or policies are changed.

Businesses are likely to be affected both by climate change itself and by policies to address it through: regulatory exposure; physical exposure; competitive exposure; and reputational – including litigational – exposure.

Sectors particularly likely to be affected include: utilities; integrated oil and gas; mining and metals; insurance; pharmaceuticals; building and construction; and real estate.

Within each sector, many firms will find ways of turning change to their advantage, while others will fail to adapt.

Already, with little impact yet felt from climate change, about 20% of firms enter and exit most markets each year, and only 60 to 70% survive their first two years of activity.

The firms that will prosper in a climate-changed world will tend to be those that are: early to recognise its importance and its inexorability; foresee at least some of the implications for their industry; and take appropriate steps well in advance.

This is likely to involve, within an overall framework of good management practice:

- Inculcating in management a constructive culture of adaptation to a changing economic landscape;
- Encouraging employees to embrace change, and equipping them to do so;
- Undertaking the requisite research and development, which is often highly industry- or even firm-specific; and
- Translating this research and development into appropriate investment in physical and human capital.

The pace of a firm's adaptation to climate change and related policy is thus likely to prove to be another of the forces that will influence whether, over the next several years, any given firm survives and prospers; or withers and, quite possibly, dies. ■

CONTENTS

SCIENCE: EVIDENCE, MECHANISMS, AND SCENARIOS OF CLIMATE CHANGE

The long-period, northern hemisphere, 'hockey stick' chart

Earth's mean temperature has risen sharply in recent decades

Reconstruction of global temperatures over the past millennium suggests that in recent decades there has been a sharp upturn in Earth's mean temperature. In one large-scale exercise, Mann et al. (1998, 1999) used historical data from tree rings, ice cores, and other 'proxies' to reconstruct the northern hemisphere's mean temperature over the past 1,000 years. This resulted in the 'hockey stick' chart (Figure 1), made famous by the 2001 report of the Intergovernmental Panel on Climate Change (IPCC).

The exercise sparked considerable debate[1]. However, it appears that the basic message of the chart, that Earth has already become unprecedentedly warm for modern times, and that this process is continuing apace, is now accepted by most scientists, including, importantly, by a specially convened committee of the US National Academy of Sciences. The committee's chair is reported as saying that it has a "high level of confidence" that the second half of the 20th century was warmer than any other period in the past four centuries, although it considers that claims for the earlier period covered by the study, from AD 900 to 1600, are less certain[2].

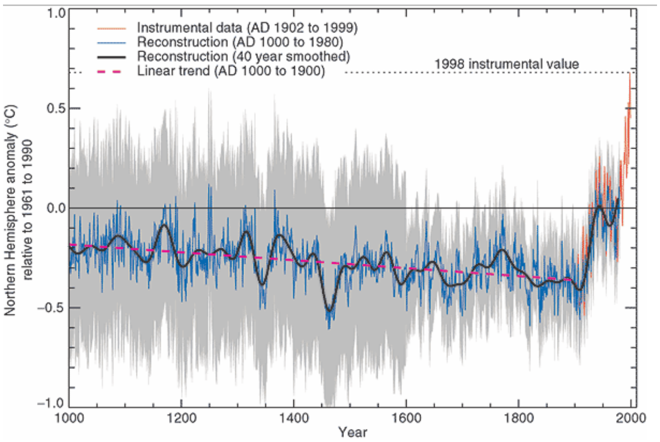
According to the IPCC, over the 20th century, the global average surface temperature has increased by about 0.6ºC. The year 2005 has recently been reported as having been the warmest year in several thousand years, and 2007 is expected to be the warmest year on record[3]. Furthermore, Shaw (2006) reports that, in the past 10 years, nine were the warmest since temperature records started, i.e. around the end of the 19th century.

A shorter-period, global, mean land-ocean-air temperature index

NASA studies also indicate global warming

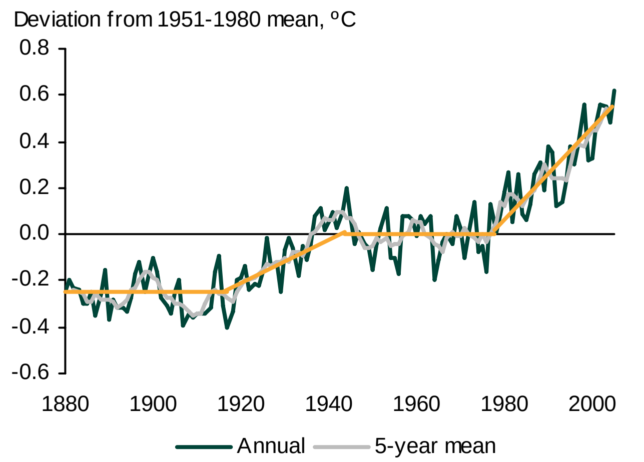
Another exercise, conducted by NASA and covering only the past 125 years, but using fewer indirect, and mainly instrumental, measurements also indicates global warming. Initially, the evidence was inconclusive: balloons showed day temperatures falling over time, but night temperatures rising. However, early sensors were inadequately insulated against sunlight, and hence were over-stating day temperatures. Furthermore, initial satellite observations were subject to calculation errors concerning the orbits of satellites around Earth. Once adjusted for these errors, the data show a consistent story of warming over the period, in four phases (Figure 2).

Figure 1. The hockey stick chart



Source: *Intergovernmental Panel on Climate Change (2001), vol.II, Summary for Policy Makers.*

Figure 2. Instrumental measurements from 1880



Source: NASA Goddard Institute for Space Studies website, <http://data.giss.nasa.gov/gistemp/>.

1 *See for example McIntyre et al. (2003, 2005a, 2005b); Mann, M.E. et al. (2003); and Jones and Mann (2004).*
2 *See Brumfiel, G. (2006), and the National Academies website, <http://www.national-academies.org>.*
3 *See The Independent, 1 January 2007.*

Visual evidence of global warming

Arctic ice is retreating and melting is accelerating

Photographic images, particularly from satellites, also show evidence of global warming (Figures 3 and 4). Arctic ice is retreating and the Arctic ice cap is experiencing a significant reduction in ice cover, especially close to the coasts of eastern Russia, Alaska, and Greenland. NASA sees rapid changes in Arctic sea ice. The melting of the ice is accelerating. In 1996, an estimated 92bn cubic metres of Greenland ice melted away. The 2005 figure was estimated at 220bn cubic metres.

In October 2006, NASA undertook a new assessment of the rate of melting. By analyzing data from direct and detailed satellite measurements, and by using a technique that examined the behaviour of individual drainage systems instead of looking at the ice sheet as a whole, researchers estimated the loss at about 100 giga tonnes of ice per year from 2003 to 2005. Although the ice mass loss observed in this study is less than half that which other researchers have reported, the broad conclusion is similar: Greenland is losing around 20% more mass each year than it receives from new snowfalls[4]. Greenland's low coastal region apparently lost 155 giga tonnes of ice per year between 2003 and 2005 from excess melting and icebergs, whereas the high elevation interior gained only 54 giga tonnes annually from excess snowfall.

Arctic perennial sea ice, which normally survives the summer melt, shrank by 14%, between 2004 and 2005, 18 times the rate of previous years. The overall decrease in the perennial sea ice totals 720,000 square kilometres, the equivalent of the size of Texas. Perennial ice can be 3 metres thick or more. It was replaced by new, seasonal ice only about 0.3 to 2 metres thick, which is more vulnerable to summer melting[5].

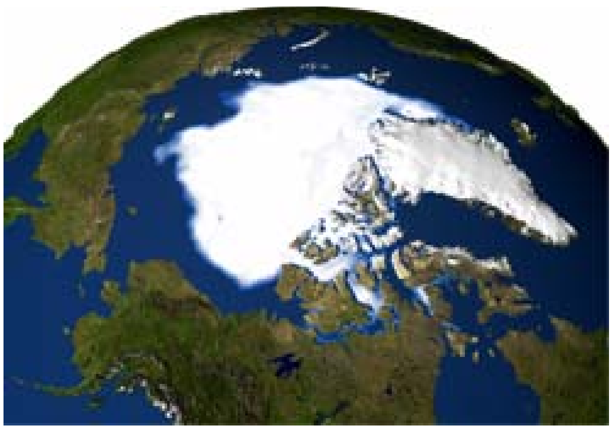
Arctic summers could be ice-free by 2040

In December 2006, researchers from the National Centre for Atmospheric Research (NCAR), the University of Washington, and McGill University, found that abrupt ice retreat could produce ice-free arctic summers by 2040[6]. Scenarios run on supercomputers suggest that the extent of sea ice each September could be reduced so abruptly that, within about 20 years, it may be retreating four times faster than at any time since records began.

Figure 3. Observed sea ice, September 1979

Source: NASA - Goddard Space Flight Center, Scientific Visualization Studio.

Figure 4. Observed sea ice, September 2005



Source: NASA - Goddard Space Flight Center, Scientific Visualization Studio.

4 *See the article on the NASA website, <http://www.nasa.gov/centers/goddard/news/topstory/2006/greenland_slide.html>.*
5 *See Nghiem, S.V. et al. (2006).*
6 *See Holland, M.M. (2006).*

Causes of global warming: the importance of greenhouse gases

Temperature and concentration of greenhouse gases in the atmosphere are highly correlated

Much of Earth's temperature changes have to do with fluctuations, however caused, in the concentration of greenhouse gases in the atmosphere: the correlation, over 400,000 years, between greenhouse gas concentration and Earth's temperature is striking (Figure 5). The processes whereby greenhouse gases – principally water vapour (H_2O), carbon dioxide (CO_2), methane (CH_4), and ozone (O_3) – cause Earth to be warmer than it would be without them are complex, but they can be stylised fairly straightforwardly.

The principal source of warmth on Earth is the energy that it receives from the sun. This is of the order of 340 watts per square metre (w/m^2), the precise figure varying over time, by ± 0.1%[7] over the 11-year solar cycle.

Earth's atmosphere is relatively transparent to the sun's short-wavelength radiation (0.2 to 4.0 micrometres). Hence, although around 100w/m^2 of energy radiated from the sun is reflected back into the atmosphere off the atmosphere's clouds and assorted aerosols, and off the shinier parts of the earth's surface (principally snow and ice), the greater part of the energy from the sun – around 240w/m^2 – gets through to the Earth's surface.

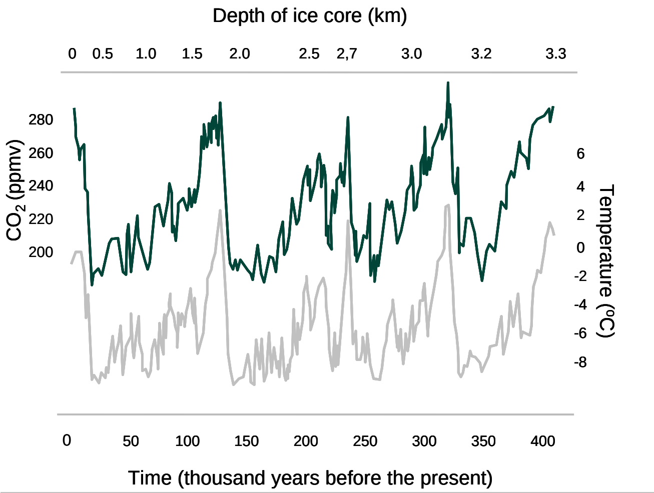
Earth's surface is thereby warmed; and in turn it re-radiates some of this energy. Because Earth is markedly less hot than the sun, the wavelength of the energy that it radiates is longer (4 to 100 micrometres). Greenhouse gases are relatively opaque to such wavelengths and so trap a considerable proportion of this energy, in turn re-radiating nearly half of it – around 180w/m^2 – back down to Earth.

The temperature of the earth/atmosphere system is in equilibrium when the system is radiating back out into space the same amount of energy as it is receiving from it, i.e. 340w/m^2. Given that 100w/m^2 is being reflected back into space from clouds, aerosols, snow, ice, and so on, this means that, in equilibrium, the earth/atmosphere system has to be radiating out into space a further 240w/m^2. And this has to come from Earth.

Hence, the temperature of Earth has to be such that it emits around (240+180) = 420w/m^2 (Figure 6). The temperature at which Earth radiates 420w/m^2 is about 15ºC, which is indeed Earth's mean temperature.

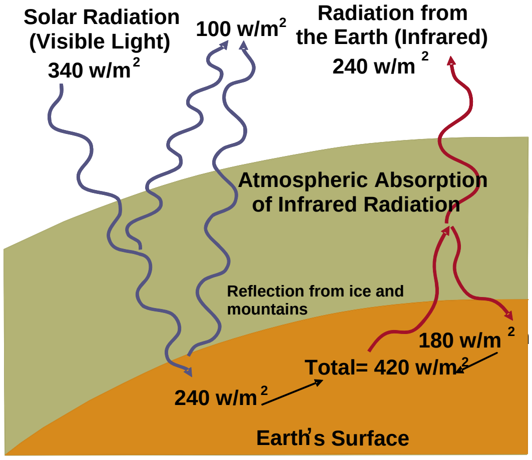
The sensitivity of the system to greenhouse gas concentration can thus be seen as follows: as the atmospheric concentration of greenhouse gases rises, the proportion of the (long wavelength) energy radiated from Earth that is re-radiated back down to Earth duly rises. Correspondingly, the amount of Earth-radiated energy that escapes to space via the atmosphere falls below the equilibrium value of around 240w/m^2.

Figure 5. Temperature and CO_2 concentration



Source: Petit, J.R et al. (1999).

Figure 6. The greenhouse mechanism



Sources: Cline, W.R (1992), pp. 15-16, and Lehman Brothers.

[7] *See Intergovernmental Panel on Climate Change (2001), vol.II, ch.6.*

Equilibrium is restored only when the net amount of energy radiated by the earth/atmosphere system rises back to the requisite (100+240) = 340 w/m^2-odd, a condition that can be met only by Earth's warming further, and thereby emitting radiation faster, up until the point where the earth/atmosphere system's net incoming/outgoing radiation is once again in balance.

A doubling of greenhouse gas concentration implies a 3ºC rise in mean temperature

A doubling of greenhouse gas concentrations in the atmosphere increases the amount of energy reflected down to Earth (radiative forcing) by about $4w/m^2$. Hence, a doubling implies that Earth's equilibrium temperature rises until it is radiating around (240+180+4) = 424 w/m^2. The temperature at which Earth radiates $424w/m^2$ is about 18ºC. Thus, each doubling of greenhouse gas concentrations raises Earth's equilibrium mean temperature by about 3ºC[8].

Nature, the carbon cycle, and man-made emissions

Carbon emissions are both nature- and man-made

Carbon emissions are generated both by nature and by man. Isotopic 'fingerprinting analysis' finds that, prior to the Industrial Revolution, atmospheric greenhouse gas concentrations, and hence Earth's temperature fluctuations, were driven primarily by orbital, volcanic, and solar 'forcings'. In the early 20^{th} century, by contrast, both natural and man-made (anthropogenic) forcings apparently contributed, more or less equally. Since mid-century, man's activities seem to have been by far the major contributor.

The most comprehensive evaluations of the respective contributions of nature and man to climate have been made for the past 100 years, using large models constructed by climatologists. These models find that the best account is obtained when both natural and man-made forcings are taken into account[9].

Some greenhouse gases are particularly potent

The quantitative importance of radiative forcing differs importantly from gas to gas:

- The atmospheric concentration of water vapour – quantitatively the most important greenhouse gas – is affected relatively little, in direct terms, by human activity. However, there are important indirect effects, which are considered in the section *Reinforcing Global Warming Mechanisms* below.
- On the other hand, emissions of CO_2, quantitatively the second most important greenhouse gas, and of methane, the third most important, are affected significantly by human activity, including the burning of fossil fuels and various agricultural activities.
- While ozone concentration in the stratosphere does not contribute to global warming, ozone in the troposphere does. Man-made NOx emissions, which are a precursor of ozone, have increased in the troposphere, thereby contributing to global warming.
- However, CFCs and HCFCs are themselves particularly powerful greenhouse gases: one molecule of CFC has about 20,000 times the heat-trapping power of a CO_2 molecule.

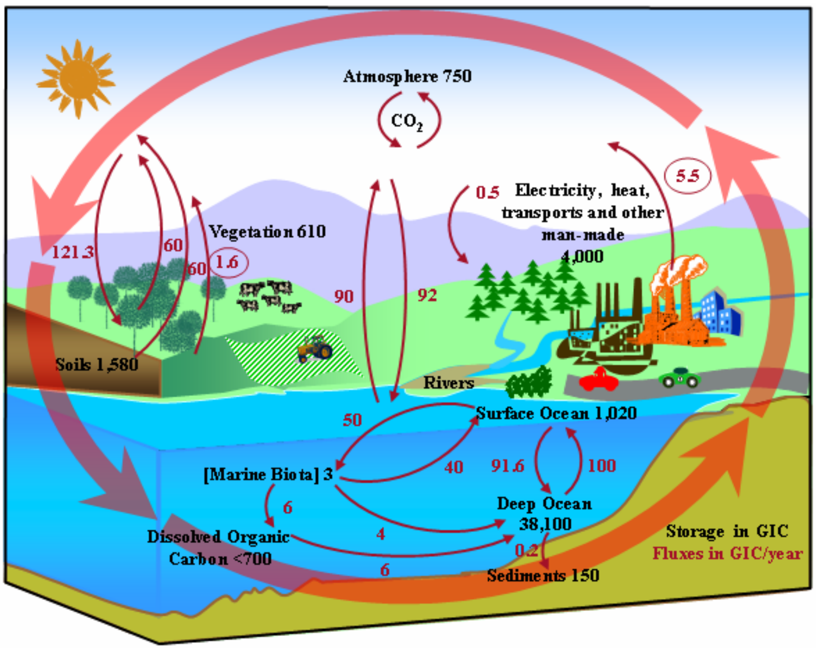
[8] *See Kerr, R.A. (2004).*
[9] *See MET Office (2004).*

Man-made emissions are a net addition to atmospheric greenhouse gas concentration

A snapshot quantifying the present-day dynamics of the carbon cycle, constructed by NASA, suggests the following principal features:

1. The stock of carbon in the atmosphere is estimated at around 750 giga tonnes; in the surface oceans at 1,020 giga tonnes; in soils at 1,580 giga tonnes; and in the deep oceans at 38,100 giga tonnes.
2. Carbon transfer (flux) between the atmosphere and vegetation nets out approximately to zero (Figure 7): around 121 giga tonnes of carbon dioxide per year flow from the atmosphere to vegetation and the soil, while much the same amount passes in the opposite direction, from the soil and vegetation into the atmosphere.
3. Similarly, carbon transfer between the atmosphere and the oceans nets out approximately to zero: around 90 giga tonnes of carbon dioxide per year flow from Earth's surface waters to the atmosphere, while much the same amount – around 92 giga tonnes – flows in the opposite direction.
4. Thus, from the standpoint of 'natural' activities, greenhouse gas concentration would, unless there was a major event, such as a change in Earth's orbit, a change in solar radiation, or a significant volcanic eruption, stay approximately constant.
5. Man-made – anthropogenic – greenhouse gas emissions into the atmosphere are currently estimated at 7.1 giga tonnes per year, mainly from power generation, heating, transport, agriculture and deforestation. Around 5.5 giga tonnes come from fuel burning and 1.6 giga tonnes from land-use changes, such as deforestation.
6. Not all the carbon that man emits remains in the atmosphere. Measurements of atmospheric carbon dioxide levels reveal that, of the approximate 7.1 giga tonnes released per year by human activity, around 3.2 giga tonnes remain in the atmosphere[10].
7. Thus, man-made greenhouse gas emissions – anthropogenic 'forcing' – represent a significant net addition to atmospheric greenhouse gas concentration.

Figure 7. The carbon cycle



Source: NASA Earth Observatory website: <http://earthobservatory.nasa.gov/Library/Carboncyle>.

[10] *See NASA Earth Observatory website, <http://earthobservatory.nasa.gov/Library/CarbonCycle/carbon_cycle.html>.*

Reinforcing global warming mechanisms

Global warming feeds on itself

A potentially important feature of the carbon cycle is the possibility – some scientists would say the certainty – that global warming feeds on itself. While the long run history of Earth's mean temperature is suggestive of a system that is ultimately mean-reverting, or 'globally stable' (Figure 5), the scientific evidence is that, between these extremes, positive feedbacks make the system 'locally unstable'.

The main known positive feedback mechanisms include:

1. Melting of the permafrost, which exposes organic matter that then decays, releasing the greenhouse gases methane and carbon dioxide. Preliminary estimates put methane emissions from thawing permafrost at around 0.5 to 1.0 giga tonnes of carbon per year[11];
2. As the atmosphere warms, the amount of water vapour it can hold rises. Because water vapour is an active greenhouse gas, this multiplies the effect of warming;
3. Rising temperatures and changes in weather patterns, particularly of rainfall patterns, are thought to damage the ability of the Earth's natural sinks – the oceans and soil – to absorb CO_2;
4. As surface water temperatures increase, the ability of the ocean to remove carbon dioxide from the atmosphere decreases;
5. Furthermore, ocean acidification, the result of dissolved CO_2, weakens the CO_2 absorption organisms.

Recent studies are raising the estimated size of the feedback effect

Considerable uncertainty surrounds these positive feedback effects on temperature, which have not yet been accurately quantified. Recent studies have, however, suggested that these effects are quantitatively more important than was previously thought, and so scientists have been raising their projections of future atmospheric greenhouse gas concentrations. According to a team of European scientists (the Netherlands, Germany, and the United Kingdom), actual warming resulting from human fossil fuel emissions may be 15-78% higher than previous estimates that did not take feedback mechanisms[12] into account.

Atmospheric greenhouse gas concentrations are increasing

CO_2 emissions increased by 3.2% per year between 2000 and 2005 …

For 400,000 years, atmospheric CO_2 concentration fluctuated between 180ppmv and 280-300ppmv. Just before the Industrial Revolution, the figure was approximately 280ppmv. Today, atmospheric greenhouse gas concentration is more than one-third higher, at an estimated 380ppmv, a level not seen in at least the past 650,000 years[13].

OECD countries used to account for approximately half of total global emissions but, while the OECD figure is increasing in absolute terms, the proportion is decreasing relative to other regions, notably Asia (Figures 11 and 12).

The pace of greenhouse gas emission seems to have accelerated in recent years. The most recent evidence is that, whereas CO_2 emissions grew on average at 0.8% per year between 1980 and 1999, in 2000-2005 they grew at 3.2% per year, a four-fold increase[14].

… and, driven by Asian emissions …

Asia, particularly China, is driving this emissions acceleration, primarily through its rapidly increasing energy consumption, mainly of coal. Emissions are, however, also rising fast in North America, and may start accelerating again in the former USSR.

In 2000, 57% of global emissions came from the burning of fossil fuels and 32% came from agriculture and changes in land use[15] (Figure 10).

[11] See Walter, K.M. et al. (2006).
[12] See Scheffer, M. et al. (2006).
[13] See Shaw, J. (2006).
[14] See Energy Information Administration (2006).
[15] See World Resources Institute (2006).

From a sectoral perspective, the biggest emitter is the power sector, which accounts for a quarter of global emissions and was the fastest-growing source of emissions between 1990 and 2002 (2.2% per year).

Emissions arising from changes in land use – the second-largest source of global emissions, accounting for 18% of the total – are driven mostly by deforestation. Just a handful of countries are responsible for this deforestation: currently around 30% of land-use emissions are from Indonesia, and 20% from Brazil.

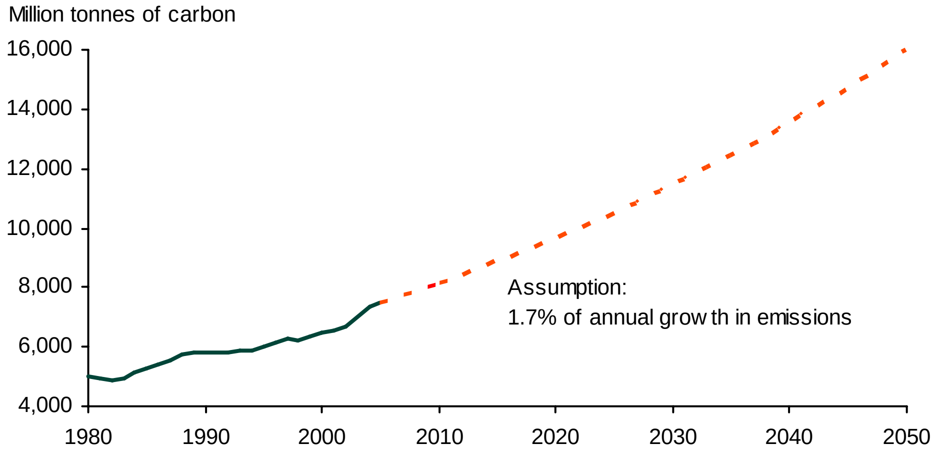
The transport sector currently accounts for just 14% of total emissions. But growth is expected to be rapid, with emissions standing to more than double by 2050. Aviation emissions in particular are expected to grow 3-fold by 2050, putting this among the fastest-growing sectors, although its emissions are expected to account for only 5% of the total in 2050.

The International Energy Agency (IEA) expects energy consumption to grow by 1.6% per year, on average (Figure 14). This figure is modest compared with the long-term average of 2.5%. However, in its Reference Scenario[16], the IEA projects emissions to grow at an annual rate of 1.7% (see the Box: *The IEA Reference and Alternative Scenarios*). On this basis, the level of emissions from the consumption and flaring of fossil fuels would exceed 10 giga tonnes of carbon per year by around 2025, reaching 15 giga tonnes by 2050 (see Figure 8).

… may well push the atmospheric greenhouse gas concentration over the 500ppmv threshold by 2050

By 2050, the atmospheric concentration of greenhouse gases will, on the assumption of 'business as usual' (BAU) trends, cross the 500ppmv threshold, a level not seen since the Eocene epoch, i.e. 36-55m years ago[17]. Other predictions suggest that, by 2100, the concentration of greenhouse gases in the atmosphere stands, on BAU trends, to reach between 540 parts per million by volume (ppmv) and 970ppmv[18] – more than double the pre-Industrial Revolution level of 280ppmv. According to the IPCC, this could result in an increase of 1.4º-5.8ºC in Earth's global average surface temperature over the period 1990-2100.

Figure 8. World carbon emissions from burning fossil fuels: history and projections

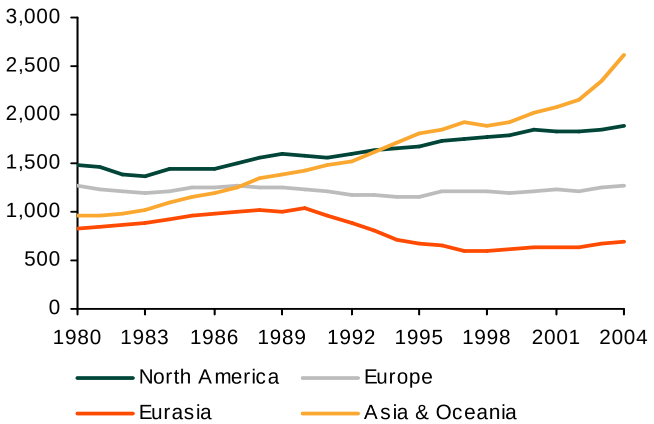


Sources: Energy Information Administration, International Energy Agency (2006a), and Lehman Brothers.

[16] See International Energy Agency (2006a).
[17] See Shaw, J. (2006).
[18] See Intergovernmental Panel on Climate Change (2001), vol.I, pp.8.

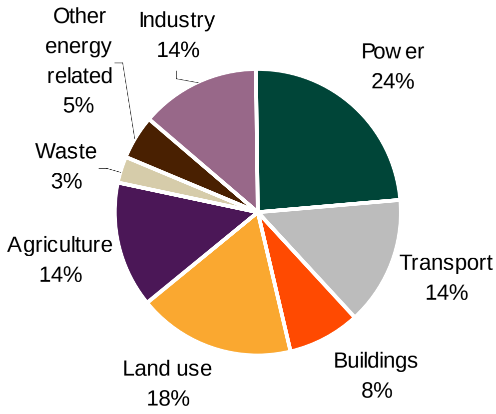
PICTURE BOOK: CARBON EMISSIONS

Figure 9. Carbon emissions history



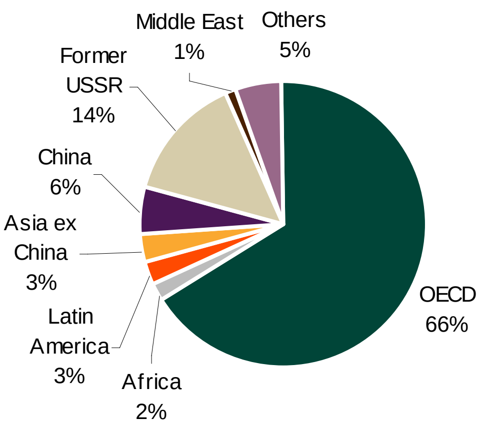
Source: Energy Information Administration website, <http://www.eia.doe.gov/environment.html>.

Figure 10. Carbon emissions by sector, 2000



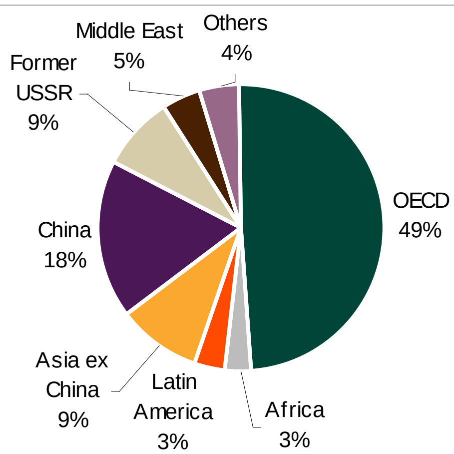
Source: World Resources Institute (2006).

Figure 11. Carbon emissions by region, 1973



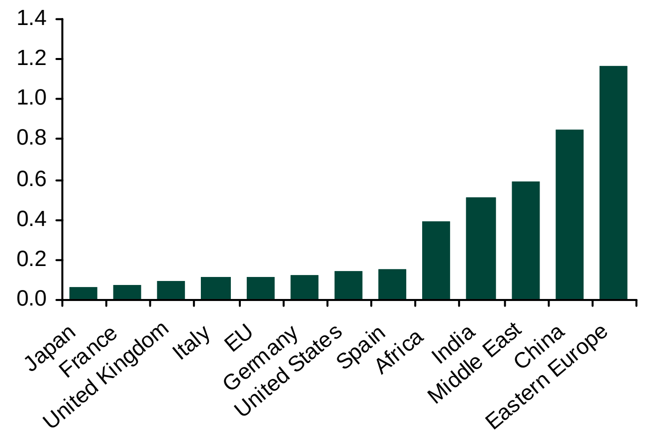
Source: International Energy Agency (2006b), pp.47.

Figure 12. Carbon emissions by region, 2004



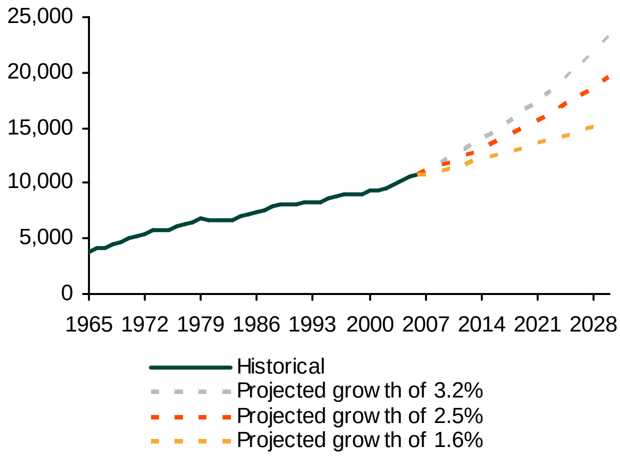
Source: International Energy Agency (2006b), pp.47.

Figure 13. Carbon emissions intensity by country, 2004



Source: Energy Information Administration (2004), table H.1cco2.

Figure 14. Energy consumption projections



Sources: BP (2006), and Lehman Brothers.

The IEA Reference and Alternative Scenarios

A measure of the extent to which policy could change the pace of CO_2 emissions in the coming decades is offered by the International Energy Agency in its *World Energy Outlook for 2006*[19]. In its Reference Scenario (set out in the section above, *Atmospheric Greenhouse Gas Concentrations Are Increasing*), the IEA describes how matters might look by 2030 on a 'business as usual' basis. The IEA's Alternative Policy Scenario, by contrast, shows how matters could look if the policies and measures that governments are currently considering are implemented.

The Reference Scenario

In the Reference Scenario, global primary demand is projected to grow by more than 50% between now and 2030, at around 1.6% per year. Fossil fuels remain the predominant source of energy to 2030, accounting for 83% of the overall increase in energy demand between 2004 and 2030. Coal sees the biggest increase in demand in absolute terms, driven by power generation. China and India account for almost four-fifths of the incremental demand for coal. Hydropower's share of primary energy use rises slightly, whereas that of nuclear power falls.

On these energy trends, which correspond quite closely to current trends, global energy-related carbon dioxide emissions increase by 55% between 2004 and 2030, at an annual rate of 1.7%. Coal overtook oil in 2003 as the leading contributor to global energy-related CO_2 emissions, and consolidates this position through to 2030. Developing countries account for over three-quarters of this increase in emissions, and they overtake the OECD economies as the biggest emitter shortly after 2010. China alone is responsible for about 39% of the rise in global emissions as a result of strong economic growth and heavy reliance on coal in power generation and industry.

The Alternative Policy Scenario

In this scenario, it is assumed that governments take stronger policy action to enhance energy security and reduce CO_2 emissions. This is achieved primarily through: improving efficiency in energy production and use; increasing reliance on non-fossil fuels; and sustaining the domestic supply of oil and gas within net energy-importing countries. Projected world primary energy demand in 2030 is about 10% lower in the Alternative Policy Scenario than in the Reference Scenario. In sharp contrast with the Reference Scenario, OECD oil imports level off by around 2015, and then begin to fall. CO_2 emissions are cut by 5% in 2015, and by 16% in 2030, relative to the Reference Scenario.

More efficient use of fuels, mainly through more efficient cars and trucks, accounts for almost 36% of the emissions saved. More efficient use of electricity in a wide range of applications, including lighting, air-conditioning, appliances, and industrial motors, accounts for another 30%. More efficient energy production contributes 13%. Renewables and biofuels together yield another 12%, and nuclear the remaining 10%. According to the IEA, it would take only a dozen or so policies to reduce CO_2 emissions by 40% by 2030.

A further conclusion of the Alternative Policy Scenario is that the new policies and measures analysed yield financial savings that far exceed the initial extra investment cost for consumers. The changes in electricity-related investment in particular yield particularly big savings. And, on average, an additional dollar invested in more efficient electrical equipment, appliances, and buildings obviates the need for more than two dollars in investment in electricity supply.

The analysis also demonstrates that each year of delay in implementing the policies would have a disproportionately larger effect on emissions. If the policies were to be delayed by 10 years, i.e. in 2015 instead of 2005, the cumulative avoided emissions by 2030 vis-à-vis the Reference Scenario would be only 2%, compared with 8% in the Alternative Policy Scenario. In particular, delays in stepping up energy-related research and development efforts in the field of CO_2 capture and storage would hinder prospects for bringing emissions down after 2030. ■

[19] *See International Energy Agency (2006a).*

Temperature-increase scenarios

Even if global emissions completely ceased today, Earth's mean temperature would continue to rise, by around 1ºC, as a result of past emissions and oceanic thermal inertia – the so-called 'climate change commitment'[20].

Base case scenarios suggest a temperature increase of between 2ºC and 5ºC over the next 50 to 200 years

Given that emissions will not cease today, Earth's mean temperature stands to rise by more than 1ºC over the coming century. Projections of temperature increase depend on postulated future carbon emissions (considered in the section above *Causes of Global Warming: the Importance of Greenhouse Gases*). If the growth of emissions remains at around the 'business as usual' rate, the concentration of CO_2 in the atmosphere will reach around 500ppmv by 2050. According to the Intergovernmental Panel on Climate Change's Third Assessment Report (IPCC TAR), and recent research by the Hadley Centre, such a continued increase in greenhouse gas emissions through the rest of the 21st century would lead to global warming of between 2ºC and 5.8ºC[21].

Table 1 gives equilibrium temperature projections for various CO_2 stabilisation levels, using the 5-95% climate sensitivity ranges. The third column shows the results obtained by Meinshausen[22] using climate sensitivity estimated from 11 recent studies.

Table 1. Temperature projections at stabilization relative to pre-industrial levels, ºC

Stabilisation level (ppmv CO_2 equivalent)	IPCC TAR 2001	Hadley Centre	Eleven studies (Meinshausen)
400	0.8 – 2.4	1.3 – 2.8	0.6 – 4.9
450	1.0 – 3.1	1.7 – 3.7	0.8 – 6.4
500	1.3 – 3.8	2.0 – 4.5	1.0 – 7.9
550	1.5 – 4.4	2.4 – 5.3	1.2 – 9.1
650	1.8 – 5.5	2.9 – 6.6	1.5 – 11.4
750	2.2 – 6.4	3.4 – 7.7	1.7 – 13.3
1000	2.8 – 8.3	4.4 – 9.9	2.2 – 17.1

Source: Stern, N. et al. (2006), ch.1.

Additional effects could drive temperatures even higher

The most recent research confirms the patterns of climate change described in the IPCC Third Assessment Report, but suggests that there is now a greater risk of reaching or exceeding the upper estimate (5.8ºC) by the end of 2100. Three additional effects are now better understood[23]:

1. **Radiative properties of aerosols:** Estimates of the magnitude of the aerosol cooling effect are moving towards higher values.
2. **Decrease of Earth's surface reflectivity (albedo):** The melting of snow and ice leads to enhanced absorption of sunlight, and hence accelerated warming.
3. **Carbon cycle dynamics:** Processes such as the oxidation of soil organic matter and the stability of carbon pools in wetlands and frozen soil, being sensitive to temperature, are expected to change significantly through this century.

These three effects may drive Earth's temperatures higher than suggested by earlier estimates, although recent leaks concerning the forthcoming IPCC report suggest that there may be little revision to its earlier temperature projections.

[20] *See Wigley, T.M.L. (2005).*
[21] *See Hadley Centre (2005).*
[22] *See Meinshausen, M. (2006).*
[23] *See Steffen, W. (2006), pp.20-23.*

CLIMATOLOGY: GLOBAL AND REGIONAL SCENARIOS

Global scenarios

Increases in global temperatures will have impacts on physical and biological systems

Increases in global temperature, and the resulting effects on climate, are likely to have numerous impacts on physical and biological systems, differentially across Earth's regions[24]. Examples of already observed changes include:

- Shrinkage of glaciers;
- Thawing of permafrost;
- Later freezing, and earlier break-up, of river and lake ice;
- Lengthening of high-latitude growing seasons;
- Earlier flowering of trees; and
- Declines in some plant and animal populations.

Water resources, agriculture and forestry, coastal zones and marine systems, and human health are perhaps the areas most susceptible to climate change. The combination of the effects on all these sectors could further amplify the impact of climate change. The impact on these sectors will also depend on the level of development, and the degree and rapidity with which countries and people adapt.

Care has to be taken when assessing the potential scenarios. Their probabilities range from virtual certainty to medium likelihood, as the Intergovernmental Panel on Climate Change emphasizes in its scenarios of projected changes in temperatures and hydrological indicators (Figures 15 and 16).

Hydrology and water resources

The resulting altered water cycle is likely to cause …

The entire water cycle stands to be altered by climate change, primarily through the increasing water-holding capacity of air: more water will evaporate. On the other hand, precipitation is likely to be more violent and intense, with more rain at high latitudes and at the Equator, and less rain in dry regions.

Figure 15. Projected changes in temperatures

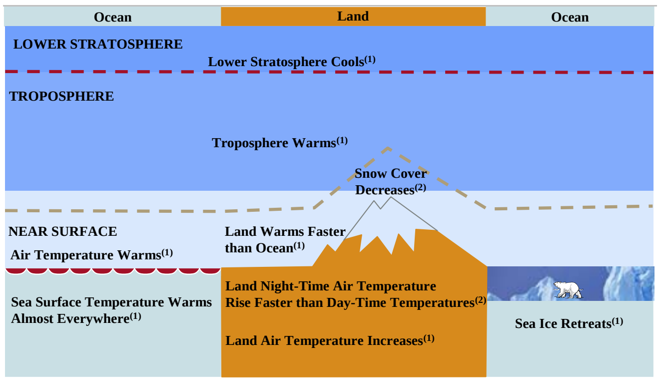
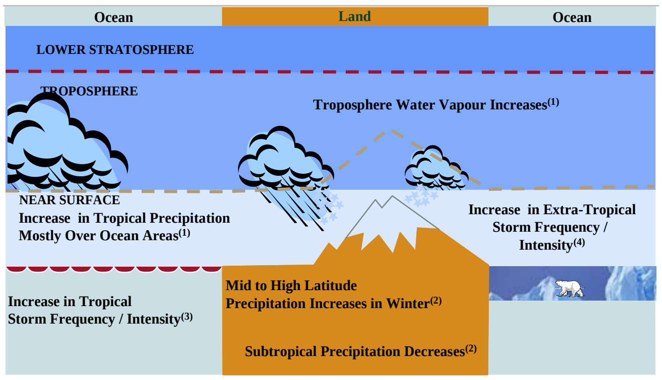


Figure 16. Projected changes in hydrological indicators



Source: Intergovernmental Panel on Climate Change (2001), vol.II, ch.9.

(1) *Virtually certain (many models analysed, and all show it).*
(2) *Very likely (a number of models analysed show it, or change is plausible and could readily be shown by other models).*
(3) *Likely (some models analysed show it).*
(4) *Medium likelihood (a few models show it, or results are mixed).*

[24] *See Intergovernmental Panel on Climate Change (2001), vol.III.*

… increased risk of drought …

Increased summer drying over most mid-latitude continental interiors, and the associated risk of drought, also stands to decrease available water resources. Even though total precipitation is expected to increase as the climate warms, the proportion of land subject to drought is expected to rise because of enhanced evaporation and some areas experiencing less rainfall. Recent research by the UK Met Office Hadley Centre has estimated the proportion of land area that would be affected by drought. Without significant abatement of emissions, by 2100 the area of Earth affected by drought is projected to double, from 25% to 50%[25]. Moreover, events associated with El Niño may lead to decreased hydropower potential in drought-prone regions.

… general degradation of water quality …

Water quality is likely to change, and in many cases to degrade, through higher water temperatures and increased pollutant loading from more intense runoff.

The retreat of most glaciers and ice shelves is expected to accelerate; small glaciers may disappear. This will likely increase flood risk during the wet season in affected regions.

… and sea level rise

This also stands to raise sea levels worldwide. Many estimates put the possible sea level rise at around 1 metre by 2100, although the IPCC suggests a more modest scenario, with a range from 0.1 to 0.9 metre[26]. Rising sea levels will increase the amount of endangered lands and likely force people to displace. Currently, more than 200m people live in coastal floodplains and many of the world's biggest cities (22 of 50) are at risk of flooding (including Tokyo, London, Hong Kong, New York, Buenos Aires, and Mumbai) – see Box: *Coastal Zones at Risk*.

Some recent estimates of a likely sea level rise have been more pessimistic. The president of the American Association for the Advancement of Science, John Holdren of the Kennedy School of Government (KSG), recently stated that if the current pace of change continued, "a catastrophic sea level rise of 4 metres (13ft) this century was within the realm of possibility; much higher than previous forecasts"[27]. He also suggested that the melting of the Greenland ice cap could increase sea levels world-wide by 7 metres (23ft), swamping many cities. Even more pessimistic are predictions by Tim Naish (Institute of Geological and Nuclear Sciences)[28]. According to his recent research, if the West Antarctic Ice Sheet and its northern counterpart on Greenland were both to melt, sea levels would rise by about 10-12 metres. However, according to what has already been leaked, the IPCC's overall tone in its Fourth Assessment Report would be that the impact of global warming on sea levels could be less than feared[29].

Furthermore, many scientists consider that the Gulf Stream may slow (it has already decreased by 30% since 1957), as fresh water from melting Arctic and Greenland ice reduces the salinity of the oceans that is believed to be fundamental for such (thermohaline) ocean circulation. A weaker Gulf Stream might, paradoxically, reduce temperatures in the countries where coasts are usually warmed by it, most notably the United Kingdom, Ireland, France, and Norway.

Agriculture and food security

Rising temperatures are likely to influence crop yields

Climate has a significant influence on food security. The impacts of rising temperatures will likely differ by region and type of crop. In tropical regions, for example, even moderate warming may lead to disproportionate declines in yield. In higher latitudes, however, crop yields may improve as a result of a small increase in temperatures, although subsequent larger temperature increases may cause them to fall.

Climate change impact also depends on the so-called 'carbon fertilization effect', whereby an increased concentration of atmospheric carbon can stimulate crop growth. But it is also likely that any such positive impact will eventually be offset by the adverse

[25] *See Hadley Centre (2006).*
[26] *See Intergovernmental Panel on Climate Change (2001), vol.II, ch.11.*
[27] *See BBC, 31 August 2006.*
[28] *See BBC, 4 December 2006.*
[29] *See Financial Times, 29 December 2006.*

effects of climate change, particularly by excessive heat and drought. Furthermore, the scenario of rising temperatures stands to increase heat stress in livestock.

Terrestrial and freshwater ecosystems

Ecosystems could be severely impacted by climate change

Many scientists consider that Earth's ecosystems are already being affected by climate change and could be affected considerably further. Over the past 40 years, some species have been moving pole-ward by 6km, on average, per decade. Cold-water fish, for example, are likely to migrate towards the poles, their traditional habitat, which are in turn becoming occupied by warm-water fish. Also striking are changes in seasonal events, such as flowering or egg-laying, which have been occurring several days earlier each decade[30].

Climate change also stands to bring about the extinction of species that cannot adapt to a rapidly changing climate. It has been estimated that, on the basis of mid-range global warming by 2050, 15-37% of species considered in a sample of regions and species will be at risk of extinction[31]. Moreover, should the Amazon get drier, this would result in dieback of forest that today exhibits the highest biodiversity on Earth.

Hotter and dryer summers imply greater risks of forest fire, destroying fauna and flora.

More intense precipitation can be expected to lead to more flooding, landslides, avalanches and mudslide damage, and soil erosion.

Coastal zones and marine ecosystems

Climate change will likely have various consequences for marine ecosystems, including: increases in sea surface temperature; increases in mean global sea level; decreases in sea-ice cover; and changes in salinity, wave conditions, and ocean circulation.

Most coastal areas stand to experience more flooding and coastal erosion, and increased damage to coastal ecosystems such as coral reefs and mangroves. The impacts stand to be even greater for high-latitude coasts, due to higher wave energy and melting of the permafrost.

Human health

Frequency of some diseases could increase

Climate change, as projected, would lead to an increase in heat waves, exacerbated by humidity and pollution in urban areas. This would most likely cause more heat-related illnesses and deaths. On the other hand, there would be reduction in cold-related deaths, in particular in the higher latitudes. Crop yields in many regions may decrease, particularly in the poorest regions of the globe, exacerbating risks of hunger and malnutrition.

The increase in flooding stands to increase the number of people exposed to vector-borne (e.g. malaria), water-borne (e.g. cholera), and diarrhoeal diseases.

Climate change has already caused additional deaths

The World Health Organisation (WHO) has estimated that climate change is already causing more than 150,000 deaths per year through increasing incidence of those diseases and estimates that a 1ºC increase in global temperature could double this figure. At higher temperatures, heat-related deaths would increase severely.

[30] *See Root, T.L. et al. (2005).*
[31] *See Thomas, C.D. et al. (2004).*

Coastal zones at risk

Between 3,000 years ago and the start of the 19th century, Earth's mean sea level was virtually constant, rising by just 0.1mm to 0.2mm per year. Since 1900, however, the level has risen at 1mm to 3mm per year; and satellite altimetry from TOPEX/Poseidon (NASA/CNES)[32] indicates a rate of about 3mm per year[33] since 1982. According to NASA, most of this rise in sea levels comes from warming of the world's oceans and melting of mountain glaciers.

In 2001, the IPCC TAR predicted that, by 2100, global warming will have led to the sea level having risen by between 10cm and 90cm. A further increase in sea levels beyond 2100 is quite possible, particularly given the likelihood of more rapid net melting of the Greenland ice cap and the West Antarctic Ice Sheet. Rising sea levels will increase the amount of endangered land and, ultimately, force people to displace. Yet increasing trade and market-driven movements continue to attract people to coasts. Today, about 10% of the world's population live in a coastal zone at less than 10 metres of elevation, although this low elevation coastal zone accounts for only about 2.2% of the world's land area.

Low coastal zone settlements at risk

A recent article[34] describes the distribution of human settlements in low elevation coastal zones (LECZs) around the world. Human settlement has long been drawn to coastal areas, in large part because of the presence of many resources and trading opportunities. Although these zones are particularly exposed to natural hazard, population in those zones has not decreased. On the contrary: about 17m people moved to the coastal zones of China between 1995 and 2000, for example. Globally, coastal zones have higher population densities than any other major ecologically defined zone, except for urban zones.

Not only are small island states put at risk by sea level rise, but also significant parts of populations in many other countries live in potentially vulnerable low elevation coastal zones – defined as contiguous land area up to 100 kilometres from the coast that is 10 metres or lower in elevation. These zones contain about 10% of the world's population and 13% of the urban population.

In absolute numbers, Asia accounts for about a third of the world's land in LECZs but, because of far higher population densities, it accounts for three-quarters of total population in these zones. The low-income countries have a higher proportion of their population living in those zones – 16% on average, compared with 10% for the OECD countries. The top 10 countries in terms of population living in LECZs are mostly large Asian countries with significant delta regions, including China (127m people), India (63m) and Bangladesh (53m). The top ten countries in terms of population share living in LECZs include various small islands, such as the Maldives (100%) and the Bahamas (88%).

Three different types of countries are at particular risk from sea level rise: islands with long coastlines, such as the Maldives and the Bahamas; countries with large delta regions and heavily populated coastal lowlands, such as Vietnam and Bangladesh; and countries with sparsely inhabited interiors and populations concentrated in small coastal strips, such as Surinam and Guyana.

Is New York City at risk from higher sea levels?

NASA scientists have recently also examined, by means of computer simulation models, the potential impact of rising sea levels and hurricane storm surge on New York City[35]. According to Vivien Gornitz, a scientist at NASA's Goddard Institute for Space Studies (GISS), "…with sea level at higher levels, flooding by major storms would inundate many low-lying neighbourhoods [of New York] and shut down the entire metropolitan transportation system with much greater frequency".

With sea levels rising, NYC faces an increased risk of hurricane storm surge – i.e. an above normal rise in sea level accompanying a hurricane. The sea level rise in the 2050s in NYC is expected to reach between 38cm (15 inches) and 48cm (19 inches). According to this study, adding as little as 45cm (1.5 feet) by the 2050s to the surge for a category 3 hurricane (on a 1 to 5 scale, with 5 being the strongest and most destructive) would cause extensive flooding in many parts of the city. Areas identified as potentially subject to inundation are the Rockaways, Coney Island, much of Southern Brooklyn and Queens, and portions of Long Island City. ■

[32] *The TOPEX/Poseidon, a joint project between the Centre Nationale d'Etudes Spatiales (CNES), the French government space agency, and the National Aeronautics and Space Administration (NASA), is a satellite altimeter to measure the ocean surface topography.*
[33] *See Intergovernmental Panel on Climate Change (2001), vol.II, ch.11.*
[34] *See McGranahan, G. et al. (2006).*
[35] *See NASA website, <http://www.nasa.gov/mission_pages/hurricanes/archives/2006/sealevel_nyc.html>.*

Regional scenarios

Polar

Polar regions will likely be the most affected

Temperature rise is likely to be at its smallest around the Equator, and correspondingly at its largest in the Polar regions, with major physical, ecological, sociological, and economic impacts in the Arctic, the Antarctic Peninsula and the Southern oceans.

Some changes have already occurred: a decrease in the extent and thickness of Arctic sea ice; thawing of the permafrost; changes in ice sheets and ice shelves; and changes in the distribution and abundance of species. These changes are already having, and will likely have, further negative impacts (on infrastructures, such as pipelines), but also positive impacts (such as the opening of the Arctic to shipping all year round, and new agricultural possibilities arising from the melting of the permafrost).

Africa

Water availability may decrease in many African regions, jeopardizing food security

Africa is particularly vulnerable to climate change because of widespread poverty and poor governance.

Major rivers are sensitive to climate change: water availability may decrease, particularly in the Mediterranean region and in many sub-Saharan countries. Increases in droughts and floods stand to degrade water resources and thereby food security and human health.

Food security may be put under pressure through shortage of water in some regions, exacerbated by an increasing number of droughts. Africa, where a major part of the population depends on rain-fed agriculture for its livelihood (more than 70% in sub-Saharan Africa), seems likely to be particularly affected.

Desertification could be exacerbated by global warming and reductions in rainfall, especially in southern, northern, and perhaps western Africa. Significant extinctions of plant and animals species are projected.

Coasts would be affected by sea-level rise through inundation and coastal erosion. Many large cities that lie on the coast or close to it would be put at risk by a sea-level rise. According to the United Nations Framework Convention on Climate Change (UNFCCC), a 1-metre sea level rise could result in the complete submergence of Banjul, Gambia's capital, which has a population of around half a million, and Lagos, Nigeria, which is one of the biggest cities in Africa and lies in a coastal plain.

Incidence of malaria and infectious diseases could increase

Human health would be affected by the rise in floods and droughts, particularly through the increased incidence of malaria and the extension of the range of infectious diseases.

Asia

Water availability may decrease in some regions, and flood frequency increase in others

Mountain snow levels may be reduced, e.g. in the Himalayas, leading to reduced flow in rivers that, as noted in Gore (2006), "…provide more than half the drinking water for 40% of the world's population". At the same time, rainfall intensity may rise. Overall, runoff and water availability may decrease in arid and semi-arid Asia, but increase in northern Asia, while temperate and tropical Asia may experience increased risks from floods.

Food security may be endangered by: thermal and water stress; sea-level rise; floods and droughts; and tropical cyclones, implying reduced agricultural productivity. However, the impact will likely differ by region and crop.

Climate change would exacerbate threats to biodiversity as a result of land-use and land-cover change, and population pressure in Asia.

Tens of millions of people could be displaced

Sea-level rise, and an increase in the intensity of tropical cyclones, could displace tens of millions of people in low-lying coastal areas of temperate and tropical Asia. Ecological security might be threatened: in particular, mangroves and coral reefs may be endangered.

If the temperature increases for all months, as commonly expected, the incidence of extreme heat effects is likely to increase. Exposure to vector-borne infectious diseases and heat stress may threaten human health in some parts of Asia.

Australia and New Zealand

Water is likely to become a particular issue in Oceania

As Earth's driest continent, drier and hotter summers may pose a particular threat to Australia. Water, in particular, is likely to become a key issue given projected drying trends and change to a more El Niño-like average state.

A drier climate may also endanger ecosystems. The Queensland rainforest in Australia may be threatened. Some species with restricted climatic niches, and which are unable to migrate as a result of fragmentation of the landscape, soil differences, or topography, could become endangered or extinct. Australian alpine systems could also be put at risk.

Freshwater wetlands in coastal zones in Australia and New Zealand are potentially vulnerable, with some New Zealand ecosystems exposed to accelerated invasion by weeds. Furthermore, coral reefs are particularly at risk from rising ocean temperatures.

Europe

Different types of climate may experience different climate change impacts

Europe as a whole is characterised by several different types of climate. Accordingly there stand to be various climate-change impacts across the continent. Mediterranean regions may see rising water stress, more intense heat waves, and forest fires. On the other hand, Northern Europe could experience positive impacts from a warmer, but wetter, climate, most notably, perhaps, rising crop yields.

Half of all alpine glaciers and large permafrost areas could disappear by the end of the 21st century, one consequence being increased river flood hazard across much of Europe.

In coastal zones, the risk of flooding, erosion, and wetland loss may increase substantially, with implications for human settlement, industry, tourism, agriculture, and coastal natural habitats. The Netherlands is at particular risk: some 70%-odd of its population would be threatened by a 1-metre rise in the level of the sea.

Finally, disappearance of the Gulf Stream would lead to the cooling of certain regions, particularly France, the United Kingdom, Ireland, and western Norway.

Latin America

The Amazon rainforest could die back

Floods and droughts would become more frequent, with floods increasing sediment loads and degrading water quality in some areas. Subsistence farming could be threatened by a shortage of water in many places.

The potential dieback of the Amazon rainforest is a particular threat for the region, as it represents home for around 1m people, and a source of income, and medical and pharmaceutical supplies for millions more[36].

Vector-borne infectious diseases transmission may increase, and it is likely that new transmission areas will appear.

North America

Storms and hurricanes could become more frequent and intense

An increase in extreme weather events is likely, notably increased heat waves, intense precipitation, which would increase risks of inland flooding, and more intense hurricanes, which may result in increased coastal flooding, particularly in areas such as the eastern seacoast and the Gulf of Mexico.

Reduced sea-ice cover and ice melting could however create opportunities in Canada, such as improved access to oil, gas and mineral resources.

Impacts on agricultural yields may be positive for moderate temperature increases and with a strong carbon fertilization effect, but negative for larger temperature increases.

[36] *See Stern, N. et al. (2006), ch.4.*

Unique natural ecosystems such as prairie wetlands, alpine tundra, and cold-water ecosystems will likely be at risk, and the rate of biodiversity loss may well increase.

Sea-level rise would result in accelerated coastal erosion; coastal flooding; loss of coastal wetlands; and increased damage from storm surges, most notably perhaps in Florida and much of the US Atlantic coast.

In the highest latitude regions of the continent, the impact of climate change could be positive in terms of human health, as it could decrease the rate of cold-related deaths. On the other hand, risks of heat stress could increase.

Does climate change imply more extreme weather events?

The term 'extreme weather events' is variously taken to mean an increase in: heat waves; precipitation intensity; the number of tropical storms; and the intensity and frequency of tropical cyclones.

In 2003, the World Meteorological Organisation (WMO) suggested a link between climate change and the occurrence of extreme weather events, saying that "… recent scientific assessments indicate that, as the global temperatures continue to warm due to climate change, the number and intensity of extreme events might increase".

Simple extreme events such as higher land temperatures and increasing intensity in precipitations are projected as highly likely, i.e. to have a 90-99% probability of occurring. One of the earlier findings was that higher mean temperatures increase the probability of extreme warm days, and decrease the probability of extreme cold days. Furthermore, as surface water evaporates as a result of global warming, heat and moisture are likely to rise into the atmosphere, leading to increases in precipitation intensity and, potentially, to increases in precipitation frequency in some regions[37]. Most climate models predict increases in rainfall at high latitudes, but there is more uncertainty about rainfall increases in the tropics.

Long-run data, although not particularly reliable, suggest hurricane activity may be cyclical, particularly in the Atlantic (the 1940s and 1950s were active periods, the 1970s and 1980s less so).

As regards the most recent past, two recent studies suggest that warming of tropical oceans has been responsible for the increasing frequency and intensity of hurricanes. Emanuel (2005)[38] reports that a measure of the power dissipated by tropical cyclones has approximately doubled since 1950 and particularly over the past 30 years. In another study, Webster et al. (2005)[39] stated that the number of category 4 and 5 hurricanes has almost doubled globally over the past 30 years.

These results have however been challenged by other scientists. Landsea (2005)[40] suggests that there is no evidence of increasing intensity of cyclones. And Pielke et al. (2005)[41] argue that it is premature to claim a strong link between global warming and hurricane impacts. They make a strong distinction between event risk – i.e. the occurrence of a particular phenomenon – and vulnerability – i.e. demographic, economic, political and social conditions that shape the vulnerability to impacts, and which may better explain the increased damage caused by hurricanes.

This is still an area of considerable uncertainty: temperature seems unlikely to be the whole story. Thermohaline circulation and associated ocean currents, the frequency and strength of vertical winds, and the magnitude of atmospheric temperature changes also likely play a – not yet well understood – role. ■

[37] *See Meehl, G.A. et al. (2000).*
[38] *See Emanuel, K. (2005).*
[39] *See Webster, P.J. et al. (2005).*
[40] *See Landsea, C.W. (2005).*
[41] *See Pielke, F. et al. (2005).*

ECONOMICS: COSTS, ABATEMENT, AND ADAPTATION

Few economists are competent to pronounce on the purely scientific elements of the climate change issue and, largely for that reason, this study takes the balance of the scientific evidence as given. However, like any members of society, economists are entitled to make their own minds up about the likely validity of the balance of the scientific evidence and argument, and we for our part assess this as sufficiently compelling to warrant taking the climate change issue seriously.

Climate change is also an ethical issue, to the extent that many, perhaps most, of the likely effects will be experienced by later generations. This aspect of the issue is not, however, considered in this study.

Climate change is an economic issue

Climate change is a classic case of an 'economic externality'

In addition to being a scientific and an ethical issue, climate change is an important economic issue, given the scale of the costs that it may impose on society. Furthermore, the characteristics of the origin of this potential cost are well recognisable by the economist: climate change is a classic case of an 'economic externality'.

Economic externalities – which may be positive or negative – arise when an action, whether by an individual, a firm, or a country, imposes costs (or benefits) on parties other than the entity taking the action.

A typical example of a positive externality is an invention: once made and accessible to the public, others benefit by exploiting it, without rewarding the inventor. Hence, patent law was invented, and in most countries enacted, to enable the inventor to benefit from his or her invention. Thus, patent laws 'internalise the externality'.

A typical case of a negative externality is pollution by a firm: while nuisance or harm is visited upon others, this damage largely falls outside the cost structure of the polluter. Similarly, emitting greenhouse gases into the atmosphere imposes costs on present and future generations, yet the emitters themselves face at most a fraction of the consequences, including the costs, of their actions.

A recognized role of public policy is to internalise externalities, such as various costs of climate change

It is therefore a recognised role of public policy to internalise such external costs into the cost structure of the polluter, so that the polluter becomes obliged to take into account the full economic costs of his or her actions, a policy often referred to as the 'polluter pays' principle.

Some characteristics of climate change differ from more customary externalities, however[42]:

- **The causes and consequences are global**. This poses particular welfare-economic issues, not least because climate change is likely to have substantially different impacts across countries.
- **Impacts will persist.** Once greenhouse gases have entered the atmosphere, some remain for hundreds of years. This raises the question of how to account for the interests of future generations.
- **Uncertainties and risks are large**. This raises the general issue of decision making under uncertainty, and in particular the extent to which policy should be directed at the risk, even if deemed small, of a potentially catastrophic event.

In addition to the general issue of externalities, the economics discipline also has relevant experience in a number of other more specific areas, including: the behaviour of complex systems; the construction and use of large-scale models; decision-making under uncertain information; and the principles of trade-offs and insurance.

[42] *See Stern, N. et al. (2006), ch.2.*

Moreover, a number of the lessons learned by economists almost certainly apply to the endeavours of scientists and climatologists.

Climate change predictions are having to be made outside the range of historical data

One such experience is that the largest forecasting errors tend to be made in the face of shocks that are simultaneously both large and novel; forecast errors rapidly become larger as the projection period increases[43].

A second experience is that forecast errors tend to be particularly large when models are used to make predictions outside the range of data from which they were estimated. Both points apply to the analysis of climate change.

How to quantify the economic costs of climate change

Climate change will almost certainly impose costs on a country's GDP

In principle, it is straightforward to understand why climate change could imply costs to a country's gross domestic product (GDP). Typically, the volume of an economy's output is considered to be a function of the quantity and quality of its capital stock, the size and quality of its labour force, and the economy's overall level of technology. Both the quantity and the quality of capital and labour stand to be affected by damage inflicted by changes in climate: an extreme weather event stands to damage land, infrastructure, installations, and so on, while labour, too, stands to be negatively affected by adverse weather conditions, for example through an increase in diseases and heat stress.

Accordingly, one – and so far the most common – way of estimating the potential costs of climate change is in terms of the reductions that it may bring to the economy's Gross Domestic Product (GDP), relative to what it would have been, had the climate not changed.

Another potential method of measuring the costs of climate change involves subtracting from GDP an estimate of what it would cost to rectify damage done to the environment by economic activity, so as to obtain an estimate of 'sustainable consumption'.

In practice, most studies to date on the likely economic costs of climate change have been of the first type. China's authorities recently produced preliminary estimates, released in September 2006, suggesting that economic loss caused by environmental pollution reached 3.1% of national GDP in 2004, of which the imputed treatment cost accounted for 1.8pp.

Projections have to look unusually far ahead, which is difficult and uncertain

Whatever principle is adopted, however, estimating the likely economic cost of climate change brings a host of empirical difficulties, not least because the calculations must take, as their starting point, projections extending many decades into the future. That problem is not unique to climate change policy, however. Many governmental policies, such as defence, have to be made long in advance for a world that is changing, sometimes rapidly.

Understanding the assumptions on which cost estimates are made is therefore crucial in assessing the appropriateness of proposed policies.

Studies of the costs of climate change

It is generally considered that the scale of the costs that will result from changes in climate will depend on, *inter alia*, the size of the temperature increase. Published estimates therefore are heavily dependent on the temperature assumptions made by the researcher, as well as on a range of other factors, including: the valuation of the impacts on rich and poor regions; and societies' and economies' ability to adapt to climate change. A selection of estimates from five models is shown in Figure 17.

Of the major studies, three took as their starting assumption a warming of 2ºC to 3ºC. A fourth, the recent Stern Review[44], is based on a bigger temperature increase, together with a number of more pessimistic assumptions.

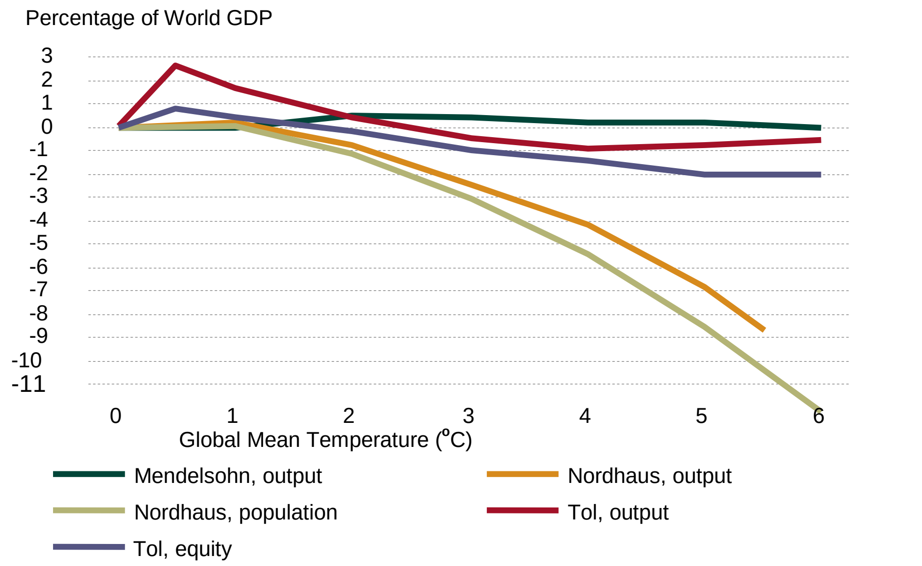
[43] *See Llewellyn, G.E.J. and Arai, H. (1984).*
[44] *See Stern, N. et al. (2006), ch.6.*

Conservative assumptions suggest moderate economic costs …

The main features of four of these models are as follows (a selection of estimates from various variants of them is shown in Figure 17):

1. **Mendelsohn** [45] **.** Detailed spatial simulations were produced using a general circulation climate model, to generate country-specific climates. Impacts were then estimated for five market sectors: agriculture; forestry; energy; water; and coastal zones. The country-specific results suggest that a 2ºC global warming by 2060, taken as the base-case scenario, would result in net market benefits for most OECD countries, and net market damages for most non-OECD countries. The estimated overall impact on global GDP was close to zero.
2. **Tol** [46] **.** This exercise took into account six market sectors (agriculture; forestry; water; energy; coastal zones; and ecosystems), and three non-market sectors (vector-borne diseases; heat stress; and cold stress). Two types of models were employed: an equity-weighted one, and an output-weighted one, both for the period 2000-2200. The estimates suggested that initial increases in global mean temperature would yield net benefits – 0.5% or 2.5% of GDP for a 0.5ºC warming, depending on the model used. However, the estimated effects on global GDP turned negative with the equity-weighted model beyond a 1ºC mean temperature rise, and beyond 2ºC to 2.5ºC with the output-weighted model.
3. **Nordhaus** [47] . A Regional Dynamic Integrated model of Climate and Economy (integrated-assessment model RICE-98[48]) was used to produce estimates by region. The estimated damage from a 2.5ºC warming ranges from a net benefit of 0.7% of GDP for Russia to net damage of almost 5% of GDP for India. The global average impact was estimated at 1.5% of GDP using 2100 output weights, and 1.9% of GDP using 1995 population weights (Figure 18). Nordhaus also attempted to estimate the possible economic cost of catastrophic climate impacts, which are responsible for much of the larger estimated cost of climate change at higher levels of warming. Catastrophic impacts are estimated as rising progressively to about 1% of GDP by 2100 for a 2.5ºC warming, and up to 7% of GDP for a 6ºC warming (Figure 19).

Figure 17. Economic costs of climate change: results from 3 economists' models



Source: Smith, J.B. et al. (2001).

[45] *See Mendelsohn, R. et al. (2000).*
[46] *See Tol, R.S.J. (2002).*
[47] *See Nordhaus, W. and Boyer, J. (1999).*
[48] *In turn, RICE-98 was based on two earlier models (DICE and RICE).*

… while more pessimistic ones suggest much more dramatic costs

4. **Stern**[49]. The central case is that 'business as usual' temperature increases may exceed the 2-3ºC warming by 2100 assumed by other studies. With a 5-6ºC warming, models that include the risk of abrupt and large-scale climate change in their assumptions produce a 5-10% loss of global GDP, with developing countries suffering costs of more than 10%. Stern considers that even those estimates may be too optimistic when account is taken of three factors additional to those in the preceding three studies:

    - **Direct impacts on the environment and human health**: these increase the total cost of 'business as usual' climate change from 5% to 11%;
    - **Recent scientific evidence**: the climate system may be more responsive to greenhouse gas emissions than previously thought; and
    - **Uneven incidence**: A number of developing countries are likely to experience disproportionate effects of climate change

Further economic impacts are possible too, such as those that might derive from consequential migration and human conflict. Some regard Darfur as the world's first 'climate change conflict'.

Terminology

The literature on climate change is inconsistent in its terminology. We have sought to use a terminology that is consistent with the balance of usage in the climate change literature; consistent with definitions given by major dictionaries; and that also avoids ambiguity. Thus:

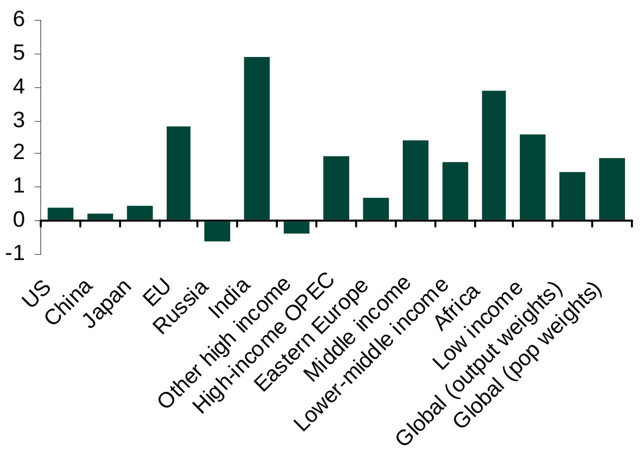
Abate. Used in this publication in the sense of "to bring down" or "to reduce or lessen in degree or intensity" and applied to the rate of emission of greenhouse gases.

Mitigate. This word is used in two different ways in the climate-change literature: (1) to take steps *ex ante* to reduce greenhouse gas emissions, i.e. to abate; and (2) to take steps to reduce, *ex post*, the effects of greenhouse gas emissions, i.e. to adapt. We do not use the word in this publication.

Adaptation. The process whereby economies adjust to the effects of climate change.

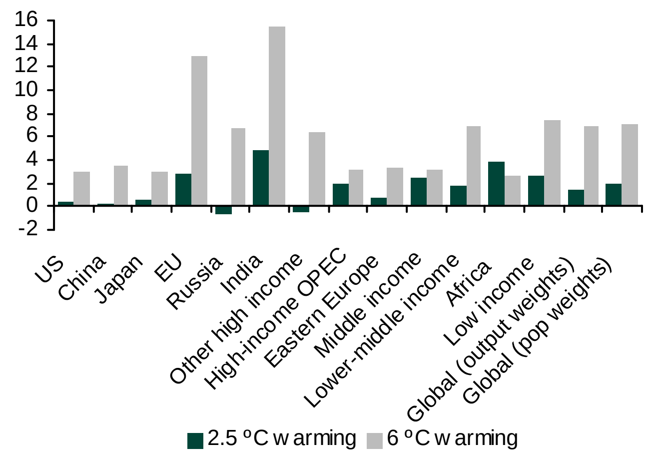
Sources: The New Shorter Oxford English Dictionary (1993); *Webster's Third New International Dictionary* (1993); and *The Cambridge Guide to English Usage* (2004). ■

Figure 18. Estimated cost of 2.5ºC global warming (% of GDP)



Source: Nordhaus, W.D., Boyer, J. (1999).

Figure 19. Estimated costs of 2.5ºC and 6ºC global warming (% of GDP)



Source: Nordhaus, W.D., Boyer, J. (1999).

[49] *See Stern, N. et al. (2006), ch.6.*

Assessing the cost of abatement

Different assumptions…

The counterpart of the quantification of climate-change-related costs is the assessment of the costs implied by abatement policies, i.e. the costs implied by the actions taken to reduce carbon emissions.

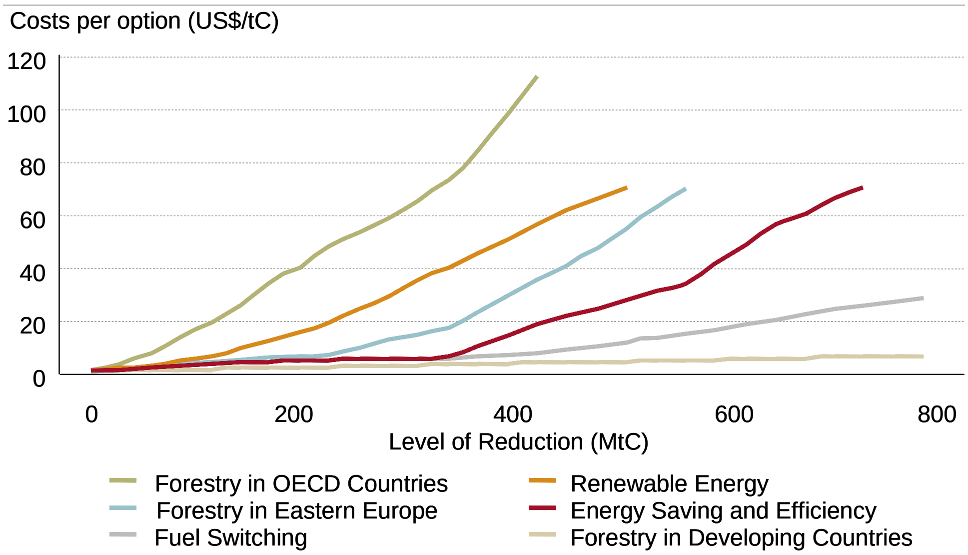
The estimated net cost or benefit of abating greenhouse gas emissions at the macro economic level is typically seen as depending on three principal factors:

- **The target level of atmospheric carbon concentration**. Costs are generally considered to be a (rising) function of the target chosen. A commonly proposed target level is 550ppmv (today's level is around 380ppmv, growing annually by 2-3ppmv). The Stern review suggests a feasible target range of 450-550ppmv, arguing that achieving a figure below 450ppmv would be unduly costly, while allowing concentrations to rise above 550ppmv risks producing catastrophic consequences.
- **The discount rate applied**. The present value of cost estimates depends considerably on the choice of discount rate. For example, applying a discount rate of 4% values $1m worth of damage in 100 years' time at about $20,000 today, whereas applying a discount rate of 8% puts the figure at only $500. The choice of discount rate in multi-generational calculations is an ethical, as much as an economic, issue.
- **The assumed pace of technological change.** If the pace is rapid, and if it implies significant substitution opportunities, this will increase the cost/benefit ratio of near-term action, compared with a situation where technological development is slow.

There are many ways in which reduction of the pace of greenhouse gas emission – abatement – can be effected, and they imply a broad range of costs (see Figure 20). Planting trees in OECD countries is a particularly expensive way of abating CO_2 emissions given the (relatively) high cost of both labour and land in those economies, whereas planting trees in developing countries is at present a particularly low-cost option. Renewable energy is at present the second most expensive method of abatement, whereas planting trees in Eastern Europe is somewhat less expensive, and energy-saving and efficiency gains are cheaper still.

The data in Figure 20 also capture a second important feature of the cost of abatement: it typically rises with the scale of abatement. The costs of abating CO_2 by planting trees in OECD countries, for example, more than doubles for a doubling of the abatement level target from 200m to 400m tonnes of carbon.

Figure 20. Abatement costs by option (US$/tC)



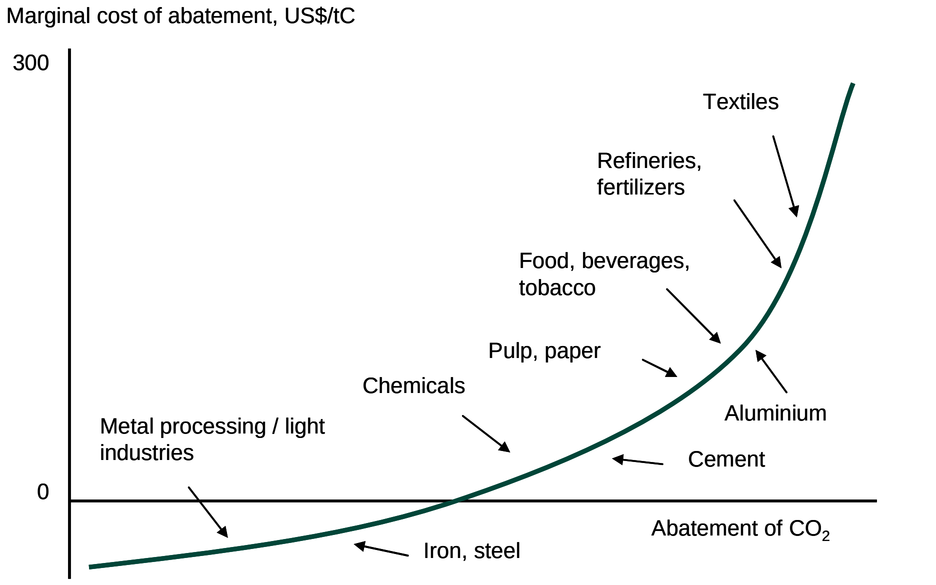
Source: Intergovernmental Panel on Climate Change (2001), vol.IV, ch.4.

… and various abatement methods …

There are perhaps four principal ways to achieve reductions in greenhouse gas emissions, relative to business as usual levels:

- **Improving energy efficiency.** The International Energy Agency (IEA) has shown that there is considerable room for adopting more efficient technologies in buildings, industry and transport. In its Accelerated Technology scenario, improved energy efficiency leads to 17-33% lower energy use than in the Baseline scenario by 2050[50]. This is the main option for the manufacturing sector, and technical potential is substantial. The cost of investing in capital and equipment to increase energy efficiency differs considerably by sector. In some, the cost of abatement may even be negative: i.e. investment in new, carbon-efficient plant may reduce the quantity of *all* inputs used. This is particularly the case for some metal processing and light industries, and for iron and steel (Figure 21). In other sectors, by contrast, the costs of reducing greenhouse gas emissions is often reckoned to be substantial, exceeding $250 per tonne of CO_2 on the basis of present technologies.
- **Cutting non-fossil-fuel-related emissions.** Agriculture and land-use currently account for around a third of global greenhouse gas emissions, and non-fossil fuel emissions in total account for about 40%. Three types of costs arise from ending deforestation: the opportunity cost of losing agricultural land; the cost of administering and enforcing effective action; and the cost of managing the transition[51]. The opportunity cost of the use of the land that would no longer be available for agriculture, if deforestation were avoided, has been estimated at $1-$2/tCO_2$. Afforestation and reforestation could save another 1 giga tonne of CO_2 at a cost of between $5-15/tCO_2$. According to the IPCC, abatement costs through forestry could be quite modest, from $0.1-20 per tonne of carbon in developing countries, and somewhat higher ($20-100/tC) in developed countries[52].
- **Switching demand away from emissions-intensive goods and services.** As policy internalises the costs of the damages resulting from greenhouse gas emissions into firms' costs, and thereby the prices paid by consumers who buy the emitting firms' products, demand could shift towards less-emission-intensive products.

Figure 21. Industrial energy efficiency costs (US$/tC)



Source: Intergovernmental Panel on Climate Change (2001), vol.IV, ch.4.

[50] *See International Energy Agency (2006c).*
[51] *See Stern, N. et al. (2006), ch.9.*
[52] *See Intergovernmental Panel on Climate Change (2001), vol.IV, ch.4.*

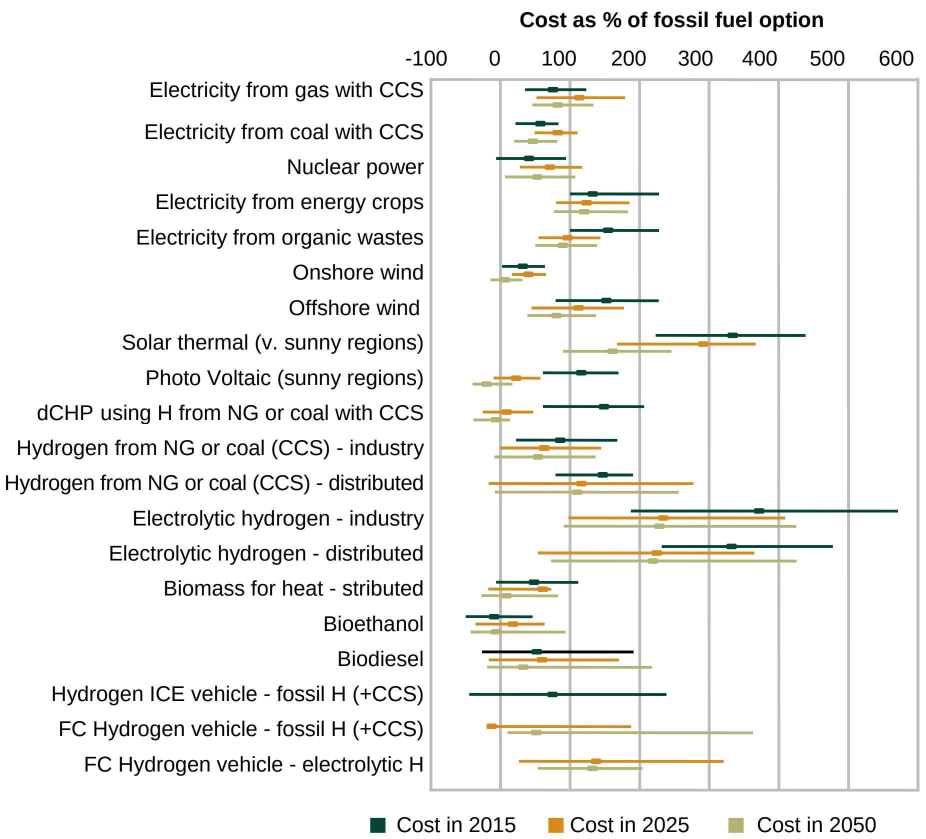
- **Switching to low-carbon technologies.** There is already a wide range of technologies, and it is expanding rapidly. However, some are currently still much more expensive than traditional technologies. There are many possibilities to move towards the decarbonisation of the electricity and heat generation sector, the transport sector, and industry, including: wind energy; solar energy; carbon capture and storage for electricity generation; production of hydrogen for heat and transport fuels; nuclear power; hydroelectric power; and bioenergy. Illustrative costs of technologies to constrain fossil-fuel emissions in the energy sector are shown in Figure 22. For most technologies, unit costs are expected to fall over time. That said, even for the near term, let alone the medium and longer terms, considerable uncertainties surround such estimates.

… yield considerable diversity of abatement costs

There is thus room for considerable diversity of results, depending on the precise assumptions chosen; in particular the rate of discount, and on the abatement scenario selected. According to the IPCC, constraining atmospheric concentration of carbon to 650ppmv, 550ppmv, and 450ppmv, would cost \$0.5-2tr, \$1-8tr, and \$2.5-18tr, respectively. Most of the model results cluster in a range between net costs running at a rate of -2% (net gains) of global GDP, and +5% (net losses) of global GDP, by 2050, while the full range of estimates, derived from many different assumption sets, extends from -4% of GDP (net gains) to +15% (net losses) of GDP[53].

The Stern Review estimates, on the basis of more recent technology-based information, that the annual cost of cutting total greenhouse gases to about three quarters of current levels by 2050 – consistent with a 550ppmv stabilisation level – would lie in the range -1.0% to +3.5% of GDP, with an average estimate of around 1% of annual global GDP.

Figure 22. Unit costs of energy technologies: proportion of fossil-fuel alternative, 2015, 2025 and 2050



Source: Anderson, D. (2006).

[53] *See Barker, T. et al. (2002).*

Designing an optimal abatement policy

In the idealised and special case of the wholly economically rational society that is concerned to limit the degree of climate change, two basic economic conditions need to be met:

1. Abatement should take place up to the point where the benefits of further emission reduction (i.e. the economic damage thereby avoided) just equal the cost of achieving this: it would be rational to spend up to €10 to avoid losing €10-worth of GDP, but not to spend €11.

2. Economic agents worldwide should face the same set of relative prices, so that a euro's worth of abatement expenditure reduces emissions by an equal amount, regardless of the country or region, and the method of abatement.

Deriving the optimal abatement strategy has both a quantity and a price dimension

Deriving the optimal strategy for abatement therefore has both a quantity dimension (via the emissions target), and a price dimension (via taxation, or trading of emissions permits): the two are inextricably intertwined, the one determining the other, and vice versa.

In practice, calculations of the optimal price and quantity of greenhouse-gas-emission reduction are difficult to make, not least because – as presented in the sections above – of the considerable uncertainty about the scale of climate change and its likely impacts, and about the potential costs of alternative levels of abatement. Nevertheless, it is worth considering the way in which such calculations should be made.

Every potential abatement level carries with it:

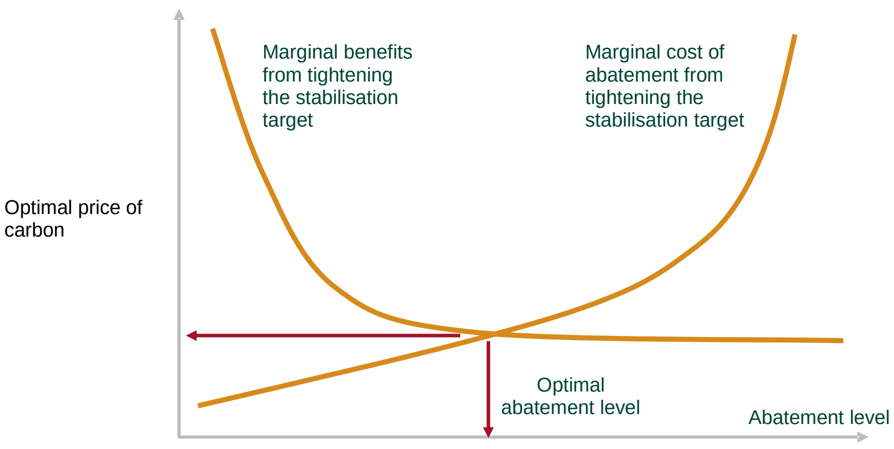
1. An associated social benefit – the reduction in the damage that (reduced) level of emissions confers on society; and

2. An associated cost – the cost of new investment and so on required to achieve the target level of emissions.

The marginal benefit of abatement is generally considered to be a decreasing function of the abatement level, i.e. limiting atmospheric greenhouse gas concentrations to 550ppmv produces fewer benefits than would flow from limiting them to 500ppmv. And the (marginal) cost of abatement is reckoned to be an increasing function of the (tightening of) the stabilisation target, i.e. it costs more to reduce atmospheric greenhouse concentration from 500 to 450ppmv than from 550 to 500ppmv.

The optimal abatement level – and the derived optimal price of carbon – is that where the two curves meet, as shown in Figure 23.

Figure 23. Choosing the optimal abatement level



Sources: Stern, N. et al. (2006), ch.13, and Lehman Brothers.

Uncertainties make the calculations difficult

The uncertainties surrounding the likely scale and timing of the impacts of climate change, and in assessing the likely future costs of abatement of greenhouse gas emissions, make it difficult to estimate the optimal abatement level with reasonable certainty. Nevertheless, policy has to be constructed on as rational a basis as possible, which implies working with the best figures available, while making appropriate allowance for likely margins of error.

A set of calculations by Nordhaus and Boyer (1999)[54] assessed, on the basis of the cost and benefit data available at the time, and using a Regional Dynamic Integrated model of Climate and Economy (integrated-assessment model RICE-98[55]), that the optimal policy would involve a reduction of atmospheric carbon concentration from a projected business-as-usual figure of 586ppmv in 2100 to 532ppmv. Such a reduction would, it was estimated, reduce the degree of global warming from 2.15ºC to 1.96ºC.

Nevertheless, a figure can be produced …

The estimated associated 'optimal', or 'social', price of carbon produced by these calculations (i.e. the price of carbon that, relative to the business-as-usual price, would produce the maximum total benefit relative to costs), rose from $6 per tonne of carbon in 2000 to $38 in 2100 (in 1990 US$). Later Nordhaus estimates put these figures at $20 and $80 respectively[56].

The net gain from such a policy was calculated as rising progressively, to reach a rate of around 0.7% of global GDP per year by 2100. By contrast, Nordhaus and Boyer's calculations suggested that some commonly advocated CO_2 emission targets, such as reducing atmospheric CO_2 concentration to its 1990 levels, would cost more to achieve than the benefit (i.e. damage avoided) that would result.

A number of criticisms can be levelled at these calculations. They do not take into account the possibility, suggested by more recent scientific evidence, that the costs imposed by climate change on the global economy could be significantly higher than previously thought. And they do not specify a range of uncertainty.

… and the calculations can be refined further

Many refinements would have to be carried out before such calculations could form the basis of an optimally designed policy. Nevertheless, the exercise is impressive in its logical completeness and important as a pedagogical exercise. Any real-world policy of economically rational emissions reduction will have to be based, at root, on such an exercise, using the best figures available at the time.

Two further reasons to pay more than the 'social' price for carbon

Society may have two reasons to pay more than the 'social' price of carbon …

In addition to being willing to spend money on any project up to the point where the benefits just equal the costs, an economically rational society might, quite rationally, spend beyond that point, to the extent that it sought additional, non-economic, benefits in the case of climate change:

… the environment in its own right…

1. **Society may care about the environment in its own right**. If for example, society prefers clean to dirty air it can be rational to spend more than €20 to save €20 worth of GDP. But society would want to know the incremental cost.

… and insurance against the unknown

2. **Society may want to avoid risk**. A society troubled that mankind is taking global temperatures somewhere they have not been before, might be prepared to spend an additional amount as a kind of insurance premium, to reduce the risk of an unforeseeable non-linearity, discontinuity, catastrophe, or whatever.

Illustratively, the amount society is prepared to pay to save €20 of GDP could thus be:

Cost/benefit warranted greenhouse gas reduction	€20
Additional environmental improvement	€3
Insurance premium to reduce unforeseeable risk	€2
Total	**€25**

[54] *See Nordhaus, W.D. and Boyer, J. (1999).*
[55] *In turn, RICE-98 was based on two earlier models (DICE and RICE).*
[56] *See Nordhaus, W.D. (2006).*

This study, however, is concerned only with the first motive for expenditure: to reduce greenhouse gas emissions, global warming, climate change and economic damage.

Adaptation versus abatement

Were emissions to cease immediately, Earth's mean temperature would still continue to rise …

It is virtually certain that, even if quite substantial abatement policies are put in place, and fairly immediately, significant climate change will result nevertheless. Scientific evidence suggests that, even if all greenhouse gas emissions were to cease forthwith, Earth's mean temperature would continue to rise, because of lagged and feedback effects, by a further 1ºC or so over the coming 50-100 years. And, in practice, greenhouse gas emissions are not going to cease immediately.

… therefore, in addition to abatement, adaptation is also needed

This means in turn that climate change abatement will, unavoidably, need to be supplemented by policies of adaptation to limit the damage, and hence cost, resulting from climate change. Conversely, costs of adaptation will rise exponentially if efforts to abate emissions are unsuccessful.

The IPCC gives a broad definition of adaptation as any "… adjustment in ecological, social, or economic systems in response to actual or expected climatic stimuli and their effects or impacts", and refers to "… changes in processes, practices and structures to moderate potential damage or to benefit from opportunities associated with climate change"[57].

There are two main ways through which adaptation can be achieved: autonomous adaptation – i.e. individual responses to actual or expected climate change, with no policy intervention; or policy-driven adaptation – i.e. the result of a deliberate policy decision.

An example of a short-run policy plan that has already been, or could be, implemented, is the improvement in emergency response, such as early warning systems. Investments to create major infrastructure plans, such as larger reservoir storage, sea-walls, or increased drainage capacity, are longer-term types of adaptation actions, which would help adaptation to rising sea levels, or to increases in flooding risks. Similarly, vaccination programmes would provide a defence against propagation of vector-borne diseases linked to climate change.

Assessing the cost of adaptation is difficult, however

However, assessing the cost of adaptation is difficult, and adaptation costs and benefits are rarely reported separately from the overall calculation of economic costs of climate change, except for some particularly vulnerable sectors. For example, some economists have tried to assess the costs of coastal protection against sea-level rise. According to one study[58], for most countries, protection costs are likely to be below 0.1% of GDP, at least for rises up to 0.5 metre. But for low-lying countries or regions, costs could reach 1%. For 1 metre of sea level rise, the costs could exceed several percentage points of GDP for the most vulnerable regions.

Adaptation costs almost certainly rise more than proportionately with temperature

Whatever the costs of adaptation may be, they are likely to rise more than proportionately with the extent of global warming. For example, if climate warming in the United States takes place slowly, it would be comparatively inexpensive, as each house comes to the natural end of its life, to rebuild somewhat further north where the climate is cooler. But if warming proceeded rapidly, so that houses had to be scrapped before the end of their natural life, or if more extreme weather events damaged or destroyed coastal properties, the cost would be higher. Stern estimates that the additional costs of making new infrastructures and buildings more resilient to climate change in OECD countries could range from 0.05% to 0.5% of GDP each year[59].

An important equity issue arises in respect of the poorest countries, which are expected to be the most severely hit, and yet which will find it difficult to afford or implement all the adaptation measures required. Costs of adaptation are even more difficult to assess for developing countries than for OECD countries, notably because of uncertainty about

[57] *See Intergovernmental Panel on Climate Change (2001), vol.III, ch.18.*
[58] *See Nicholls, R.J. and Tol, R.S.J. (2006).*
[59] *See Stern, N. et al. (2006), ch.19.*

the precise impacts of climate change and its various effects. However, macro-level assessments suggest that disaster risk reduction measures have a high benefit-to-cost ratio. For example, in China, the $3.15bn spent on flood control between 1960 and 2000 has averted losses that, it is estimated, would have been of the order of $12bn[60].

Adaptation policies and measures are already being implemented

Many public adaptation plans have already been implemented, in developed countries as well as in poor regions. In response to a greater risk from flooding in future years, the Environment Agency in the United Kingdom has set up the Thames Estuary 2100 Project to develop a tidal flood risk management plan for London and the Thames Estuary. In France, following the summer 2003 heatwave that caused an estimated 15,000 extra deaths, the government has spent €300-400m on the "plan canicule". The plan has three levels: further vigilance during the summer; alerts and action in the case of heatwave risk; and requisition, i.e. the application of exceptional measures in case of sanitary, environmental, or economic consequences.

In poorer countries, too, actions have been taken to adapt to climate change effects. In Bangladesh, the economy's sensitivity to monsoon flooding has been significantly reduced, the result of substantial investments in recent years: structural change in agriculture with a rapid expansion of much lower-risk dry-season-irrigated rice; better internal market integration; and increased private food imports[61]. Through the Kiribati Adaptation Programme, the World Bank is helping this island to adapt its economic development plans and actions in ways that will make it more robust to the potential effects of climate change, such as sea level rise and greater storm frequency and intensity[62], for a total cost of $6.59m.

[60] *See Environmental Resources Management (2005).*
[61] *See Overseas Development Institute (2005).*
[62] *See the World Bank website, < http://www.worldbank.org/>.*

POLICIES: DESIGN, IMPLEMENTATION, AND INTERNATIONAL COOPERATION

Issues in practical policy design

There is almost always a gap between an ideal policy and what can be done in practice

There is almost always a gap between the policy that would be ideal on theoretical grounds, and the policy that, because of practical, political, and other considerations, actually gets put in place.

For example, while in principle it is desirable, in the interests of economic efficiency, that economic agents worldwide should face the same set of relative prices, realism dictates otherwise for the foreseeable future. It is almost certainly unavoidable that countries will operate a mixture of targets and instruments across sectors, which will mean that it costs significantly more to reduce carbon emissions in some sectors, and in some countries, than in others.

While there is no point in being too purist, however, there are risks in being too pragmatic, particularly if climate change is invoked as a cloak to hide protectionism. One such recent suggestion – the so-called ‘food miles initiative’ – calls for a ban on food imported from a distance, because of the fuel burned in its transport. If enacted, it would confer a considerable added degree of protection to local agriculture. But it would be better for the global environment, and for the economies of developing countries, as well as more efficient in abating carbon emissions, for such food to continue to be imported, rather than grown, for example, in the UK or the EU in energy-using hothouses[63].

Generally speaking, several criteria must be met in designing a good policy:

- Credibility – i.e. people have to believe that the policy will endure and be enforced;
- Predictability and transparency – i.e. people must be able to predict the circumstances under which the policy will change; and
- Flexibility – i.e. policy has to be able to be adjusted rapidly in the event of new information or circumstances.

Various types of greenhouse gas abatement policies can be, and have been, implemented, at the national or regional level to reduce greenhouse gas emissions: price (tax)-based schemes; volume-based schemes; technology policy; and regulation. Beyond the theoretical arguments, each has its practical advantages and disadvantages, or difficulties of implementation.

Designing an appropriate abatement policy – price-based versus quantity-based targets

Policy theory

The price of carbon and the volume of emission abatement are co-determined

Given that the price of carbon and the volume of emission abatement are co-determined, it follows that policy making can, in principle, specify either an emissions volume target; or an emissions price target. But policy cannot specify both: in either case, the one having been set by policy, the other is determined by the market.

A price-based policy, such as a carbon tax, that raises the price of emissions relative to what it would have been on a ‘business as usual’ basis, has the political advantage that the price that will be paid by consumers is known in advance. However, the counterpart is that the effects on emissions volumes will initially be uncertain: price elasticities of demand are generally known only well after the event.

[63] *In similar vein it has been claimed that the 89,000 tons of flowers Kenya exports to the EU every year could be grown in the Netherlands, and transported at a much lower carbon-emissions cost. Yet importing from Kenya evidently produces only 1/8th of the CO_2 emissions that would result were the flowers to be grown in Holland. Source: BBC Radio 4, The Farming Programme, 10 November 2006.*

Conversely, a volume-based policy, such as a 'cap-and-trade' system, which lowers the permitted volume of emissions relative to what they would have been on a 'business as usual' basis, has the important – some would say overriding – advantage that the consequences for the volume of emissions are (comparatively) certain. However, as argued particularly by Cooper (2006), the counterpart is that the price that will be paid by consumers will initially be uncertain.

There is no practical guarantee that any given price/volume combination matches the optimum

Regardless of which of the two basic methods is used to determine the price and volume of carbon emissions, there is no guarantee that the resulting price/volume combination will be equal, or even reasonably close, to the optimum: the target, whether for volume or price, could well be set either too high or too low, thereby producing an outcome far from maximising benefit relative to cost.

A further consideration is that many scientists consider that the risks from global-warming-induced climate change will increase extremely sharply when greenhouse gas concentrations reach around 550ppmv. Partly for this reason, therefore, many scientists, and some economists, prefer a volume-based target, rather than a price-based one.

Examples of price (tax)-based schemes

Scandinavian countries (Sweden, Denmark, Finland, and Norway) all introduced a carbon tax in the 1990s. It seems that this system has provided incentives to businesses to invest in technological innovation. For example, Statoil, the Norwegian state oil company, has undertaken important research for the storing of excess carbon dioxide, in response to the imposition of carbon tax for releasing excess CO_2. In 2006 in China, VAT export rebates were lowered for energy-intensive or environment-unfriendly products, such as steel, aluminium and coal, while a new export tax was introduced to discourage cheap, environment-unfriendly production of energy-intensive products for export.

It is difficult to implement a carbon tax that precisely equals the 'social' cost of carbon

However, as with a trading scheme, it is difficult for governments to implement a carbon tax that will exactly equal the social cost of carbon. The Scandinavian experience also highlights the difficulty of creating a harmonized taxation system: these countries, notwithstanding a long track record of cooperating well with one another, nevertheless have not yet found a way to harmonise their carbon taxation systems.

Examples of volume-based schemes

The judgement that a volume target is preferable to a price target was made in instituting the (cap-and-trade) regime that was designed in the United States by the George H.W. Bush administration, and first implemented in 1995, to limit the sulphur dioxide (SO_2) emissions that produce acid rain. The same reasoning underpinned the Kyoto cap-and-trade regime to reduce the CO_2 emissions that cause global warming. Stern, too, proposes an emissions-based target upper limit, of 550ppmv.

The EU ETS is the principal example of a volume-based scheme

The main example of an emission-trading scheme is the European Union Emissions Trading Scheme (EU ETS), launched in January 2005 (see Box: *Emissions Markets*). The use of such trading schemes is expanding, such as in Norway, where an emissions trading scheme for energy plants and heavy industry was instituted in January 2005, and in the Australian state of New South Wales for electricity retailers. The Chicago Climate Exchange is an example of a voluntary carbon market.

Nonetheless, it is not proving easy to implement an efficient mechanism, mainly because of credibility and predictability issues; the need for reasonable stability in the supply of, and demand for, permits; and the need for perfect information on prices. A number of conditions will have to be met before the emissions trading market can be said to be working well, including: greater liquidity in the carbon market so as to avoid erratic price movements; the setting of initial allocation levels below the actual level of emissions; and resisting political pressure to grant supplementary permits.

Emissions markets

Eva Karra (ekarra@lehman.com)

The Kyoto Protocol

In December 1997, representatives from both the developed and the developing world met in Kyoto to negotiate their participation in a multilateral treaty that would seek to reduce global emissions. The treaty was underwritten by governments and is governed by global legislation enacted under the UN's shield. Under Kyoto's main principle, governments are separated into developed countries, referred to as Annex 1 countries (which have accepted greenhouse gas emissions reduction obligations); and developing countries, referred to as Non-Annex 1 countries (which, although they do not have legally binding greenhouse gas caps, must submit and monitor their annual greenhouse gas inventory).

The Kyoto Protocol came into force in February 2005. As of January 2007, 166 countries and other governmental entities had ratified the Accord. Notable exceptions include the United States and Australia, although they are signatories. Ratifying countries have committed to reduce, by 2008-12, their emissions by 5.2% below their 1990 levels. The Protocol provides three mechanisms:

1. Emissions trading among Annex 1 countries;
2. Joint Implementations (JIs), which allow Annex 1 nations to obtain emission credits (Emission Reduction Units – ERUs) for projects that reduce emissions in other Annex 1 countries; and
3. Clean Development Mechanisms (CDMs) whereby Annex 1 countries can obtain permits (Certified Emission Reduction units – CERs) for projects that reduce emissions in non-Annex 1 countries.

The European Union Emissions Trading Scheme (EU ETS)

The EU ETS is considered the paradigm of environmental markets. Above all, it represents the European Union's commitment to spearhead efforts to combat climate change, both by setting an example, and by fulfilling its pledge to reduce its emissions by 8% from 1990 levels by 2012. The EU ETS came into effect in January 2005, prior to the ratification of the Kyoto Protocol, and is the largest multi-country, multi-sector, greenhouse gas emissions trading scheme.

In the first phase (2005-07), the EU ETS includes some 12,000 installations, representing approximately 45% of total EU CO_2 emissions. The sectors included in this phase are: power generation; ferrous metals production and processing; chemical processes: minerals; and pulp, paper and board. The European Commission has announced its intention to include aviation in the EU ETS in the second phase (2008-12), given the large and rapidly growing emissions of the sector. The proposed directive will cover emissions from flights within the EU from 2011, and all flights to and from EU airports from 2012.

The principal objective of the EU ETS is to internalize the external cost of carbon, i.e. institutionalise the 'polluter pays' principle and use market forces to encourage innovation and carbon reduction initiatives. However, critics remain sceptical whether the resulting carbon price will prove sufficient to drive or induce the requisite innovation for the EU to reach its Kyoto emissions reduction targets.

Through the Linking Directive, the EU allows both the corporate and the private sector to participate in the wider Kyoto scheme by allowing the trading of government permits, namely CERs. The number of such permits that a corporate is allocated to use for compliance purposes is capped and regulated at the national level (and are part of the National Allocation Plan (NAP) proposals), following strict EC guidelines.

NAPs are a direct function of each country's progress vis-à-vis its own Kyoto targets and the EC's directives. In the first phase, several countries allocated themselves annual allowances covering 12% more CO_2 than they actually produced in 2005, which led to a near-collapse of the market in April 2005 (from €30 a tonne to €14). But Phase II NAPs, the first of which were announced in November 2006, sent, in the words of the EU Environment Commissioner, Stavros Dimas, "…a strong signal that Europe is fully committed to achieving the Kyoto target and making the EU emission trading scheme a success". The result seems likely to be an average cut of nearly 7% below the 2005 emissions level. In addition, the Commission has indicated that it will limit the proportion of allowances that can be offset by external credits, namely CERs and ERUs.

Going global

Greenhouse gases, unlike aerosols, diffuse quickly through Earth's atmosphere, so that reducing greenhouse gas emissions is equally effective regardless of where the reduction is effected. Kyoto recognises this through its flexible mechanism tools, which allow countries to use externally gained credits to offset domestic emissions. Similarly, as mentioned above, the EU extended this principle to the corporate sector, allowing companies to use those external credits for their compliance needs. However, trading between countries is limited. Each nation is charged with its own responsibility to retain its emissions within its pre-agreed cap, both by trading offsetting credits and through domestic abatement actions.

Japan recently stressed the importance that it attaches to a balance being struck between the use of external credits and domestic abatement action.

Clean Development Mechanisms

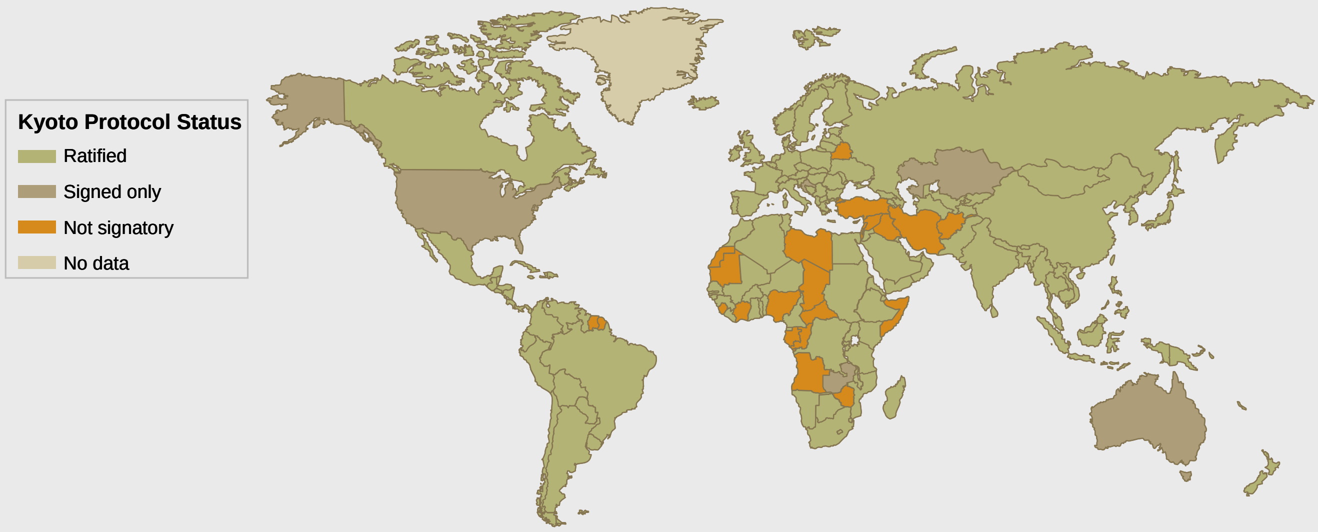
Emissions Trading Schemes, and the CDM mechanism, are effective tools in helping countries achieve reductions in the most cost-effective way, on a global scale. At the same time, as emphasised, for example, by Cooper (2006), such schemes carry with them an inherent risk of corruption because of the potential scale of transfers between countries. This specific system is run by the United Nations Framework Convention for Climate Change (UNFCCC) and is a project-based reduction mechanism, designed in particular to minimise corruption risk. The procedures involved, from the early stages of the project to actual issuance of those credits by the UN, tend to be complicated and lengthy. Specifically, in the CDM world, CERs may be produced only from UN-registered projects that have been verified by independent Designated Operating Entities (DOEs) approved by the UN. Issuance of CERs is then undertaken only by the Executive Board of the UNFCCC, and is irrevocable. This process requires considerable due-diligence, throughout the project's life (5-7 years, on average).

Currently China is the biggest 'host' country for CDMs (44% of the global total). India has the largest *number* of registered projects, but they are on average smaller (50,000 credits per annum per project). To date, the great majority of issued CERs have come from large-scale HFC23 (Hydro-fluorocarbon 23) projects, which have the potential to generate hundreds of millions of credits. Those credits will be key for future Kyoto negotiations.

The demand for CERs comes either from the private sector, mainly to meet corporate compliance obligations, or from the public sector, in the form of governmental purchasing schemes. So far, the biggest buyers in the governmental compliance market have been Japan (through its global corporations) and some EU countries, whereas Canada recently revised downward its procurement plan.

Overall, however, most of the European Union's activity is still originated by private-sector initiatives, targeting mainly the EU compliance market. The public sector seems to be lagging, perhaps with the most notable exception being the government of the Netherlands, which has committed to many external projects – 23 JIs and 4 CDMs – for a total contracted volume of 18m tonnes of CO_2. ■

Figure 24. Countries' Kyoto Protocol status, January 2007



Source: World Resources Institute website, <http://earthtrends.wri.org/updates/node/105>.

Technology-based schemes

Policy theory

To create momentum for further innovation, incentives for the firms are needed …

While the higher price of carbon, whether achieved by a price (tax)-based or a volume-based policy, will motivate firms to invest in inventing and implementing technological changes, a number of scientists and technologists consider that this process may be too uncertain, or too slow, or both. They consider that, to create real momentum for further innovation, more incentives will have to be given to firms.

Certainly, most of the new alternative technologies (e.g. wind energy, solar energy, nuclear power, carbon capture and storage, etc – see Box: *New Technologies: Potential Costs and Hurdles*) are currently more expensive than existing technologies. If it is judged likely that it will be a long time before these new technologies become competitive, the private sector may be reluctant to engage in heavy up-front investments.

Moreover, there is an inherent tendency at the global level towards an undersupply of innovation, because such knowledge is an 'externality': inventors or developers of the relevant technology know that they will be unable to reap the full economic returns that flow from their investments.

… whether through technology push or market pull

To address those difficulties, two polar views have been advanced[64]:

1. **Technology push**, i.e. the development of specific low-emission technologies, through publicly funded R&D programmes, such as the Japanese programme to put solar panels on the roofs of a million homes, or the Danish support for wind power; and

2. **Market pull**, i.e. the technological change coming primarily from the business sector, in response to economic incentives. This view gives priority to regulatory measures such as: technology-based regulatory limitation; greenhouse gas emissions caps; and charges. Profit-seeking business will respond by innovating.

Further problems arise where technologies have been developed and are commercially available, but volumes are small, so that costs are correspondingly high. One appropriate response can be a policy for strategic deployment, such as a feed-in tariff, which sets a specific price to be paid for electricity generated from renewable sources. Another appropriate type of answer can be renewable obligations, which require utilities to obtain a specific proportion of their electricity from renewable sources.

In particular, clean-coal technologies need to be encouraged and developed further

In particular, many scientists advocate further development of clean-coal technologies because, regardless of how fast new technologies develop, the world as a whole will nevertheless have to rely more on coal for power generation over the next 50 years. While energy demand will rise worldwide, partly because of projected global population growth of 50% by the end of this century, and largely because per capita energy use in countries such as China and India will rise towards the levels of developed countries, constraints on energy supply will likely tighten. Known global reserves of oil will last around 40 years; natural gas, 67 years-odd; but coal remains abundant, particularly in China and the US. Although nuclear, hydropower, geothermal, wind, solar and biomass energy sources will probably form part of the solution, many scientists believe that only greater use of coal will bridge the gap between energy supply and demand.

Coal is, however, the dirtiest of the fossil fuels. Today, two leader technologies would allow energy demand to be met by coal, while bearing down on atmospheric CO_2 emissions: coal gasification, which is relatively well developed; and CO_2 sequestration (also known as carbon capture and storage), which, as yet, is not – see Box: *New Technologies: Potential costs and hurdles*. Price signals, or other forms of policy guarantees, stand to be particularly important in determining the pace of development of such important new technologies.

[64] *See Grubb, M. (2004).*

Examples of technology-based policies

It is estimated that around $10bn was spent in 2004 on renewable deployment. Around $16bn is spent annually to support existing nuclear energy, and around $6.4bn is spent annually supporting biofuels[65].

Technology-based policies concern the automotive sector …

The introduction of catalytic converters in vehicles was an early example of a ‘technology forcing’ policy – the development of a new technology through the setting of standards. In 1970, the US Clean Air Act specified new, unprecedentedly demanding, pollution limits on automobile emissions and, in 1973, the Japanese government enacted the similar Pollution Control Law. Neither the automobile lobby nor Japan’s Ministry for International Trade and Industry (MITI) felt able to object particularly strongly to the proposed strictness of the standards, not least because environmental and economic considerations converged, the joint standards obviating the need for automobile companies to produce different cars for different major markets. The development of the catalytic converter was financed by the private sector, but the policy was buttressed by the policy decision to introduce lead-free gasoline, necessary because tetra ethyl lead, a then widely used additive, is both dangerous to human health and destroys the functioning of catalytic converters.

A recent instance of a technology-forcing policy is afforded by the Fédération Internationale d’Automobile (FIA), which is proposing new regulations for Formula 1, to stimulate research and development. Regulations to come into force in 2009 will encourage the conservation of the kinetic energy customarily lost under braking. If this energy can be captured and stored, it can later be used to assist the propulsion of the vehicle, thereby reducing the amount of fuel used per kilometre. Ultimately such systems could be applied to road car hybrids also. FIA regulations to come into force in 2010 will encourage capture of the waste energy from exhaust and cooling systems, too.

… renewable energy sources …

Development of renewables in energy portfolios, in particular, has been supported by many governmental policies. In Germany for example, feed-in tariffs have been introduced to encourage the deployment of on-shore and off-shore wind, biomass, hydropower, geothermal and solar photovoltaics. These tariffs should help the country to achieve its renewable energy goals of 12.5% of gross electricity consumption in 2010, and 20% in 2020.

In the United Kingdom, the Renewables Obligation, introduced in 2002, requires all commercial electricity suppliers to supply a specified proportion of their electricity from renewables: that proportion will increase each year until 2027, from a 3% requirement in 2002-03, to 15.4% by 2015-16.

In California, the Global Warming Solution Act promotes the development of renewables, and requires three major utility companies – Pacific Gas and Electricity, Southern California Edison, and San Diego Gas and Electric – to produce at least 20% of their electricity using renewable sources.

China and India too are encouraging large-scale renewable deployment, and now have respectively the largest and fifth largest renewable energy capacities worldwide[66].

…, and clean energy initiatives

As a key element of the EU-China partnership signed in September 2005, the United Kingdom is supporting a new initiative on near Zero Emission Coal with Carbon Capture and Storage (nZEC), to tackle increasing greenhouse gas emissions from the use of coal in China. The first phase will be a 3-year feasibility study, examining the viability of different technology options for the capture of CO_2 emissions from power generation and the potential for geological storage in China, and leading towards a possible demonstration project starting up between 2010 and 2015. The UK is leading the first phase of the nZEC project, and supporting it with £3.5m of funding.

[65] *See Stern, N. et al. (2006), ch.16.*
[66] *See Stern, N. et al. (2006), ch.16. Note that these figures from 2005 exclude large scale hydropower.*

New technologies: Potential costs and hurdles

Renewables[67]

Hydropower is a mature technology and, under appropriate geological and meteorological conditions, commercially competitive. Existing large plants are often some of the lowest-cost electricity generation sources today, primarily because they were built many years ago, so that their costs have been fully amortized. Hydroelectric power supplies 19% of world electricity, and 6% of total power generation. In new large plants, the cost of electricity generation is generally between $0.03 and $0.04 per kWh. However, given that many of the low-cost hydro resources have already been developed, hydropower is not a major option for meeting the incremental energy demand of fast-developing economies. However, micro-hydro can be a viable option for applications such as single farms, homes, or small businesses. There is a need to improve designs and control systems, and to meet environmental and social concerns, particularly those that surround dams for large hydro schemes that may have significant environmental or population impacts.

Geothermal power, which derives from the heat in the Earth's centre that is a product of radioactive decay in the core, is limited to geologically active regions, although there is further potential from other sources, such as hot dry rocks. Power generation costs have dropped substantially since the 1970s. For example, costs of electricity generation in the United States from geothermal power are today between $0.015 and $0.025 per kWh. However, there are several barriers to overcome, particularly: long project development times; and the risks and the costs of exploratory and production drilling. Furthermore, saline fluids and escaping waters from some aquifers present environmental risk.

Wind power currently produces less than 1% of electricity globally, but accounts for 23% in Denmark, 8% in Spain and 6% in Germany. Production costs vary considerably: depending on differences in sites, capital costs and wind speed ranges, they range from $0.03 to $0.20 per kWh. In most markets, wind power is not competitive today, but it is often helped by 'feed-in' tariffs. Various deployment policies over the past 30 years have been successful. Costs have decreased considerably; improvements have been made in the size and reliability of turbines; and public awareness has increased. Evidence for this success is the 23% of annual growth in wind power generation since 1990. However some hurdles persist, such as the public acceptability of wind farms, the intermittent nature of wind, and its impact on grid stability.

Solar energy has already reached a commercial stage in some niche markets but, even if the potential is vast, the International Energy Agency (IEA) does not expect it to become ready for mass deployment before 2030. Energy generation costs depend largely on the level of insulation. In superior locations, with up-to-date technology, solar energy generation costs between $0.10 and $0.15 per kWh, whereas in the Mediterranean area, for example, it costs triple that. The main advantage of solar energy is its inexhaustibility. But barriers exist, such as the high costs of investment and the intermittency.

Ocean energy, whether deriving from waves, tides, marine currents, thermal energy, or salinity gradients, has been functioning for decades, but the number of sites is still limited, and their environmental impact controversial. Costs depend on the resource quality and grid connection. Those costs must be added to the production cost. This type of energy is essentially still at the R&D stage.

Biomass is not a zero-emission technology, involving as it does the release of energy from biological material. Through photosynthesis, plants produce sugar from atmospheric carbon dioxide and water using sunlight energy, and emit oxygen as a by-product. The process is reversed when biofuel is burned: the energy that has been stored is released, producing carbon dioxide as a waste product. Nevertheless, the use of biofuels in transport does result in emissions savings of 10-90% compared with burning gasoline. Biomass is grown principally from a limited number of plants, notably switch grass, corn, willow and sugar cane. The power generation cost ranges from $0.02 per kWh if the biomass is free, to $0.05 if not. Hurdles are mainly public reluctance, particularly vis-à-vis energy generation from waste burning, and the costs that flow from a larger scale deployment – i.e. costs of feedstock production, harvesting and transportation.

Carbon capture and storage (CSS)

This three-stage process – the separation of carbon dioxide from industrial and energy-related sources; the transporting of it to a storage location; and its long-term isolation from the atmosphere – could prove extremely important, through enabling the control of CO_2 emissions from fossil fuel-based production of electricity, which still stands to account for around half of all energy supply by 2050[68]. Once captured, the gases can either be processed and compressed into liquefied CO_2, or chemically changed into solid, inorganic carbonates. Captured CO_2 can be transported either through pipelines or by ship.

[67] *See International Energy Agency (2006c), ch.3.*
[68] *See Stern, N. et al. (2006), ch.9.*

Storage can be effected in various ways: in the deep ocean, as a mineral carbonate; or in geological structures (in most cases, the captured CO_2 is injected in gaseous form and stored in non-porous underground rock foundation).

It is estimated that the application of CCS to electricity production might increase electricity generation cost by $0.01-$0.05 per kWh[69], depending on the fuel, the specific technology, location, and national circumstances. However, this technology has yet to be proven on the large scale that would be needed to have a significant impact on greenhouse gas emissions at the global level. If the technical issues can be solved, the contribution to cumulative abatement effort worldwide until 2100 could be between 15% and 55%. However, important hurdles remain. First, it is not yet price-competitive: it is unlikely that industry will invest in deployment of CCS under current market conditions. CCS might become more viable under schemes where value (i.e. cost) is attached to carbon. Second, there are regulatory and legal barriers concerning operations in the subsurface, and there are also environmental concerns that CO_2 could be released during transport and injection. Finally, major R&D gaps still have to be bridged.

Integrated gasification combined-cycle (IGCC)

This system combines two technologies: coal gasification, which uses coal to create a clean-burning gas (syngas – a mixture of carbon monoxide and hydrogen); and combined cycle technology, which is more efficient than conventional power generating systems because it re-uses waste heat to produce additional electricity. IGCCs are among the cleanest and most efficient clean-coal power-production technologies. The technology is still in its demonstration phase but has already achieved efficiencies of 45%. The International Energy Agency expects efficiencies of around 50% to be achieved by 2020. IGCC could become a key enabling technology for Carbon Capture and Storage, given that the cost of CO_2 capture at IGCC plants is lower than in coal-fired steam cycles.

The main hurdle to further development of this technology, however, is its high capital costs, upwards of $1,400 per kWh, which is around 20% higher than conventional plants. Moreover, more research will be needed to overcome several technical issues, related in particular to gasifier size and maintenance requirements.

Nuclear power

The controlled use of nuclear reaction to generate energy is currently limited to nuclear fission and radioactive decay. Nuclear fission technologies are generally classified into four generations. While certain generation II and III technologies are ready for mass deployment, generations III+ and IV will not be ready for commercial deployment for at least two or three decades. The United States is the world's largest producer of nuclear energy (accounting for 20% of its total electricity production), while France is the largest producer in terms of share in national electricity production (80%). As of 2006, the United Kingdom has 23 nuclear power reactors, generating around 20% of its electricity. China has five nuclear power plants (nine nuclear power generating units) and 18 nuclear reactors in operation, and is investing heavily in this sector. Construction of new plants declined after the 1979 Three Mile Island and 1986 Chernobyl accidents: the share of the world's electricity coming from nuclear generation has stagnated at around 16% for many years. Lately, however, governments have been showing renewed interest, given higher oil prices. And low greenhouse gas emissions from nuclear power could help governments meet their Kyoto targets.

The operating costs of generating electricity from nuclear power are not significantly different from those of coal- or gas-burning plants (around $0.03 per kWh). But the capital costs of nuclear plants are significantly higher than for equivalent coal-fuelled or gas-fuelled plants, particularly given the need to maintain a substantial 'spinning reserve' for periods when a large nuclear plant is shut down for maintenance. Moreover, the recent liberalisation of the energy market makes the building of nuclear plants even less attractive: previously, a monopolistic provider could guarantee output requirements decades into the future, whereas private generating companies now have to accept shorter contracts and the risk of future competition. Furthermore, in many countries, licensing, inspection, and certification of nuclear plants have added delays and building costs.

Some progress is being made, through various safety devices and procedures and the development of new technologies, with: the problems of radioactive waste; the risk of potentially severe radioactive damage; and the weapons proliferation risk. In November 2006, a treaty was signed between the European Union, Japan, China, Russia, South Korea, the United States, and India, to launch an international research and development project, ITER, which aims to demonstrate the scientific and technical feasibility of fusion power. An experimental nuclear fusion plant is to be built in the South of France in 2008. While fusion represents a potentially unlimited source of energy, and one that produces no radioactive waste, it seems unlikely that fusion-generated electricity will be available in commercial quantities before 2080. ■

[69] *See Intergovernmental Panel on Climate Change (2005).*

Regulation and standards policies

Regulation is another way to tackle climate change …

Another type of policy to tackle climate change is the implementation of regulation and standards. Such policies may be particularly appropriate in cases of imperfect markets, which may inhibit climate change policies, such as policies to price carbon, volume-based policies, or technology support policies.

… particularly in the building and construction sector …

Performance standards help to limit energy demand, encourage the removal of energy-inefficient products from the market, and accelerate their replacement by more efficient solutions. Standards are wide-spread in the building and construction sectors. As part of the European Energy Performance of Buildings Directive, the European Commission established a framework to realize an estimated cost-effective savings potential of around 22% of present energy consumption in buildings across the European Union by 2010. In the United Kingdom, recent regulation requires that new and refurbished buildings reduce carbon emissions by 27% from present levels.

… as well as in the appliances sector

Standards are also imposed on appliances. China first introduced appliance standards in 1989, and expanded their application during the 1990s to include refrigerators and air-conditioners, for example. In 1998, the Chinese government changed the name of the State Environmental Protection Bureau to the State Environment Protection Administration (SEPA), and elevated it to ministerial level. SEPA is now an organisation with a direct reporting line to the State Council, China's highest government body. Energy savings are projected to reach 33.5 TWh by 2010, or about 9% of China's residential electricity. This is equivalent to a CO_2 emission reduction of 11.3Mt[70]. By the end of 2005, China had promulgated more than 800 national environmental protection standards. For the past three years, China has launched special environmental protection campaigns to sanction enterprises that have discharged pollutants in violation of the law. The Chinese government has also pledged to deregulate fuel and water prices. Further, more than 800 enterprises and 18,000 products have received labelling certification.

In Japan, the Top Runner Standard acts as a countermeasure to ongoing energy and consumption increases in the residential, commercial and transportation sectors[71].

[70] *See China Energy group website, < http://china.lbl.gov/china_buildings-asl-standards.html>.*
[71] *See Japanese Top Runner Program website, < http://www.eccj.or.jp/top_runner/index.html>.*

Country examples of policies implemented

Australia. Australia has not ratified the Kyoto Protocol. However, the country signed, along with the United States, the Asia Pacific Partnership on Clean Development and Climate in June 2005. State actions have started to emerge, such as the implementation by New South Wales of an emission trading system, the NSW Greenhouse Gas Abatement Scheme.

Brazil. Brazil is currently the world's largest producer and consumer of ethanol. Brazil's ethanol programme was launched in 1975. The current Brazilian Constitution incorporates the notion of environmental conservation as fundamental to the development process. Many programmes are in place, such as PROINFA (Incentives for Renewable Energy Sources) created in 2002, the objective of which is to increase the share of alternative renewable energy sources to 10% by 2030. Furthermore, there are programmes to protect public forests by designating areas that must remain unaltered.

China. China is showing increasing signs of concern, and is focusing on the quality rather than the quantity of GDP to create a "harmonious society" – the Beijing 2008 Olympics have increased this urgency. China's 11th five-year plan calls for a 20% reduction in energy consumption for every percent of GDP growth, a 10% reduction in pollution, and a 15% share of energy production by renewables within the next 10 years: Beijing is stipulating how much each province and locality and the top 1,000 factories must improve. Furthermore, China recently asked the Organisation for Economic Cooperation and Development (OECD) to conduct an environmental Review, the conclusions of which were released in November 2006. And its authorities have published a set of 'green' national accounts that seek to quantify the cost of environmental damage resulting from economic growth.

France. Under the Kyoto Protocol, France has committed to stabilize its greenhouse gases emissions at their 1990 level by 2010. A further national objective is to reduce the levels of greenhouse gas emissions by 25% by 2020, compared with 1990 levels, and to achieve a fourfold reduction by 2050. Many policies have been implemented to achieve these objectives, gathered under the "Plan Climat". Measures and objectives that have been agreed include: an increase of the share of biofuels to 5.75% by 2010; tax incentives for buildings using solar equipment and for purchasers of 'clean' cars; and the increase of the share of energy from renewables to 10% by 2010.

Germany. Under the Kyoto Protocol framework, Germany has committed to cap greenhouse gases emissions and then to decrease them by 21% relative to their 1990 levels by the period 2008-12. The German government has recently proposed to reduce emissions by 40% by 2020 (compared with 1990 levels) if the European Union agrees to reduce its own emissions by 30%. Furthermore, the Renewable Energy Sources Act specifies an objective of reaching 20% of energy supplies from renewables by 2020.

India. Being a developing country, India has no binding commitment to reduce emissions under the United Nations Framework Convention on Climate Change. However, some national measures have been taken, notably: the National Autofuel Policy, which mandates cleaner fuels for vehicles; the Conservation Act, which outlines initiatives to improve energy efficiency; and the Electricity Act, which encourages the use of renewables.

Russia. The country ratified the Kyoto Protocol treaty in November 2004, which enabled the accord to be brought into force 90 days later. Its commitment is to cap greenhouse gases emissions at 1990 levels by 2008-12.

United Kingdom. The main national objective is to reduce carbon dioxide emissions to 20% below 1990 levels by 2010, and to 60% below 2000 levels by 2050. The Renewable Obligation targets an increase in the proportion of electricity provided by renewable sources to 10% of electricity supply by 2010. It requires suppliers to source a specific, and annually increasing, proportion of electricity from renewable sources. The obligation in England, Wales, and Scotland is 5.5% for 2005-6, rising to 15.4% by 2015-6. This obligation will remain until 2027. Parallel to that is the Renewable Transport Fuel Obligation, which requires that 5% of all UK fuel sales come from renewable sources by 2010-11. Matters were taken slightly further in the 2006 Pre-Budget Report.

United States. Although a signatory member of the Kyoto Protocol, the United States has not ratified it. However, the government has implemented some tax incentives to spur the use of cleaner, renewable energy and more energy-efficient technologies. In response to the relative inaction of the federal government, a number of state initiatives have emerged. Under the Northeast Regional Greenhouse Gas Initiative (RGGI), signed in December 2005, North-East, and Mid-Atlantic States agreed to a 'cap-and-trade' system, aimed at reducing CO_2 emissions from power plants in their region. The leader in state action, California, has committed to reduce emissions to 2000 levels – i.e. by 11% – by 2010; to 1990 levels – i.e. by 25% – by 2020; and to 80% below current levels by 2050. California's Global Warming Solution Act will enforce the 2020 target. ■

International action on climate change: a game theory analysis

Climate change is a global issue and requires an international approach

Various actions at the national or regional level to tackle climate change have been identified: price-based mechanisms; volume targets; technology pushes; and regulation policies. However, climate change is a global issue, and cannot be solved unilaterally: it requires an international approach.

Addressing climate change raises both the problem of the provision of a global common good (the so-called "tragedy of the commons"), and the 'free-rider' issue.

But climate change embodies the "tragedy of the commons" issue …

The "tragedy of the commons"[72] issue arises from free access to a finite resource: the parable itself derives from the mediaeval right of private individuals to graze animals on common land. The individual animal owner reasons that it pays him to put as many animals as possible on to the common land. But if all animal owners behave similarly, the result is over-grazing and, ultimately, the destruction of the common land. The parallel with over-use of the atmosphere's capacity to absorb carbon is evident.

… and gives rise to the 'free-rider' problem …

The free-rider problem arises in turn because, in deciding what to do in such circumstances, an economic agent has two options: he can either elect to protect the common good; or he can pretend that he will, and thereby possibly induce others to protect also; but then renege, thereby becoming a 'free rider'. Again, the parallel with international agreements to limit greenhouse gas emissions is clear.

The immediate consequence of at least some agents seeking to free-ride is undersupply, or over-exploitation, of the common good. In the case of emissions control, this would mean a sub-optimal level of emissions reduction. Table 2 shows illustrative pay-offs for two countries that have to decide whether or not to cooperate.

The pay-off calculations are based on the following assumptions: the cost (i.e. damage from climate change) of doing nothing is taken to be -3 for each country; the cost of implementing the optimal policy is -12 for each country; and the benefit from implementing the policy is +8 if one country acts alone, but +16 if both countries act in concert.

Hence, if only one country cooperates, its pay-off is (-12+8) = -4, while the pay-off for the other country, which did not cooperate, is a net benefit of (0+8) = +8. If both countries cooperate, each has a net gain of (-12+2*8) = +4.

Table 2. Cooperation vs. non-cooperation: pay-offs for two countries

Country A / Country B	Cooperation	Non-cooperation
Cooperation	**+ 4 / + 4**	**- 4 / + 8**
Non-cooperation	**+ 8 / - 4**	***- 3 / - 3***

Source: Lehman Brothers.
** Nash equilibrium.*

… which risks leading the countries not to cooperate

If a country judges that the other will cooperate, its optimal strategy is to not cooperate, and thereby free-ride on the benefits of the other country's action. The (Nash) equilibrium therefore is for the countries not to cooperate – which is not optimal. In a multi-round exercise, it is generally not in the interests of participants to cheat for very long, however, lest they be excluded from participating in the wider range of international treaties and agreements, an outcome that few countries would wish to contemplate, given the number to which most are party.

[72] *The term derives originally from a parable published by William Forster Lloyd in his 1833 book on population. It was then popularized and extended by Garrett Hardin in his 1968 Science essay The Tragedy of the Commons.*

It is therefore the role of international diplomacy and negotiation to:

- Design a policy that is capable of producing an optimal outcome, in the interests of all countries taken together; and
- Provide a credible punishment for any participant who tries to be a free rider.

Prospects for international cooperation on climate change

It is easy to presume that the difficulties in getting countries to agree on anything are so considerable that the likelihood of securing a global policy to limit greenhouse gas emissions in the foreseeable future is slight. However, while recognizing and, we trust, not underestimating these difficulties, we ourselves are not that pessimistic.

Admittedly, it seems unlikely that many governments will take the lead, ahead of their publics, in undertaking major, expensive, action to reduce greenhouse gas emissions. However if, or as, the public mood changes, governments can be expected to wish to follow, perhaps quite quickly. Our sense is that, in quite a number of countries, the public mood is moving in this direction.

Nevertheless, over the past 60 years, countries have cooperated on various important issues

If, or when, the majority of major countries decide to limit greenhouse gas emissions, it will then become necessary to overcome the 'free rider' problem. However, over the 60-odd years since the end of the Second World War, countries have in fact cooperated on a number of important issues, in a range of spheres, including the following substantial examples:

- Successive rounds of tariff cutting, under the auspices first of the *General Agreement on Tariffs and Trade (GATT)* and then the *World Trade Organisation (WTO)*, which have reduced tariffs progressively since the end of the Second World War from double-digit rates to less than 4% on industrial goods;
- A raft of agreements concluded under the auspices of the *Organisation for Economic Cooperation and Development*;
- The *World Health Organisation* (WHO) coordinated effort whereby almost all countries cooperated in the elimination of smallpox and diphtheria, and the near-eradication of polio;
- The *United Nations Convention on Law of the Sea*, which provides universal legal controls for the management of marine natural resources and the control of pollution;
- The *Montreal Protocol*, whereby 50 nations agreed to phase out the production and use of CFCs and other ozone-depleting substances. For each group of halogenated hydrocarbons, it provides a timetable whereby the production of those substances must be phased out. Due to its widespread adoption (as of November 2006, 191 nations had become party to the treaty), and implementation, it has been highlighted as an example of particularly exceptional international cooperation. Kofi Annan called it "perhaps the single most successful international agreement to date";
- The *Financial Action Task Force*, whereby 21 nations have taken a number of policy actions to inhibit money laundering;
- The *International Telecommunications Union* (ITU) agreements on a world-wide allocation of the radio broadcasting spectrum;
- The *World Meteorological Organisation's World Weather Watch,* whereby every nation contributes to an integrated global observing effort, and on which each can draw; and
- The *Antarctic Treaty* whereby 12 nations agreed to suspend their claims to parts of Antarctica and open up the continent for scientific research.

Typically, such international cooperation has occurred when five conditions have been met:

1. The proposed policy is in the perceived national interest of the countries in question;
2. It is recognised that the solution has to be international, to avoid the 'free rider' problem;
3. Each country knows that no gains can be expected from free-riding because, if it does not participate, neither will the others;
4. There exists a well designed and workable policy proposal; and
5. A major country – typically the United States – is committed to, and actively pushing, the policy.

Some international cooperation on climate change has already taken place …

A significant number of countries – basically those of the European Union, together with Japan, South Africa, and Canada – already perceive control of greenhouse gas emissions as being in their national interest. Europe is perhaps especially concerned given that, among the developed economies, its climate-change damage could be particularly costly.

Furthermore, it is widely recognised that the nature of the policy requires that, because of the free rider problem, it be enacted internationally in order to be effective. And there already exists, in the European Union Emissions Trading Scheme for example, a policy that is not only well designed but which is already in operation (this type of policy was invented by the George H.W. Bush administration in 1990, and introduced successfully in 1995, although only within the US, to limit the SO_2 emissions that cause acid rain).

… but big polluters are still missing from the international cooperation scene

However, so far at least, not all countries perceive such a policy as being in their national interest. In particular, the official position of the United States, the world's largest emitter of greenhouse gases, is against the Kyoto Accord: even though a signatory, it has not ratified the agreement, claiming that enactment would be detrimental to the US economy.

And while China, the second largest emitter, has ratified the agreement, its non-Annex 1 country status means that it is not required to reduce its carbon emissions. Australia, too, has so far declined to join Kyoto. Accordingly, while the European Union is actively pushing for policies to limit greenhouse gas emissions, the world's largest single economy, and the nation that for the past 60 years has taken the lead in pushing for international agreements, is currently not doing so.

Matters may not always remain thus, however. In the United States, California has adopted an ambitious reduction target of achieving 1990 greenhouse gases emission levels by 2020, and plans to achieve this target through existing incentives for energy efficiency and renewables, as well as the creation of new programmes, such as a market-based system for emission reductions. Former Governor Pataki of New York spearheaded an agreement (the Regional Greenhouse Gas Initiative – RGGI) between seven New England and Mid-Atlantic states – Connecticut, Delaware, Maine, New Hampshire, New Jersey, New York, and Vermont – to reduce carbon dioxide emissions from power plants by 10% by 2019. Maryland has passed legislation compelling its Governor to join RGGI in 2007. Under the US Mayors Climate Protection Agreement, 320 cities have pledged to reduce emissions by 7% by 2012. Many US companies, including, for example, GE and Wal-Mart, have also adopted ambitious targets for direct and indirect emission reductions.

China, too, which has 20 out of 23 of the world's most polluted cities, is showing increasing signs of concern and asked for an OECD Environmental Review, the conclusions of which were released in November 2006[73]. Australia, meanwhile, is reportedly considering shifting its opposition to Kyoto, with hints that it might be willing to sign up to a new, more comprehensive, post-Kyoto accord.

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[73] *See Organisation for Economic Cooperation and Development (2006).*

Were therefore the United States authorities to come to consider climate change, and hence the control of man-made greenhouse gases, a matter of concern, the basic ingredients for international cooperation in this area would be in place. One possible catalyst for a change in stance at the federal level might be concern over energy security.

We put the probability at 50% or higher that, within 5 years, an international agreement will be in place

Although any such prediction is unavoidably uncertain, we would put the probability at greater than 50% that, within, say, five years, the present scheduled end of Kyoto phase II, some sort of international agreement will have been put in place whereby all the major emitters of greenhouse gases commit themselves to reducing their emissions, probably through some sort of emissions trading scheme.

The US political dimension

Kim Wallace (kwallace@lehman.com)

Global cooperation over climate change policy, as indeed most areas of international economic cooperation, will be influenced importantly by the stance of the United States government. Indeed, the US position could well be the determining factor in whether individual country or regional policies can be made to add up collectively to a coherent and global policy.

The policy direction of the US government is influenced importantly by domestic political developments: and here the situation appears to be in a state of flux.

US Senators are elected to staggered six-year terms and only 40% of the Senate is needed to obstruct legislation. Hence, while the Democrats' victory in the 2006 Congressional elections increases the prospects for climate change legislation, it seems unlikely that the US will enact a tough mandatory carbon cap before the 2008 elections.

That said, we judge that there will be a significant building of momentum on the global warming issue. Senator Barbara Boxer (D-CA), who chairs the Environment and Public Works Committee, has expressed her commitment to pursuing greenhouse gas legislation along the lines of the law that recently passed in California. While the 110th Congress will almost certainly bring hearings, and possibly votes on proposed legislation, there is not yet consensus for a tough mandatory greenhouse gas cap, the minority Republicans could likely muster the 40 votes necessary to prevent a vote on such a bill, and, failing that, the President could veto it.

Even among climate change allies, the working out of the details of a carbon cap involves picking winners and losers, which can be expected to splinter the coalition. For example, in 2005, some carbon cap advocates opposed a bill to limit greenhouse gas emissions, because of its incentives for nuclear power, a contentious issue among environmental advocates.

There are four primary arguments against our predictions, however, and they are likely to grow in importance:

- First is the growing feeling in the voting public that climate change must urgently be addressed, and among US industries that carbon caps are inevitable;
- Second, it might as a result be deemed better by businesses to have a law written under this Administration, rather than endure the continuing uncertainty and piecemeal state-level movements, and a more aggressive president of either party in the next administration;
- Another catalyst for Congressional action could be global warming lawsuits at various levels, including a Supreme Court case over whether the Environmental Protection Agency should regulate greenhouse gases from automobiles under the Clean Air Act;
- Finally, media comments by advisers have led some observers to suspect that President Bush, interested in establishing a legacy in his final years in office, might experience a global warming conversion. ■

BUSINESS: CHALLENGES AND OPPORTUNITIES FOR SECTORS AND FIRMS

The selected climate change scenario

In considering how climate change may affect business, the climate change assumptions adopted for the sections below are based on a commonly-assumed baseline rise in global temperature of between 2ºC and 5ºC. Some studies estimate that such a rise will occur by 2100; others, in the light of more recent evidence on positive feedback effects, see such a temperature increase as coming sooner.

It is assumed that such a temperature rise will result in, *inter alia*:

- Changes in seasonal patterns;
- Shrinkage of glaciers and thawing of permafrost;
- Rising sea levels (by around 1 metre);
- More extreme weather events, such as tropical storms and cyclones;
- Increased risk of drought, and more violent and intense precipitations;
- Increase in heat waves; and
- Declines in some plant and animal populations.

We take it that the economic damage caused by climate change will build progressively to a rate of 0-3% of global GDP per year by the time that Earth's mean temperature has risen by 2ºC-3ºC, and at considerably more for larger temperature increases.

In the light of such prospective economic costs, we judge that:

1. An increasing number of governments will implement policies to reduce greenhouse gas emissions; that however
2. It will progressively come to be accepted that tackling global climate change will require that *all* major greenhouse-gas-emitting countries take action; and that
3. There is a somewhat greater than 50% probability that in five years' time some sort of emissions trading regime will be in place, across at least the major economies and the more important sectors. ■

Climate change: a slow but inexorable force

Governments should be concerned particularly with the upper tail of likely events

There is a chance that global warming, particularly if it takes place at the upper end of present estimates, will induce sudden, transformational changes that will bring major, possibly catastrophic, ecological damage. This would come at considerable associated cost to economic activity, employment and incomes.

It is to such a possibility, even if small, that governmental policy should in our view be principally directed. A current analogy is terrorism. While the chances of a catastrophic terrorist attack may be small, governments direct substantial resources to minimising its likelihood because, were it to occur, the consequences would be so serious.

Business, by contrast, should focus on more-likely outcomes

More likely, however, at least on present evidence, is that climate change, while a powerful force, will impose change on business slowly, but inexorably. It is this more central scenario, rather than the upper-tail event, that is probably the more appropriate for most businesses to work to when formulating their plans. In that respect, climate change may influence business in ways that are somewhat similar to those being wrought by demographic change, and by globalisation, both of which are slowly but inexorably changing patterns of demand, structures of production, geographic location, and other key parameters that influence firms' behaviour.

Climate change can be seen as imposing a slow but inexorable force on business

Just because an influence is slow-moving, however, does not mean that its effects will always be commensurately slow. Slow-moving forces can on occasion impact business quite sharply and suddenly: indeed, in some circumstances, consequences can be brought right forward to the present. For example, houses built on low-lying land have, in some countries, already become difficult or impossible to sell or to insure in the light of recent evidence on the likely incidence of flooding.

Even slow-moving forces imply sharp changes in asset values

Moreover, policy response to a slow-moving change can induce sharp change in asset values: thus it has been recently, for example, with demographic change. The combination of falling equity market values and bond yields from 2001-3 not only exposed the mismatch between many insurance and pension funds' assets and liabilities, but also exacerbated it, many private schemes going into significant deficit. Consequential regulatory changes led funds to move their asset allocation further in favour of government bonds. But this pushed bond yields down further – some estimates suggest by a hundred basis points or more – further increasing the funds' deficits.

Just as ageing was a slow-moving driver in the pensions case, so will climate change prove to be a slow-moving force. But as or when it induces a policy response, the effects on some asset prices may be sharp.

Various effects of climate change

Climate change impacts on business through various domains

Regions, sectors, and firms, may be impacted through various domains of influence:

- **Regulatory exposure** from national and international policies and regulation designed to reduce greenhouse gases emissions;
- **Physical exposure** resulting from temperature rises and extreme weather events;
- **Competitive exposure** from a rise in the costs of energy-intensive processes, and a decline in demand for energy-intensive products;
- **Reputational – including litigational – exposure** from customers' and investors' perceptions of action or inaction on climate change; and
- **New technological and business opportunities** resulting from increased demand for low-carbon, high efficiency goods and services.

Some of these factors may affect regions similarly but industries differently: other factors may affect regions differently, but industries similarly. Even more important, perhaps, firms will be affected differently: climate change will result in important winners and important losers.

Flowing from this broad, and quite possibly conservative, scenario, the sections below consider first some of the apparently more likely consequences at the sectoral level[74], and then some of the potential implications at the level of the firm.

Regulatory exposure

National and regional regulation policies currently concern only some sectors

Although an optimal global policy would, as outlined above in the section *Policies: Design, Implementation, and International Cooperation*, impose a uniform charge on greenhouse gas emissions across all sectors in all economies, regulations in many countries are likely in practice to be somewhat sector or industry specific, with some sectors targeted more than others.

Not surprisingly, given their relative importance in contributing to greenhouse gas emissions, policy makers' attention has thus far tended to focus on the automobile industry (but not the transport industry more generally); utilities; integrated oil and gas companies; building and construction; and cement manufacturers.

Automobiles. Manufacturers are indirectly exposed to greenhouse gas emissions regulations and directly exposed to emissions regulations on private and commercial vehicles. Car makers are subject to various external regulations, especially in Europe, including: the implementation scheme of the European directive on the trading of

[74] *Some of these implications come from the readings of companies' answers to the Carbon Disclosure Project questionnaire – see the website <www.cdproject.net/responses.asp>.*

greenhouse gas emissions quotas; labelling regulations pursuant to the CO_2 directive; tax policies; and green purchasing by public authorities and large corporations. Legislation or regulation changes will likely oblige an increase in fuel economy and/or a lowering of CO_2 emission intensity. In the United States, although new emissions caps have not yet been determined, the industry may find itself obliged to make substantial investments to meet future targets. The European Union Emissions Trading Scheme (EU ETS) is already stimulating greenhouse gas reduction efforts beyond Europe. And leading global manufacturers have already established self-imposed greenhouse gas reduction targets for facilities outside the jurisdiction of the EU ETS. Ford has done this in the context of the Chicago Climate Exchange, and Toyota has announced that by 2010 it will reduce its carbon dioxide emissions per unit of sale by 35% compared with the 1990 level. In March 2006, China enacted a 20% tax on large cars in an effort to decrease the demand for those polluting vehicles.

Transport. This sector is currently excluded from the EU Emissions Trading Scheme, and there are no plans to include road and rail transport in future phases. Airlines, however, would be brought in under an October 2005 European Commission proposal to cap CO_2 emissions for all aircraft departing from EU airports. This provides for airlines to trade their potential surplus credits on the European Emissions Trading Scheme (EU ETS). In December 2006, the European Commission went further and proposed legislation to bring greenhouse gas emissions from civil aviation into the EU ETS. Emissions from flights within the EU would be included from 2011 and emissions from all flights to and from EU airports from 2012. To limit the rapid growth in aviation emissions, the total number of emission allowances available will be capped at the average emissions level in 2004-06. It is estimated that by 2020, CO_2 savings of as much as 46% could be achieved each year. The European Parliament also backs the introduction of taxes on aviation fuel (kerosene); requires taxes on all domestic and intra-EU flights; and calls on the European Commission for the global introduction of more regulation. Assuming airlines fully pass on any extra costs to customers, by 2020 the price of a return flight within the EU could rise between €1.8 and €9. The price of long-haul trips could increase more depending on the journey length as a result of higher environmental impact.

Utilities. Greenhouse gas regulation presents an immediate financial charge on utilities, as companies are obliged to reduce output, switch fuel sources, invest in new technologies, or purchase carbon credits to reduce their exposure. In Europe, energy activities are covered by the EU ETS, pursuant to which power stations are required to have a permit for each tonne of CO_2 emitted. This is already leading utilities to engage in Clean Development Mechanism projects (CDMs) or Joint Implementation projects (JIs). Tokyo Electric Power Company (TEPCO) recently announced involvement in a biogas supply project at a tapioca factory in Thailand. In the United States, even though no federal regulation is in place so far, some regulation is nevertheless already in place at the state level. In November 2005, seven north-eastern states agreed to reduce the emissions of regional electric utilities, through the Regional Greenhouse Gas Initiative (RGGI). This scheme is underpinned by a multi-state cap-and-trade system: all 600 power plants in these states with capacity equal or greater than 25 MW which burn more than 50% fossil fuel, are expected to come under this system. Furthermore, leading electric utilities have begun to establish self-imposed reduction targets, for example in the context of the Chicago Climate Exchange. US utilities with gas-powered generation are also starting to commit themselves to voluntary self-restraint of their greenhouse gas emissions. In China, the government has signed bilateral ‘contracts’ with the six largest electricity generators in which the latter guaranteed the amount of SO_2 reduction within five years.

However, there is uncertainty around future regulation, even in Europe, where leaders have pledged to extend Kyoto beyond 2012. Utilities outside the EU face similar concerns, including in Japan, the United States, and South Korea, where governments have not yet instituted mandatory greenhouse gas reductions. In China, while the current regulations focus more on the reduction of SO_2 emissions, it is likely that regulations on CO_2 emissions will follow.

With regulation already in place in many regions of the world, there is growing development of renewable portfolios. In Germany, the Act on Renewable Energies aims to increase the market share of renewable energy in the German power system to 20% by 2020. In the United States too, renewables are becoming more popular, the California Solar Initiative being one example. In China, the 11th Five-Year Economic Plan sets a target for the share of energy production by renewables at 15% by 2020.

Integrated oil and gas. Because of uncertainties surrounding the future of greenhouse gas legislation and regulation, particularly taxation, industry leaders are allocating more resources to Clean Development Mechanism (CDM) projects, which are the most viable mechanism for complying with current and likely future regulation. Repsol YPF has invested over $14m in CDM projects that involve energy efficiency, renewable energy, and fuel switching in developing countries. The impact of the EU Emission Trading Scheme will also include the costs of monitoring and reporting. Such costs stand to be offset, in part, by the revenue from sales of surplus emission allowances, and through market changes that promote the use of natural gas in particular.

Furthermore, following regulation on renewables, companies are recognizing the commercial potential offered by renewable energy, with many integrated oil and gas companies already developing their renewables portfolios.

Building and construction. In Europe, new regulations have set tighter standards for the energy efficiency of new buildings. The EU Energy Performance of Buildings Directive imposes standards for all buildings in Europe. And local authorities have their own guidelines to encourage sustainable construction and development. Regulation is likely to become increasingly stringent: indications are that, over the coming, say, 10 years, many planning authorities may require that development projects be carbon neutral.

Cement. The cement industry produces a significant amount of the world's carbon dioxide emissions (upwards of 5%), both directly, in the actual process of manufacturing, and indirectly in the use of electricity (from coal-based plants), and transportation (from shipping for example). Cement companies in Europe are likely to face particular challenges as a result of the Kyoto Protocol. The regulatory exposure has two sides. First, the cement industry will suffer higher electricity costs, as tighter regulation increases the cost of energy. Cembureau, the representative organisation of the cement industry in Europe, estimates that average electricity costs have increased from 14% of production costs to 25% across the sector. Furthermore, buying carbon permits will increase the cost of manufacturing. To meet carbon emission standards, European cement players will have to engage in: increased capital expenditure to upgrade manufacturing units; the replacement of fossil fuels with alternative fuels; and the reduction of the clinker/cement ratio through the use of slag or fly ash, by-products of the steel and power industries. Clean Development Mechanisms projects are also being undertaken by some manufacturers, which enable them to have more carbon permits, compensating for excess carbon emissions in other projects.

Physical exposure

Infrastructures and installations are put at risk by climate change

The melting of glaciers, a rising sea-level, and a rise in the frequency and intensity of violent weather events could put installations and infrastructure at significant risk in the more affected regions. The sectors most affected would probably be utilities; integrated oil and gas companies; insurance; and real estate, along with building and construction.

Physical exposure also includes exposure to changes in health conditions, and resulting changes in the incidence of various categories of disease. The pharmaceuticals and healthcare sector may be particularly affected.

Utilities. Climate change in general, and more frequent extreme weather events in particular, poses threats to infrastructure. Entergy, an American electricity utility, estimates that hurricane Katrina resulted in $1.5bn in restoration costs, not including lost revenues. Climate change impacts are unlikely to be uniform across regions: it is probable that infrastructures will be more threatened in North America than in Europe, where extreme weather events seem likely to be less common. But drier summers with reduced hydro power production and diminishing river cooling water for power stations could become a problem in Europe. Furthermore, climate variability could disrupt regional infrastructures that have been established to meet traditional peak loads in demand, by transforming areas that hitherto have not been large peak communities into regions of heavy demand: higher temperatures may well decrease demand for heating and hot water, but increase demand for electricity to power air conditioning systems. Gas infrastructures and installations meanwhile may be put at risk by extreme weather.

Water utilities are likely to be affected by climate change, through effects on the quantity and the quality of free water resources available for public supply. Reduced summer river flow is likely to reduce the water available for public water supply. The natural recharge of aquifers from which groundwater is taken is likely to start later in the season, which may reduce water availability. Water quality may also be affected by increasing numbers, or severity, of rainstorms. Reduced river flows may reduce effluent quality standards, as lower flows reduce the dilution of treated wastewater discharges. And further water quality issues may arise through rising temperatures reducing levels of dissolved oxygen[75].

Integrated oil and gas. The location of some infrastructures, especially in the United States, could put the sector at significant risk. Examples include oil and gas rigs and refineries in the Gulf of Mexico and the south-eastern US. These regions are also susceptible to climate-change-induced increases in sea level, and perhaps also to stronger and more frequent hurricanes and other 'natural' events. In 2005, the hurricane season demonstrated the susceptibility of oil and gas infrastructures to weather events. This has led the industry to re-examine the safety and operational integrity of existing facilities. Chevron reported a negative financial impact of $1.4bn from reduced production and damage to facilities after hurricane Katrina. Furthermore, if the melting of the Alaskan permafrost continues, it could cause the collapse of the northern half of the Alaska pipeline, through which half of all US oil production flows.

Insurance. Property, life, and health insurance are all potentially impacted by climate change. Consequences that stand to be particularly important to the insurance, and particularly the reinsurance, industry include: increased precipitation; the creation of drought-like conditions; stronger tropical storms and hurricanes; and periodic flooding resulting from abnormally heavy rainfall. Liquidity problems could arise from larger weather-related losses. Increases in population and infrastructure densities multiply the size of maximum potential losses from extreme weather events. Increased risk to human health (thermal stress; vector-borne disease; and natural disasters) may also affect insurance companies.

On the other hand there is a potential positive development in demand for property insurance. Insurers have a major opportunity to develop creative loss-prevention solutions, as well as products that will reduce climate-related losses[76].

Building and construction, and real estate. Predictions of the physical risk from climate change with respect to commercial real estate include: increases in sea level; and a rising frequency and intensity of storms, including a lengthening of the hurricane season. Heavier-than-normal rainfall may threaten property foundations. Rising temperatures and sea levels stand to reduce the value of commercial and domestic properties in flood risk areas. Moreover, flooding and other extreme weather events may result in delays in construction. Despite these important physical risks, demand for

[75] *See Thames Water website, <www.thameswater.co.uk>.*
[76] *See Mills, E. and Lecomte, E. (2006).*

properties in regions at risk (close to the sea, and rivers, for example) has apparently so far not decreased with natural events; indeed, the demand for development in these regions has increased. According to the United Nations Environment Programme (UNEP), 40% of the world population lives within 60 km of a coast and, of the world's 23 mega cities (over 2.5m inhabitants), 16 are on the coastal belt. By 2010, the UNEP estimates, 80% of the world population will live within 100 km of a coast.

On the other hand, extreme weather events bring a business opportunity for developers, as refurbishment and new developments may be needed as a result of more frequent and severe weather events.

Changes in health conditions put the pharmaceuticals sector on the front line of climate change impacts

Healthcare and pharmaceuticals. Temperatures are likely to rise more in urban regions than in rural regions. This stimulates growth rates of plants such as ragweed and poison ivy, which already have produced a 60% increase in pollen counts, raising the frequency of asthma and other respiratory illnesses. Droughts and increased precipitation also stand to harm individuals and ecosystems: droughts have been shown to affect predator species of insects to a larger extent than those of vector classification. Vector-borne diseases, such as dengue and cholera, may increase or become prevalent in areas where they had previously been eradicated. Rural and urban regions have experienced an increase in the number and intensity of heat waves over the past decade.

However, while human health may suffer from climate change, healthcare companies may improve their financial situation as a result of an increase in demand for their products.

Competitive exposure

Consumers can be expected to shift their demand towards less energy-intensive products

As regulation imposes an additional cost on carbon-intensive products, consumers can be expected to shift demand towards less energy- and carbon-intensive products, bringing both commercial challenges and commercial opportunities. Another aspect of competitive exposure is the increase in costs of energy- and carbon-intensive products, following the tightening of regulation standards. This will have a negative impact on the margins of sectors using those kinds of products. These two competitive exposure sides stand to affect particularly the automobile, utilities, integrated oil and gas, mining, and technology sectors.

Automobiles. Components used particularly by auto manufacturers – steel, aluminium, and glass – may increase in (relative) price, as climate change regulation imposes higher costs associated with CO_2 emissions on sectors which supply to the automobile sector. More stringent fuel economy standards are likely to divert consumer demand towards smaller and more fuel efficient cars. Because Original Equipment Manufacturers' (OEM) product mixes differ with respect to carbon intensity standards, average OEM costs per vehicle to meet new carbon constraints could differ by a factor of 25, from $650 for BMW to $25 for Honda[77]. In China, the consumption tax will be reduced by 30% for auto producers if they reach the low-pollution emission standards ahead of schedule.

Utilities. Prices of the fuels used to generate electricity are particularly important to this industry. If the price of electricity is increased by emission regulations, this will be largely passed on to consumers because the industry typically operates with small profit margins. Because coal is more greenhouse gas-intensive than other fuels, the price of electricity generated from coal may increase particularly. Consumers may then switch to cleaner generators.

Integrated oil and gas. Increases in costs resulting from higher energy prices, especially downstream and in chemicals, may put downward pressure on the sector's profits. Because natural gas emits relatively little CO_2 when it is burned, demand for this energy source is projected to increase under more stringent greenhouse gas regulations. Should

[77] *See Austin, D. et al. (2005).*

the price become prohibitively high for consumers, it will accelerate demand for newer technologies.

Mining. Companies with worldwide operations have already been expressing concern over the rising cost of energy. To avoid the threat to profit margins, sector leaders are working to decrease energy intensity. Some materials will be in heightened demand, because of their intrinsic characteristics, e.g. aluminium because of its low density (important in achieving lower fuel consumption of cars), and platinum (for catalytic converters used to oxidise pollutants).

Technology. Consumer awareness is likely to lead to a positive effect on some technology sectors. Particular opportunities may well be created for the telecommunications sector, which has the potential, through improvements in communication over distance and time, to enable interlocutors to meet face to face without their having to use cars or other modes of transport. A similar argument applies to the software sector, to the extent that information technology provides connectivity without the need for physical travel.

Reputational – including litigational – exposure

Reputational issues arise for industries with a large exposure to the retail market

In the short term, there will be an even more substantial effect on the growth prospects of companies in sectors where the impact of consumer behaviour is disproportionately higher than any of the other impacts. This might be the case in particular for industries with a large exposure to the retail market. For such industries, taking a position that goes in the direction of environmental protection and action against climate change, will be viewed positively by consumers, and will thereby enable companies to gain a competitive and reputational advantage over competitors (see Box: *Business Moves Ahead)*. For example, Tesco recently announced that it would open six new regional buying offices to increase local sourcing and make it easier for small producers to sell goods through the United Kingdom's leading supermarkets.

Consumers tend to regard poorly sectors that have a particularly detrimental impact on the environment. Airlines are a case in point. Although this industry accounts for only 2% of global CO_2 emissions today, it is often depicted as one of the main culprits. And oil and gas companies tend to be similarly regarded (as a result of leakages, for example).

Conversely, sectors such as renewables are well regarded, as they are perceived to be contributing to solving the climate change problem. Another sector with a positive image and good reputation is the technology sector, particularly telecom equipment, because it enables people to communicate without using transport, thereby avoiding carbon emissions.

Reputational exposure is even more important at the firm level

Important though reputation is at the sector level, it is potentially more important at the firm level. Within a given sector, some companies may have, or develop, a good climate reputation, whereas others may suffer a loss of reputation. For example, when Shell was planning the disposal of the Brent Spar platform out at sea, it suffered a consumer boycott on its forecourts in Germany.

There may be even a converse risk, in some cases, of excessive reputational inflation – a type of 'reputational bubble'. Presumably, as evidence becomes clearer and cost estimates more precise, it will be possible to make better assessments and valuations of companies' environmental situations.

Business moves ahead

Some parts of business are moving several steps ahead of governments and regulators in reducing their carbon emissions. This is partly out of a desire to jump before being pushed: regarding legislation as imminent, certain companies want to be pro-active and embrace (and perhaps thereby shape) new rules. But what seems to be mainly spurring companies into action is a wish to gain a competitive and reputational edge over rivals. With the exception of insurance – which is special in having to absorb the climate change risks that all other sectors run – the common thread linking most of the early movers on carbon emissions is that they all have a retail presence – 'consumer-facing' in the jargon.

Integrated oil. This even goes for the big oil companies, which are almost unique among industrial operators in having their own branded retail outlets (garages) to sell their manufactured wares (fuel) and thereby a consuming public to face directly. BP made the decisive shift in this sector in 1997 when it abandoned the Global Climate Coalition (that had been assembled to thwart action against climate change), began to market itself as Beyond Petroleum, and found itself followed by several of its European peers, such as Shell, and a few in the US, including Texaco. But the trend to carbon reduction and offsetting now stretches right across retailing.

Supermarkets. For some time, rival chains have been trying to 'out-green' each other (by, for instance, promoting recycling and reducing packaging) as a way of differentiating themselves to shoppers. But in this competition to out-green each other, climate change is now playing a bigger role, as is clear in the efforts of UK retailers to show how they are cutting down on the carbon emissions in sourcing and transporting food. Tesco, Waitrose, Asda, Sainsbury, and Wm Morrison have all announced a switch from road to less carbon-intensive rail freight in transporting food within the UK, while several now vaunt the amount of local UK produce they sell in order to cut down on 'food miles' that imported food must travel.

Financial services. A number of companies in these sectors have announced their intention to go 'carbon-neutral' by 'offsetting' carbon emissions that they themselves cannot reduce. Taking the lead among the retail banks has been HSBC, which has said that it will plant trees, reduce energy use, and buy 'green' power to become carbon neutral at an extra cost to the bank of $7m a year. In terms of financing, carbon reduction and energy efficiency has graduated from being the preserve of a few groups of concerned investors into the mainstream of the capital markets. Major investment banks are lining up sizeable funds to invest in this area.

Insurance. Swiss Re, the big re-insurer, has also made the pledge of carbon neutrality. Furthermore, opportunities in adaptation to climate change fall essentially to the insurance industry to ease the financial impact of more extreme weather. This is already taking its toll, with claims related to natural catastrophes rising twice as fast as general insurance claims. But growing awareness of climate change is also likely to encourage an increase in insurance cover not only by individuals and companies, but perhaps even by governments and international organisations. The United Nations has, for instance, taken out a policy with Axa-Re to cover Ethiopian farmers against drought, a move that could provide that country with a sounder alternative to reliance on humanitarian aid or disaster relief.

Infrastructure and communications companies. BT has an incentive to show off its climate change credentials to its subscribers, but also – as a fixed line operator – an interest in doing anything it can to ward off the sort of storms that down its cables. So BT, one of the UK's biggest industrial power users, decided in 2004 to sign up with Npower and British Gas in what it calls "the world's biggest green energy contract" from renewable or fuel-efficient combined heat and power (CHP) sources. As a result, BT claims, its CO_2 emissions were 70% lower in 2005 than in 1991. Furthermore, it claims that, by using conference calls and home-working, it has saved its employees 315m miles of travel and its own finances some £360m. BskyB, for its part, has pledged to become carbon neutral by making more use of electric or hybrid cars in its operations.

Manufacturing groups and intermediate producers. These companies face a much more difficult task than do services companies in offsetting all their relatively higher emissions. Yet Reckitt Benckiser, which has many consumer-facing brands in its array of household and health products, announced in 2006 that it would plant 2m trees in Canada's British Columbia, at a cost of several million pounds, to offset the carbon emissions of some 8bn products that it will manufacture in 2006-7.

The most telling signs of a shift to a low-carbon economy come among those companies that are neither directly affected by regulation (like utilities in Europe) nor have a retail image to burnish (like oil or food companies). And the most striking indication of this shift is from General Electric. GE has put some 40 of its 'clean technologies' into what it calls its Ecomagination programme, which will be a focus of future R&D spending. It nearly doubled sales of these energy-efficient products from $6.1bn in 2004 to $10.1bn in 2005, and aims at a further doubling by 2010. ■

New technological and business opportunities

Technological innovation is stimulating growth in new and existing industries

Climate change does not only impose costs on producers, however. It also presents considerable opportunities. Recent and rapid technological innovation is stimulating growth in new and existing industries, as markets receive somewhat clearer signals about, and draw inferences concerning, the long-term growth potential of 'low-carbon' products and services. In some cases, technological innovations may not only reduce emissions of *carbon*, but lead to firms becoming more efficient in the use of *all* inputs, boosting net profit. Sectors which may benefit particularly from new technological opportunities include: automobiles; utilities; integrated oil and gas; and chemicals.

Automobiles. The main domains in which innovation is likely to be needed include: the cutting of emissions of pollutants and CO_2; reduction of fuel consumption; and development of the use of renewable energies. To meet these objectives, hybrid technologies continue to develop, boosted by increasing fuel efficiency standards in major markets, and rising consumer demand. Alternative fuels are gaining increasing attention (e.g. bio fuels). Original Equipment Manufacturers (OEMs) will likely bring a variety of fuel-saving vehicle technologies to market, including: hybrid power-trains; cylinder deactivation technology; advanced diesel technology; and an array of emerging technologies. OEMs best able to contribute to the production of vehicles with lower carbon emissions stand to gain global market share and improve financial performance.

Utilities. In response to growing consumer demand, and in order to be able to reduce carbon emissions significantly, electric utilities are developing an increasingly diverse array of generating capacities. The development of nuclear power generation, and an extended use of renewable energy (solar, wind, and hydroelectricity) are all likely steps in reducing CO_2 emissions. In the United States, as elsewhere, utilities are developing diverse portfolios of generating activities. American Electric Power generates over 300MW through wind power. China's 7th richest person, Shi Zhengrong, has already built a $1.4bn fortune on solar-photovoltaic-panel technology[78].

The introduction of more efficient methods of power production, such as the development of terrestrial and geological carbon sequestration projects, could lead to significant decreases in generation costs. RWE, a German utility company, is planning to build a CO_2-free coal-fired plant that utilizes integrated coal gasification combined with CO_2 sequestration and storage.

Integrated oil and gas. Renewable energy portfolios continue to grow in response to rising consumer demand and probable sector regulation. Climate change stands to stimulate efforts to: improve energy efficiency; promote cogeneration (simultaneous production of power and steam, for energy conservation and efficiency); and the use of (low-emission) natural gas. In 2005, BP launched BP Alternative Energy, a business dedicated to the development, marketing and trading of low-carbon power. Oil and gas companies are also increasingly active in technology research and development (e.g. in advanced vehicles and fuel technology, and hydrogen generation technologies). There are also important strategic opportunities in carbon sequestration technology development.

Chemicals. Research allows the production of new energy-efficient products. BASF recently launched a bio-degradable plastic. Furthermore, the need for low carbon-intensive energy creates the need for new processes, such as electricity production using photovoltaic cells. There is also significant potential for biotechnologies, which could increase energy efficiency.

Climate change also brings new business opportunities

Climate change not only brings technological opportunities, it also enables new businesses to appear and develop. Carbon emission offsetting has indeed become a business in its own right. For example, the Carbon Neutral Company was established to help other companies measure, reduce, and offset their carbon emissions. It has what it

[78] See *International Herald Tribune, 7 December 2006.*

calls a 'warehouse' of technology and forestry carbon offset projects into which would-be offsetters can buy and thereby obtain CO_2 absolution.

Some offset schemes have been criticised, especially those involving the planting of trees, an activity that allows the planter to take a carbon credit for the estimated full life of the trees, even if that is foreshortened by logging or fire. Nonetheless, offset offers to individuals are proliferating. The ClimateSure company, for example, will provide car and travel insurance that has the cost of the requisite carbon offset already built into the premium. In the same way, Britain's Co-operative Bank helps its mortgage customers offset the carbon emissions of their houses.

Implications at the firm level

Within sectors there will be winners and losers

However important the implications of climate change may be at the sectoral level, the ultimate consequences are manifested at the level of the firm. Regardless of whether, overall, a sector benefits from or is harmed by climate change, there will be some firms within the sector that will do well, and others that will do badly.

Already, with little impact yet being felt from climate change, firms are obliged to respond to the challenge of an economic environment that is continually evolving, the result of technological change, changing patterns of demand as societies get richer and older, and changing sources of competition as a result of globalisation. Evidence from the United States and Europe between the late 1980s and the first part of the 1990s indicates, *inter alia*, that[79]:

- Each year, about 20% of firms enter and exit most markets. This process involves about 5-10% of total employment, because exiting, and especially entering, firms tend to be smaller than average.
- Entry and exit rates are highly correlated across industries, particularly when weighted by employment: entries and exits are apparently part of a process whereby a large number of new firms displace a similarly large number of inefficient ones (which may themselves be relatively new), without significantly affecting the total number of firms in the market.
- Although there are substantial differences in entry rates across sectors, high-entry industries at one point in time do not necessarily rank at the top of the industry distribution 5-10 years later: product cycles are apparently important in explaining industry dynamics, over and above more stable effects stemming from market structure and institutional factors.
- Market selection is harsh: only about 60-70% of entering firms survive their first two years of activity. And, although failure rates decline with duration, only about 40-50% of firms entering in a given year are still in business seven years later.
- Small businesses are much less likely to survive than are bigger ones, which also tend to grow more rapidly.
- The cross-industry variability in the failure rate of young firms is similar to that in entry rates: certain industry characteristics create not only barriers to entry, but also barriers to survival.

Firms which prosper most are those with the best management practices

As might be expected, the firms that prosper most in this modern-day environment tend to be those with the best management practices. Evidence from more than 700 medium-sized manufacturing firms in the United States, France, Germany and the United Kingdom is of a strong correlation between measures of the quality of managerial practice and firm performance, whether in terms of productivity, profitability, Tobin's Q, sales growth, and – particularly importantly perhaps – firm survival[80].

[79] The information on firm turnover below draws heavily on Scarpetta, S. et al. (2002).
[80] See Bloom, N. and Van Reenen, J. (2006).

Many of the most successful firms will be those which foresee the implications of climate change

Climate change is likely to be another major factor that alters the economic environment in which firms operate. It may well prove to be somewhat akin to globalisation: a slow, but powerful and inexorable force that progressively changes relative prices, relative costs, structures of demand, and hence the structure of production.

The firms that will prosper are most likely to be those that are early to recognise the importance and inexorability of climate change, foresee at least some of the implications for their industry, and take appropriate steps, well in advance.

In our judgement, this is likely to involve, within an overall framework of good management practice:

- Inculcating a constructive culture of benefiting from change in senior and middle management;
- Encouraging employees to embrace change, and enabling them to do so through a structured programme of staff training;
- Undertaking the requisite research and development, which is often highly industry- or even firm-specific; and
- Translating this research and development into appropriate investment in physical and human capital formation.

In short, the pace of a firm's adaptation to climate change is likely to prove to be another of the forces that will influence whether, over the next several years, any given firm survives and prospers; or withers and likely dies.

Lehman Brothers accreditation

Lehman Brothers became recently one of only 200 organisations in UK to attain the Energy Efficiency Accreditation Award for work it has undertaken in London to reduce the impact that the Firm has on the environment. Since 2004, Lehman Brothers has decreased its total electricity consumption by 7.5%, and its consumption per employee by 34%. The resulting cost saving funded a switch to a green electricity supplier in October 2006, and will eliminate 23,000 tonnes of power-related carbon dioxide emissions per year.

At the same time, Lehman Brothers is examining its impact on the environment in other areas and is reviewing its procedures as part of its commitment to the continual improvement of its business operations and to improve environmental performance. For example, Lehman Brothers recently eliminated landfill as a destination for waste, and now recycles or reuses 100% of its waste. ■

ANNEX 1: OPPORTUNITIES FOR SOCIALLY RESPONSIBLE INVESTORS

Socially Responsible Investment Team

Arthur Moretti
+1 212 476 5804

Ingrid Dyott
+1 212 476 5908

Sajjad Ladiwala
+1 212 476 9012

- *Global climate change, and its implications for business's long-term sustainability, should in our view be a significant consideration for the investment management industry; regulatory changes in response to public sentiment regarding climate change can create a significant liability for a business or, at a minimum, increase the cost of doing business.*
- *Companies which are aware of the impact their business practices have on the overall environment, including climate change, and proactively take actions to mitigate any unfavourable impact, may create a significant competitive advantage compared with companies which, through a lack of awareness, become blindsided by regulations. There is also potential for attractive investment opportunities to arise from new industries or businesses that may be created to address the challenges of global climate change.*
- *As active investors whose value proposition is to drive superior risk-adjusted returns through stock selection, and identifying companies that are leaders in their field from a business, financial and social perspective, we judge that it is crucial to our overall success – and that of our clients – to be aware of the science behind climate change, understand its implications from both an industry and company perspective. Then, in turn:*
- *This needs to be integrated into an investment framework that provides a structure for analyzing a company's progress, or failure, towards achieving our investment thesis.*

At the same time, we recognize that a company's responsiveness or lack thereof, to these powerful yet slow moving forces, much like an ageing population or globalisation, represents just one component of a company's longevity and success. From our perspective, companies which are responsive to the changing economic, social and environmental landscape, brought about by trends related to climate change, will create opportunities (that will not come without challenges) to grow their businesses, and in turn create wealth for their stakeholders.

From an investment perspective, such factors have to be continually weighed against other business fundamentals, and equity valuation, in determining whether a company's share price offers an attractive risk/reward opportunity.

Given the size of the asset management industry, investment companies are in a strong position to influence business managers to focus on these issues.

Size and Scope of the Asset Management Industry

- Global asset management presents a wide range of investment strategies and products, encompassing traditional investments, such as cash, equity, and fixed income, as well as non-traditional investments, such as hedge funds and private equity.
- Assets managed by registered investment companies reached $9.5 trillion at the end of 2005, a $900 billion increase over 2004. Mutual funds represent the bulk of the industry's asset size, accounting for $8.9 trillion, or 94% of total investment company assets. For comparison purposes, consider that closed-end fund assets totalled $276 billion; exchange-traded funds (ETFs), $296 billion; and unit investment trusts (UITs), $41 billion[81].

Arthur Moretti, Ingrid Dyott and Saijad Ladiwala are portfolio managers of Neuberger Berman, LLC's Socially Responsive Investments team. This material is intended as a broad overview of their style, philosophy and process and is subject to change without notice. Their views may differ from that of other portfolio managers as well as the views of Neuberger Berman, LLC, Lehman Brothers Inc. and their affiliates. Client account holdings and characteristics may vary since investment objectives, tax considerations and other factors differ from account to account. Portfolio characteristics are subject to change without notice. Past performance is not indicative of future results.

[81] *See Investment Company Institute (2006).*

- Corporate equity funds comprise approximately 25% of the investment industry's assets, with municipal, corporate, and government fixed income investments making up the balance[82].
- Over the past three years, net new flows to actively managed equity funds have generally been more than double net new flows to passively managed equity funds, indicating growing interest in actively-managed strategies[83].

The science is real

Scores of scientific articles, a number of which are referenced in this study, provide evidence that climate change is real and, as such, point to a long-term trend that informed investors are taking seriously. While there are various unpredictable permutations as a result of global warming, the contributing cause and result are clear: greenhouse gases and climate change.

Earth's history has been characterized by extended periods of warming and cooling, often occurring in cycles of approximately 100,000 years, mainly as a result of changes in the Earth's solar orbit. Evidence presented in the first part of this study indicates that Earth warmed by 6/10 of a degree over the past century. This recent period of warming has been caused largely by an increase in atmospheric CO_2 concentration since the pre-industrial period from 280ppmv (parts per million per volume) to 380ppmv, and there is a scientific near-consensus that it is human activity and industry that have caused most of the recent climate change.

Sentiment is equally important

We recognize the empirical case for climate change and its relationship to human activity and industry, but judge that public sentiment is equally important in the effort to understand and address climate change and its implications. An analysis of the increasingly diverse cross-section of stakeholders who are making tangible efforts to grapple with these issues highlights its importance on several levels:

Government. As the 'owner' and 'enforcer' of the regulatory environment, the government plays a critical role in developing regulations intended to minimize the effects of global climate change and enforcing them. Below are some particularly compelling examples:

Kyoto Protocol – The Kyoto Protocol is an agreement made under the United Nations Framework Convention on Climate Change (UNFCCC). Countries that ratify this protocol commit to reduce their emissions of carbon dioxide and five other greenhouse gases, or engage in emissions trading if they maintain or increase emissions of these gases. The Kyoto Protocol now covers more than 160 countries globally, and over 55% of global greenhouse gas emissions.

Assembly Bill 32 – In September 2006, California Governor Arnold Schwarzenegger signed Assembly Bill 32, which is legislation that requires the California Air Resources Board (CARB) to develop state regulatory and market mechanisms designed to reduce the production of greenhouse gases in the state by 25% by 2020. The Bill also set a deadline for the establishment of source caps by 2012, and requires CARB to begin measuring greenhouse gas emissions of industries it determines are significant sources of emissions[84].

Renewable Portfolio Standards (RPS) – A renewable portfolio standard is a State policy that requires electricity providers to obtain a minimum percentage of their power from renewable energy resources by a certain date. Currently 20 states, plus the District of Columbia, have RPS policies in place. Together these states account for more than 42% of the electricity sales in the US. Two other states, Illinois and Vermont, have non-binding goals for adoption of renewable energy instead of an RPS[85].

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[82] *See Investment Company Institute (2006).*
[83] *Morningstar data as of 8 December 2006.*
[84] *See California Climate Change website, <http://www.climatechange.ca.gov>.*
[85] *See US Department of Energy – Energy Efficiency and Renewable Energy, <http://www.eere.energy.gov>.*

Industry. From an industry standpoint, companies also collectively recognize the importance of banding together to better understand the implications of climate change and its long-term impact on their respective businesses. The increasing proliferation of industry-wide networks and public/private partnerships, such as those outlined below, speaks volumes about the significance of this subject and the need for businesses thoughtfully to incorporate it into their overall strategy:

The Chicago Climate Exchange – The Chicago Climate Exchange (CCX), the Chicago Climate Futures Exchange (CCFX), and the European Climate Exchange are industry-driven exchanges that, in the case of the US-based exchange, administer a voluntary, legally-binding program for reducing and trading greenhouse gas emissions. Membership consists of the following:

- CCX members include municipalities and corporations, such as the State of Illinois, Ford, General Electric, and the City of Chicago;
- Members must, by end December 2006, reduce greenhouse gas emissions by 4% below a baseline period of 1998-2001. In addition, members must participate in Phase II, which extends the CCX reduction program through 2010, and requires a 6% reduction below the baseline;
- CCX membership dictates extensive, and expensive, corporate behaviour changes, but firms assume that it offers them a series of advantages over the long term. First, members participate in governing committees which may help shape government policy in the 21st century. Current committee decisions can potentially influence the future regulation of emission baselines, audits, monitoring and verification, offset projects, and trading practices. In addition, membership may lead to global exposure, competitive advantages, and improve or enhance a member's reputation[86].

The Pew Center on Global Climate Change – The Pew Center brings together business leaders, policy makers, and experts to build a new, non-partisan approach to global climate change:

- Established in 1998 and based in the US, the Center conducts analysis in areas of science/impacts, economics, policy (domestic and international), and solutions. Its reports are available for free to thousands of subscribers worldwide and through the Center's website[87];
- In addition, the Pew Center seeks to play an active role in the policy world, offering briefings to members of Congress, key Executive Branch and state officials, and international leaders;
- Finally, through the Business Leadership Council, the Pew Center has reached out to business leaders, creating a forum for business and policy players to discuss a long-term approach to climate change;
- The Council includes 42 major corporations, primarily large members of the Fortune 500. Together, the firms employ more than 3.4 million people, and represent $2.4 trillion in market capitalization.

World Business Council on Sustainable Business - The WBCSB is an organisation of 180 international companies, with a commitment to sustainable development through economic growth, ecological balance, and social progress:

- Formed in 1991 in anticipation of the Rio Earth Summit of 1992, the Council now draws from more than 30 countries and 20 sectors. In this way, it differs from the Pew Business Leadership Council, which is composed predominantly of US firms;

[86] *See Chicago Climate Exchange website, <http://www.chicagoclimateex.com>.*
[87] *See Pew Center website, <http://www.pewcenter.org>.*

- The Council has no fixed criteria for membership, and companies do not commit to any set protocol for corporate behaviour – a different model from, for example, the Chicago Climate Exchange;
- On balance, the Council sponsors between four and six projects or initiatives, which include research work and recommendations for businesses. Current projects include an examination of water and sustainable development;
- The WBCSB is also a joint partner on the Greenhouse Gas Protocol[88], which a significant number of companies are using to put in place better management systems in their efforts to measure and reduce greenhouse gases, while at the same time providing greater transparency.

The asset management industry has also begun to organize itself more effectively, in an effort to raise awareness, and discuss practical applications for analyzing companies' levels of responsiveness in the investment research process. The momentum that global climate change and its implications have gained over the past several years points to the fact that the investment community is not only embracing the science behind it, but is recognizing that a company's responsiveness to these issues is critical to the long-term sustainability of its business model.

The Carbon Disclosure Project (CDP), a coalition of institutional investors that collectively manage in excess of $31 trillion, represents a collective force within the asset management industry that is thinking hard about these issues, and finding ways to pressure the companies in which they invest to disclose their efforts to address climate change. Below are highlights of the Project:

The Carbon Disclosure Project – Participation in the CDP project has grown substantially in the six years since its launch in 2000.

- Between 2005 and 2006, the project gained $11.5 trillion in assets, and now includes some of the most important companies in the investment community;
- The CDP assumes that climate change – and the accompanying possibility of greenhouse gas regulation – creates both winners and losers in different industries. It seeks to examine the long-term prospects of participating firms with respect to greenhouse gas liabilities and opportunities;
- The coalition requests information on corporate risks and operations associated with climate change from over 2,000 firms globally, focusing its efforts on the 500 largest public firms (the FT 500);
- The CDP conducts an in-depth survey and questionnaire designed to assess the risks and opportunities embedded in each firms' treatment of its carbon footprint;
- Firms have responded to investor pressure: 72% (some 360) of the FT 500 now respond to the survey. Respondents include Chevron, CITI, Ford, and GE. Wal-Mart became a respondent in 2006;
- The most recent survey suggests that just under half (48%) of the firms that consider climate change a risk to present commercial positions have implemented a greenhouse gas reduction program[89].

[88] *See Greenhouse Gas Protocol website, <http://www.ghgprotocol.org>.*
[89] *See Carbon Disclosure Project website, <http://www.cdproject.net>.*

Real investment opportunities can arise from climate change

The likelihood that businesses will be affected by global climate change is fairly certain. However, the degree to which they will be affected will be heavily dependent on a number of factors, the most obvious being the sectors within which they operate. All companies will have, to varying degrees, exposure to reputational and competitive issues relating to climate change that ultimately could have a financial impact. Utilities, integrated oil and gas, mining and metals, manufacturing and other resource intensive industries, have the greatest sensitivity to regulatory issues, while insurance; pharmaceuticals; building and construction; and real estate, because of the nature of their respective operations, stand to be the most affected by physical exposure.

Companies that stand to benefit from climate change include those that recognize its importance early on, anticipate to some degree the implications for their respective industries, and work proactively to adapt their existing business models in response to changes in policy and the competitive landscape. The challenge for business to tackle the issue is significant, and will necessitate solutions driven through human ingenuity and technological advancement.

Below we highlight areas that, from both a business and an investment standpoint, increase a company's chances of long-term success. Companies stand to perform better to the extent that they:

Regulatory

Opportunities:

- Benefit from favourable reputational impact of using environment-friendly business practices;
- Avoid high cost associated with regulatory compliance;
- Improve evaluation of capital projects by incorporating potential costs of environmental remediation.

Risk: Higher operating costs in the short run compared to competition which may wait for regulations before addressing compliance issues.

Physical

Opportunities:

- Proactively develop clear and concise contingency plans in the event of natural disaster or terrorist activity;
- Manage exposure to certain geographies, keeping in mind the long-term implications of climate change.

Risk: Certain sectors (such as real estate) and companies operating in specific geographies are more susceptible to changing weather patterns (such as the Gulf of Mexico) and therefore are at higher risk than others.

Competitive Advantage

Opportunities:

- Develop new products and services. Example: the automotive components industry manufactures 70% of the products that reduce emissions and drive fuel efficiency[90];
- Implement energy efficient manufacturing to gain a cost advantage over competitors;
- Consider renewable energy sources in manufacturing as alternatives to further depleting existing resources.

[90] *Source: Neuberger Berman SRI.*

Risks:

- Potential loss of cost advantage and market share if energy inefficient;
- Failure by long tail businesses to accurately price in risk and higher cost of doing business.

Reputation

Opportunity: Improve community relations and public opinion – crucial for companies whose right to operate and expand is dependent on public approval, such as utility companies and waste management.

Risks:

- Loss of clients/customers;
- Hostile regulatory environment.

The challenge: incorporating climate change into the investment process

As investment management professionals who are focused on providing attractive long-term returns for our clients, we are cognizant of, and frustrated by, the inherent conflict between company management teams that are pressured by investors to maximize short-term performance yet at the same time see the need to address longer term issues such as climate change.

To illustrate, consider that, over the past ten years, turnover rates for equity mutual funds have ranged between 85% and 100%, indicating that investors refresh their portfolios nearly once per year. These statistics have extensive implications for industry management, as they suggest that investors, including institutional investors who typically have longer time horizons, operate under a relatively short 12-month timeframe. Clearly, pressures on business executives to maximize short-term profits result in a lack of long-term vision.

Furthermore, around 85% of companies have failed to set multi-year performance targets for executive compensation[91]. Of course, there are other factors that influence a company's executive compensation structures, but the uncertainty of the timing and magnitude of climate change makes it difficult to incentivize management around this issue. The fact of the matter is businesses are best at executing when there is a definitive time horizon for taking specific action, and an immediate economic impact from failure to do so.

Transparency, or lack thereof, represents another hurdle for investors seeking to evaluate a company's responsiveness to climate change. Although initiatives such as the Carbon Disclosure Project are a step in that direction, the lack of standard disclosure from companies on key metrics, including carbon intensity and energy intensity of businesses, makes it difficult to evaluate their progress in this area.

We do not believe that the short-term focus of company management or the current lack of disclosure is an obstacle that cannot be overcome; but will be necessary in order to achieve meaningful corporate climate change policy. Currently, when corporate disclosure on climate change is far from comprehensive or standard, we seek to obtain a baseline understanding of a potential investment's exposure through a three-pronged analytical framework: strategy; data; and systems.

We seek to understand the following:

- What strategy, if any, a company has in place as regards climate change;
- What data they manage and disclose; and
- What types of systems are in place to support their strategy (see Figure A1).

[91] *See Directors and Boards (Winter 2005).*

As with other major forces shaping the economic landscape, we judge that climate change is too important to the future longevity and success of corporations to be ignored for an extended period of time, and that failure to do so will have economic consequences.

Figure A1. Investment framework for climate change analysis

Industry Research

- Characterise end market competitive dynamics
- Identify and measure the company's total and served markets
- Understand secular / cyclical dynamics
- Monitor industry specific social issues
  - Regulatory environment
  - Emission intensity
  - Energy intensity
  - Range of technological advances in marketplace

Management Profile

- Track record of success
- Alignment of management's economic interest with common shareholders
  - Environmental health and safety programs
  - Supply chain management
- Check for stated disclosure statement / strategy on global climate change
- Corporate governance and culture respects interest of multiple stakeholders
  - Reputation of management with regulators

Company Research

- Understand business model, management strategy, and customer value proposition
  - Emission / energy intensity of manufacturing
  - Environmental attractiveness of products or services
- Determine the source and sustainability of the company's competitive advantage
  - Spending on IT and research & development
  - Environmental health and safety programs
- Quantify potential ROIC and earnings power for the business
- Evaluate historic social record / understand future road map
  - Stated climate change strategy combined with supportive systems / data

Source: Lehman Brothers.

ANNEX 2: ESSAYS ON INDIVIDUAL SECTORS

AUTOS

Christopher Will
LBIE, London
+44 20 710 22843
crwill@lehman.com

- *The European auto sector could be the first casualty of increased climate change concerns, in our view.*
- *Yet the industry has far bettered global peers in achieving sharp CO_2 emission reductions.*
- *It is highly unlikely that the industry will meet the demanding 2008 CO_2 emission undertaking – there is a consequent danger that it will be made a political scapegoat.*
- *But perhaps the industry holds a solution. A more 'global' voluntary target would be more achievable – yet reduce total CO_2 output to a much greater extent.*

The implications of the first part of this study are particularly worrying for the European automotive industry. Not because of the dramatic changes likely to result in the coming 50 years. But because the European industry – and most notably its profitability – could suffer markedly within the next five years.

From an equity investor's perspective, the European auto sector could conceivably be the most affected sector, globally, within a 2-3 year investment timescale. However, we estimate that it is responsible for no more than 1.5% of global CO_2 emission – half that of the US auto industry and two-thirds of Asia Pacific. Moreover, it has been a visible 'good citizen' in reducing CO_2 emissions on new cars sold, by one-sixth since 1997.

So the focus of our commentary is not on the *eventual* winners and losers. Rather, it is on the European industry, where there could be losers in the immediate term.

The longer-term global winners will certainly include those involved with alternative propulsion technologies: fuel cells, advanced hybrid systems, and alternative fuels; as well as certain component makers, notably suppliers of lightweight materials, low resistance transmission systems and low rolling resistance tyres.

Of today's established vehicle manufacturers, relative winners within Europe might logically be those already skewed towards smaller, lighter, vehicles. Our picks would include ***Renault*** (established small, low emission, car expertise, and a Nissan synergy-based cost reduction strategy to ensure financial resilience in the meantime) and ***Piaggio*** (scooter market leader, developing products appropriate to older and inexperienced riders). Eventual relative losers could include manufacturers in the German industry predominantly focused on larger cars for the European market.

PLEASE SEE ANALYST CERTIFICATIONS AND IMPORTANT DISCLOSURES INCLUDING FOREIGN AFFILIATE DISCLOSURES ON PAGE 134.

However, circumstances exist which could affect the European carmakers – and their stock prices – within a much shorter timescale. It appears likely that today's heightened concerns regarding climate change could affect European auto companies long before their global rivals, even though they are the *least* culpable in terms of CO_2 emissions, and have invested the most to reduce them.

Why is the auto industry a target? Cars are a high profile source of CO_2, and thereby have an impact on climate. Of the 20-25% of global warming gases generally believed to derive from the transportation industry, 10-12% is variously estimated to derive from cars (and their light commercial vehicle derivatives). Whereas the power generation and industrial manufacturing industries produce substantially more emissions, these industries present a somewhat vague, amorphous, image, to even the informed citizen. Cars are visible to the public and to the press – and therefore present an easy target for populist European politicians.

But why the *European* industry? This is where the story turns somewhat irrational. Of the approximately 55.9 million cars likely to be sold globally in 2006, 42.3 million (76%) will be sold in the three big markets, the US (15.3 million), Western Europe (14.7 million) and Japan/Asia-Pacific (12.3 million). In each, cars are predominantly produced locally.

Of the three markets, unit CO_2 emission per car sold is lowest – by some margin – in Europe. In 2005, the European average CO_2 emission was 160g/km. In the US, it was approaching twice that (data is unpublished). Asia lies between the two. One significant reason for Europe's lower emission rates is the high – and growing – share taken by diesel cars. Market share has risen from 23% in 1995 to approximately 51% in 2006. Diesel cars typically emit 15-20% less CO_2 than their petrol equivalents. In addition, European (and Asian) cars are markedly smaller and lighter than in the US. Finally, the European industry has invested more than its peers in technology to increase engine efficiency, thereby reducing emissions (see Box: *BMW Technology Cuts New Mini CO_2 Emissions by 18%*). Most has been achieved in the area of direct injection technology, first for diesel engines, and now for petrol.

Western Europe accounted for approximately 26% of global car sales in 2006 (US 28%, Asia-Pacific 22%). In terms of CO_2 emissions, we estimate the ranking might be US 30%, Asia-Pacific 18%, and Europe 15%. This would imply that the US auto industry is responsible for approximately 3% of global CO_2 emissions, and Europe just 1.5%.

So why is pressure focused solely on the Europeans? It is difficult to avoid the conclusion that this is more the result of populist EU politics than scientific fact. The European electorate is more 'green' than counterparts elsewhere. But, depressingly, this appears not to be accompanied by any great hunger for the facts. And the EU machine seems content to knowingly take advantage of the confusion, despite the clear evidence that a regional approach is illogical, and, in climate change terms, irrelevant.

Will the European industry be punished? Worryingly for the producers, an awkward catalyst lies just two years away.

In 1996, the EU approved a strategy to reduce the average CO_2 output on new cars sold by 35%, from 185 grams per kilometre travelled in 1995 to 120g/km in 2005 (2010 latest). In response, the European Automobile Manufacturers Association (ACEA) committed to reduce output by 25%, to 140g/km, by 2008. In exchange for that commitment, the EU delayed its 120g/km target to 2012. But this concession came with the warning (reiterated regularly) that failure to meet the voluntary target would result in mandatory ones.

And ACEA *will* miss the target. It has made progress. By 2005, average CO_2 output had fallen by 14% to 160g/km. But the data reveal that the easy improvements are behind, and progress is now at an ever slowing rate.

BMW technology cuts new Mini CO_2 emissions by 18%

For all its chic appeal the Mini – launched in 2001 – was not a particularly green car, with its old technology, Chrysler-designed petrol engine. But the new Mini is the first high volume BMW product to utilise its industry-leading direct petrol injection engine system. The consequence? An 18% reduction in CO_2 output on the core Mini Cooper variant, from 166g/km to 139g/km. Although the scale of the gain is exaggerated by unusually high output of the US-designed predecessor engine, it is nevertheless an indicator of the real progress the industry is making. Note that the engine, although based on BMW technology, is a joint venture product with Peugeot, and will be increasingly used on Peugeot products. BMW's direct petrol injection system spreads to its biggest volume seller, the 3 Series, through 2007.

Between 1998 and 2001 the annual improvement averaged 2.5%. But since 2001, it has averaged just 0.75%. The easy technology shift – accelerating the move towards modern, turbocharged, direct injection diesels, for example – is done (see Box: *Alternative Propulsion Cars*). In the earlier period, the annual improvement for diesels was 3.7%, and for petrol cars 1.9%. Since 2001 these rates have fallen to nil and 0.4%, respectively, as the law of diminishing returns takes hold.

The greatest opportunity for improvement occurs when a car is replaced. The drivetrain can be updated, and weight reduced. But an examination of a sample of high volume European cars replaced in 2005/2006 shows a like-for-like improvement of just 1.3%. And these products will not be replaced again for 6-7 years, so this benefit needs to be spread over an extended period. Hence, even taking into account further mid-life drivetrain updates, progress from here will likely be modest.

Worryingly, the data reveal that the principal driver for CO_2 emission reduction since 2001 was the diesel penetration increase, from 36.4% to 49.7%. This mix change reduced overall emissions by 0.7% annually.

However, the rate of increased diesel penetration is slowing. Between 1999 and 2004, the diesel share of the European car market increased by 3.0-4.5 pts annually (from 25.5% to 48.5%). Progress then slowed, and growth to 2008 is forecast at approximately 1.2 pts annually. This would result in an annual mix-driven emission improvement of just 0.3pts.

Based on these factors, our projection is that average CO_2 emissions are no lower than 157g/km by 2008, missing the 140g/km target by 12%. Technology can do little more. In the end, only Europe's supposedly 'green' consumers can bring down emissions, by choosing to buy the growing number of small or hybrid cars which exceed the 140g/km target, many with ease. If they will not, perhaps Europe's legislators might turn their attention to encouraging them by fiscal means. Or, better still, working to encourage governments outside Europe to persuade *their* producers to replicate the 'easy win' technology-driven improvements already achieved in Europe.

Alternative propulsion cars

Alternative propulsion cars are a reality. However, providing their fuel is an intractable challenge.

Alternative propulsion technologies are not science fiction. The latest Honda FCX fuel cell car has been driven by journalists, to general acclaim. BMW's hydrogen powered 7 Series has been running for some years. And selected individuals may be able to lease either in 2007.

But it may be 2050 before hydrogen powered vehicles are a reality for the mass market. The problem is not the engine technology. Rather, the challenges relate to the fuel. First, although hydrogen powered cars produce no CO_2, today's hydrogen production processes do. Second, not only is there no hydrogen supply network, but it is unclear how it can be safely and economically stored.

In the meantime, petrol-electric hybrids must grow in popularity. But their image somewhat exaggerates their true green credentials. Biofuels are already a reality, but benefit the environment by using renewable energy sources, rather than by materially reducing CO_2 emission.

What will the European car producers do? We think that they may well believe that attack is their best defence. Rather than wait to discover the Commission's response to failure to meet the 140g/km target, we think it would be wise for ACEA to grab the initiative. The European companies are closely integrated within the global industry – notably in respect of the US. Ford and GM have significant European operations, which are stand-alone ACEA members and together account for a quarter of European car sales. Mercedes' parent DaimlerChrysler owns Chrysler. Renault owns 44% of Nissan, the fastest-growing car producer in the US. So, to a significant extent, the same corporations are involved.

We ask why not offer to cut CO_2 emissions in the US as well as Europe, by creating an average to be achieved across the regions? For the cost of achieving an immaterial incremental improvement in Europe, a far greater saving in US output could be achieved, given the much higher starting point. The resulting saving in global emissions would be a multiple of that possible in Europe alone. And perhaps the Japanese industry – growing fast in the US – would participate also. Could the Commission refuse such an offer?

But the EU still talks of Europe-only compulsion. And for an industry where the average operating margin is barely 3%, and the potential cost of further progress (scrapping larger models, to improve mix?) astronomical, there is reason for investor concern.

For now, the equity market appears unconcerned. In a recent interview, one industry CEO stated that he saw meeting European CO_2 targets (while simultaneously meeting US NO_2 limits) as his company's biggest challenge. And the CFO of one of Europe's big five producers told us on an investor roadshow that the issue is his single greatest short-term worry. Yet investors never asked about it. ■

AVIATION

AVIATION – DIFFICULT SOLUTIONS YIELD SLIGHT REDUCTIONS

Gary Chase
LBI, New York
+1 212 526 5752
gary.chase@lehman.com

- *Aviation has moved into the sights of greenhouse gas regulators, despite contributing relatively little to global warming so far.*
- *To the extent they pose a problem, aircraft emissions are particularly hard to reduce technically for lack of obvious jet fuel alternatives and easy improvements in engine efficiency.*
- *If European Union regulation is to work it will have to apply to US airlines, as well as all others, flying in and out of Europe, and will have a negative impact on a historically low-margin business with minimal pricing power, at least in the short-run.*
- *Airports could also be exposed to further regulation – in particular, through traffic and congestion control.*

Aviation risks, at least in Europe, becoming one of the public villains of climate change. This perception was reinforced by Richard Branson's recent announcement that he intended to invest US$3bn over the next 10 years to develop alternative fuels, including for aircraft. Nonetheless aviation emissions are a concern. This is less because of their current volume – which according to the UK government's recent Stern review amounts to only 1.6% of global greenhouse gas pollution – and more because of their high-altitude nature. For instance, water vapour, innocuous at ground level, can when emitted at high altitude trigger condensation trails that tend to warm Earth's surface. Aviation emissions are also rising fast, though from their very low level. On present projections, they would amount to 2.5% of global greenhouse gas emissions by 2050 according to the Stern review, which also predicts that because of aero engine emissions other than carbon dioxide, aviation could account for 5% of the total warming effect by 2050.

Recent increases in fuel prices highlight the difficulty of improving fuel efficiency without major technological advances

The rise in oil prices in recent years has put the industry on its mettle to conserve fuel, which in turn has a natural, albeit incidental, pay-off in lower emissions of carbon dioxide and other greenhouse gases. As a result of higher fuel prices, airlines around the world have looked to ways to conserve fuel. Airlines have found ways to improve fuel consumption, but there exists no known silver bullet that will materially improve the efficiency of the current global fleet. In recent years, airlines have fitted winglets to wing tips to reduce aerodynamic drag and improve efficiency, and have changed operating procedures to reduce fuel burn. Examples include using single engine taxi procedures, using ground power rather than aircraft generated power while at the gate, and reducing on-board fuel reserves when weather and safety permits.

Congestion in the air is also a fuel-waster, especially in the crowded US north east, but less so than in Europe which is struggling to introduce more unified, therefore smoother, traffic control under its Single European Sky programme. The importance of reducing the 'stacking' of aircraft above airports should not be underestimated; for air traffic congestion can increase aircraft emissions on short haul flights by as much as 50%. There is also a problem of congestion on the ground at airports, which can play into the debate on climate change. For instance, in the UK, a country which is politically exercised about global warming and whose south east corner is exceptionally congested, the London airport of Stansted has had its application for a new runway voted down by the local council, citing the Stern review's warning on aircraft emissions. More generally speaking, the fact that airports may not get permission to expand also means that airlines will not have the capacity to grow, which will in turn influence aircraft design – favouring the Airbus theory of larger hubbing aircraft, vs. Boeing's point-to-point philosophy.

As for the jet engine manufacturers, they remain under pressure to reduce emissions as well as noise. The airlines globally are looking for innovation in design that would lower the weight and fuel consumption of new jet engines to put on the next generation of aircraft, such as the A380, the 787 Dreamliner, A350XWB, as well as the next generation of narrow body successors to the A320 and 737. Europe has its Advisory Council for Aeronautics Research in Europe (ACARE), which has committed the industry to developing technology that would cut CO_2 by 50% per passenger kilometre, as well as to halve perceived noise levels. If ACARE can meet, or come close to meeting, its goals, this could have a wider impact internationally as airlines insist on other manufacturers keeping up with progress on fuel efficiency. In the US, the National Aeronautics and Space Administration (NASA) has set goals for the US aerospace industry similar to those of ACARE. But the realistic outlook is for the aerospace industry to make only incremental improvements in engine fuel efficiency. The question of how quickly new engine improvements actually show up in airline fleets also depends on the rate of new orders. US airlines such as American or Delta are talking of upcoming 're-fleeting' initiatives, but the full replacement cycle will be on a timescale of 10-15 years. Hence the current focus by some governments and regulators in Europe on curbing the demand side of aviation, or at least making airlines and their passengers bear the cost of the externality, or emissions, they put into the atmosphere.

Taxing or Trading?

The bluntest instrument to achieve this is to increase tax on passengers. This is precisely what Gordon Brown, the UK Chancellor of the Exchequer, has just done with his decision to double air passenger duty at UK airports in February 2007. A less crude measure would be to tax aviation fuel. This tax is on average very low, largely because of longstanding agreement within the International Civil Aviation Organisation (ICAO) forbidding the levying of tax on international flights. Individual countries, and perhaps the EU as a whole, could impose new taxes, or raise existing taxes, on flights within their national boundaries, or possibly within the EU. But emissions from these domestic flights are less than half those generated by international flights out of the EU.

For these reasons, setting pollution permits for aviation but allowing the industry to trade these permits within the existing European emission trading scheme (ETS) is seen as the lesser evil. Not because airlines will be able to make big cuts in their emissions and to sell their surplus permits to others – they won't, because aviation can only offer one of the most expensive forms of carbon reduction. Rather, participating in Europe's ETS would offer a wide choice of much cheaper carbon reductions that airlines could buy from other sectors. This is why ICAO has endorsed the concept of an emissions trading scheme for aviation, and in December 2006, the European Commission proposed legislation to bring airlines within the ETS. The proposal covers emissions from flights with the EU from 2011 and all flights from and to EU airports from 2012, regardless of the nationality of carrier, in order to comply with non-discrimination provisions of international law and to avoid distortion of competition. Like all other industries already included in the EU ETS, airlines would be able to sell surplus allowances if they reduced their emissions, and would need to buy additional ones if their emissions grew. The total number of emission allowances will be capped at the average emissions level in 2004-2006.

The corporate consequences

An increase in aviation taxes will result in higher costs for airlines either directly, or indirectly to passengers. Ultimately, this tax leaves less revenue and/or higher costs for all airlines affected and will likely result in capacity reductions at the margin. In the short term, the result is weaker margins and lower profits in a historically low margin industry with little pricing power. In effect, the tax is similar to the impacts of increased fuel prices in an industry with limited ability to pass along those additional costs in the short-run. Over a longer period, slight reductions in service will be needed in order to offset the higher costs, resulting in less capacity.

While higher taxes are a negative for all airlines, two sets of airlines are likely to protest loudest at being drawn into the European ETS. One will be Europe's low-cost carriers which will not want to raise their ticket prices to reflect the extra cost of buying emission permits; the ability to stimulate additional traffic with low costs and fares is critical to their continued expansion. The other will be the US airlines, where international markets provide some of the most profitable opportunities for US legacy carriers and would be hesitant to see any additional cost on those routes.

The European Commission estimates that, once airlines are included in the EU ETS, and assuming that they fully pass on any extra costs to customers, by 2020 the price of a typical return flight within the EU could rise by between EUR 1.8 and EUR 9. Long trip costs could increase more, depending on the journey length, owing to higher environmental impact. However, ticket price increases should be lower than the extra costs passed on to consumers owing to world oil prices in recent years. ■

BANKS

Nick Anderson
LBIE, London
+44 20 710 22504
nianders@lehman.com

- *Banks in general do not stand to be beneficiaries of climate change and will be affected in absolute terms to the extent that economic activity is curtailed (the key to the impact being the likely effect on asset quality).*
- *Relative to the overall European equity market, we see the impact for the European banks sector as being broadly in-line, i.e. the sector should be relatively less affected than others either positively or negatively.*
- *Within the sector, there will be winners and losers both by geography (Dutch and Iberian markets most at risk in Europe?) and by type of banking (investment banks are likely beneficiaries given the role of primary and secondary capital markets during periods of economic change).*

To best understand the possible impact of climate change on banks, we first review the key characteristics of banks:

- **Growth is geared to GDP**. As the main means of disbursing credit to the economy, banks are broadly exposed to the whole economy, principally the corporate and household sectors. Bank credit volumes and overall revenues therefore tend to grow in-line with, or slightly ahead of, nominal GDP.
- **Profitability is high and stable**. Commercial banks are oligopolies with the implicit support of their central bank/regulator. Supernormal returns are tolerated since the economic cost of high bank charges/prices is less than the cost of bailing out a failing banking system. This also allows banks to maintain stable returns, compensating pressure on returns in one part of their business with higher returns elsewhere.
- **The key risk to commercial banks earnings is credit quality.** Commercial bank profitability can be likened to writing call options. Banks earn stable (supernormal) returns when expected credit losses occur, but incur the occasional material loss when unexpected, systemic losses happen (although the dispersion of risk through broader financial system via CDSs has partly offset this).
- **Capital markets are key to investment bank earnings** and increasingly important for commercial bank earnings. Volatility in these markets is therefore a source of risk.
- **Economic stability provides the optimal conditions for profitability** measured by ROEs. We define such stability in terms of interest rates and economic growth. Very high or very low interest rates tend to be associated with economic distress, i.e. inflation and disinflation, respectively. Bank ROEs tend to be maximised when interest rates are low and stable. Corporate credit quality is correlated with economic growth and household credit quality with unemployment; thus stable economic growth is associated with lower credit losses.

Given these characteristics, how might banking be affected by climate change? Assuming that climate change could involve higher temperatures, raised sea levels and changed rainfall patterns, we would make the following observation:

- **Bank lending volumes and revenues will contract** (or grow more slowly) to the extent that climate change leads to lower levels of economic activity (or just slower growth). The impact on inflation of such a slowdown will be key for the sector. As the Japanese banking system in the 1990s showed, economic contraction combined with disinflation destroys substantial equity/value.

- **Bank profitability pre loan loss provisions is likely to remain stable** given the oligopolistic characteristics of the industry noted above. The impact of climate change on branch network costs can be mitigated by the use of alternative distribution channels. The cost of offsetting actual carbon emissions is minimal allowing banks to limit easily reputational risk. HSBC has committed to becoming carbon neutral and has estimated the annual cost at US$7m maximum (0.03% of 2005 PBT).
- **Impact on asset quality is the key issue for commercial banks**. Credit losses will be determined by the ability of banks to anticipate the impact of climate change on their customers and therefore to reduce credit to those sectors most at risk, sell the risk into the financial system through CDSs, etc. The impact on collateral values (in many cases real estate) may or may not be covered by customers' insurance. Increased economic instability that may arise from climate change will make it more difficult for the banks to manage their credit quality, increasing the probability of credit losses (cf Japanese banks through 1990s, Asian banks post 1997, etc).
- **Different segments of banking may experience differing effects**. The geographical impact is perhaps easier to predict than the effects on retail, corporate and investment banking. Investment banking is probably a relative beneficiary but the relative impact on retail and corporate is harder to predict.
- **Geographically**, climate change will affect banks in differing countries to the degree that climate change affects some countries more than others. Rising sea levels flooding the Netherlands and desertification in Iberia leading to population relocations are two examples within Europe.
- **The impact of climate change on capital markets** will be a key influence on sector profitability. Investment bank profitability is strongly correlated to the capital markets while commercial banks are increasingly dependent on it both for generating trading gains in their treasury operations and for selling investment products to retail customers (disintermediation undermines commercial banks' traditional role as collectors of deposits and providers of loans).
    - *Primary markets*: The capital markets, in their role as allocators of capital, will likely benefit from any rapid technological change and associated investment that takes place to address the impact of climate change (cf. the 19th century railway boom and the 1990s Internet boom). *The Economist* recently quoted estimates that total investment in clean energy would amount to US$63bn in 2006 vs. US$30bn in 2004. It also noted that it consumes 10% of US venture capital investment.
    - *Secondary markets*: Investment banks will also gain from new trading markets, e.g. carbon emissions, weather futures etc, not least given the central role envisaged for market prices in addressing the impact of climate change. Outstanding weather futures contracts on the Chicago Mercantile Exchange (CME) grew 800% between end 2004 and September 2005 to reach US$22bn. The World Bank recently estimated the size of the global carbon trading market at US$22bn in September 2006, representing annualised growth of 167%. The impact on proprietary trading profits from existing secondary markets will also be important. If global warming leads to greater market volatility owing to an uncertain economic outlook, trading revenues may be impacted. If, however, monetary authorities substantially loosen monetary policy (cutting interest rates and increasing liquidity) to offset any economic dislocation, trading revenues are likely to benefit (compare the first half of this decade).

As a final point, we would note that coincident trends make the prediction of the impact of climate change on banks difficult. Two trends we would highlight are ageing European populations and M&A. Ageing populations will likely both reduce the total population and therefore franchise footprint for banks, and also lead to shifts in where people live anyway. Cross border M&A may result over the next decades in the emergence of broad, diversified banking conglomerates, thus meaning that the risks of climate change are spread evenly across a handful of banking conglomerates. ■

CAPITAL GOODS

Lisa Randall
LBIE, London
+44 20 710 21883
lrandall@lehman.com

- *The largest positive impact will be on those companies that supply plants and equipment to the power generation industry. The main technology beneficiaries will be: nuclear, wind, hydro, and for emerging technologies, coal gasification, photovoltaics, and utility scale energy storage (fuel cells).*
- *Access to clean water, as well as security and containment will drive investment and demand into water plants, equipment and technology development.*
- *Equipment for transportation markets will increase investment levels into energy and fuel efficiency, though demand levels may actually come under pressure. Energy efficient transportation infrastructure will continue its secular demand growth.*

Despite the prospect of rising input costs, it is more likely that on balance, global capital goods companies will be net beneficiaries of the likely implications of climate change. We have based our analysis on the assumption that the primary cause of global warming is the build up of CO_2 in Earth's atmosphere creating the greenhouse effect.

Our sector is heterogeneous, supplying capital equipment across a wide span of end markets from consumer to industrial, and to state funded companies.

ELECTRICAL GENERATION

Summary

The largest impact for our companies will be on those that supply equipment and plants to the power generation industry. Of the companies under our current coverage, over 10% of total sector revenues are derived from supply of equipment and services to electrical utilities. As the major contributor to global CO_2 emissions, the drive for clean or cleaner generation of electricity will continue to build momentum. The main technology beneficiaries will be nuclear power, wind power and hydro. On a longer-term horizon, technologies such as photovoltaics and the holy grail of electricity generation electrical storage via utility scale fuel cells, stand to be the main beneficiaries. We would expect to see significant investment not only in the afore mentioned technologies, but also in innovations that raise the efficiency of existing fossil fuel CO_2 emitting technologies, such as coal and gas. We would expect to see a number of new companies especially in the emerging technologies (fuel cells, photovoltaics and biomass), come to market. The suppliers of power generation equipment will continue to diversify their exposure away from conventional emission–intensive technologies, into emerging zero-emission technologies. The major global operators are expected to continue to deploy their considerable balance sheets to maintain their dominance.

Background

Nuclear generated power and renewable generation technologies such as wind, photovoltaic (solar), fuel cells and hydro are the only technologies available today that produce zero CO_2 emissions. Biomass, however, is more debatable. Unfortunately, c. 30% of the world's installed generation capacity today is coal-fired power plant and a further c. 25% is gas-fired. Among the renewable technologies, nuclear and wind are the major commercial technologies today. Nuclear is already undergoing a resurgence in demand that is set to continue as it is the only large scale generation capability that can replace large shares of the coal-fired installed capacity. Wind turbines have seen the fastest growing technology, responding to the fastest growing demand over the last 10 years (albeit from a very low base). However, it is also set to continue but intrinsically has limitations owing to its volatility, unless energy storage capabilities improve. The ability to store large amounts of electricity is the holy grail of the industry, and would be a major complement to all existing forms of electricity generation, in particular those more volatile such as wind and hydro. Technologies such as fuel cells, photovoltaic and even wave power, and biomass, are still emerging technologies, with significant investment expected to be deployed in the coming years. The dominant suppliers of fossil-fuel generation equipment are already investing heavily into raising the efficiency of combined cycle gas turbine technology (the most efficient fossil fuel technology) and into coal gasification technology.

Our capital goods companies not only develop and supply the prime equipment into power plants, such as turbines and generators, but also supply balance of plant such as utility heat recovery boilers, environmental controls systems (that reduce emissions of other contaminants but not CO_2) and electrical controls solutions.

OIL, GAS AND COAL MINING

Our companies also supply equipment into the oil and gas, and coal extraction industries. As ultimately the use of all fossil fuels will be undesirable, the long-term impact for our companies with exposure to oil and gas extraction and coal mining will not be positive. However, it is more likely that in the near term, as the cost of the fuels remains high, the drive will be the improvement of the efficiency in the extraction processes. This will continue demand for capital equipments that allow higher efficiency levels.

WATER

We assume that global warming may bring dryer weather conditions to already arid environments and more volatile weather conditions in general. Access to clean water, already an issue for one third of the world's population, is set to increase as is security and containment of the water supply. Capital goods companies already provide equipment (filtration systems, separation systems, pumps, pipes, controls systems) and build turnkey water facilities for industrial customers. Industries that use water or produce it as a by-product will be incentivised to recycle and re-use all grey water and will therefore require the equipment and plants to do that. Agricultural and domestic water supplies will be increasingly scarce and significant investment is likely to take place in the infrastructure for the containment, storage and transport of water. Water desalination technology is also likely to see significant investment in coming years to improve the economics of the process.

GENERAL INDUSTRIAL AND CONSUMER RELATED END MARKET

We assume energy costs inputs will increase, i.e. gas, oil and electricity costs for all industrial and domestic activities.

General industrial processes will be driven to reduce their fuel and electricity input costs. This will mean a continuous drive towards increased efficiency of energy usage – requiring more efficient electrical distribution and control products, and increased use of energy monitoring and energy saving systems. Buildings, industrial, commercial or residential will increasingly look for energy efficient solutions. Demand for reducing energy intensive functions in buildings, e.g. heating, ventilation, air-conditioning and security, will intensify and there will be an increased call for use of less energy intensive building materials such as cement. There will be an increased demand for distributed energy solutions, ideally with neutral emissions, which will favour smaller scale wind technology, photovoltaic, fuel cells and even microturbines. Metering solutions will become more complex, with net metering available (ability to sell back into the grid when excess electricity generated).

TRANSPORTATION

The supply of equipment into the transportation services will be strongly affected. As the automotive industry continues to look to reduce fuel emissions, capital good suppliers of automotive components will continue to develop more light-weight materials, with greater electronic components (to reduce heavy mechanical parts and to improve the efficiency of the combustion cycle). There has already been in recent years a dramatic increase in the quantity and complexity of sensors and controls in cars. Should restrictive measures reduce the use of cars in general, our component suppliers will face a reduction in base demand. Truck engine manufacturers will, akin to automotive companies, be required to continue to invest in reduced emission engine technology, a cost which has little impact on base level demand. Costs of R&D will continue to drive industry consolidation. The rail network, both intercity and urban rail networks, remains one of the most energy efficient methods of transporting goods and people across land. Any restrictions on car travel will require increased investment in the rail networks, including signalling systems, rolling stock, locomotives, and electrification equipment. We would expect shipping vessels to continue the trend of bigger is better, including use of Suezmax, and Ultra Large Crude Carriers (ULCC) and corresponding port expansion and use of deep water ports.

Capital goods industry's responses to climate change

General Electric sees more profit in going greener

One of the biggest recent corporate converts to reducing greenhouse gas emissions is the General Electric Company (GE), whose size and diversification gives its actions on climate change particular weight. In 2005, it launched its "Ecomagination" programme committing itself to:

- Double its R&D spends on clean technologies to the level of US$1.5bn a year by 2010, and over the same period to double sales of these technologies to US$20bn a year.
- Cut by 1% the absolute level of greenhouse gas emissions from its own manufacturing operations by 2012, in contrast to the 40% growth in emissions that would otherwise occur under business-as-usual conditions.
- Reduce by 30% the relative intensity of its own greenhouse gas emissions by 2008.

Though making no firm profit forecasts for its Ecomagination initiative, GE expects to make money and stresses that "Eco" stands for economy as much as ecology. So while GE has joined the Business Environmental Leadership Council of the Washington-based Pew Center on Global Climate Change, and the company's chairman and CEO, Jeff Immelt says "it is time for the private sector to assume its rightful place as a major catalyst for environmental change", the company is also motivated by demand pull from its clients. Mr Immelt sees "the growing market for environmental technology [as helping to] get us where we need to be". The 40 technologies that GE now puts under the marketing umbrella of its Ecomagination range cover a wide span of energy, industrial and transport products. They include gas and wind turbines, solar PV, cleaner coal technology, some of its newer aero-engines, water desalination equipment, rail locomotives, energy-efficient light bulbs and consumer durables. GE is also a major nuclear reactor equipment supplier. But so far it does not appear to be trying to market nuclear equipment under the Ecomagination label, even though such an inclusion could be justified in terms of a low-carbon energy source.

Siemens – environmental compatibility designed in at the outset

Siemens has been a member of the Dow Jones Sustainability Index (DJSI) since 1999 and a member of the Climate Leadership Index of the Carbon Disclosure Project (CDP4), since 2005, one of only two industrial conglomerates to be selected. Unlike many other industries and the public sector, Siemens considers there is no considerable risk to the company from climate change. On the contrary, it thinks that business opportunities are created from the wider range of products and services for energy efficiency and renewable energies that Siemens has to offer. The financial impact on the company of proposed future regulation of greenhouse gas emissions is expected to be small, but the product range on offer will continue to be adapted to help customers fulfil greenhouse gas regulation requirements. Siemens has defined an internal standard for the development of environmentally compatible products, which is mandatory for all groups when they are developing new products. Examples already span across all Siemens' groups.

A non-exhaustive list of highlights includes:

- Power Generation: increased efficiency of power plants – including the currently under test 530MW combined cycle power plant with an efficiency of over 60%; increased efficiency retrofit of coal fired power plant, development and building of biomass power plants, and geothermal power plants. Siemens has become a major operator in the wind industry through the acquisition of Bonus Energy and through the acquisition of Sustec-Group, a major player in the development of coal gasification technology.
- Automation and Drives: Instabus – automation control technique – enables the conservation of up to 80% of energy consumption in buildings.
- Osram – Halogen lights with IRC coating – higher light efficiency, higher energy efficiency and longer life than traditional lamps.
- Siemens VDO: Piezo technology – joint development with Robert Bosch GmbH of Piezo injection technology for diesel and gasoline engines, allowing extremely precise metering of the amount of fuel injected into the combustion chamber and allowing for a substantial reduction of fuel consumption and pollutant emissions. ■

CHEMICALS

Jenny Barker
LBIE, London
+44 20 710 24093
jbarker@lehman.com

Jean de Watteville
LBIE, London
+44 20 710 24098
jean.dewatteville@lehman.com

- *In summary, we see the main risks and opportunities for the chemical industry from global warming as follows:*
  - *Risks: physical; regulatory; and possible trade diversion;*
  - *Opportunities: technological change relating to new, low emission manufacturing processes; new materials; carbon capture; energy storage; and biotechnology (e.g. lignocellulosic for biofuels).*
- *Chemicals are the building blocks of manufacturing, and, as an overall category, demand tends to be price inelastic. This is because 'natural' alternatives (e.g. natural fibres, glass and paper) tend not to be economical substitutes in high volume applications, even under high energy and chemical raw material costs.*

Physical risk

Around the world, major chemical sites tend to have been built at – and continue to be planned for – coastal and riverside ports accommodating bulk cargo vessels (Figures A2, A3, and A4). Of the estimated gross actual and planned global ethylene capacity of 173 million tonnes, we estimate 45% is at high risk of flooding, and a further 28% at medium risk (Table A1). Both increased protection and relocation inland would have significant capital and transport costs.

Table A1. Global ethylene capacity at risk of flooding

Million tonnes	Low risk	Moderate risk	High risk	Total capacity
Existing	34	22	47.8	103.7
Potential new projects (by 2012)	12.1	26.5	30.7	69.3
Total	46.1	48.5	78.5	173.0
%				
Existing	33%	21%	46%	100%
Potential new projects (by 2012)	17%	38%	44%	100%
Total	27%	28%	45%	100%

Sources: Lehman Brothers estimates, CMAI[92] and ICIS[93].

Possible regulatory and trade diversion risk

Chemical manufacturing processes variously release the full range of greenhouse gases: CO_2, methane, nitrous oxide and F-gases (e.g. perfluorcarbon, sulphur hexafluoride). As such, the industry is subject to emissions controls and, in Europe, carbon permits. In our view, the commercial risk of tighter restrictions in future depends on whether abatement measures are imposed globally or selectively by region. Because, in general, demand for chemicals is price inelastic, we would expect the industry to be able to pass on higher regulatory costs to its customers *provided those costs are imposed globally*, which is our assumption on a five-year view. However, should regulatory costs be imposed in some countries but not others, companies in the regulated regime would be put at a competitive disadvantage to those elsewhere.

[92] *Chemical Market Associates, Inc.*
[93] *International Chemical Information Services.*

Figure A2. Location of ethylene plants – the Americas

Sources: CMAI, ICIS and Lehman Brothers estimates.

Figure A3. Location of ethylene plants – Europe, Middle East and Africa

Sources: CMAI, ICIS and Lehman Brothers estimates.

Figure A4. Location of ethylene plants – Asia and Oceania

Sources: CMAI, ISIS and Lehman Brothers estimates.

Opportunities

Opportunities: new, low emission manufacturing processes

Combined Heat and Power (CHP) is an example of lower emission technology. So-called cogeneration units produce steam (a key chemical industry input) and electricity simultaneously. As well as producing less CO_2, CHP is 15-30% more energy efficient than technology that produces steam and electricity separately. Currently most CHP is based on natural gas, but some projects are already using biomass and, in the longer term, hydrogen derived from low-carbon sources may be an option. Cogeneration expertise tends to be shared between chemicals, industrial gases and energy operators.

Another potential new energy source is gas-to-liquid (GTL). This turns natural gas, coal, or biomass at source into liquid fuel by blending it with pure oxygen under heat and pressure to produce synthesis gas, which in turn gets transformed into diesel-like fuel molecules. In our view, large scale GTL development is likely to involve energy companies working in partnership with industrial gases companies.

As well as exploring new opportunities to reduce its own emissions, chemical industry R&D is also exploring ways to offer lower emissions to its customers. For example, new after cleaning products for the textiles industry can reduce energy consumption by 60% and water usage by 40%. And suppliers of auto OEM (Original Equipment Manufacturer) coatings have produced new coatings that eliminate a round of primer application, resulting in reductions per car coated of energy, solvents, and emissions.

Opportunities: new materials

The need for sustainable energy creates direct requirements for new materials, for example for photovoltaic cells, new energy storage media. Also, the need to be more energy efficient stimulates demand for lighter, thinner materials, for example for autos and aircraft. The chemical industry plays a vital role in materials development. Current examples include research into nanoporous foams for heat insulation (e.g. for buildings and aircraft). For energy storage, chemical companies are researching jointly with autos the possibility of storing hydrogen in nanocubes.

Opportunities: carbon capture

Carbon capture is the process of removing carbon emissions from the exhaust gases of power stations and other large scale emitters. Currently industrial gases companies are researching a pure oxygen combustion process to recover CO_2 emitted from boilers fired by coal and by heavy petroleum residues; and chemical companies are investigating solvent recovery of CO_2. Once recovered, carbon dioxide can either be recycled into industrial processes, or stored. If it proved effective, carbon capture and storage (CCS) could help reduce emissions from the flood of new coal-fired power stations planned over the next decades, especially in India and China (see Box: *Clean Coal Technology – A Snapshot* in the *Utilities* section).

However, as it stands today, there are a number of obstacles to CCS. Not only is the carbon capture side still problematic, but there are a number of obstacles on the storage side, e.g. environmental concerns over stored CO_2 leakage, legal issues over CO_2 ownership.

Opportunities: biotechnology

The potential for biotech in the context of global warming is to achieve production at increased energy efficiency. This could be production of industrial products, e.g. by using enzymes instead of metal catalysts, as well as production of plants through genetic modification (GM) to increase yield per acre or enhanced properties such as oil content for bioethanol. An area of particular interest in the context of alternative energy supplies is lignocellulosic technology, which could improve the efficiency of conversion of biowaste materials into energy.

Summary: winners and losers

In Table A2 we present a summary of the generic characteristics of chemical operations for which we believe global warming is a threat; and those for which we believe global warming is an opportunity. ■

Table A2. Potential chemical industry winners and losers from global warming

Winners	Losers
Materials innovation expertise	High share of sites with high flood risk exposure
Strong R&D	High share of manufacturing in regions with asymmetrically high abatement regulation
Industrial gases expertise	

Source: Lehman Brothers.

CONSUMER

Ian Shackleton
LBIE, London
+44 20 710 21820
ishackle@lehman.com

- *Rapid change brings opportunity for consumer staples companies strong in innovation and R&D.*
- *However, there will be challenges around sourcing of many raw materials.*
- *Consumer behaviour could become more cautious and demographic patterns could change.*
- *Tighter regulation is likely to increase the cost of doing business.*

Introduction

Whereas climate change may alter the very nature of some industries, its overall impact on the consumer staples companies is likely to be less direct. Our definition of consumer staples includes manufacturers of food, beverages, tobacco, and household goods as well as luxury goods. Within these industries there are, naturally, product categories that may benefit from global warming – ice cream, beer, suncream and sunglasses, for example – whereas others – tinned soup, thermal underwear – would appear to be at risk. However, even this could be an oversimplification, as the impact of climate change on consumer behaviour in current cold regions, such as the Polar regions or Northern Russia, looks likely to be different from what may happen in equatorial regions. As we discuss below, it appears to us that, within consumer staples, it is the food and beverages industry which may face the most immediate challenges, particularly around the sourcing of raw materials.

Who will be the winners?

Global warming would potentially represent a major change factor for consumer staples companies. As with any major change, this could bring huge opportunities for those companies which are able to steal a march over the competition. Gaining a competitive advantage could involve introducing new products which are more suitable to a world with global warming, or new packaging, or new routes to market. This would tend to favour companies with a track record of spending on R&D and a culture of innovation.

We would highlight the household products companies where there has been a strong track record in this area. In particular, Reckitt Benckiser has historically depended on an innovation based model to drive top-line growth, aiming to derive 40% of its sales from products introduced in the preceding three years. In terms of pure R&D, we think L'Oreal stands out as a leader – the company remains focused on R&D as a key tool to differentiate and improve its products.

In addition, it will become increasingly important for companies to have, and to be seen to have, environmental-friendly policies in order to be considered good corporate citizens. It will become increasingly important to present an acceptable corporate image to consumers, who are likely to become more concerned about the impact on the environment of the production of consumer products. We would highlight several companies that are already highly visible with such policies.

LVMH has been one of the pioneers within the luxury industry in terms of instituting environmentally friendly policies. In 2005, Bernard Arnault signed the “Environmental Charter” which asks each company to establish high-performance environmental management. The aim of LVMH is to align its environmental conduct with the world’s best practices. Among the processes introduced is compliance with the ISO 14001 certificate which guarantees a well-run environmental policy – this is to be implemented not only at LVMH but also with its suppliers.

Diageo has been honoured as best in class in its approach to climate change, in a report released by the Carbon Disclosure Project, a coalition of global investors. This focused on the strategic awareness of the risks and opportunities of a carbon constrained economy, as well as the quality and effectiveness of programmes put in place to reduce greenhouse gases.

Several of the international alcoholic beverages companies, such as SABMiller, Inbev, and Heineken, have produced reports on sustainable development, which address several issues, including the efficient use of raw materials, especially water.

Furthermore, consumers are likely to react more aggressively to issues around product quality. There have already been some high profile examples of this. The Coca Cola Company has encountered product quality issues in several markets in recent years, e.g. with the failed launch in 2004 of the bottled water product Dasani in the UK which was contaminated in the bottling plant. Equally, governments could intervene to protect consumers, e.g. some Indian state governments have implemented bans on the Coca Cola product after reports that claimed that the product contained unsafe levels of pesticide.

We can identify several challenges for companies to succeed in this new world which we assess below.

Sourcing

In theory, higher temperatures could stimulate global crop growth; however, this is likely to be offset by the adverse effects of climate change, such as excessive heat and drought in many regions. One risk from global warming would be a deterioration in water quality resulting from rapid melting of the Polar icecaps, exacerbated by more extreme weather conditions which bring both flooding and drought. This could make the cultivation of crops more difficult, and could have a dramatic impact on where manufacturers source their raw materials for many consumer products, particularly in food and beverages.

It is likely that global warming will have a major impact on where certain agricultures are located. Many crops which have traditionally been grown in warmer climates, e.g. cocoa, tea, coffee, and many fruits, may become more suitable for cultivation in what have been more temperate climes; equally, the traditional crops of the temperate climes, such as most cereals and vegetables, may become more suitable for geographical regions which have previously been too cold to be considered.

It is feasible that northern Russia could become the bread basket for Europe, growing most of its cereals. Equally, the traditional wine growing areas of the world have historically been just outside the tropical areas in both northern and southern hemispheres; global warming would likely move these areas both towards the north and the south. The tobacco plantations in the US could be moved further north.

For livestock, there would be similar issues, with the cost of maintaining domestic animals in warmer climates rising. This could lead to the farming of livestock also moving towards what were colder climates. With cattle and sheep being significant producers of greenhouses gases, there will be pressure from consumers and from governments to develop more acceptable farming methods. This could also increase the cost to consumers of meat products, leading to a growth in protein substitutes.

It is possible that governments in regions subject to enormous economic change from global warming could institute rationing for basis foodstuffs. Higher energy prices are set to have some impact both on production costs and on some input costs, especially in the household goods industries, as well as in certain packaging costs. If these were to become material, it could hold back, and possibly reverse, the trend towards convenience in many food and drink areas. It will be important for companies to be more flexible around sourcing raw materials and manufacturing processes.

Consumer behaviour

Consumer behaviour could move in several directions. At times of great change, consumers can often become more cautious in their spending habits, looking to hoard basic foodstuffs and doing without luxury items – this could of course be exacerbated, possibly by rationing imposed by government. However, the change in local climate is also likely to result in the availability of new products, especially in food and drink, and this increased level of innovation could actually spur consumer spending. For example, we would think that innovation behind skin/suncare products would increase with global warming. Companies such as L'Oreal will step up their level of innovation in this area, and consumers may spend more on products that help protect them from the environment.

A key issue will be whether the climate changes have implications for demographic patterns. If there is reduced availability of basic foodstuffs, this could lead to lower birth rates, which could have a particularly negative influence on industries which depend on young consumers, e.g. beer. In addition, it could encourage large-scale immigration across the globe, with people leaving the hotter regions and relocating to what were previously almost uninhabitable regions in the extreme north and south. In addition, as ocean levels rise, it is likely that people would also leave low-lying areas, such as parts of northern Europe (Holland), or ocean islands, or parts of the US (e.g. New Orleans, Florida).

It would also raise questions about the continuance of certain 'consumer cultures', e.g. would countries such as the UK and Germany still support a strong beer culture, or would they move more towards the wine culture of most of Southern Europe today? The seasonality of many industries would also be called into question.

Regulation

In the face of material change, it is likely that governments will look to legislate. As we suggested above, this could, in extremis, result in rationing of basic foodstuffs if their availability is reduced. At the very least, we would expect an increase in health and safety legislation around food and beverage quality, especially if water quality becomes an issue. And this will increase the cost of doing business.

This could in turn lead to greater regulation of non-essential consumer products, such as alcohol and tobacco. It is also possible that the move towards more global free trade could be halted by increased local protectionism which restricts the ability to export high value consumer products, such as luxury goods, premium spirits, cigars etc. This could potentially reverse the bringing down of trade barriers, which has been visible for over a decade now as an increasing number of companies have joined WTO. ■

HEALTHCARE AND PHARMACEUTICALS

European Healthcare Team
Jo Walton
LBIE, London
+44 20 710 22266
jowalton@lehman.com

US Major Pharmaceuticals
Anthony Butler
LBI, New York
+1 212 526 4410
abutler1@lehman.com

US Generics/Speciality Pharma
Richard Silver
LBI, New York
+1 212 526 5387
richard.silver@lehman.com

Japanese Pharmaceuticals
Toshihide Yoda
LBJ, Tokyo
+88 3 6440 1648
tyoda@lehman.com

- *Climate change could alter health patterns, with increases in respiratory disease and in infections from water and vector-borne pathogens driving growth in vaccination but less growth in treatment of 'diseases of the elderly' (cancer, neuro-degeneration) if people succumb earlier to the pressures of extreme temperatures. In this review we look at the incremental impact of climate change to our forecasts which otherwise clearly anticipate demand growth fuelled by an ageing population and technology improvements partially offset by government funding constraints in those countries with centrally funded healthcare.*
- *In Medtech, we believe climate change could increase demand for low tech products (wound dressings, splints) relative to current expectations for growth of high tech medical technology (joint replacement, spinal fusion).*
- *Governments are the big buyers of healthcare in many markets. So any negative impact on GDP and therefore on public finances, could, especially in Europe, depress government spending on healthcare, leading to drug price cuts and reduced access to more modern, innovative medicines.*
- *Few manufacturing sites are near coasts, and in any case the production of small volume, high value items such as pharmaceuticals could be adapted fairly easily to new locations if necessary. But India contributes much of the world's generic manufacturing capacity, and as one of the economies expected to be most hit by climate change, the effect on its manufacturing potential could have global implications, perhaps shifting production to China.*

In the following section we set out some thoughts around the Pharmaceutical, Biotechnology and Healthcare sector implications of proposed climate change scenarios, as described in the first part of this publication. We discuss these implications in three broad categories – healthcare impact (changes in disease and treatment implications), economic impact (changes in GDP and what it means for healthcare) and practical impact (factory locations, manufacturing challenges). We conclude that, although the sector will have the tools to cope with increases in various diseases, any revenue benefit may well be offset by increased pressure in the reimbursement environment if European GDP growth declines.

We would also point out that, when discussing the implications for the sector, it is important to note that the direct financial impact on the sector will largely be dependent on the branded healthcare products on sale towards the end of this century. We would highlight that these branded drugs will be a number of generations of R&D beyond the current marketed portfolios. For example, patents on today's earliest Phase 1 compounds (just being tested in man) will have expired by the time that many of the climate change impacts are expected to materialise.

Healthcare impact

1. **Increase in respiratory disease:** Climate change is expected to increase the prevalence of respiratory diseases such as asthma and bronchitis. Increases in greenhouse gases will increase the growth rates and pollen production of plants such as ragweed – a common asthma allergen.
2. **Increase in water-borne and vector-borne pathogens:** Climate change and the associated flooding of low-lying areas are expected to increase the level of water-borne and vector-borne diseases into areas currently not exposed to these problems. Key pathogens could include malaria, cholera, diphtheria, West Nile virus and trypanosomiasis (sleeping sickness). Today, treatment of these diseases does not make a major financial contribution to the branded pharmaceutical industry.

Interestingly, the main active ingredient in modern malaria therapy is artemisinin, extracted from the Chinese wormwood plant. The artemisinin content of the plant is known to be dependent on environmental factors and thus climate change may affect this supply. Attempts to genetically engineer yeast to produce artemesinin are ongoing.

3. **Reduced growth rates in diseases of the elderly:** More extreme weather patterns may reduce the average lifespan of people around the world as severe weather, and extremes of weather and flooding provide significant challenges to the elderly. For this reason, we could see a relative reduction in 'diseases of the elderly' such as cancer and central nervous system disorders, including Alzheimer's, Parkinson's and Schizophrenia. These are all seen as strong growth areas for the short term based on the ageing population seen in current demographic trends.
4. **Growth in vaccination:** We expect that increasing concerns over the risk of contracting 'tropical' illnesses in the western world is likely to drive an increase in demand for vaccination. Today, these vaccinations largely focus on the travel market.
5. **Low tech vs. high tech medical technology:** We expect that population disruption from changing weather patterns and flooding is likely to have a positive impact on 'low tech' medical technologies such as wound dressings, splints, etc., if extremes of weather lead to mass population movements. In contrast, 'high tech' medical technologies such as hip and knee replacement and spinal fusion, may suffer from reduced abilities for governments to fund them. Weather-related disruptions to manufacturing of highly-refined medical devices (i.e. casting and polishing of metal on metal hips) could adversely affect their quality and overall medical safety. In contrast, low-tech medical devices (i.e. wound dressings, stoma appliances) may benefit from the portable nature of their manufacturability (i.e. without affecting their quality) in addition to being more readily transportable and available.
6. **Increased generic penetration:** If emerging healthcare markets today such as Russia become more dominant this could favour generics given the historic strong generic usage in these markets. As Teva shows today these markets can be penetrated by Western-based companies.

Economic impact

1. **Threat to EU health spending:** In 2005, IMS Health estimates that the EU market represented 30% of global pharmaceutical spending. Unlike the US, the European market is dominated by government reimbursement. For this reason, any negative impact on the economic outlook in Europe could put significant pressure on government spending on healthcare. Historically, this pressure has been felt through drug price cuts and reduced access to more modern, innovative medicines. This could have a significant negative impact on the financial performance of the healthcare industry.
2. **US:** In contrast to other major Western markets the US healthcare system is currently less than 50% funded by government. The US system where the healthcare dollar follows the patient (providing either pharmaceuticals or hospital services) could perhaps more easily adapt to changing demand patterns than the more compartmentalised funding of other countries.
3. **Russia emerging as new healthcare market:** In contrast to Europe, Russia is forecast to experience an increase in GDP as rising temperatures and improving access to natural resources drive economic growth. This may accelerate the growth of Russia as an emerging healthcare economy. In 2005, the Russian pharmaceutical market was estimated to total US$3.75bn – representing 0.7% of total pharma spending. We note that any growth would have to be highly significant in order to offset the threat from declines in Europe. Any impact may be multiplied if this

improved economic wealth can be harnessed to reverse the current declining life expectancy trends in the region.

4. **ETS carbon trading:** The pharmaceutical industry is currently not covered by the European Union's ETS carbon trading scheme; although this situation could change in the coming years, we believe that because this industry remains one of the less energy intensive of the manufacturing sectors, any such extension of the scheme is unlikely to cause significant financial harm.

Practical impact

1. **Manufacturing:** A short survey of today's pharmaceutical manufacturing sites suggests that there would be only a limited threat to manufacturing capacity from rising sea levels. The majority of pharma manufacturing is not coastal.
2. **Indian generics:** India represents a significant proportion of the world's manufacturing capacity for generic drugs. As one of the economies expected to be most negatively hit by climate change, any negative impact on Indian manufacturing potential would have global implications. Although sufficient manufacturing capacity would likely be available in the western world, the cost of production would be considerably higher. Although the low cost credentials of Indian manufacturing are clear from current use, significant economies of scale and vertical integration from API (active pharmaceutical ingredients) to finished dosage manufacturing can offset this advantage with production based in other regions as witnessed by Teva today.
3. **Antibiotic manufacturing:** Antibiotic manufacturing requires cool weather temperatures and limited temperature fluctuations. Changes in weather patterns could negatively affect production capacity.

Healthcare and pharmaceuticals potential winners & losers

Although this industry is characterised by high levels of research and development spending, and new scientific knowledge is increasing potential development leads, there are areas such as anti-infective research where new classes of drugs are proving elusive. It is not possible to predict the winners so far in the future, but they are likely to be heavily committed to R&D either internally or through licensing.

- **Increase in respiratory diseases:** Companies that could benefit from this increase, based on today's drug portfolio, include GlaxoSmithKline (Advair), AstraZeneca (Symbicort), Sepracor (Xopenex) and Teva (Ivax portfolio).
- **Change in emphasis away from diseases of the elderly:** Companies exposed today to these categories which may be less relevant in the future include Orion (Comtan/Stalevo), Roche (oncology), Eisai (Aricept), and AstraZeneca (Seroquel). The slowdown in CNS disorders of the elderly may be offset by an increase in anxiety and depression associated with the changing environment.
- **Companies with a relatively high focus on the 'diseases of the developing world'** include GlaxoSmithKline (malaria, leishmaniasis), Novartis (malaria, dengue, haemorrhagic fever & tuberculosis) and Sanofi-Aventis (malaria, dengue).
- **Companies exposed to the 'low tech' wound management** market today include Smith & Nephew, Mølnlycke and Coloplast.
- **Major operators in the tropical diseases vaccine market** today include GlaxoSmithKline, Sanofi-Aventis, Merck Inc, Wyeth, Novartis, Crucell, Intercell and Acambis. ■

INSURANCE

Andrew Broadfield
LBIE, London
+44 20 710 24095
abroadfi@lehman.com

Thomas Dorner
LBIE, London
+44 20 710 26804
tdorner@lehman.com

Nick Holmes
LBIE, London
+44 20 710 21543
nholmes@lehman.com

Matt Lilley
LBIE, London
+44 20 710 21884
mlilley@lehman.com

Claudia Gaspari
LBIE, London
+44 20 710 26887
cgaspari@lehman.com

- *The insurance industry relies on statistical data in order to predict the size and frequency of losses and provide economically viable cover. If the rate of climate change is too quick and the consequences too unpredictable to establish reliable statistical data, this may make it very difficult to accurately price insurance risk or determine its correlation with other indirect risks (e.g. environmental liability claims or asset impairment).*
- *In the short term, there may be an opportunity for the industry to capitalise on the heightened awareness of climate change. This could lead to an increase in insurance rates following the raised public perception of the risks of climate change.*
- *In the longer term, we expect market competition to erode any over-pricing. Furthermore, if the frequency and severity of extreme weather events do increase and this is properly reflected in risk pricing, we believe insurance costs could rise to unaffordable levels in some areas. This could lead potential insurance customers to either: i) not take out insurance and retain the risk themselves; ii) cease whatever activity exposes them to the risk; and iii) turn to state protection. All of these options could ultimately have a negative impact on the insurance industry.*
- *Although natural catastrophes attract more attention, they only account for a portion of weather related losses. The impact of climate change is unlikely to be limited to a series of large scale natural catastrophes. Therefore, we expect the impact of climate change to be gradual and probably of increasing severity over time.*

Introduction

Insurance is principally used as a method to transfer risk. Individuals and companies buy insurance to reduce their exposure to predefined future events. Insurance companies pool the risks of many counterparties, each in return for a premium.

Insurance companies are able to make a profit if they can earn premiums and investment returns in excess of the costs of reimbursing policyholders for their losses. In order to do this they need to be able to make accurate estimates about the likelihood of future losses. The ability of insurers to do this could be significantly affected by climate change.

Why does the climate matter to insurers?

The insurance industry provides cover for a vast range of different risks to policyholders. Many of these risks are impacted either directly or indirectly by climate change. The industry is generally divided into the following three categories and each has its own exposure to changes in global climates (see Table A3):

Table A3. Insurance sectors and climate change

Insurance sector	Purpose	Impact of climate change
P&C insurance (non-life)	Protection of personal and commercial property and liability (e.g. buildings, cars, employee accident)	Claims patterns could differ from pricing data for both property and liability claims, increasing the risk that pricing is inadequate
Life insurance	Protection in event of ill health or death	Climate change may change the risk of ill health or premature death
	Pensions and savings	Climate change may lead to uncertainty in financial markets
Reinsurance	Protection bought by insurers against significant losses on their own business	Increased exposure of primary insurers will increase the cost of reinsurance and large losses may decrease the reinsurers ability to meet the costs of losses

Source: Lehman Brothers Research.

The impact of climate change on the insurance industry as a whole is wide ranging. The key effect will be an increase in the level of uncertainty surrounding future events. This will compromise the ability of insurers to determine the potential losses on any given risk and potentially increase the cost of insuring it.

Why is macro uncertainty a bad thing for insurance companies?

Since insurance companies accept risk on behalf of their policyholders, they need to be able to make reliable assessments of the level of risk they are taking. In order to do this, they rely on modelling future events based on historical loss experience. Reliable forecasting is critical for insurers in the following three areas:

- Deciding which new risks to accept;
- Determining at what level new business should be priced;
- Managing the correlation and aggregation of risks across their entire portfolio.

Climate change will add a significant degree of uncertainty to each of these. This will make writing insurance business more precarious. Indeed, the vast range of views on the precise effects of climate change serves to illustrate the level of uncertainty that we can expect it to bring to the insurance industry also.

What is the impact of climate related uncertainty?

The impact on the insurance industry created by climate uncertainty can be considered in the following areas:

Increased underwriting risk

Climate change makes profitable underwriting more difficult for insurance companies for the following reasons:

- There will be significant uncertainty over the frequency and severity of future losses – although this could lead to an increase in premium rates in the shorter term;
- Risk modelling will become more complex and the quality of risk management will become increasingly important;
- Certain risks will become uninsurable and the responsibility for helping those affected may fall to governments.

Increased macroeconomic risk

Insurance companies have large balance sheets and are highly geared to equity and bond markets. Therefore the impact of climate change on the financial markets is magnified for insurers, especially the life insurance industry:

- Falling equity markets cause life insurers to suffer a double hit as i) sales of products depending on investment performance will decrease and ii) balance sheets will be weakened by falls in the value of their equity holdings;
- If economic slowdown causes bond yields to fall, this would put pressure on the capital strength of insurers with long duration policyholder guarantees.

Increased capital risk

If climate change leads to increased risk for insurers then their capital positions would also be affected:

- Regulators and rating agencies would increase insurance companies' capital requirements (as experienced after Hurricane Katrina in 2005) and investors would increase the cost of capital to compensate for uncertainty over future losses;

- Capital strain would be largest on smaller and less well diversified insurers, whereas better capitalised and diversified insurers would benefit indirectly. This could lead to consolidation in the industry.

Using the capital markets to protect against extreme events

Increasingly, the insurance industry is looking for alternative ways to protect balance sheets or to free up risk based capital. The fastest growing avenue is Insurance Linked Securities (ILS), which include catastrophe bonds. These are high yielding bonds held in trust which default when a predetermined event takes place.

This is attractive to insurers because currently the marginal cost is less than standard reinsurance and the credit risk of the capital markets is generally lower than that of reinsurers.

It is also attractive to the capital markets, because they are able to acquire exposure to a risk which is relatively uncorrelated with the financial markets (except at the extreme tail of the risk) and so diversifies the investor's risk.

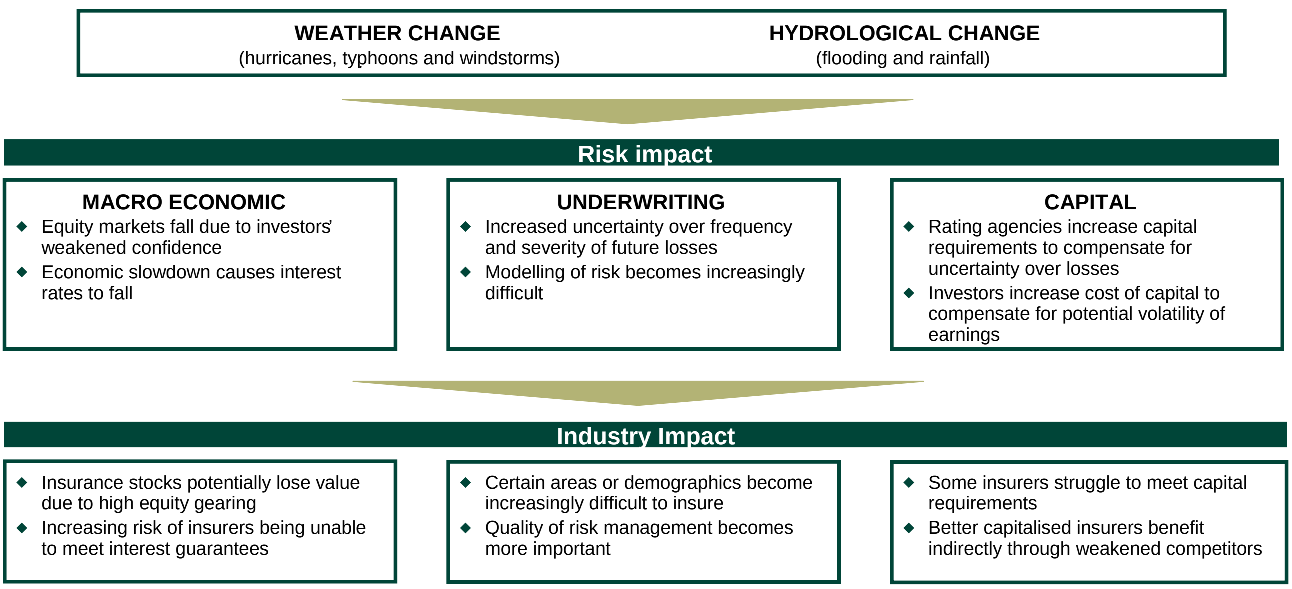
However, for the bond to be attractive to all parties:

i) The underlying risk and trigger event must be sufficiently well understood by non-specialist capital market investors;

ii) The covered risk must be sufficiently close to the insurer's unique underlying exposure.

In order to find buyers, the bonds are often designed around event parameters such as a hurricane reading by an independent monitoring body. This creates comfort for the buyer as the event and its trigger are clearly defined. However, it also creates a 'basis' risk for the insurer, because the insurer's underlying risk is not 100% aligned with the risk covered by the bond. This can create a mismatch in the pricing and also in the protection level.

Appendix – the impact of climate change (causal analysis)



Reactions of the insurance industry to climate change

The insurance industry is very proactively dealing with the impact of climate change. We include below just a few examples of the many actions the industry is taking to explore the risks created by the uncertain consequences of climate change.

Conferences

Climate Change 2007 – the proactive and profitable management of climate change. This conference has grown from the Insurance Times' Forces of Nature event, which brought together just over 200 delegates in March 2006. This event is sponsored by AXA.

Lobbying bodies

Association of British Insurers – flooding and insurance website. This webpage provides an overview of ABI's work on flooding issues. It sets out how the insurance industry is working with the Government and other stakeholders to ensure that flood risk is effectively managed, so that flood insurance remains readily available to the vast majority of customers. This association has been actively lobbying the government to increase the investment in flood defences to ensure properties in high flood risk areas remain insurable.

The chief risk officer forum. The Chief Risk Officers of the leading insurers and reinsurers in Europe have formed a forum in which they discuss key risks facing the industry and coordinating a response to it. One of the areas it has begun to address, is the impact of climate change – *CRO briefing – Emerging Risk Initiative – Position Paper, 'Climate Change & Tropical Cyclones in the North Atlantic, Caribbean and Gulf of Mexico'.*

Corporate awareness

Lloyd's 360. Aims to generate discussion and debate on how to manage risk in today's environment. It is a long-term initiative addressing different aspects and elements of risk across a range of issues. It recently published a report on the impact of climate change on the industry, and among other things, highlighted the need for the industry to partner government and business to address the issues.

Benfield hazard research centre. With over 50 researchers and practitioners, the Benfield UCL Hazard Research Centre is Europe's leading multidisciplinary academic hazard research centre. Joint action between Benfield reinsurance brokers and University College London has been implemented.

Munich Re – Geo risks research. Covers all the pertinent disciplines like meteorology, seismology, geology, geophysics, and geography. It gives advice and provides services for all in-house departments and external users dealing with issues related to natural catastrophes and needing geoscientific knowledge. It has published many reports on the impacts of climate change on the insurance industry. ■

INTEGRATED OIL

Lucy Haskins
LBIE, London
+44 20 710 21417
lhaskins@lehman.com

Paul Cheng
LBI, New York
+1 212 526 1884
pcheng@lehman.com

- *We judge that oil companies will be part of the solution to global warming.*
- *Downstream segment is more demand-sensitive but surprisingly robust to higher prices so far.*
- *Clean hydrocarbons are still cost competitive with alternatives.*

"*If the whole world thinks CO_2 is a huge problem then it is a great opportunity for Shell*" Jeroen van der Veer, CEO Royal Dutch Shell.

There are two main issues oil & gas companies will need to address in the face of global warming. The first is demand: both in terms of temperature impacts and – much more significantly we believe – governmental measures to improve energy efficiencies. The second will be how the companies can position themselves to be part of providing the solution rather than just being part of the problem.

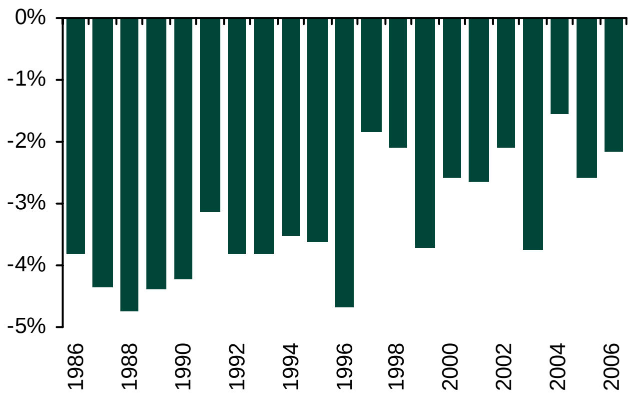
We believe a 1-2ºC rise in temperatures would see a seasonal shift in demand rather than a big fall per se, with heating demand being replaced by air conditioning demand. An element of this swing can be observed by how quarterly demand has moved in recent years – as a higher proportion of demand growth comes from the non-OECD nations, we perceive a bigger uptick in 2Q demand with Asian air conditioning requirements in part offsetting lower seasonal heating demand from the Northern hemisphere (see Figure A5).

The area where oil companies would be more immediately affected by demand issues would be changes to government policies to reduce fuel consumption. As can be seen from Figure A6, there is a very wide divergence in terms of per-capita energy consumption around the world.

The market place that looks most vulnerable to efficiency measures is the US, with average consumption on a per-capita basis some 4x the global average (2.1 tonnes per capita). There is considerable scope for US government action to address the issue of relative inefficiencies within the consumption chain. Gasoline taxes are very low in the US compared to other OECD economies. Figure A7 shows gasoline tax rates in the major consuming markets of the world alongside per-capita gasoline consumption.

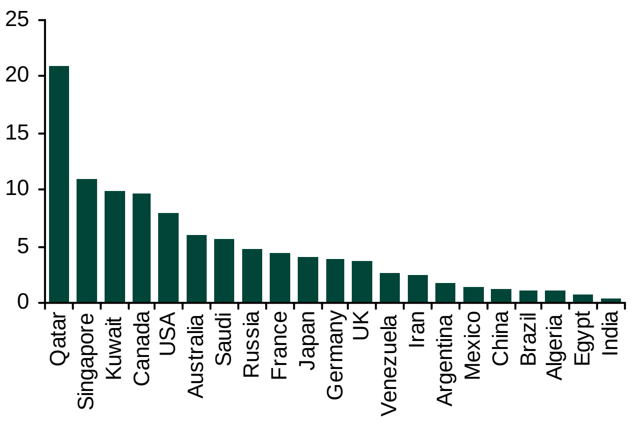
Interestingly, we might have thought that US demand would already have been harder hit given the 76% rise in US pump prices we have already seen over the 2000-06 period as a result of higher oil prices. Consumers may not see gasoline as a discretionary spend – and indeed it is still the case that even in the UK, with gasoline taxes of close to 80%, the

Figure A5. Quarterly oil demand growth, y-o-y%



Source: International Energy Agency (2006a).

Figure A6. Energy consumption per capita by country



Sources: BP (2006), and Lehman Brothers Estimates.

per litre cost of gasoline at 90p/litre is less than the c. 525p/litre equivalent cost of a Starbucks coffee. So far there has been little demand destruction for gasoline because of the lack of substitute transport fuels.

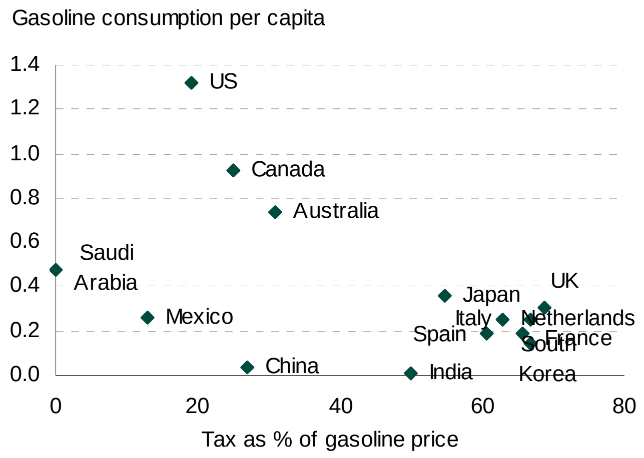
Given voter sensitivity surrounding pump prices we think it unlikely that there would be a swift move to lift US gasoline taxes to parity with Europe. However, it is clear that measures will be taken over time to increase the cost of driving – through penalties on gas guzzlers, increased road taxes and higher gasoline taxes. This leaves the downstream-biased companies as more immediately sensitive to our way of thinking than the upstream. This can be demonstrated by movements in relative profitability when demand last came under pressure in 2002 in the aftermath of 9/11 – downstream profits hit a decade low point while upstream profits proved relatively robust (see Figure A8).

It could be argued that the US refiners look the most vulnerable to any measures to reduce gasoline demand, albeit the European refiners will also be exposed in terms of gasoline because much of Europe's current gasoline surplus is exported to the US. There is an ancillary issue for the Gulf Coast refiners as well, which is the risk of rising sea levels. As we saw with the hurricane disruptions in 2005 – when at one point almost 20% of US refining capacity was shut owing to flooding – billions of dollars of costs were incurred to restore capacity and to proof against a repeat.

In the longer term, it might be argued that a drive to higher-specification gasolines could provide an opportunity for refiners to extract a higher ongoing margin as some refining plant becomes outmoded and is retired. Certainly, European refiners are now focussed on delivering more diesel than gasoline as that is where there is a perceived tightness in European product supply. Diesel is not 'cleaner' than gasoline but is a more efficient fuel and typically carries more favourable tax treatment in most European markets to reflect this.

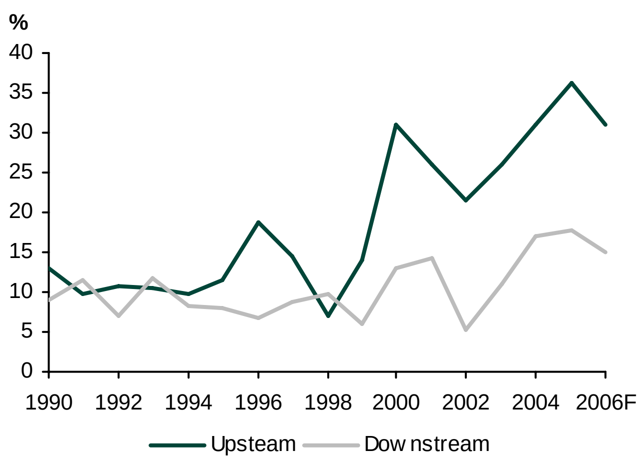
Our US colleagues would argue that tighter product specifications and stricter environmental standards will mean that margins will not return to the levels we saw at the bottom of the last cycle as it is going to be a tighter market. Two reasons account for this: first, higher proportion of spending going on environment and therefore, less remaining for growth projects. Even after the completion of new product spec changes, we have not seen spending come down owing to spending on clean air act. Second, higher turnaround time – refiners typically take down refineries for maintenance in the spring and fall and they are the low demand seasons. In 2006, we saw an extended turnaround with all the new equipment to comply with product spec changes. This takes supply off the market for a longer period of time.

Figure A7. Gasoline consumption per capita vs. tax rate



Sources: Eni (2006), IEA, EIA, and Lehman Brothers Estimates.

Figure A8. Upstream and downstream RoCE



Source: Lehman Brothers Estimates.

We estimate that new ethanol plant construction could continue to increase the industry's annual capacity by 1-1.5 billion gallons per year through 2009, even if oil prices should trend below US$60 by late 2007. To put this into perspective, an annual capacity increase of 1 billion-1.5 billion gallons translates into 65,000-100,000 b/d of new ethanol supply per year. Taking into consideration ethanol's lower fuel efficiency, we estimate the higher ethanol supply could potentially displace up to 50,000-75,000 b/d of annual gasoline demand from 2H07 through 2009 (which assumes a 25% fuel mileage loss).

Our oil price thesis is supply driven rather than demand driven with the key issue for us being the rising cost of supply – both structurally – as the easily exploitable oil has been mostly recovered – and cyclically – as investment is only just beginning to recover post the under spend of the last decade. At present, this thesis is supported by the cost of alternative energies. Figure A9 shows the equivalent cost per kilo watt hour of oil, gas, hydro electric, nuclear, solar and wind according to Areva.

Oil and gas are comparatively low cost energy supplies even after the 130% oil price increase seen in the first part of this decade. The IEA, which has recently published its World Energy Outlook for 2006, sees fossil fuels as remaining the primary source of energy out to 2030, with their share of world demand edging up from 80% in 2004 to 81% by 2030. Under their current Reference Scenario the IEA sees coal showing the biggest increase in demand in volume terms followed by oil. Oil remains the single-largest fuel in the primary fuel mix in 2030 though its share drops from 35% now to 33%. ExxonMobil in its long-term forecasting has alternatives – including nuclear and hydro – providing only 17% of world energy by 2030. Wind and solar are expected to account for less than 1% (see Figure A10). The IEA estimates that wind, solar, wave and tidal and geothermal technologies will have a slightly higher proportion of total energy use at 1.7% in 2030, up from 0.5% today.

Figure A9. Relative costs between energy sources

	Average MWh cost for new plants (Europe)	CO_2 emission / MWh generated (in kg)
Nuclear (uranium @ 40$/lbU3O8)	€30	6
Hydropower	€30	4
Combined cycle gas (@ $6/Mbtu)	€45	427
Wind	€50	3 to 22
Coal (@ $50/ton CIF)	€40	978
Oil	€100	891
Solar	> €450	60 to 150

Source: AREVA (October 2006).

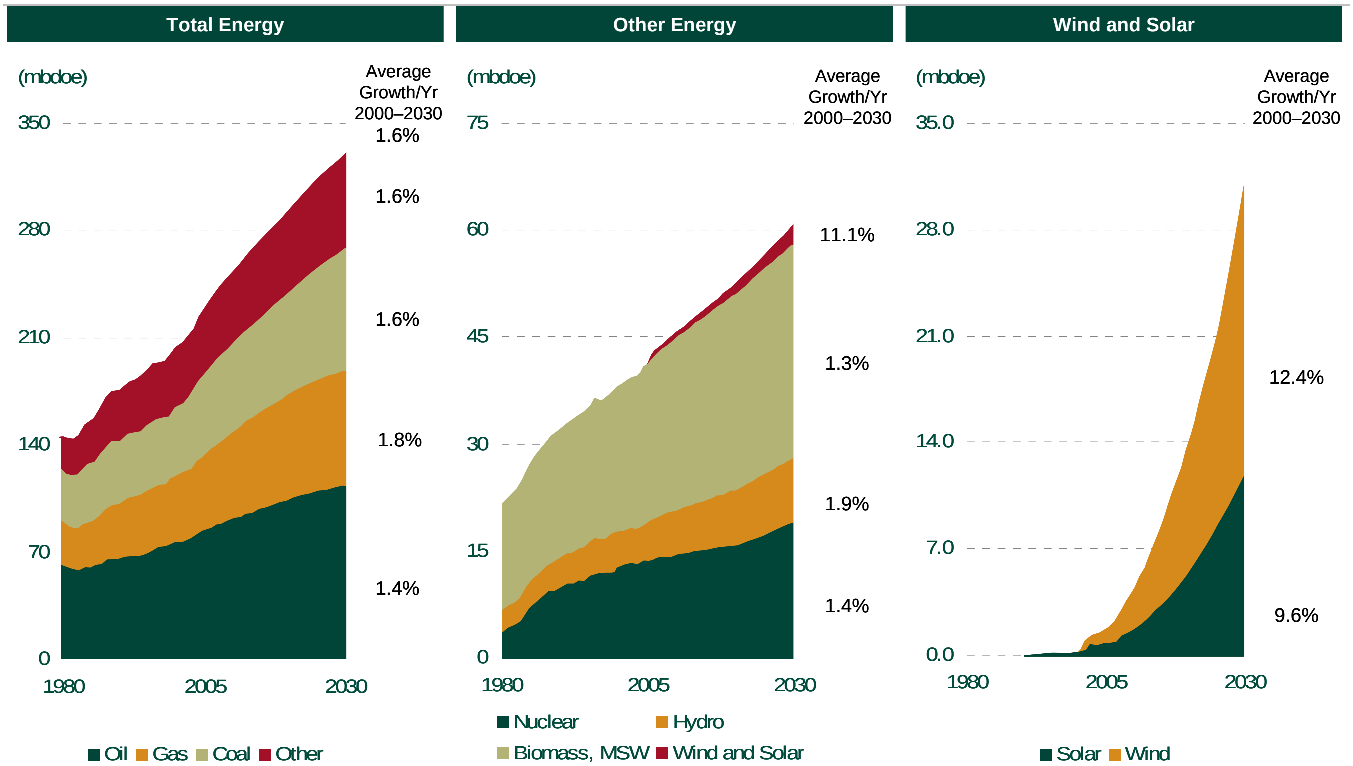
Interestingly, the IEA World Energy Outlook for 2006 also considers an Alternative scenario which assumes that policies and measures currently being considered by governments at mitigating CO_2 emissions are implemented. According to the IEA, this would result in an overall reduction in energy demand by 2030 of almost 10% relative to the Reference scenario. This scenario would still see average oil demand growth of 0.9% out to 2030 and gas demand growth of 1.5% pa. Oil demand in 2030 is still estimated at 103m b/d compared to the IEA's estimate of 2005 demand of 84m b/d. It is significant that the World Energy Outlook would suggest that even in a 'green' outlook, demand for oil and gas will still rise.

The second issue the companies will need to address is what measures they can take to provide the low CO_2 alternatives. This could be cleaner variants of the existing products or alternative products. Post Kyoto, many oil companies appreciated that demand for gas might be higher than the demand for oil and started to target gas volumes. Companies also looked to make the gas market more fungible so that liquefied gas could be delivered to the highest margin markets. Interestingly, gas demand has proven to be more vulnerable to demand destruction in the US than gasoline demand. This is because there are more obvious opportunities to substitute power generation demand – in recent years away from high priced gas into low price coal – whereas there is no real alternative to gasoline at present.

But though there is now a converging view among the oil majors about the fact of climate change – even ExxonMobil is funding some research into global warming at Stanford University – they remain divided on precisely what to do about it. The largest major, ExxonMobil, still refrains from following the European majors in investing in alternative energy. It argues that renewables and nuclear (in which it invested in the 1980s) is still uneconomic. Although ExxonMobil's relative inactivity in the face of climate change may have tarnished its image in the eyes of some NGOs, two points need to be borne in mind. First, the correlation between environmental behaviour and financial performance is not (yet) strong. In other words, it is not clear that environmental problems such as the Brent Spar row that faced Shell in 1995 or the Exxon Valdez oil spill of 1989 caused any lasting impact on the companies in question; nor that 'green' ad campaigns raise market share or equity rating. Second, technical competence has a bearing on environmental performance and potential. BP's 'green' image has been tarred by its leaking pipes in Alaska (as well as operational difficulties), while Exxon's avowed technical competence would undoubtedly help it play catch-up in renewable energy were it to decide this was a commercial proposition.

Global warming could prove a threat to global oil, with our view being that downstream demand is the vulnerable segment. However, the oil companies have managed a number of dramatic changes over the past century including nationalization of assets, upstream tax rates as high as 90% in parts of the world; consumer taxes in some countries of close to 80%. We believe the oil companies will be part of an evolving solution to the CO_2 challenge. If the 20^{th} Century could be argued to be the hydro carbon age, the 21^{st} Century may become the clean hydro carbon age.

Figure A10. Alternative energy outlook to 2030



Source: ExxonMobil (2006).

Reactions of the integrated oil industry to climate change

Big Oil is already pursuing strategies to find cleaner versions of their existing products. Shell's current focus is on Gas to Liquids technology. Their first world scale project Pearl is due to come onstream in Qatar in 2010 and will produce 140 kb/d of clean diesel. This represents 2% of the group's current total refined gasoline production. BP has a separate Alternative Energies business, albeit the financial contribution is contained within the group's Gas and Power line. BP is planning to invest US$8bn in low carbon power and alternative energy business over the next decade and aims for US$1bn of operating profit by 2015. This target profitability would appear to arise from the group delivering its normal corporate return aspiration on this invested capital.

Bio fuel initiatives are typically at very preliminary stages for the Big Oil companies. Total has probably gone furthest down this route and is planning a joint venture with Neste at one of French refineries. Targeted volumes will represent less than 1% of Total's overall product volumes. Neste is also pursuing two other bio fuel initiatives – at the Schwechat and Porvoo refineries. Bio fuels will account for about 5% of Neste's volumes by 2010. In some respect this shows the relatively slow pace at which change is being effected without major Governmental action. The IEA makes the point in its World Energy Outlook for 2006 that even the current low level of biofuel production – less than 1% of global transport fuel market – requires arable land the size of France and the conflicts with food production are also likely to cap the pace at which bio fuels can develop. Even if companies do not have direct exposure to the production of bio fuels it is certain that the Major's distribution chains will be used to distribute cleaner products to consumers – Shell and BP are already market leaders in the distribution of the world's biofuels. ■

MEDIA

Richard Jones
LBIE, London
+44 20 710 22099
richard.jones@lehman.com

Colin Tennant
LBIE, London
+44 20 710 21105
ctennant@lehman.com

Matthew Walker
LBIE, London
+44 20 710 24459
mawalker@lehman.com

- *One of the sectors less affected by climate change with the major impact being advertising sensitivity to reduced GDP.*
- *Reduced travel and storm damage could have small negative impact on exhibitions, parks and outdoor.*
- *Severe economic decline causing political instability would raise issues around media ownership and regulation.*
- *Small potential positives include increased news consumption and greater scientific endeavour.*

The media sector should be one of the sectors less affected by global climate change, although it is not immune. The major impact is likely to depend on the scale of any negative impact on overall GDP, as this will hit advertising, which is one of the major drivers of the sector. There could also be small negative impacts for the exhibitions, parks and outdoor segments, from a potential reduction in travel, while outdoor and parks have the main exposure to increased storm damage. At an extreme level, should economic decline lead to severe political instability then media ownership and regulation could become serious issues, while the more aggressive assumptions of global warming scenarios also lead to a far greater negative economic impact in Europe than in the US.

The small positives could come in areas such as increased consumption of news, while medical and science journals could see a small benefit from increased scientific endeavour, some media consumption could benefit from increased public transport, and the media will help with consumer education and to advertise innovation. The sector may also see a slight relative positive benefit from its position as one of the smaller contributors to global pollution, while the paper providers are actually net contributors to trees rather than net users.

Within the sector, theme parks and outdoor look likely to see the greatest negative impact followed by newspapers, magazines, radio, TV and directories. Agencies should see a slightly lower negative impact while professional publishers could even see a slight positive effect.

Economic impact

Advertising accounts for 60% of revenues of the companies in the media sector on average, and spending is driven primarily by economic growth, with the advertising cycle tending to exaggerate the economic cycle. Ad spend has also grown slightly off nominal GDP over the past 30 years, rising as a proportion of GDP as the level of GDP increases and has only tended to grow ahead of nominal GDP when real GDP growth is above 2-2.5%. During an economic downturn, ad spend has tended to fall by mid-single digit rates, and can fall by double-digit rates in extreme circumstances.

As such, the main consequence for the sector would come from the impact on overall economic activity, which could cause advertising to fall as a percentage of GDP, so compounding the negative impact on GDP. A base case forecast of a 1.5% negative impact on GDP by 2100 caused by a 2.5ºC global warming (cf. the Nordhaus' results described in the first part of this report) would imply low-single digit declines in advertising as it falls slightly as a proportion of GDP. However, a more aggressive scenario of a 6ºC increase in temperatures which would cause a greater negative impact on GDP could imply double-digit declines in ad spend as global consumption and global advertisers come under severe pressure.

Contributing to this, sectors such as autos and fast moving consumer goods which account for close to 30% of advertising could see growing regulatory pressure to reduce their contribution to pollution, on top of any economic impact.

Geographically the forecasts imply a varying impact, with greatest negative implications for Europe. Indeed, according to Nordhaus' results shown in the first part, under the 2.5ºC scenario, the US is projected to see a negative impact on GDP of only 0.5%, compared to close to 3% in Europe. Under the 6ºC scenario, the US is projected to see a negative impact on GDP of around 3%, but this is close to 13% for Europe, which would likely cause a dramatic drop in ad spend.

Within the sector, the negative implications for advertising would have the greatest impact on Free TV, radio and Outdoor test extent, followed by the newspapers and magazines, while music sales and parks have also tended to be very cyclical. Pay TV and agencies are slightly less cyclical, but not immune, while professional publishing companies should see the smallest negative impact.

Reduced travel

Exhibitions rely on international travel so any increase in expense or restrictions would have some negative impact, as occurred following 9/11 and the SARS crisis in Asia. Outdoor advertising also relies on travel and general increases in mobility. Reduced air travel has a very direct impact on airport advertising, which is close to 15% of the global outdoor market while reduced car usage would also have a slight negative on billboard and furniture advertising. Historically, theme park visitors have also seen a negative impact from reductions in air-travel.

Physical damage

Outdoor advertising has the main potential exposure to physical storm damage, and some of the companies have suffered material exceptional charges over the last couple of years owing to hurricane damage in the US. Theme parks also respond poorly to extreme weather, as do general retail sales which can have an impact on music sales (although as the latter transfer fully to digital the impact would reduce).

Political instability

More aggressive assumptions of negative impact on global GDP by 2100, including big discrepancies across regions, could be high enough to cause significant political instability. During such times, restriction on media ownership and regulation can increase significantly with scant regard for shareholders.

Potential positives

During times of crisis consumption of news tends to increase materially, and while advertisers will often shy away from such programming it could still lead to some opportunity on either an advertising or a paid-for basis. Indeed, UK cinema attendances increased by 60% during World War II as this was one of the major sources of news. The reliability and credibility of news services is also important in such scenarios, while media consumption of newspapers and eventually TV, could increase from a shift to public transport, although this could be at the expense of radio.

Medical and scientific journals could see a small positive benefit from increased interest in and funding of scientific endeavour to attempt to solve the problems of global climate change, as well as potential growth in diseases. The media will also be required to play a role in consumer education as well as advertising new products driven by the need for innovation.

As the concerns over global climate change increase, investors may increasingly choose to favour those companies which contribute the least to the problem, while even the paper suppliers for newspapers are net contributors rather than net users of trees. With physical manufacturing fairly limited, and moving increasingly online in any case, the media sector could benefit slightly from such a shift in sentiment.

Examples of media companies’ responses to climate change

Several leading media companies have instigated policies to limit their negative impact on the environment, although the nature of their businesses means they are not generally major polluters anyway. For example, **BSkyB** announced in July that it had become the world's first carbon neutral media company and only the second FTSE100 company to achieve this. It also has a commitment to reduce CO_2 emissions by 10% from 2003 to 2010.

In the UK, close to 100% of **EMI**’s electricity requirements are met through renewal energy sources. Last year their worldwide energy use decreased by 6%, though this was mostly a result of the sale of a manufacturing plant, and indeed their environmental impact has reduced materially since they began outsourcing their own manufacturing in 2004. Associated carbon dioxide emissions dropped by 7% last year.

Within its Corporate Social Responsibility report, **WPP** commits to minimising its impact on the environment. It has prioritised energy consumption, paper use and recycling and is focusing initially on its 20 largest locations, which accounts for around 16% of its workforce, where it is tracking energy use and recycling. It is also identifying preferred suppliers in major markets to make it easier for group companies to set up recycling programmes and source paper from sustainable sources. ■

MINING AND METALS

Chris LaFemina, CFA
LBIE, London
+44 20 710 29080
chris.lafemina@lehman.com

Abhishek Shukla
LBIE, London
+44 20 710 29123
abishek.shukla@lehman.com

- *Economic policies based on climate change could positively affect the demand for some commodities, such as uranium and aluminium, and negatively affect the demand for others, such as thermal coal and steel.*
- *Commodity prices are a function of supply and demand. In the long run, the price of any commodity should be set by the marginal cost of production of that commodity as long as the world's undeveloped resources of that commodity have not been fully depleted. Greater demand for a commodity, such as uranium, owing to changing environmental policies should only affect the long-term price of that commodity if these policies affect its marginal cost of production.*
- *Despite the potential for higher commodity prices as a result of new environmental regulations, higher costs for mining companies owing to these same regulations (especially as a result of higher prices of energy used intensively in mining and metals processing) could limit the impact on profitability and returns in the mining sector.*

Environmental policies based on climate change can significantly affect the metals and mining sector. In general, mining and metals production is energy intensive. Higher costs for energy as a result of tighter environmental regulations would likely result in higher costs to produce commodities and higher commodity prices (as a result of cost-push inflation). For some commodities, such as uranium and scrap aluminium, more stringent environmental regulations could be a fundamental positive despite potentially higher production costs. Conversely, coal and steel fundamentals would likely be negatively impacted by tighter environmental regulations, in our opinion.

Uranium

The uranium industry is likely to significantly benefit if tighter greenhouse gas emissions regulations are put in place. The burning of fossil fuels (coal, oil, and natural gas) to generate electricity is a major source of greenhouse gases. However, approximately 16% of all electric power is generated from the world's 440 nuclear reactors. These reactors, which use enriched uranium as a fuel, have very low operating costs and are 'clean' in that they do not emit any carbon dioxide.

A widely publicized challenge for the nuclear power industry is safe storage of nuclear fuel wastes. In addition, public opposition to new nuclear power plants in some regions of the world, including the US, and a long lead time to permit and build these plants are factors that could somewhat restrain global market share gains for nuclear power over the next decade. That said, new nuclear power plants are indeed currently being built in some regions of the world. More than half of the 60 reactors expected to be built in Asia alone over the next decade are in China and India. New plants are also being built in Europe. From a demand perspective, we believe the outlook for uranium is encouraging.

On the supply side, uranium mine production has been far below consumption for many years. Of the roughly 180 million pounds of uranium consumed each year, just 110 million pounds come from mines. This mine supply 'deficit' is offset by supply of uranium from secondary sources, including excess producer and consumer inventories, recycled material, Russian government inventories, and highly enriched uranium (HEU) from dismantled Russian nuclear weapons. The longer-term availability of supply from these secondary sources is questionable and it is not clear that uranium mine production growth will be great enough to fill the potential gap. The spot price for uranium has increased from US$10 per pound in 2003 to US$60 per pound today as uranium markets have tightened. With a reasonably strong demand outlook and some factors that could limit supply growth from secondary sources, uranium still has a favourable price outlook despite its very high price today, in our opinion. Canada's Cameco, France's Cogema, and diversified miners Rio Tinto and BHP Billiton are large uranium producers.

Aluminium

Aluminium fundamentals could improve if tighter greenhouse gas emissions regulations are put in place, but most of the benefit is likely to accrue to recycled aluminium and not to primary aluminium.

Aluminium can be produced either from a primary production process or from recycling. Primary aluminium is produced by refining aluminium ore (bauxite) into alumina and then smelting the alumina into aluminium. This is a highly energy intensive process as at least 15 megawatt-hours of energy is typically required to produce one tonne of aluminium. This process also typically generates close to 10.5 tonnes of greenhouse gases per tonne of aluminium produced. Recycling aluminium from scrap, however, requires less than 5% as much energy and generates much less greenhouse gas than primary aluminium production.

The transportation sector is the largest end market for aluminium, accounting for more than 31% of the western world demand for the metal. Aluminium's market share in motor vehicle production has been rising for years (at the expense of steel) for a variety of reasons, including fuel efficiency. One pound of aluminium can often replace more than two pounds of steel and thereby help reduce the weight of a vehicle. Lighter vehicles are more fuel efficient and generate less greenhouse gas emissions than heavier vehicles, all else equal. Based on our estimates, one tonne of aluminium used instead of steel in the transportation sector should result in a roughly 24.5 tonnes total decline in greenhouse gas emissions.

When we consider the entire aluminium market and not just the transportation sector end market, we believe that primary aluminium is close to being greenhouse gas neutral. The production of one tonne of primary aluminium generates about 10.5 tonnes of greenhouse gases, but of this one tonne of aluminium, only about 0.31 tonne is used in the transportation sector. Based on our estimates, using this 0.31 tonne of aluminium instead of steel in the transportation sector would reduce greenhouse gas emissions by about 7.4 tonnes. Note that greenhouse gas reductions from switching to aluminium in other end markets are not clear and are probably not significant.

Although primary aluminium production and use may be close to greenhouse gas neutral, the use of recycled aluminium in the transportation sector in place of steel reduces greenhouse gas emissions significantly. We believe that aluminium recycling rates would increase as a result of tighter greenhouse gas emissions regulations, and aluminium would probably continue to gain market share in the transportation sector at the expense of steel. Note that higher prices for scrap aluminium should be supportive of higher primary aluminium prices, all else equal. Alcoa, Alcan, Rio Tinto, BHP Billiton, and Russia's Rusal are all large aluminium producers.

Steel

The steel industry as a whole is likely to be a modest net loser if tighter greenhouse gas emissions regulations are adopted worldwide. However, the integrated steel producers would likely bear the brunt of the additional costs although mini-mills might actually benefit from this potential change.

Steel is produced by either the integrated (blast furnace/basic oxygen furnace (BOF)) process or the mini-mill process (electric arc furnace). The integrated blast furnace/BOF process requires refining of iron ore and typically releases roughly two tonnes of greenhouse gas per tonne of liquid steel produced. Mini-mills, however, recycle steel scrap and release roughly 0.64 tonne of greenhouse gas per tonne of steel. Integrated and mini-mill steel production generates less greenhouse gas than primary aluminium production.

Automotive applications account for more than 15% of global steel consumption. Aluminium has steadily replaced steel in the automotive market because the use of aluminium instead of steel results in lighter, more fuel efficient vehicles. This trend would likely accelerate owing to tighter emission regulations. Note that most of the steel used in the automotive market is produced by integrated operators because mini-mill steel tends to be lower quality.

Overall, integrated steelmakers would probably be competitively disadvantaged owing to tighter greenhouse gas emissions regulations. Relative to mini-mills, integrated mills produce more greenhouse gas in the steel production process and are much more exposed to the automotive market. Mini-mills would likely gain some market share in other steel applications as cost pressures would be more significant for their integrated competitors.

Coal

The coal industry would likely be negatively impacted by tighter greenhouse gas emissions regulations. With its relatively reliable supply and enormous resource base, coal is a key fuel being used to meet growing global power demand, especially in China and the United States. Although coal is currently used to generate about 40% of the world's electricity, a problem with coal is that it is not a clean fuel. Coal is predominantly carbon, and when carbon is burned, carbon dioxide is emitted. It is very difficult to capture and store carbon dioxide emissions from coal-fired power plants (see Box: *Clean Coal Technology – A Snapshot* in the *Utilities* section).

We believe carbon dioxide emission regulations in regions of the world, including the United States where such regulations are not currently in place, would increase the cost of burning coal in those areas. In the short- to medium-term, this would probably mean higher electricity prices in these regions. Some switching from coal to natural gas for power generation would also be expected to occur, but (as we have seen in the European power market), coal would likely still have an economic advantage over gas. In the longer term, we believe new carbon dioxide emissions regulations would provide a greater incentive to build more nuclear capacity. Longer term, we believe the solution to the global warming issue is increased acceptance of nuclear power, which emits no carbon dioxide. However, nuclear power plants virtually everywhere in the world take several years, at least, to permit and build. Growth in nuclear capacity is unlikely to steal significant market share from coal over the next decade, in our opinion. So although global coal demand growth may be affected in the long run as new nuclear power plants come online, we believe the international outlook for coal demand is still very good for the foreseeable future.

On the supply-side, coal production growth should be strong enough to meet demand growth, but we expect global coal markets to be tight for years. Growing US imports and China potentially shifting from a net exporter to a net importer of thermal coal over the next few years are factors that should support coal prices at relatively high levels. We have a positive view on the outlook for coal. Xstrata, BHP Billiton, Rio Tinto, Peabody Energy, and Arch Coal are our preferred coal producers.

Mining industry response to climate change

The world's leading mining companies, including BHP Billiton, Rio Tinto, and Anglo American, have been proactive in their management of greenhouse gas emissions. BHP Billiton, for example, established a goal in 2001 to reduce greenhouse gas emissions by 5% per unit of output by 30 June 2007. BHP is ahead of schedule, having reduced its greenhouse gas emissions per unit of output by 8% from 2001 to fiscal 2006. We believe efforts to reduce greenhouse gas emissions via efficiency improvements and new technologies by BHP Billiton and other miners will intensify in the years ahead as mining is an industry where corporate reputation can affect the speed and ability of a company to secure permits to develop new projects.

The coal mining industry is working to help electric power generators develop clean coal technologies. Coal companies are studying carbon capture and sequestration technologies, but development of these technologies has been slow. In some regions of the world, including Europe, carbon emissions allowance trading is being used to create a real cost for carbon emissions from electric power generating facilities. These costs should increase the industry's incentives to invest in new clean coal technologies. However, we believe an economic argument could be made against investing in these technologies. After all, if you are a large power generator and your largest competitor invests significant capital in carbon capture and storage technologies, that same competitor would likely use those technologies that it successfully develops. The end result, all else equal, would be cheaper carbon credits as demand for these credits would fall since your technologically advanced competitor may need fewer or no credits. This creates something akin to a prisoner's dilemma scenario. The 'loser' in the technology race may really be the winner because the free-riding loser would benefit from cheap carbon credits with minimal or no investments in new technologies at the expense of the winner.

Despite challenges in developing clean-coal technologies, a consortium of mining companies and electric utilities along with the US Department of Energy is building the US$1bn FutureGen clean coal project. The goal of this project is to assess the feasibility of producing hydrogen and electricity from coal by creating a 'zero-emissions' 275 megawatt prototype fossil fuel power plant. The project will consist of coal gasification, combined cycle electricity generation, and carbon dioxide emissions sequestration. Members of the FutureGen Alliance include BHP Billiton, Rio Tinto, Anglo American, Xstrata, and other coal mining companies. ■

REAL ESTATE

Chet Riley
LBIE, London
+44 20 710 25895
chet.riley@lehman.com

Bart Gysens
LBIE, London
+44 20 710 26265
bart.gysens@lehman.com

Mike Prew
LBIE, London
+44 20 710 25734
mike.prew@lehman.com

David Harris
LBI, New York
+1 212 526 1790
dharris4@lehman.com

- *Building emissions contribute 8% of the worldwide carbon footprint, according to various research advisory services, such as DTZ. So, sustainable energy and the development of 'green' buildings should be a key focus for most governments and local authorities. We see more pressure for this in Western Europe than in the rest of the world.*
- *Property developers face the challenge of having to deliver energy-efficient buildings and meet sustainable energy targets that are costly, deliver lower overall returns and face the risk of functional obsolescence as new legislation and technology are introduced.*
- *Most Western European property developers are working to mitigate the long-term physical risks of climate change and have established environmental risk committees. The US, however, has lagged Western Europe in this regard.*

Commercial properties are substantial energy consumers, requiring significantly more power per square foot than residential properties. We identify three key challenges faced by the sector:

Regulatory risk: European, government, and local authorities are implementing more stringent energy efficiency/sustainability regimes, with ever-increasing compliance costs. The EU Energy Performance of Buildings Directive goes some way towards harmonisation, but member states have interpreted and implemented them differently. Carbon capping is a looming issue faced by the UK. Implemented without due care, we believe carbon capping could lead to capital migration.

Energy efficiency and functional obsolescence: Sustainable energy and energy efficiency are key issues for all major companies across the EU but less so, it appears, in the US and other major global regions. The key challenge facing companies is the requirement to meet on-site sustainable energy requirements and improve the quality of older stock. Energy labelling (performance certificates) is also likely to have a significant impact on property values.

Mitigating the physical risks: Physical risks, including weather extremes, water shortages, potential flooding, etc. are currently on the radar of large property companies, which are developing strategies to alleviate potential problems.

Regulatory risk

The US and emerging global real estate hubs, China and India, appear significantly to lag the rest of the world, particularly Western Europe, on buildings/environmental issues. We perceive generally much lower levels of awareness around environmental issues in these countries relative to Western Europe. In the US, this appears to stem from the country's long history of dependence on cheap energy and the reluctance of elected officials to tell voters that they will need to pay more for energy to help minimise environmental damage. The US federal government's stance is well known[94]. However, there appears to be growing momentum at the state level (e.g. California) to respond to curbing emissions. Moreover, some major corporations are becoming aware that they are at a growing disadvantage with their global competitors with regard to 'green' products.

There are a handful of 'green buildings'. For example the Durst office development on New York City's Times Square, and one of the few global US REITS – ProLogis – has said its energy-efficient-design experience in the UK could be replicated in countries like China and India, which are currently attracting much foreign investment and development. China and India are growing their real estate sectors very rapidly and, as

[94] *The United States, although a signatory member of the Kyoto Protocol, has not ratified it.*

high returns attract increasing levels of capital, the pace of construction continues to outpace global regulatory calls for 'greener buildings'.

A few years ago, California landlords quickly became focused on energy issues during a period of blackouts. This was, however, more focused on providing back-up generators than on conservation.

Spain has been the latest country to introduce tough new guidelines on newbuilds in an effort to raise its standards of energy efficiency. New residential and commercial developments are now required to be 30% more energy efficient than under the previous rules.

The UK could force developers overseas

In the UK, government's plans to reduce carbon emissions will likely have a significant impact on commercial property values.

Regulations state that new and refurbished buildings must meet new standards aimed at reducing carbon emissions from current levels by 27%. Architects are being asked to design buildings that emit less carbon (i.e. better insulation, increased levels of natural light, and more use of sustainable energy sources). London has introduced additional sustainability requirements on buildings in excess of 200,000 sq. ft. Currently, 10% of the energy consumed by buildings must come from on-site renewable sources (photovoltaics, wind turbines, heat traders, solar shading, etc). Some politicians want to increase this to 20%, but we think this is implausible: developers are already struggling to meet the current 10% quota, so achieving 20% would be almost impossible, given current technology.

Ultimately unachievable targets would likely curtail local development, which would run down the stock further or force developers to go overseas, where regulations might be less stringent. The general sector consensus is that a district-based energy approach is more practical than a building-by-building approach because off-site energy generation (i.e. out of town) is more cost effective than on-site generation, where economies of scale are limited.

A further requirement in London is that space should be left empty for future energy saving initiatives. This reduces the 'lettable' space, further reducing the developers' margins, i.e. costs are higher and achievable rents potentially lower.

EU harmonization and energy ratings

The EU plans to introduce energy performance certificates but the exact timing has not yet been established. Buildings will be awarded energy ratings and we think it is very likely that lower-rated buildings will attract lower rents. Larger companies with established environmental divisions, such as Land Securities, Unibail and British Land, should not be greatly affected, but smaller companies with run-down portfolios could incur additional compliance costs.

The next logical step would be to impose carbon taxes on inefficient buildings. To preserve the investment balance and capital flow, however, we believe energy efficiency policies must be cross-border. Additional carbon capping may have a detrimental effect on the UK real estate sector. Under existing EU carbon trading rules, individual buildings do not qualify for carbon trading; however under the UK trading scheme, individual buildings will have to comply.

Energy efficiency and functional obsolescence

Sustainability has become a reputational issue for the property sector and will be critical for attracting large, socially responsible corporate occupiers. DTZ, the property agency, estimates that 60% of occupiers consider whether a building is 'green', when making a renting decision. However in a recent survey, DTZ noted that only 27% would be prepared to pay higher rents. There is some debate as to whether companies will derive a benefit from direct investment in sustainable technology. In our view, property companies should concentrate on property, not on the development of technology. However, collective funding of third-party research houses may benefit the whole sector.

One of the key challenges property companies will face is the treatment of existing stock. Refurbishments will ultimately have to comply with new regulations; therefore, we would expect to see some polarisation between the larger, more efficient companies, which would most likely choose to upgrade stock, and smaller companies without the scale or financial capacity to do so. These are the companies that will likely suffer more from functional obsolescence.

However, landlords do not have sole responsibility for the energy efficiency. The landlord is responsible for only around 8% of the internal area of a building, whereas the corporate tenants are responsible for 92%. British Land, a leading UK property owner/developer, has formed environmental groups to engage with tenants to promote collective sustainability (i.e. at its Broadgate office complex in London). Land Securities also has an in-house energy management team. Companies developing these types of initiatives will ultimately be rewarded, in our view.

Mitigating physical risks

Within our European coverage universe, Land Securities and British Land have perhaps the most comprehensive sustainability and environmental programmes. Land Securities has had a climate change risk committee for more than two years. Strategies have been developed to consider the effects of climate change, e.g. subsidence in foundations caused by drought or heavy rainfall. Buildings are being designed with less obvious obstructions to wind flows in the event of more frequent and higher winds. The possibility of water shortages has been considered and the construction of larger water tanks in new development sites – e.g. three days water supply instead of one – should prove a competitive advantage in future. Landlords normally guarantee a certain level of temperature stability (i.e. air conditioning and heating) and must meet certain targets to avoid performance penalties. In the event of more extreme temperatures, lease terms could be amended to index performance to mitigate the risk of missing targets.

As noted in the body of this report, rising sea levels will almost certainly be a physical consequence of climate change. If we consider a 1m rise in the base case, most of the European stock can be protected. If levels increase further, there is an even greater risk to some of Europe's key financial areas and large pockets of commercial property, particularly in Amsterdam and London's Canary Wharf. ■

RETAIL

FOOD RETAIL

Matthew Truman
LBIE, London
+44 20 710 21154
matthew.truman@lehman.com

Peter Yik
LBIE, London
+44 20 710 24603
pyik@lehman.com

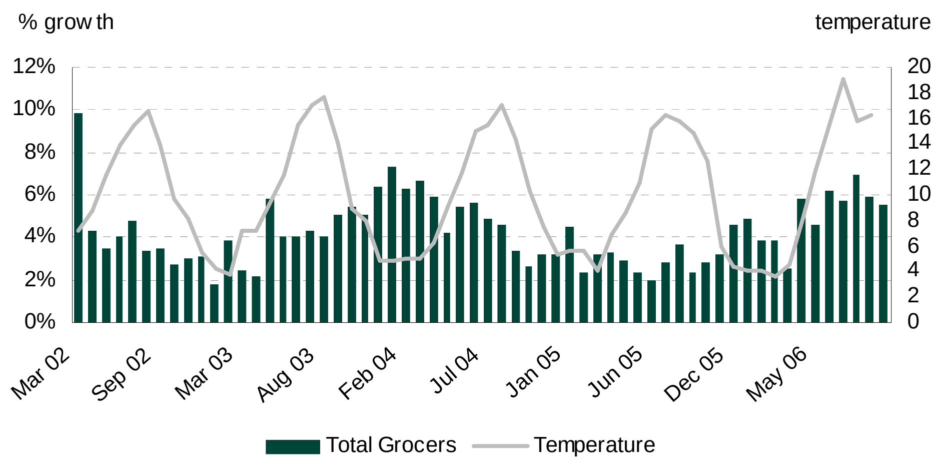
- *Global warming and consequent climate change will provide a balanced scorecard of risk and reward.*
- *As a consequence of climate change, we anticipate supermarkets moving back to a more localised infrastructure, in particular in supply chain sourcing.*
- *We preview how the future might look, and conclude that higher costs, such as energy costs, actually mean investment in higher 'green' orientated technologies, which can generate a return on investment for supermarkets that previously was not available.*

Linking the perceived risks of climate change already outlined in this document directly to food retailing; we consider inflation; falling GDP; increased carbon emission taxation, transport and energy costs; brand image; and sourcing costs and product mix, as having a direct effect on the key returns related relationship of sales, margins and space growth. Broadly we conclude that global warming and consequent climate change will provide a balanced scorecard of risk and reward which may de-globalise the supply chain and return the food retailing model to a more domestic proposition. Compensating this, we see considerable opportunity in the sales line around the higher margin categories.

The sales mix opportunity

Weather changes will drive an increasingly greater opportunity for food retailers. Global warming is now scarcely disputed and with predictions estimating temperature increases of around 2.5ºC over the next 100 years, the trend towards fresh produce should increase for food retailers. A reflection of space apportionment shows that fresh produce as recently as 2000 used to account for only 25% of a stores selling space. On recent visits, the traditional 30k sq ft supermarket has allocated 40-45% to fresh produce and organic foods. This is not in itself a consequence of the early recognition of global warming, but more a trend towards healthy eating. Nevertheless, supermarkets may be able to take advantage of a continued trend towards fresh produce. Although a more difficult product category to manage for a food retailer, it is generally a higher margin sale if wastage is minimised.

Figure A11. The relationship between temperature and grocery sales



Sources: TNS, and Lehman Brothers Research.

Increased taxation on carbon emissions is also likely to inflate input costs for supermarkets which may in turn be passed through to the end consumer. However, given a predicted fall in GDP and disposable income because of increased taxation, not all food retailers will win as volumes fall. The relationship between price and volume is crucial in maintaining margins, and inflation in the wake of low consumer confidence and falling spend is not therefore conducive to guaranteed success. An added effect of the increase in transportation costs is that consumers may be less willing to drive to out of town retail parks, leading to resurgence on the high street.

Managing supply chain costs

Global sourcing has not affected food retail in such a profound way as general retailers and in particular clothing retailers. Nevertheless, for those multinationals which operate global store networks while also having an exposure to non-food products, there are likely to be significant implications. Rising transport costs (via a tax on fuels for example) may offset the gain made from global sourcing and food retailers may be tempted to return to the traditional sourcing model. Significant streamlining and supplier rationalisation have largely led to the abandonment of local supplier networks by the global multinationals. A return to a nationally focused supplier chain would likely favour the highly flexible ‘on market’ national purchasing models. Arguably this would favour the medium-sized food retailer with a distinct cluster of stores in one geographic area. However, sourcing from the UK for instance is undoubtedly more expensive than the current globally diversified network. Gross margin may come under pressure as a result, although this may be mitigated by pricing increases across the board.

Administration costs

Although not the most material aspect of a supermarket’s cost base, transport, distribution centre running costs and intense mechanisation means costs could go up and affect already slender margins – especially if taxes are levied on carbon emission, and production and sourcing are returned to their more localised roots. With margins at some retailers as thin as 2-3%, any cost inflation could place margin pressure on the supermarkets over the longer term. Although we anticipate that transport costs are no more than 2-3% of sales, this is still 60% of EBITA in some instances.

Given the potential water level increase, it is feasible to expect that real estate prices may indeed rise. Significant flooding risk is advertised to occur, and hence retailers will have to come up with more robust and design orientated stores, especially on coastal locations or in countries such as the Netherlands, which are currently below sea level. This will add capital cost to the expansion process. In addition, if supply of real estate opportunities falls, then prices shall increase for land and property in general. With lower consumer confidence and GDP, an increasing disparity between house prices and consumer affordability will emerge, threatening the stability of the housing market. Increasingly many retailers may look for other selling channels, with the Internet and catalogues likely favourites to replace bricks and mortar as the key growth driver.

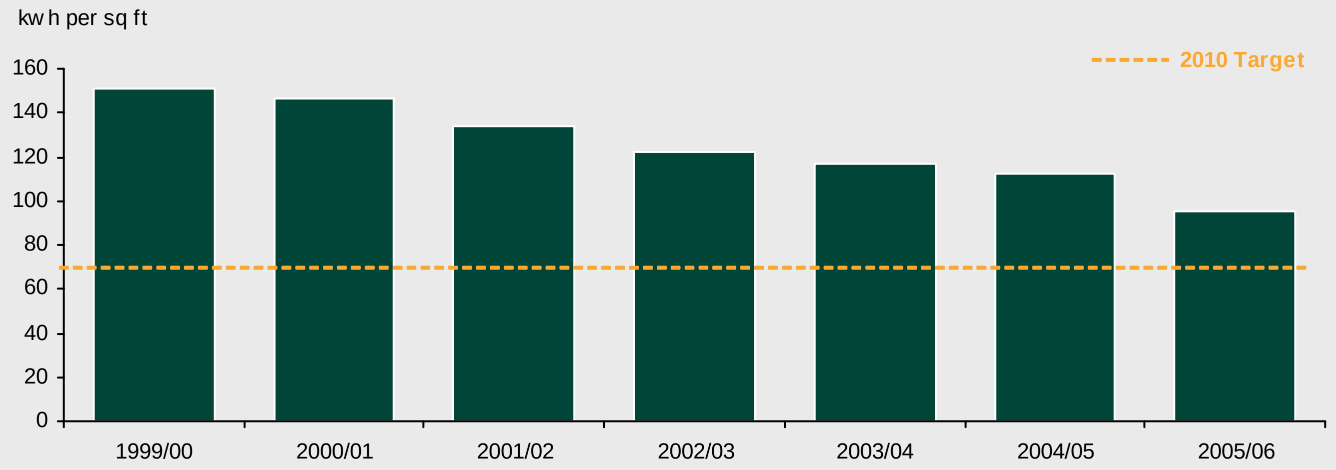
Tesco: a case study

In a bid to earn ongoing customer loyalty, many retailers have already started focusing on behaving in a responsible and sustainable way. Last year alone, Tesco achieved a 15% reduction in energy costs. Tesco has changed energy routines, installed more modern energy saving focused technology such as automatic timing controls and light sensitive switches and built a new energy database to track store by store progress. In addition, Tesco has announced a £100m investment in sustainable technology including wind turbines, solar power, geothermal power and gasification. The first ‘energy efficient’ store was in Diss in Norfolk and opened in December 2005. This store uses 20% less energy than an equivalent standard store. Tesco subsequently got better; the second store in Swansea saves 30% in energy costs. In addition, Tesco has launched promotions on sustainable products, for instance at 140 stores on GE low energy stick light bulbs. The overall target is to halve energy use per sq ft of store space by 2010.

The future

But, with its store in Wick, on Scotland’s Caithness coast, Tesco has gone further to adapt to the threat of global warming. The Wick store uses a range of energy-saving technology and clever design to dramatically reduce the carbon footprint of the store. In particular, it has been built with a timber frame instead of a steel one, saving 122 tonnes of carbon (or what 22 average households would produce in a year). All the building materials, too, were transported to Wick by ship in one load, in contrast to the 75 round trips by road (approx to 37,000 miles) that transport by lorry would have entailed. To let in the sunlight, the store has glass panels in a roof on which there are also wind turbines to power the tills (among other things). ■

Figure A12. Tesco’s improving energy usage



Source: Tesco Energy presentation.

GENERAL RETAIL

Frazer Ramzan
LBIE, London
+44 20 710 22593
framzan@lehman.com

Allegra Perry
LBIE, London
+44 20 710 21541
allegra.perry@lehman.com

Christopher Walker
LBIE, London
+44 20 710 24057
cwalker@lehman.com

- *Expect lower sector demand and increased seasonality/volatility.*
- *Higher costs in the supply chain may limit further gross margin gains and favours those with 'fast fashion' models which source in nearby markets.*
- *Multi-channel retailing (internet, home delivery, store) is likely to grow and has benefits in variability of costs.*
- *Returns may be sustained if capital costs are reduced (rent/freeholds), but this may take some time owing to the long property cycles.*

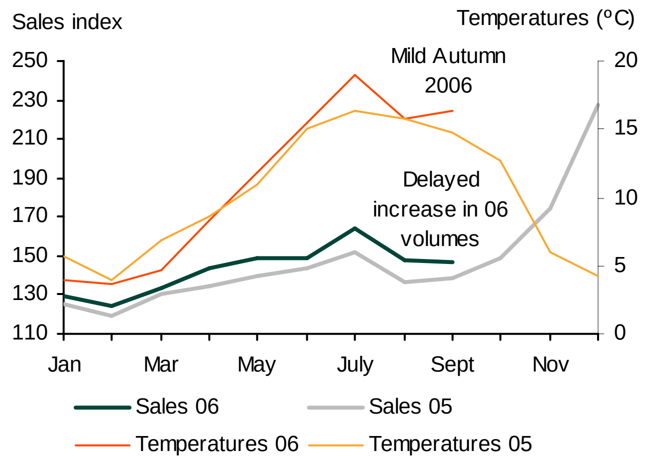
The retail profit/return equation is driven by three key factors: sales, margin and capital costs. These are in turn a function of demand, sourcing and real estate related factors. In considering the return implications of potential global warming it is sensible to judge the impact on these three factors.

Seasonality

The annual retail cycle today in Western Europe is driven by distinct seasonal factors (clothing is sold for autumn/winter and spring/summer) and related event-based marketing (Christmas, Easter, summer holiday). Looking at the annual demand for clothing in the UK it is clear that significantly larger volumes of heavier clothing items with a higher average selling price are sold in Autumn/Winter rather than in Spring/Summer. Frequent disruptions to supply chains are already occurring as a result of record changes to temperatures year over year. For example in September 2006, record warm temperatures led to a slowdown in clothing volumes relative to the previous year as consumers shunned autumn clothing. A warmer climate might lead to a lower absolute level of demand for clothing by value in the medium term, while the scenario which envisages colder temperatures in northern Europe as a function of a slowing Gulf Stream might have the opposite impact. Clothing retailers will need to adapt their design, buying and merchandising functions to accommodate this change. H&M for example has stated that it is hesitant (given its Swedish heritage) to expand in the less seasonal southern United States at present. A look at monthly clothing demand in the UK for example demonstrates these seasonal differences.

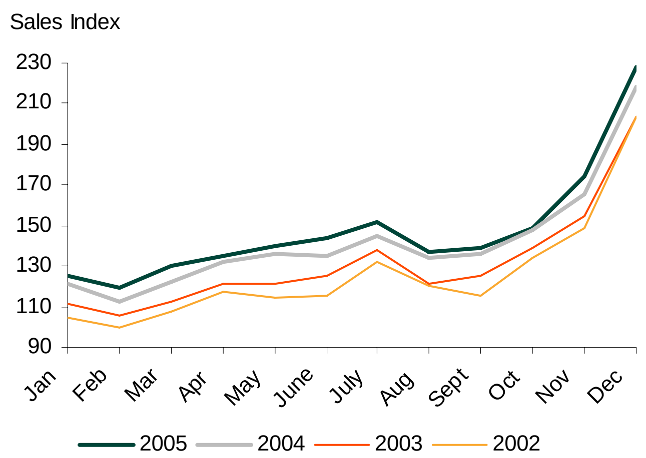
In the hardlines space (non-clothing products), demand for cooling appliances has increased dramatically in recent years, while garden/outdoor products continue to grow apace as climate change has stretched the outdoor season.

Figure A13. Temperatures and clothing sales



Source: Lehman Brothers Research.

Figure A14. Sales index in 2002, 2003, 2004 and 2005



Source: Lehman Brothers Research.

Changes to tastes

The most successful retailers we cover see their purpose principally as distributors to "give the customers what they want". As such the recent increase in consumer interest in environmental factors has already begun to influence product ranges. Organic vegetable box schemes locally sourced, detailed provenance information on food packaging, organic cotton textiles, wind turbines and solar panels now available in mass merchants such as B&Q and Curry's all suggest that this issue will dramatically change what consumers want to buy and where it will be sourced from over the next few years.

Higher prices

The doubling of clothing volumes sold over the past 10 years as global sourcing has reduced average selling prices by 35% attests to the price elasticity of demand for some retail products. M&S today sources 5% of its clothing sales in the UK vs. 80% in 1996. Value retailers and supermarkets have been able to take increase market share away from traditional department stores and mail order catalogues as new customer groups have been enfranchised to shop on the high street. However, for fashion retailers overseas, sourcing has a trade off of lower flexibility to respond to changing fashion trends.

Although globalisation has been profitable for the consumer, the environmental cost from transportation and textile production ranks among the highest (see earlier section). If increased carbon taxes were to significantly increase these elements of cost in the supply chain, it might encourage retailers to return to buying more of their goods closer to home. This would favour retailers of high fashion/quick turn product at the expense of those with more traditional/basic merchandise.

Table A4. Component cost of a typical pair of jeans sourced from China

Process	$	% Total price
Fabric	4.00	36.5%
Accessories	1.00	9.1%
Transport	0.17	1.6%
Production (of which labour $0.49)	2.00	18.2%
Processes	1.00	9.1%
Total	**8.2**	**74.5%**
Producer Margin	0.88	8.0%
Quota	0.65	5.9%
Shipping	0.16	1.5%
Duty	0.80	7.3%
Comms	0.30	2.7%
Retailer Cost	**11.0**	**100%**
Bought-in margin	60.0%	
Retail price	27.4	
	10.3	
	17.1	
Bought-in margin ex-quota	**62.4%**	

Sources: Marks & Spencer and Lehman Brothers Research.

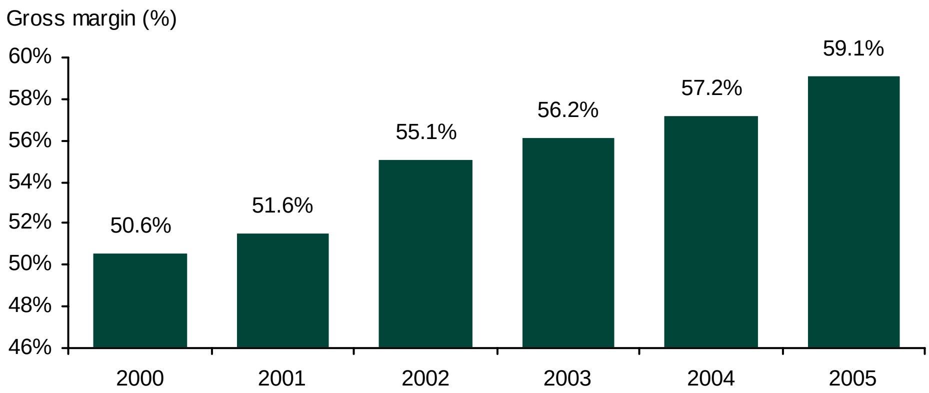
Gross margins

Over the past five years, gross margins have risen sharply in the non-food retail sector even as average selling prices have fallen. This to an extent reflects the benefits to the retailer of global sourcing (gains not passed on), but also greater accuracy with respect to predicting customer demand. Fashion retailers have one of the more 'perishable' garments as this season's product may not be to the taste of consumers next season. For the Autumn/Winter season retailers typically characterise late October as the 'point of no return' after which time adjustments to inventory cannot be easily made ahead of the post Christmas markdown/sale period. Increased volatility in global weather patterns/consumer demand, could lead to lower gross margins. In order to compensate for local cost increases, higher average selling prices would be necessary to compensate for lower volumes in order to maintain margins.

Operating costs

Although stock, staff and rent costs are by far the largest components of retail costs, the category of 'other operating costs' includes energy, local business taxes, insurance and distribution costs. The principal source of carbon emissions in the retailing process is in distribution from manufacturer to retailer distribution centre, consolidation of product and then onward to the store. This can account for around 5% of sales. At the store level, heat, light and power can account for 2-3% percent of sales. With retailers working to EBIT margins typically between 5-15%, sudden large shifts in energy costs can have a large impact on margins. With a typical 40% gross margin, most retailers 'need' around 3% annual like for like sales growth to absorb around 4% cost growth (from wages and rents) in order to hold cash profit margins. Although energy saving has become an area of increasing focus at the fast turn end of the supply chain in food retail, it has yet to become core to the operations of slower moving non-food retailers.

Figure A15. H&M gross margin



Source: Company data.

Property costs

Over the past few years strong growth in consumer demand has driven above trend retail sales growth and helped to drive strong growth in rental values in the commercial property sector. If the base case scenario of negative impact on GDP should prove accurate, this would undoubtedly impact on consumer demand, and in turn demand for property. The lumpy nature of the UK property cycle (25-year leases with 5-year upward only rent reviews), might mean that the lower rate of medium term growth becomes evident over an extended period of time. However, it is worth considering whether this will simply accelerate an already observed trend on the high street of lower footfall, driven in part by the emergence of the internet as a competing distribution channel. It is worth considering that one Tesco.com delivery van can fulfil 20 customer shopping visits, while the costs associated with online models of distribution are inherently more variable (e.g. Argos rents stores in secondary location with sparse staff, delivers 30% of sales to home and has a distribution cost/sales ratio 2x its peers).

In summary, it seems likely that the principal impact of climate change on the retail sector will be lower sector demand and increased volatility. Those retailers which can respond with more flexible supply chains – from design, buying and merchandising, to multi-channel distribution in store and for home delivery – will likely continue to generate strong returns. Lower levels of absolute demand and higher levels of inflation/costs may not mean lower return on capital as long as capital (rent, freeholds) is priced at a more moderate level. ■

TECHNOLOGY

TELECOM EQUIPMENT

Stuart Jeffrey
LBIE, London
+44 20 710 24702
sjeffrey@lehman.com

Navdeep Sheera
LBIE, London
+44 20 710 21912
nsheera@lehman.com

Tim Luke
LBI, New York
+1 212 526 4993
tluke@lehman.com

Overview

We expect the telecom equipment industry to be a net beneficiary of global warming. Potential demand drivers for new equipment seem likely to more than offset any increase in costs, with a focus on new technologies offering scope for market share changes.

Key industry features

The telecom equipment industry is heavily manufacturing focused, with manufacturing and related costs accounting for about 60-70% of total industry revenue. The customer base (telecom operators) is global and tends to use similar equipment across regions. Differentiation between vendors is driven by strong R&D (10-15% of sales), economies of scale in manufacturing and customer relationships.

Impact of higher energy prices

We expect rising energy prices to have a net positive impact on telecom equipment vendors. Although costs may rise a little, we believe that demand would likely rise faster still. This is particularly true for infrastructure equipment; in handsets the impact is likely to prove more muted.

We do not expect higher energy prices to have a dramatic impact on vendors' cost bases, owing to:

- Low energy intensive manufacturing processes (factories usually just assemble components);
- Low cost of transportation relative to total product cost – especially true for network equipment;
- Offset by higher component costs, as detailed in our semiconductors section below.

Demand for new equipment could be stimulated by higher energy prices though. The main drivers include:

- Faster replacement cycles if new equipment is considerably more energy efficient (a lot of equipment currently needs to be operated in an air-conditioned environment);
- Increased video conference calling as companies seek to reduce travel expenses, especially if the EU ETS is applied to airlines, thus boosting demand for network capacity and specialist applications.

Impact of rising sea levels

Should sea levels rise materially (which is still uncertain), network operators are likely to have to move/replace a significant amount of network equipment. First, equipment positioned in sites at risk of flooding would need repositioning. Equipment vendors benefit by offering to undertake this repositioning for operators and from some equipment likely being upgraded a little earlier than planned (see the *Telecom* section highlighting the cost to Bell South in the US of replacing equipment damaged by Hurricane Katrina in New Orleans). Second, displaced populations would likely require new networks to be built. These issues not only offer an opportunity for higher overall industry growth, but also for market share changes.

We do not see a significant risk to vendors' cost base from rising sea levels. Factories are relatively cheap and easy to relocate while retail networks are run by third parties. Some companies may have R&D facilities in flood prone areas, but these are again easy to move.

Extreme weather patterns

An increase in extreme weather patterns may benefit equipment vendors as governments look for better early warning systems. Once weather risks are identified, governments need to communicate with their citizens. TV and radio have traditionally filled this role, but mobile phones may prove better suited in the long run as almost everyone has a phone with them at all times.

Should winter weather patterns in the northern hemisphere deteriorate, people may become more housebound than is currently the case. The net effect could be to drive increased demand for personalised entertainment, likely provided over faster and more capable broadband networks. There is a positive correlation between good weather and mobile phone use, with Mediterranean countries having higher monthly usage levels than northern European countries – although some of this difference is likely cultural. Colder winters may thus reduce mobile phone usage, while warmer summers may increase it. As mobile networks need to be built for peak traffic, this may actually require increased investment in capacity, but also more flexibility in capacity allocation to ensure networks are not under-utilized in winter.

SEMICONDUCTOR INDUSTRY

Overview

We expect the semiconductor industry to see positive and negative effects owing to global warming, although the likely outcome is net negative at the outset. Many of the manufacturing facilities (fabs) are in potential danger zones, especially if sea levels rise materially but this is somewhat balanced by new equipment requiring a higher semiconductor content.

Key industry features

The semiconductor industry is also heavily manufacturing focused. On average, capital spending is up to 20% of sales, and R&D spending is around 15% of sales. The customer base is global, similar to telecom equipment, but much of the manufacturing bases for semiconductor companies and the customers are based in Taiwan, Korea and Japan. Although IP is a differentiator, economies of scale and scope are important also.

Impact of higher energy prices

Although we do not foresee a significant impact to semiconductor component pricing owing to increased energy costs (>80% of the cost of a semiconductor device is equipment), we would expect an impact owing to higher transportation costs. Although manufacturing of semiconductor devices tends to be concentrated in certain geographical regions, the packaging and testing is usually done elsewhere, and of course sales are worldwide. As a result, higher transportation costs will have an impact, but the scale of impact will be lessened to the high volumes of devices that are manufactured.

We would also expect an increased emphasis on the energy consumption of semiconductor devices and of the products they are sold into. This would impact R&D spent at the semiconductor component level, as companies strive to ensure that the devices manufactured are more energy efficient.

Impact of rising sea levels

For semiconductor manufacturing shorter term, we would expect a sizeable impact owing to rising sea levels. Many fabs are positioned in the probable danger zones. Newer fabs are being designed on a three layer basis, with the middle layer (possibly 10m above ground level) housing the mission critical equipment, but many of the supplies are at ground levels, which may imply an evolving need for additional protection.

Extreme weather patterns

Semiconductor fabs have tended to be at risk to earthquakes and other extreme non-predictable events and are no more immune from potentially more extreme weather patterns. It has been noted historically, however, that earthquakes in Asia have an immediate upward effect on semiconductor pricing, owing to fears of short supply. Thus stock pricing could be affected positively if supply is constrained owing to extreme weather patterns.

IT SOFTWARE AND SERVICES

Overview

We expect the net effect on the IT services and software sector from global warming to be positive. Given the low capital intensive nature of the industry, higher energy costs and regulations around it would only be a slight negative for the companies. This would be offset by an increase in demand for new solutions that would enable compliance in a more heavily regulated environment, more energy efficient manufacturing processes, increased surveillance and remote connectivity.

Key Industry Features

The IT services and software industry is significantly less capital intensive than most other sectors, with Capex to sales in the low single digit percentages. The industry mainly derives its value from IP and personnel capabilities. The customer base and manufacturing base (labour pool) to a large part is global, albeit concentrated more in North America and Western Europe. There is an increasing trend in the IT Services industry of work being shifted towards Asia (India and China), owing to the pervasive phenomenon of offshoring. Key differentiators in the IT services industry are technological/vertical expertise, global sourcing capabilities and scale. For the software industry, key differentiators are product offerings, R&D, scale and to a lesser extent global sourcing capabilities.

Impact of higher energy prices

Higher energy prices should not have a material effect on costs, given that energy costs account for a very small part of overall costs, and are mainly related to electricity charges for computer/office usage. Transportation costs are very minimal as well, given that the products are typically delivered online or through storage devices such as CDs. Personnel travel expenditure is decreasing gradually as well owing to better networks and increased capabilities to deliver solutions remotely.

Higher energy prices, however, would drive customers to increase spending in new logistics software/systems in order to reduce transportation costs, as well as software that would result in more energy efficient manufacturing processes. We would also expect customers to invest more in building up a more robust network that would enable more video conferencing, and thereby reducing travel expenses.

Impact of rising sea levels

The IT services/software companies do not have a disproportional high presence in coastal areas. Also, an increasing amount of work in the IT services/software space is being done remotely. Therefore rising sea levels would not dramatically increase costs, as the companies would gradually set up new delivery centres in less risk prone areas and the cost of shifting such facilities would not be prohibitively high.

Rising sea levels, however, would require customers to move away from coastal areas. This would cause an increase in spending towards redeploying IT systems in new locations, and possibly an upgrade in software systems related to this shift.

Extreme weather patterns

Increase in extreme weather patterns would result in higher expenditure by the government on weather surveillance as well as more spending by corporations on monitoring systems. It would also result in an increased need to enable working remotely from home. This would lead to increased spending towards new hardware and software products as well as a more robust network.

As increasing amount of work is being done in this industry from remote locations, this gives the industry a high degree of flexibility, when faced with inclement weather patterns in certain locations. Therefore, extreme weather patters would not significantly disrupt production/delivery of services. ■

TELECOM

Graeme Pearson
LBIE, London
+44 20 710 21602
grpearso@lehman.com

Keval Khiroya
LBIE, London
+44 20 710 21548
keval.khiroya@lehman.com

- *Telecom companies are generally considered carbon-light relative to their contribution to GDP.*
- *Impact of CO_2 emission regulation is indirect – telcos are one of the largest electricity consumers.*
- *They can be adversely affected by the increasing number of severe weather events.*
- *Telcos are in the unusual position of being able to do something to help offset the effects of climate change as the products and services can contribute to displacement of goods, and reduction of travel.*

Telecom companies are generally considered carbon-light relative to their contribution to GDP. However this does not mean that telcos' own carbon emissions can be merrily ignored, since they are still one of the largest electricity consumers. Also they can be adversely affected by the increasing number of severe weather events. But the Information and Communications Technology industry in general, and telcos in particular, are in the unusual position of being able to do something to help offset the effects of climate change as the products and services can contribute to displacement or rationalisation of the movement of goods, and reduction of travel.

One of the largest energy consumers

With the telco sector being one of the largest energy consumers, it is likely to be disproportionately affected by rising energy costs. For instance, BT estimates that it accounts for 2% of the electricity consumed by UK businesses. Although a large portion of the energy they use is now renewable (90% of the energy consumed by T-mobile Netherlands is green for example, as is 80% of Orange UK's), operators admit that a shortage of green energy forms may lead to considerable price increases, a problem likely to increase in the event of more businesses opting for renewable energy. Telecom operators also run some of the largest fleets and will therefore be impacted by controls on emission levels; Deutsche Telekom runs 41,000 vehicles in Germany and BT runs 32,000 vehicles in the UK.

Climate change is likely to increase the operators' energy demands: higher temperatures will result in more air conditioning in the exchanges; network damage will require trucks to be used for repairs; and operators are likely to run more back-up generators in areas experiencing extreme weather conditions. There is likely to be increasing demand for IP based networks, especially given the higher bandwidth and lower energy requirements than for copper networks. However, energy requirements are predicted to increase while the new IP networks are rolled out. A ramp-up in demand for broadband services will also increase energy needs – OECD broadband penetration is currently less than 40% but is expected to increase to more than 60% by the end of the decade.

Companies will try to mitigate the impact of higher energy costs and emission controls by generating renewable energy on their own sites and by using vehicles that rely on alternative fuel technologies. Some operators have already made progress on this front; France Telecom and Vodafone for instance are using solar energy in some of their exchanges and base stations while Deutsche Telekom and BT are introducing natural gas vehicles. This will help partially offset the impact of higher energy costs; but given the scale of energy consumed by the sector, it is unlikely to satisfy the total energy demand.

Physical risk to networks is significant

Extreme weather conditions could result in network damage and rising insurance costs. For example, TeliaSonera's fixed network last year faced damage costs equivalent to 2% of sales as a result of the storms in southern Sweden. The damage is likely to be worse in

North America, where more severe weather conditions are predicted; BellSouth last year estimated that Hurricane Katrina resulted in US$400m worth of network damage.

As a result, operators are thinking carefully about where to place the new nodes for next generation networks and are working on more resilient, water-tight cable joints. Operators are likely to invest in protecting or relocating elements of their network which could become exposed to damage from severe weather conditions. Wireless networks have in general proven more resilient to extreme weather and could therefore attract additional investment.

After the severe 2005 hurricane season, companies like Inmarsat saw increased interest in hybrid terrestrial and satellite networks with obvious users being various emergency response units. Cingular, for example, invested US$60m in a mobile command centre which provides satellite communication capabilities in the event of network failure, highlighting that the satellite sub-sector may be a beneficiary.

The poorest developing countries will be hit earliest and hardest by climate change, even though they have contributed little to causing the problem. Any negative effect on farm incomes will increase poverty and reduce the ability of households to invest in a better and higher technology future. One study suggests, for example, that more than a fifth of Bangladesh could be under water with a 1m rise in sea levels, highlighting the risk to telecom companies investing in such regions.

But telecom forms part of the solution

People and businesses are still only taking advantage of a tiny fraction of services available via the internet. So there is a significant opportunity for telcos in the development and marketing of innovative products and services which reduce dependence on carbon-intensive travel, especially as travel becomes more expensive. The sector could also possibly benefit from less severe regulatory measures; recognition of the positive externality the sector creates by allowing others to reduce energy consumption.

Companies may opt for homeworking, video conferencing, electronic billing and online filing of tax returns for example. A Deutsche Telekom study showed that a video conference over a distance of 100 km uses less than 5% of the primary energy that would be consumed if the participants were to travel by car – much more with increasing distances and the use of air travel. Companies may choose to relocate operations to areas where energy costs are lower or where regulation is more benign.

Consumers may do more online shopping, watch IPTV and engage in social networking over the internet at home. Academic institutions can use online learning to teach a worldwide student body. There may also be opportunities for telcos to provide carbon management services, including data monitoring and facilitation of carbon trading.

Mobile phones may be well suited to address some of the issues, although curtailed travel (including via the impact of EU ETS) could reduce roaming revenue. Text messages can be a powerful tool for early warning of tsunamis, while Scandinavian utilities have started to introduce electricity and gas meters that can be read via SMS. China Mobile provides information to help farmers optimise crop rotation depending on weather conditions and also the latest pricing for agricultural products. In Japan, users can remotely adjust the temperature in their homes and receive updates to help avoid traffic congestion.

What remains unclear is how much further the telcos should and could go. There will be a clear limit to homeworking in terms of practicality, but what is it? How much further can teleconferencing reduce travel? And in what ways can the telcos actively encourage this change? One thing that seems certain is that these new products and services will become an ever more important backbone of social and economic life within a carbon-constrained world. ■

UTILITIES

Martin Young
LBIE, London
+44 20 710 21536
martin.young@lehman.com

Anuradha Parekh
LBIE, London
+44 20 710 22119
anuradha.parekh@lehman.com

Daniel Ford
LBI, New York
+1 212 526 0836
daford@lehman.com

- *Individual country CO_2 national allocation plans (NAPs) for the second phase of the EU Emission Trading Scheme (ETS) are currently being analysed by Brussels – we expect further tightening to ensure that the correct signals are sent.*
- *We look for upward pressure on utility company budgets as renewables, clean coal, and nuclear are all built up.*
- *The US is behind the curve, but beginning to catch up.*
- *Clean coal technology is being developed, and carbon capture and storage could be in use by 2014 – we profile the technology.*
- *Climate change will cost, and power prices look well supported – great for utility profits but bad news for energy intensive industries.*
- *Companies set to benefit include EDF, RWE, E.ON, Suez, Entergy, Excelon, Florida Power and Light, and Constellation Energy.*

Climate change has been a significant issue for the energy sector for some time now, and the industry has arguably made greater strides in addressing change than have many others. Many utilities already have significant portfolios of renewable generation assets (usually wind), and the introduction of the EU Emission Trading Scheme (ETS) has had a significant influence on electricity prices across the continent, as well as investment decisions for replacement capacity. Dry and hot summers could also scale back hydro production, and require river water cooled power plants to be operated at reduced power (e.g. EDF in 2003 and 2006).

The EU ETS – the story so far

In addressing the issue of how climate change affects the power sector, the logical place to start is with a brief overview of the ETS. The first phase of the ETS kicked off on 1 January 2005, with four broad activities covered by the scheme: energy activities, production and processing of ferrous materials, the mineral industry, and other activities. It is estimated that these four activities account for 46% of EU CO_2 emissions and, with 52% of this coming from the energy sector, it is clear that the development of the scheme is of critical importance to the sector, especially given the long duration of assets.

Under the ETS, each power station with a capacity exceeding 20MW is required to have a permit for each tonne of CO_2 it emits, such permits being allocated via the National Allocation Plan (NAP) of the country in which it is located, or purchased either as a EUA (EU Allowance) or via what are known as flexible mechanisms[95]. As far as the ETS is concerned, the initial stage of Kyoto consists of two phases, I and II, and it is in phase II that the EU-23[96] countries have to meet their obligations under what is known as the Burden Sharing Agreement.

The introduction of the ETS saw the price of EUAs increase sharply in the first half of 2005, owing to the upward trend in gas prices and adverse hydro conditions in Iberia, hitting a peak of EUR 29.15/t in July, before settling around the EUR 22/t level in the second half of the year. The early months of 2006 saw a similar pattern, with the traded price hitting EUR 30.55/t in April before collapsing to EUR 11.45/t (see Figure A16) as initial indications regarding 2005 emissions pointed to a significant surplus of EUAs when compared to phase I NAPs, something which the verified emissions data (see table A5) upheld.

As indicated above, the market fall in EUA prices in late April was due to initial indications that there would be a significant surplus of EUAs in 2005 when consumption

[95] Joint Implementation (JI) and Clean Development Mechanisms (CDM).
[96] Malta and Cyprus do not have greenhouse gas emission reduction targets under the Kyoto Protocol.

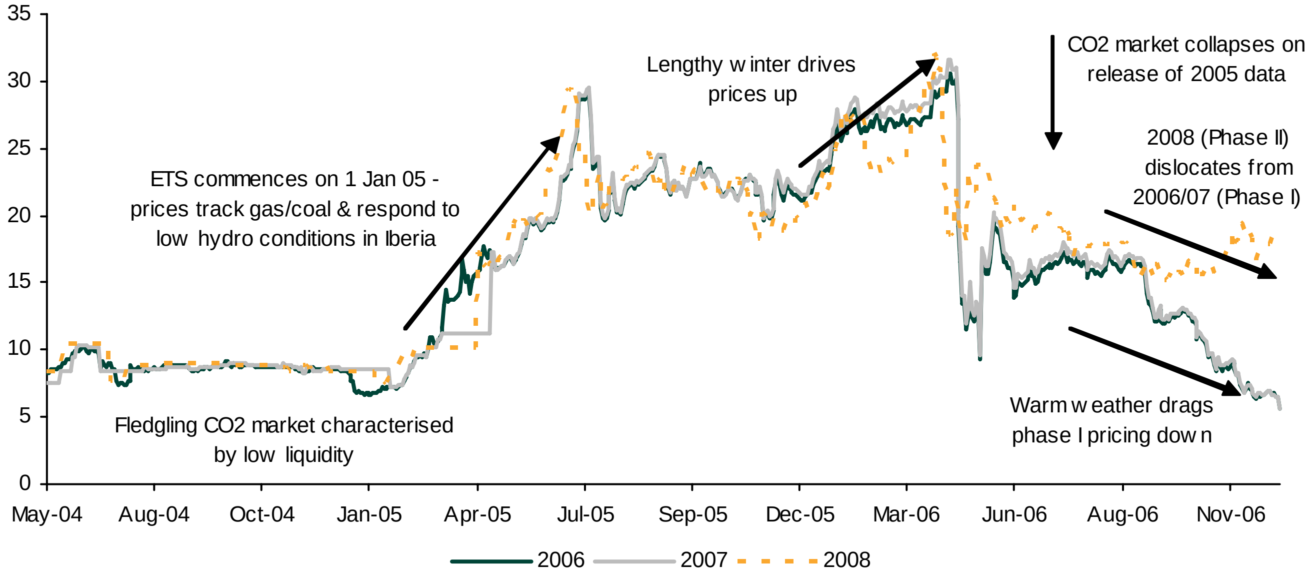
was compared to actual allocations. This indeed proved to be the case; as can be seen from table A5, we estimate that the EU 25 was in surplus by approximately 73mt in 2005; the fact that surplus EUAs can be transferred from year to year within a phase is one of the reasons why the Phase I price has continued to trend down. The dislocation of the 2006-07 prices from the 2008 price, however, is due to the fact that EUAs can be transferred to phase II only in limited and specific circumstances.

Phase II is drawing ever near – the EC has already ruled on a number of NAPs

But why has the phase I price not fallen to zero as simple economic theory might suggest? There are a number of possible explanations, including the fact that demand for EUAs is likely to have increased in 2006 as the winter was longer, and there is every possibility that the supply side has held back from trading permits. In our opinion, however, the EUA price in phase I is of decreasing relevance to the utility companies, owing to relatively good coverage from free allocations, and the hedging strategies that have been adopted. Phase II is a completely different issue, and it arguably is here that the worlds of climate change and utility strategy really collide.

At the time of writing, 23 of the EU 25 had submitted[97] draft phase II NAPs, though many did not meet the 30 June 2006 deadline. At present, these plans appear to indicate a limited amount of tightening in phase II NAPs relative to phase I, but at levels above verified emissions for 2005. Given that EEA's recent report *Greenhouse Gas Emission Trends and Projections in Europe 2006* indicated that Kyoto mechanisms[98] and carbon sinks will be needed to meet Kyoto obligations, we support the view that NAPs will be tighter in phase II. However, prices in the ETS will be determined by supply and demand, and therefore allocations relative to historical emission levels are arguably of greater importance, and if 2005 is taken as the base year, the future of the ETS does not look that rosy. The EC recognises this and, in ruling on ten phase II NAPs, has called for a 6.9% reduction against submitted plans.

Figure A16. EUA price evolution (May 04-Jan 07, EUR /t)



Sources: Reuters and Lehman Brothers Estimates.

[97] *Or published consultation papers.*
[98] *ETS, Clean Development Mechanisms (CDM) and Joint Implementation (JI).*

Table A5. EU ETS – Phase I NAPs, phase II draft NAPs and 2005 out-turn

Member states	BAU 1990 level (A)	2003 level (B)	Ph 1(2005-07) ETS Allocation (C)	Average annual ETS allowance (mt) (D=C/3)	Implied % CO_2 within ETS (E=D/B)	2005 ETS Allocation (F)	Reported (G)	Surplus/ (shortfall) (I=G/D-1)	Draft phase II (mt) (N)	% increase/ reduction from 2005A (O=N/G)	% increase/ reduction from phase I (O=N/D)	EC decision (mt) (P)	% Cut (P/N)
Austria	79	92	99	33	36%	**32**	**33**	3%	**32.8**	-1.7%	-0.6%		
Belgium	147	148	189	63	43%	**58**	**55**	-5%	**63.1**	14.1%	0.3%		
Cyprus	6	9	17	6	62%	**6**	**5**	-7%	**7.7**	51.6%	36.4%		
Czech Republic	192	145	293	98	67%	**97**	**82**	-15%	**97.0**	17.6%	-0.6%		
Denmark	70	74	101	34	45%	**37**	**26**	-30%	**24.5**	-6.1%	-26.9%		
Estonia	44	21	57	19	89%	**17**	**13**	-25%	**24.6**	94.7%	29.6%		
Finland	70	86	137	46	53%	**45**	**33**	-26%	**39.6**	19.7%	-13.0%		
France	568	557	470	157	28%	**150**	**131**	-13%	**156.1**	19.0%	-0.3%		
Germany	1,248	1,018	1,497	499	49%	**495**	**474**	-4%	**482.0**	1.7%	-3.4%	**453.1**	**-6.0%**
Greece	112	138	223	74	54%	**71**	**71**	0%	**75.5**	6.3%	1.5%	**69.1**	**-8.5%**
Hungary	122	83	94	31	38%	**30**	**26**	-15%	**30.8**	19.9%	-1.3%		
Ireland	54	68	67	22	33%	**19**	**22**	16%	**22.6**	0.9%	1.2%	**21.2**	**-6.4%**
Italy	510	570	698	233	41%	**216**	**224**	4%	**197.0**	-11.9%	-15.3%		
Latvia	25	11	14	5	43%	**4**	**3**	-30%	**7.7**	169.8%	68.6%	**3.3**	**-57.1%**
Lithuania	51	17	37	12	71%	**14**	**7**	-51%	**16.6**	151.4%	35.3%	**8.8**	**-47.0%**
Luxembourg	13	11	10	3	30%	**3**	**3**	-23%	**4.0**	51.9%	17.3%	**2.7**	**-31.6%**
Malta	2	3	9	3	101%	**3**	**2**	-30%	**3.0**	49.5%	0.9%	**2.1**	**-29.1%**
Netherlands	213	215	286	95	44%	**86**	**80**	-7%	**77.9**	-3.1%	-18.3%		
Poland	565	384	717	239	62%	**214**	**201**	-6%	**270.5**	34.7%	13.1%		
Portugal	59	81	115	38	47%	**37**	**36**	-1%	**33.9**	-6.8%	-11.1%		
Slovakia	72	52	92	31	59%	**35**	**25**	-29%	**41.3**	63.6%	35.4%	**30.9**	**-25.2%**
Slovenia	20	20	26	9	44%	**9**	**9**	-5%	**8.3**	-4.8%	-5.3%		
Spain	286	402	523	174	43%	**172**	**183**	7%	**152.7**	-16.5%	-12.5%		
Sweden	72	70	69	23	33%	**22**	**19**	-13%	**25.2**	30.5%	10.0%	**22.8**	**-9.5%**
UK	751	651	736	245	38%	**206**	**242**	18%	**246.2**	1.6%	0.4%	**246.2**	**0.0%**
Total	**5,352**	**4,925**	**6,572**	**2,191**	**44%**	**2,079**	**2,006**	**-3.5%**	**2,140.6**	**6.7%**	**-2.3%**	**860.2**	**-6.9%**

Sources: European Environment Agency, Point Carbon, European Commission, and Lehman Brothers estimates.

In our opinion, all is not lost:

- The EC has invested a significant amount of political capital in Kyoto compliance, and the success of the ETS. It appears that during 2007 the EC will make proposals to amend the ETS, though these are unlikely to come into effect until the third trading period in 2013.
- Climate change is being pushed up the agenda with publications such as the Stern Review, and it would not be unreasonable to contemplate that stiffer targets will be set in the course of time.
- Discussions are ongoing as whether transport is brought into the scheme.
- 2005 was warmer than average, reducing emission levels.
- The EC which has ruled on ten phase II NAPs required cuts in all bar that of the UK, with the overall reduction versus submission being 6.9%. We expect further cuts when the EC rules on the remaining plans.

In our opinion, demand for EUAs will exceed supply in phase II, hence ensuring that a market remains, and that abatement measures will be needed. The energy sector remains best placed to undertake such measures, the simplest of which is the switch between coal and gas, the economics of which can be used to estimate the market price of CO_2, on the basis that, above certain levels, the switch makes economic sense.

Our analysis based on the base case assumptions of EUR 55c/therm gas and US$22/tonne coal suggests that the so-called indifference CO_2 price is EUR 24/t (see Figure A17), in line with the EUR 25/t that we factor into our models. Based on current exchange rates, this is very slightly above the implied CO_2 price from an analysis of the costs of building a carbon capture and storage equipped coal plant.

The ETS will drive investment decisions – Capex could increase

The simple conclusion of the above is that gas (CCGT) plant should progressively replace coal plant, but there is a technological limit as to how far abatement in this way can go, as well as questions over the price and security of gas sourcing. The energy sector is therefore likely to look at alternative measures, which will have implications for capital expenditure budgets:

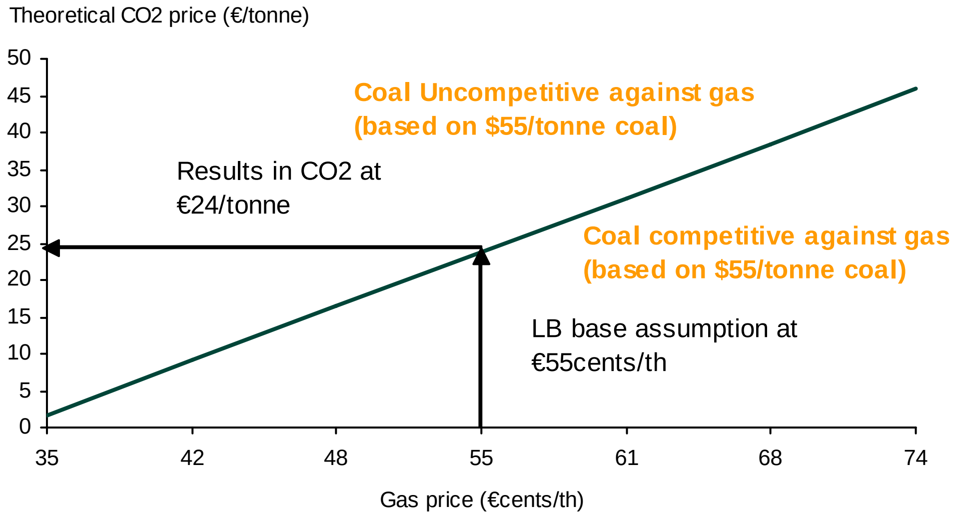
- **ERUs and CERs** – these relate to JI and CDM projects, respectively, and are an alternative form of abatement. Various estimates (Point Carbon et al.) put the average cost of such projects within the EUR 5-10/tonne range but, as emission reductions are made outside the EU, the decision about the extent to which they can be admitted into the ETS is largely political. The EC will set limits on the amount of JI/CDM credits that can be used, but 10% of an installation's emissions are to be taken as a minimum. Companies that are active developers of such projects include Endesa and EDF.

- **Renewables** – many utility companies have already invested significant capital in renewable capacity (mostly wind), and countries such as Germany and Spain are well penetrated. Other countries are playing catch-up, and we expect that investment in renewables will become an increasingly important part of utility company budgets over the rest of the decade, especially given that the EC will set out a medium-term roadmap in January. Companies at the forefront of renewables development include Iberdrola, ScottishPower, EDP and EDF Energies Nouvelles.

- **Clean coal technology –** another area which will receive EU backing in January, clean coal technology in its simplest form involves reducing carbon intensity, but there are projects under development by E.ON and RWE that seek to develop CO_2-free coal generation. Compared with conventional coal technology, the construction cost per MW is double; so the potential impact on Capex budgets is clear. We profile this in more depth later in this chapter.

- **Nuclear –** a technology which is undergoing a renaissance, nuclear new build is on the agenda of many countries, with plants already under construction in Finland and in France. CO_2 free it may be, but the cost (around EUR 2m/MW) will put upward pressure on utility budgets.

Figure A17. CO_2 indifference price



Source: Lehman Brothers estimates.

Capex is therefore likely to increase as a move to cleaner forms of generation gathers pace, which will impact the utilities at one level; but all of this has to be paid for, and the cost of environmental compliance does not come cheap. With an assumption of EUR 25/t CO_2 in phase II, and the need to finance new build, we look for power prices to be well supported at EUR 50/MWh, particularly given the costs of clean coal and renewable technologies. This should be good for the sustainability of utility company profits, with the impact on other industries being discussed in the rest of this report. Those companies that have significant generation portfolios are best placed to benefit, particularly those with nuclear capacity. In this respect, we highlight EDF, RWE, E.ON, Fortum, and Suez.

The US – behind the curve, but starting to play catch-up

Compared with Europe, the US is behind the curve, but is seemingly now beginning to take the issue of climate change more seriously. Moving ahead of regulation at the national level, a group of Northeastern state governors are developing a regional cap-and-trade plan to reduce CO_2 emissions from power plants. A working group has crafted a model rule, made public in August, which established a common structure and enforcement regime. Each member state now needs to adopt a version of the rule, either through legislation or via regulatory rulemaking. In most cases, the states have approximately a year to ratify the agreement, leaving most of 2008 to implement the distribution mechanism (likely an auction) for the 25+% of allowances held back for public benefit.

Participating states include Connecticut, Delaware, Maine, Maryland, New Hampshire, New Jersey, Rhode Island, and Vermont. Maryland has enacted a law requiring the Governor to sign onto the Regional Greenhouse Gas Initiative (RGGI) in 2007. Pennsylvania and Canada have also sent representatives to observe the process. Key elements of the model include:

- In general, RGGI will cover power plants with capacity equal to or greater than 25MW which burn more than 50% fossil fuel.
- Similar to SO_2 and NOx emissions programs, RGGI establishes an emissions baseline (average carbon emissions from 2003-2005), issues credits based on those historical emissions, and then ratchets down the granted emissions over time to achieve aggregate carbon reductions. Emission allowances can be banked or traded. At least 25% of emission allowances will be set aside for public benefit purpose,

such as promoting renewable energy and energy efficiency, or to mitigate possible increases in consumer energy prices. Vermont and New York have proposed setting aside 100% of their allowances.

- Offsets will be allowed, with the level depending on the price of the allowances. The RGGI states have agreed to a set of standards for five initial offset categories.
- There will be a rolling three-year compliance period, which should mitigate costs from of single-year weather events and energy price spikes.

The framers of the initiative have used a nationwide power sector model (IPM, the same model used by the EPA) to forecast emissions allowance prices under a variety of different scenarios and, on the basis of offsets meeting about 50% of the required CO_2 reductions, have suggested low single-digit marginal costs for allowance pricing under the RGGI regime. We remain very cautious about these conclusions, as data from the EU ETS indicates that few such low-cost offsets exist, with our estimate for allowance pricing in phase II of the EU ETS being considerably higher at EUR 25/t. In our view, the price of emissions allowances should converge to the marginal cost of compliance via pollution control, such as clean coal technology which we profile later in this chapter, and our analysis suggests that such technology would be viable at allowance prices in excess of US$29/t.

RGGI earnings impacts

At this stage, we have not presented an analysis of the possible earnings impact of such a scheme at an individual company level, preferring to make general observations about how it could affect unregulated generators in the participating states. Our key conclusions are:

- Although nuclear generators benefit considerably under all potential scenarios, RGGI also looks to be accretive to coal and gas-fired generators under most scenarios.
- Generally speaking, generators do better in scenarios with a smaller amount of allowances auctioned. Analysis of marginal economics (e.g. nuclear operators) indicates that auctioning 75% of the allocated allowances makes the net effect of compliance margin-neutral. Granting less than 75% amounts to a windfall for utilities, whereas auctioning a larger proportion generally has a negative impact on margins. Higher emissions price scenarios have divergent effects on generators. For nuclear operators, increased EA costs are unambiguously good, as power prices increase without additional cost. For fossil-fired generators, increased emissions costs may be positive or negative, depending on a host of factors related to generation mix, relative carbon intensity, and regional price-setting fuel.
- When emissions caps begin to ratchet down in 2015, changes in fossil-fired profitability will be determined by the continued availability of low-cost offsets, as well as regulatory re-jigging of the allocation scheme. Any perceived windfall profits may be legislated away after the initial compliance phase.
- Nuclear operators such as Exelon, Entergy and Constellation Energy would be the unequivocal beneficiaries of any carbon regime. Florida Power and Light would also benefit via its nuclear and wind asset portfolio.

Federal legislation

Though there are currently no mandatory federal compliance limits on CO_2 emissions, sentiment in Congress has moved towards recognizing the issue's importance (illustrated by the non-binding 'Sense of the Senate on Climate Change' resolution in 2005).

Several bills have been introduced in Congress in the past few years. In 2005, the Climate Stewardship Act introduced by Senators McCain (R-AZ) and Lieberman (D-CT) was voted down 60-38, but variations on the cap-and-trade approach have since been offered by multiple legislators. In 2005, Senator Bingaman (D-NM), now the chairman of the Senate Energy Committee, drafted but did not formally introduce a bill outlining his preferred approach. In 2006, Senators Jeffords and Boxer (D-CA), now chairman of the Senate Environment and Public Works Committee, and Senators Kerry (D-MA) and Snowe (R-ME) introduced two alternative cap-and-trade bills. Senator Feinstein (D-CA) has offered another approach in draft legislation expected to be introduced shortly, and Senators McCain and Lieberman are expected to release a revised version of their bill in 2007 as well. In addition, Senator Carper (D-DE) has offered a bill that would cap CO_2 emissions along with other pollutants from the utility sector. Multiple bills have been introduced in the House of Representatives as well.

The consensus view around federal involvement in regulating CO_2 emissions seems to be that greenhouse gas controls are in some sense inevitable, though there is some disagreement around timing. Though most pundits previously discounted the likelihood of passing climate change legislation before Bush's departure, there are some indications that the newly elected Democratic majority may not be prepared to wait that long. Intimations from Senator Boxer point towards more vigorous efforts to move the carbon issue to the fore.

A recently circulated theory posits that Senator Boxer may have support from an unlikely ally, namely the utility industry. The logic behind this is that most utilities have begun to see carbon regulation as a matter of 'when' rather than 'if', and that some firms and industry lobbyists may well be hoping to push legislation through while they are still in a position to help shape it. Some in the industry sector have even called for a carbon tax rather than a cap-and-trade system. From their perspective, a more uniform US$/t$CO_2$ tax might provide a number of advantages, including avoiding the risk of perceived egregious windfall profits that have plagued the European ETS system of late, earmarking of the proceeds towards federal carbon capture R&D, and provision of political cover for Republicans (including the President) who can refuse to support the program because it is a tax.

This discussion may be mooted entirely if a recession or runaway power prices put costly environmental fixes on the back burner. On the other hand, it may accelerate dramatically if an event, such as a uniquely damaging weather event, spurs the public's demand for action. Nevertheless, on balance, we see the institution of carbon regulation in the form of a nationwide tax or cap-and-trade system as a 2009-10 event (with implementation in 2012), likely precipitated by growing advocacy efforts as well as leadership from the White House.

Clean coal technology – a snapshot

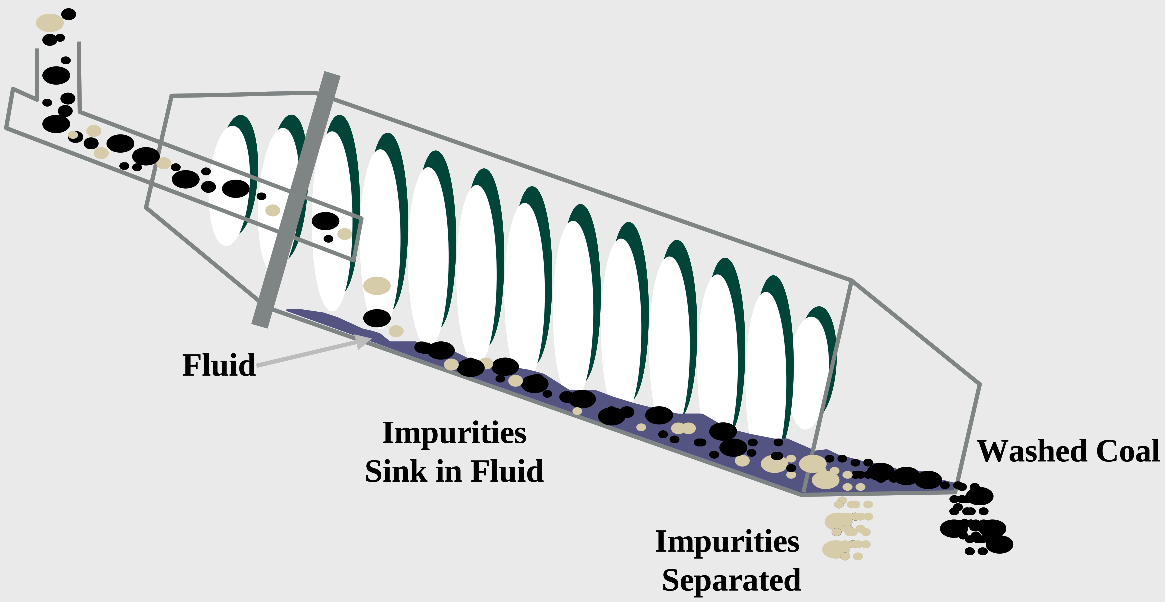
We made reference earlier to clean coal technology (CCT) as being a possible growth area for electricity generation in the future: but what is it?

Clean coal is the name attributed to coal that is chemically washed of minerals and impurities, sometimes gasified, which is then burned, with the resulting flue gases treated with steam to almost completely eradicate SO_2, and then re-burned so as to make the CO_2 in the flue gas economically recoverable. The CO_2 can then be captured and stored instead of being released into the atmosphere. In the wider sense, CCT encompasses all or some of the following techniques:

Coal preparation

Coal arriving at a power plant contains mineral content that needs to be removed before it is burnt. A number of processes are available to remove unwanted matter and make the coal burn more efficiently, i.e. with reduced SO_2 emission. One of these is coal washing which involves grinding the coal into smaller pieces and passing it through a process called gravity separation. The coal is fed into barrels containing a fluid that has a density which causes the coal to float, with unwanted material sinking and being removed from the fuel mix. The coal is then pulverised and prepared for burning.

Figure A18. Coal washing



Source: Department of Trade and Industry.

Integrated gasification combined cycle systems

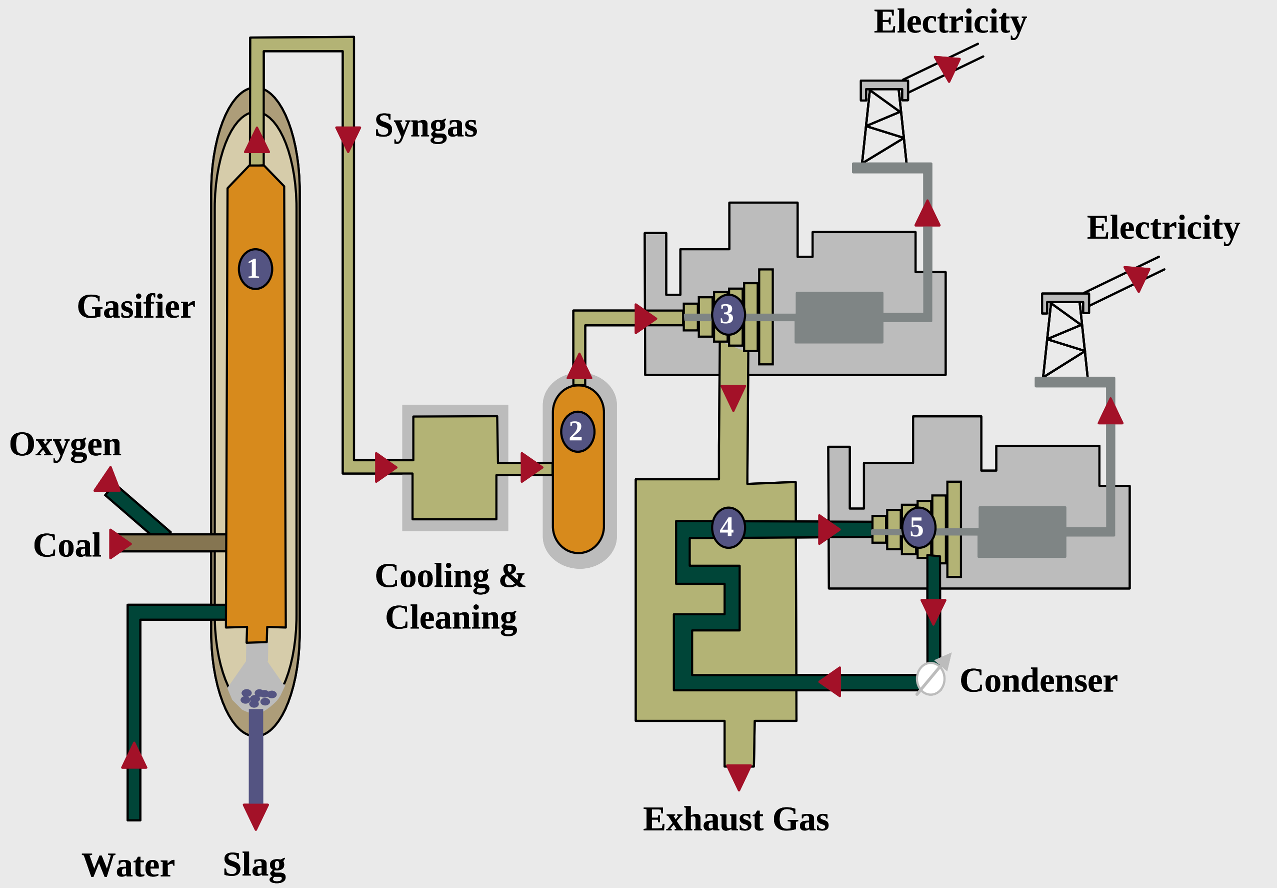
Coal gasification plants are finding favour with some because of their flexibility and efficiency, with Integrated Gasification Combined Cycle (IGCC) arguably the technology of choice. Here the burning of the washed coal does not drive the turbine, but instead it is burnt with oxygen and steam to form a 'syngas' (mainly hydrogen) via a three-step process. Higher thermal efficiencies than in a regular coal plant are achieved, as the burnt gas drives both a gas and steam turbine, while corrosive ash elements such as chloride and potassium can be refined out by the gasification process, allowing higher combustion temperature.

Four IGCC plants already exist, two in the US and two in Europe (Spain and the Netherlands). The technology is now being developed to include a second stage, involving a 'water-shift reaction' to produce a concentrated and pressurised CO_2 stream which can then be separated and geologically stored, with the hydrogen produced, firing the gas turbine. It is this technology that has the potential to provide the so-called 'zero emissions', (in reality, extremely low emissions of the conventional coal pollutants and low CO_2 emissions), as can be seen from Table A6, is economically viable at allowance prices in excess of US$29/t (EUR 15/t). IGCC is a focus for an increasing number of operators in the sector, notably RWE.

Table A6. Cost comparison of IGCC and clean coal technology in US

	IGCC			Pulverized Coal		
	No Capture	**Carbon capture**	**Change**	**No capture**	**Carbon capture**	**Change**
Net capacity (MW)	425	405	-5%	462	329	-29%
Heat rate (Btu / kWh)	7,915	9,226	17%	8,841	11,816	40%
Capital cost (US$ / kW)	$1,251	$1,844	47%	$1.281	$2,219	73%
Energy costs						
Capital	$30.30	$44.70	48%	$31.10	$53.80	73%
O&M	$7.60	$9.60	26%	$10.00	$17.10	71%
Fuel	$9.80	$11.40	16%	$10.40	$14.70	41%
Total	**$47.70**	**$65.70**	38%	**$51.50**	**$85.60**	66%
CO_2 capture cost (US$ / ton)		$24			$35	
Sequestration cost		$5			$5	
Implied EA cost (US$ / ton)		$29			$40	

Figure A19. Integrated coal gasification combined cycle plant



Source: World Coal Institute (1. Coal burnt to produce syngas, 2. Syngas burnt in combustor, 3. Hot gas drives gas turbines, 4. Cooling gas heats water, 5. Steam drives steam turbines).

Post combustion technology

Burning coal produces a range of pollutants that harm the environment: SO_2 (acid rain); NOx (ground-level ozone); and particulates. There are a number of options to reduce these emissions, and the main advantage of these technologies is that they can be retrofitted onto existing stations. Post combustion technology, as it is known, is already in wide commercial use.

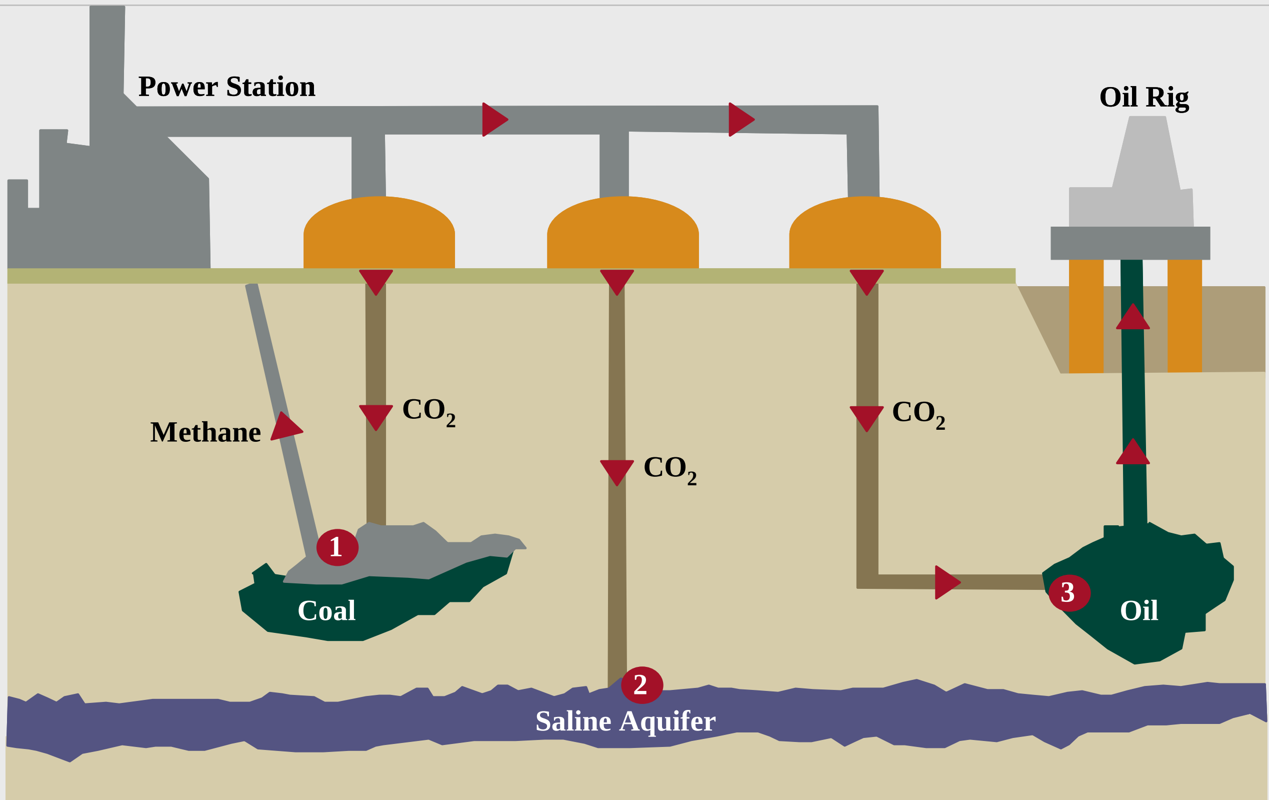
- **SO_2** - Flue gas desulphurisation (FGD) systems are used to remove SO_2. 'Wet scrubbers' are the most widespread method, and can be up to 99% effective (depending on the level of sulphur in the coal).
- **Nitrogen oxides (NOx)** - NOx reduction methods include the use of 'low NOx burners'. These specially designed burners restrict the amount of oxygen available in the hottest part of the combustion chamber where the coal is burned, minimising the formation of the gas and requiring less post-combustion treatment. Low NOx burners reduce nitrogen oxide emissions by up to 40% and, coupled with re-burning techniques, NOx emissions can be reduced by 70%.
- **Particulates emissions** - electrostatic precipitators can remove more than 99% of particulates from the flue gas. The system works by creating an electrical field to create a charge on particles, which are then attracted by collection plates. Other removal methods include fabric filters and wet particulate scrubbers.

Carbon capture and storage

Carbon capture and storage (CCS) involves capturing the CO_2 and storing it deep underground. A range of approaches to CCS have been developed and have proved to be technically feasible, but are yet to be made available on a large-scale commercial basis because of the costs involved. Technology for capturing CO_2 is already commercially available for power plants, but storage is a relatively untried concept, and no power plant currently operates with a full CCS system.

Applied to a modern coal plant, CCS could reduce CO_2 emissions to the atmosphere by approximately 80-90%, but the process requires a significant amount of energy, thereby increasing fuel consumption by about 10-40%. This makes CCS-equipped plant 30-60% more expensive than conventional technology, and we estimate that allowance prices of at least EUR 20.5/t (US$40/t) would be required to make the technology economically viable. The first fully functional CCS system is not expected to be ready until about 2014.

Figure A20. Options for carbon capture and storage



Source: World Coal Institute (1. CO_2 pumped into disused coal fields displaces methane which can be used as fuel, 2. CO_2 can be pumped into and stored safely in saline aquifers

Three different types of technology exist for carbon capture:

- **Post-combustion** - the CO_2 is removed after combustion of the fossil fuel, this being the scheme that would be applied to conventional power plants with the CO_2 being captured from flue gases. The technology is well understood, but not yet available on a commercial scale.
- **Pre-combustion** - widely applied in fertilizer, chemical, gaseous fuel and power production, the fossil fuel is gasified, with the resulting CO_2 being captured from a relatively pure exhaust stream.
- **Oxyfuel combustion** - this has the potential for retrofitting to existing pulverised coal plants, and involves feeding oxygen and recycled flue gases into the boiler. This reduces the overall volume of flue gases, and increases the CO_2 concentration to allow more ready capture for sequestration.

After capture, the CO_2 must be transported to suitable storage sites, either by pipeline (cheaper), or by ship. Both methods are currently in commercial use. Storage of the CO_2 is envisaged either in deep geological formations, deep oceans, or in the form of mineral carbonates:

- **Geological storage** - also known as geo-sequestration, this method involves injecting CO_2 directly into underground geological formations. Oil fields, gas fields, saline formations, and unminable coal seams have been suggested as storage sites and, in the case of declining oil fields, the injected CO_2 can increase oil recovery. For well-selected, designed, and managed geological storage sites, the IPCC estimates that CO_2 could be trapped for millions of years, and that the sites are likely to retain over 99% of the injected CO_2 over 1,000 years.
- **Ocean Storage** - two main concepts exist, 'dissolution' which injects CO_2 into the water column at depths of 1,000m or more, and the 'lake' type which deposits CO_2 directly onto the sea floor at depths greater than 3,000m. The environmental effects of ocean storage are generally negative, but poorly understood, and much more work is needed to define the extent of the potential problems.
- **Conversion to bicarbonates/hydrates** - a third concept is to convert the CO_2 to bicarbonates (using limestone) or hydrates. This approach would reduce the pH effects and enhance the retention of CO_2 in the ocean, but increases costs and other environmental impacts.

The additional fuel consumption requirements of CCS also have potential negative environmental consequences, including those related to mining, a reduction in air quality, and the possibility of leakage. ■

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Annex 2: Essays on individual sectors

Tables

Science: Evidence, mechanisms, and scenarios of climate change

Policies: Design, implementation, and international cooperation

Annex 2: Essays on individual sectors

Boxes

LIST OF ABBREVIATIONS

ABI	Association of British Insurers
ACARE	Advisory Council for Aeronautics in Europe
ACEA	European Automobile Manufacturers Association
API	Active Pharmaceutical Ingredient
BOF	Basic Oxygen Furnace
CARB	California Air Resources Board
CCFX	Chicago Climate Future Exchange
CCS	Coal Capture and Storage
CCT	Clean Coal Technology
CCX	Chicago Climate Exchange
CDM	Clean Development Mechanism
CDP	Carbon Disclosure Project
CDS	Credit Default Swap
CER	Certified Emission Reduction unit
CFC	Chlorofluorocarbon
CHP	Combined Heat and Power
CMAI	Chemical Market Associates, Inc
CME	Chicago Mercantile Exchange
CNES	Centre National d'Etudes Spatiales
CO_2	Carbon Dioxide
CRO	Chief Risk Officer
DICE	Dynamic Integrated model of Climate and Economy
DJSI	Dow Jones Sustainability Index
DOE	Designated Operating Entity
DTI	Department of Trade and Industry
EBIT	Earnings Before Interests and Taxes
EBITA	Earnings Before Interests Taxes and Amortisation
EC	European Commission
EEA	European Environment Agency
EERE	Energy Efficiency and Renewable Energy
EPA	Environmental Protection Agency
EIA	Energy Information Administration
ERU	Emission Reduction Unit
ETF	Exchange-Traded Funds
EU	European Union
EUA	European Union Allowance

EU ETS	European Union Emissions Trading Scheme
FGD	Flue Gas Desulphurisation
FIA	Federation Internationale d'Automobile
g/km	grams per kilometre
GATT	General Agreement on Tariffs and Trade
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GISS	Goddard Institute for Space Studies
GM	Genetic Modification
Gt	Giga tonnes
GTL	Gas To Liquid
HCFC	Hydro-chlorofluorocarbon
HEU	Highly Enriched Uranium
HFC23	Hydro-fluorocarbon 23
ICAO	International Civil Aviation Organisation
ICI	Investment Company Institute
ICIS	International Chemical Information Service
IEA	International Energy Agency
IGCC	Integrated Gasification Combined-Cycle
IPCC	Intergovernmental Panel on Climate Change
IPCC TAR	Intergovernmental Panel on Climate Change Third Assessment Report
ITU	International Telecommunications Union
JI	Joint Implementation
KSG	Kennedy School of Government
kWh	kilowatt-hour
LECZ	Low Elevation Coastal Zone
MITI	(Japanese) Ministry for International Trade and Industry
Mt	Million tonnes
NAP	National Allocation Plan
NASA	National Aeronautics and Space Administration
NCAR	National Centre for Atmospheric Research
NGO	Non-Governmental Organisation
NOx	Nitrogen Oxides
NSW	New South Wales
nZEC	near Zero Emission Coal
OECD	Organisation for Economic Cooperation and Development
OEM	Original Equipment Manufacturer
PBT	Profits Before Tax

pp	percentage point
ppmv	parts per million per volume
PV	Photo-Voltaic
RGGI	Regional Greenhouse Gas Initiative
RPS	Renewable Portfolio Standards
SEPA	State Environment Bureau to the State Environment Protection Administration
SO_2	Sulphur Dioxide
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
R&D	Research and Development
RGGI	Regional Greenhouse Gas Initiative
RICE	Regional dynamic Integrated model of Climate and Economy
RoCE	Return on Capital Employed
ROE	Return on Equity
ROIC	Return On Invested Capital
tC	tonnes of carbon
tCO_2	tonnes of carbon dioxide
TWh	Terawatt-hour
UIT	Unit Investment Trust
ULCC	Ultra Large Crude Carriers
UNEP	United Nations Environment Program
w/m^2	watts per square metre
WBCSB	World Business Council on Sustainable Business
WHO	World Health Organisation
WMO	World Meteorological Organisation
WRI	World Resource Institute
WTO	World Trade Organisation

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LEHMAN BROTHERS