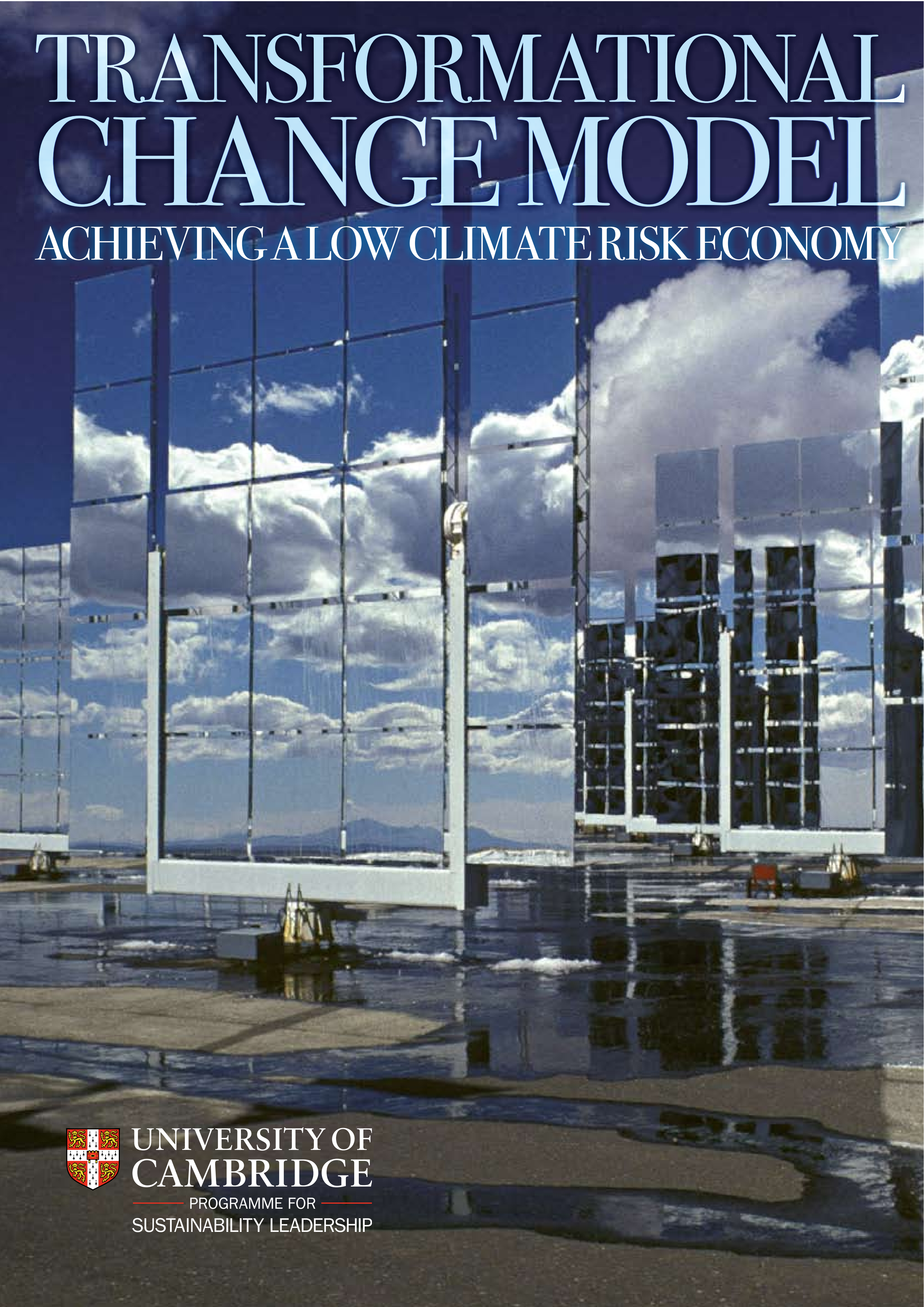
TRANSFORMATIONAL CHANGE MODEL

ACHIEVING A LOW CLIMATE RISK ECONOMY



UNIVERSITY OF CAMBRIDGE
PROGRAMME FOR SUSTAINABILITY LEADERSHIP

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Introduction

Background

Over the past year, the University of Cambridge Programme for Sustainability Leadership (CPSL), previously the Cambridge Programme for Industry, has identified the need to develop a transformational change model (TCM) which provides a draft framework for action to achieve a low climate risk economy. Our Senior Associates and Faculty – and the leaders who participate in CPSL's programmes – are stressing the imperative for a step-change in society's approach to climate change if the risk of serious social, environmental and economic harm is to be limited (we are beyond the point where risk is avoidable). Business leaders recognise that although they may have a vision of where they want their particular company to be in the future, they lack clear frameworks to support them in reaching those objectives.

The TCM is designed to inform a wider policy debate about sustainability transformation. It is designed to be a practical proposal for action. It will be used by business leaders and groups in their discussions with political leaders to help structure their call for transformational change. In addition, the report will be made available to Special Advisors in key governments.

The findings of the report will also be used in CPSL's learning programmes and leadership group discussions. This will be a two-way process – insights from CPSL's learning programmes and leadership groups will inform a continually developing 'view of the world' that will feed into the transformational change model.

Developing a model for the future?

We have decided to call this work a model for a low climate risk economy rather than for a low carbon economy. It is increasingly clear that as a result of delaying a response to tackling climate change over the past 20 years the world now faces significant impacts due to the emissions that have already occurred (and continue to occur). In this report we present three scenarios for the future: Shut Down, Task Manager and Work Offline. We identify the Task Manager scenario as our preferred way forward and the report discusses the key elements that are required to achieve the vision it outlines. It is no longer enough simply to take carbon out of the system but we also need a strong framework that delivers adaptation across society to protect existing assets: hence the focus on a 'low climate risk economy'.

The scenario is built on interviews with the TCM sponsors[1] and leading experts from

Task Manager

In a Task Manager world political leaders recognise the risk of dangerous climate change and decide to scale-back emissions in order to make the transition to a low climate risk economy as smooth as possible. Every country takes on strong emission reduction targets with developed countries agreeing to targets in the current round of negotiations (coming into force by 2012) which would be met mainly through efficiency measures and developing countries agreeing to targets in the subsequent round of negotiations (which should conclude by 2020). These targets are guided by science and result in no net emissions by 2050 (greenhouse gas concentrations are stabilised at around 550ppm). This would require a global emission reduction target of at least 50% by 2050 over 2000 levels (implying between 60 and 90% reductions for developed countries). By 2100, the global economy is based on a fully electrified, hydrogen and renewable system. Significant climate impacts will still be seen and strong adaptation measures are put in place including flood defences, changes in agricultural practices and infrastructure protection from extreme weather events.

[1] Arup, Jupiter Asset Management and Maersk Oil & Gas

the University of Cambridge academic community and on discussions with members of The Prince of Wales's regional and sector Corporate Leaders Groups on Climate Change. It was supported by dialogues and workshops with policy and business leaders through programmes such as the Climate Leadership Programme and Chevening Programme on the Economics of Climate Change (the Acknowledgements for the full list). Throughout the interview process, participants were asked for their thoughts on the scale of the challenge; whether there were particular technologies or behaviour changes that were essential to tackle this challenge; what were the barriers to adopting those technologies or behaviour changes; and what types of policy interventions could help remove those barriers.

It is important to note that the TCM has not been developed as a consensus amongst all of those consulted, but brings together all their views into one place in an attempt to move the discussion around policy formulation forward. We do not present this model as the definitive solution, nor as a consensus view, but as a framework for those parties to come together to begin active discussions.

It is also important to note that while the TCM outlines the changes that are needed in the policy framework under which business operates, this is not intended to be used as an excuse for inaction on behalf of business. All of the leaders consulted in this process are developing strategies and actions that respond to the challenges of climate change now. Many have already implemented incremental change to respond to the challenge. However, they all recognise that the scale of change that is required is much bigger than they can deliver alone. To create real momentum – and transformation – in the market they need to be able to see the long-term goals and mechanisms to achieve them.

Creating transformational change?

Transformational change covers many aspects of the global economy and business practice and requires an integrated systems approach. This approach includes embedding climate risk into decision-making processes; developing a global value on carbon; scaling-up investment and innovation in low carbon technologies; ensuring the sharing of low carbon technologies between developed and developing countries; creating new service businesses (e.g. energy efficiency); and the global fair-sharing of the costs of adaptation. In particular, a shift from short-term decision-making to long-term sustainability is essential in developing a real solution to the climate problem.

In 2006 the Stern Review, commissioned by the UK Government, developed a new economic understanding of the impact of climate change by including risk into standard cost/benefit analysis. With the finance system in turmoil as a result of bad risk management, a new stimulus for the economy is needed to ensure that we can continue to grow and avoid the worst outcomes from a credit crunch. A 'green' growth push, led by governments and supported by business, has the potential to rebuild confidence in the economic system and should incorporate climate risk into its framework from the beginning.

How to create the right politics and policies?

Since 2004 CPSL has been working with business leaders who believe that there is an urgent need to develop new and longer-term policies for tackling climate change. These leaders are brought together in The Prince of Wales's Corporate Leaders Group on Climate Change. At present CPSL runs two regional groups – a UK group and an EU group, and three sector groups – pensions, insurance and travel and tourism. The regional groups are cross-sector, encompassing energy producers, manufacturers, banks, retailers, utilities and others. They have been active in progressing action on climate change, working with national governments, international fora and within the business community.

For example, in November 2007 the groups published The Bali Communiqué (www.balicommunique.com). Supported by 170 companies from around the world, the Communiqué called on world leaders to agree a comprehensive, legally binding United Nations framework to tackle climate change. The initiative represented an unprecedented coming together of the international business community and included some of the biggest companies and brands from around the world, including the United States, Europe, Australia and China.

The Bali Communiqué called for:
- A comprehensive, legally binding United Nations framework to tackle climate change;
- Emissions reduction targets to be guided primarily by science;
- Those countries that have already industrialised to make the greatest effort;
- World leaders to seize the window of opportunity and agree a work plan of negotiations to ensure an agreement can come into force post-2012.

The groups have been calling for increased political attention to the urgent issue of tackling climate change. With governments and politicians now increasingly focused on this issue, and with a strong call from business to create the political space required to start detailed discussions on the implementation of policies, it is now important to move beyond a vision for emissions reductions (usually outlined as emissions reduction targets) and into real action to identify the particular pathways that we are to take to achieve these targets. As the letter from the UK Corporate Leaders Group on Climate Change to UK political party leaders in September 2008 outlined: "Government and business must now work together to demonstrate real change on the ground by delivering the new projects and practices that are needed to create a low climate risk economy."

Transformational Change Model – Achieving a Low Climate Risk Economy

This report includes six main chapters:

- **Scenarios for the Future** outlines our three proposed scenarios and some of the possible solutions to climate change that policy makers may wish to encourage;
- **Climate Science and Impacts** gives an overview of the recent scientific updates given in the IPCC Fourth Assessment Report (AR4), published in 2007, together with a review of possible impacts;
- **Policies and the State of Politics in 2009** sets out some of the current policies that are in place, which give us a platform on which to build real momentum;
- **Policy Requirements** outlines some of the necessary policy changes at international and national levels that will support business in delivering the transformational change;
- **Technological and Behavioural Changes** summarises some of the key energy supply technologies and principles around technology development for energy use that will help us achieve the emissions reduction targets;
- **Organisational Change Case Studies** brings together some examples of current initiatives by business.

This model for transformational change is a first attempt to move beyond the politics into policy frameworks and to identify a structure for policy implementation that will give business the certainty it needs to start the transformation to a low climate risk economy.

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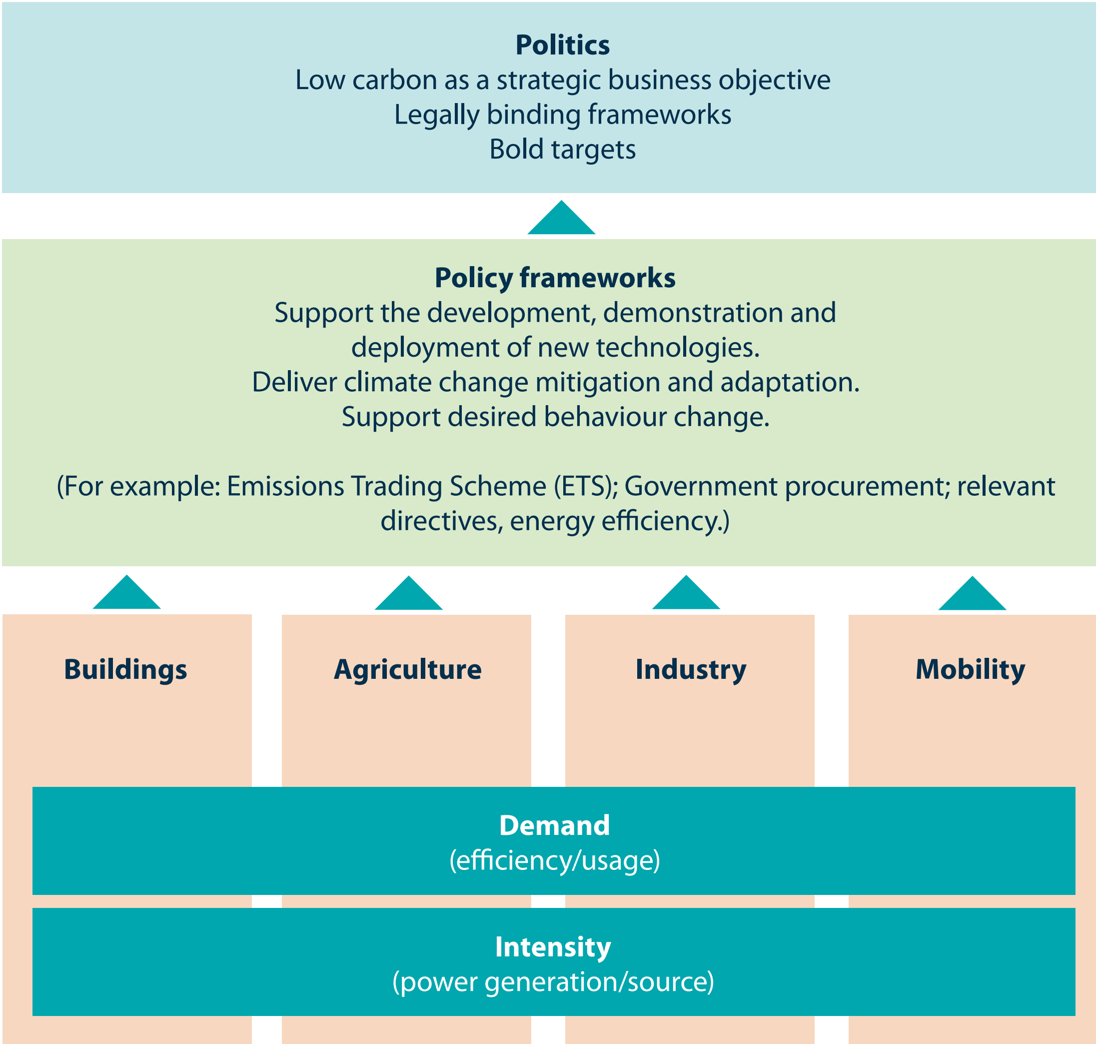


There is a need for real momentum at each level of government: politics, policy frameworks and policies to deliver real change across each sector.

Scenarios for the Future

Background
It is clear that in developing a policy framework for action it is important that we understand what we are trying to achieve. This is not about picking a 'winner' but about knowing the types of behaviour change in business and the public that we wish to encourage. Once we appreciate the required outcomes, we can begin to create a market to deliver them.

This chapter, and the Technological and Behavioural Changes section, outline some of the possible options to reduce the risk of climate change that policy makers may wish to encourage.

Over the past few years many organisations have been developing scenarios for the future. These scenarios usually (but not exclusively) include a view on the likely technology mix that could be expected in 2050 and the emissions reductions that are possible based on their proposed mix of technologies. In addition to the interviews with academics, policy makers and business leaders that took place as part of the research for this report, we looked at the following scenarios, to get a baseline idea of the breadth of options available to help tackle climate change:

- World Business Council for Sustainable Development (WBCSD), *Pathways to 2050 – Energy and Climate Change*
- WWF, *Climate Solutions*
- Shell, *Energy Scenarios*
- International Institute for Environment and Development (IIED) and New Economics Foundation, *Up in Smoke*
- World Bank, *Strategic Framework on Climate Change and Development (SFCCD)*
- International Energy Agency (IEA), *World Energy Outlook 2006*
- United Nations Foundation, *Framework for a Post-2012 Agreement on Climate Change*
- Princeton Wedges
- International Finance Corporation – *Energy Efficiency in Russia: Untapped Reserves*
- PricewaterhouseCoopers – *The World in 2050: Implications of Global Growth for Carbon Emissions and Climate Change Policy*
- Mackay, D. *Sustainable Energy – Without the Hot Air*, UIT Cambridge

A common vision?
In this report we highlight the principles of an approach to creating a marketplace that will itself pick the 'right' technology and behaviour winners. However, it is important that we do not pre-judge the solutions too closely as this may mean that policies are put in place that may not deliver the change that we desire, or may have unforeseen consequences.

For example, in early 2007 the European Commission announced its plans to cut its greenhouse gas emissions by 20% by 2020 compared to 1990 levels (30% if international agreement was achieved). The plans included a proposal that 10% of transport fuel should come from biofuels by 2020. However, in early 2008 the European Commission admitted that the policy was potentially contributing to increased environmental damage and greenhouse gas emissions. This is because there were no criteria set which assessed whether the biofuels were produced in a sustainable way. Therefore, the EU has now relaxed the 10% target and is setting criteria by which biofuels will be measured.

Solutions for large-scale 'carbon wins' fall into three categories:

- **Reducing carbon demand:** the amount of energy needed to perform a particular task;
- **Reducing carbon intensity:** the relative amount of emissions per unit of energy produced;
- **Preserving carbon sinks:** being able to store carbon both naturally and technologically.

A list of possible solutions to reduce greenhouse gas emissions, or to create the right adaptation measures to cope with climate change, include (but are not limited to) energy efficiency, renewable energy (wind, solar, geothermal, tidal), low carbon technologies, carbon capture and storage, nuclear, biofuels, hydrogen or electric vehicles and reduced deforestation. The Technological and Behavioural Changes chapter of this report examines each of these solutions in more detail.

However, it is clear that there is no silver bullet and no single technology will be the solution. It is how the technologies are integrated that is important. For example, if we are to really tackle this problem, the key infrastructure components of energy, water, waste and mobility must work in unison rather than following the historical disconnected route.

Taxpayers, consumers and shareholders comprise the stakeholders of today's economy and are often one and the same. During the interview process, with academics, policy makers and business leaders, many of those interviewed questioned whether there is a democratic way to effect this scale of change. There is a real concern that the timescales involved in the political process of democracies are too short to initiate real change and that we will not be able to respond to this threat in time to reverse, or even slow, its progress. However, history has shown that when faced with a real challenge, the 'power' of democratic governments is unprecedented when steps towards a solution are presented and people are asked to support them. Unfortunately this may come too late. All forms of government have similar issues when presented with such a global challenge; now is the time for governments (and other agencies, public and private) to work together to demonstrate the need for transformational change.

A scenario for the future?

To achieve a low climate risk economy we see three possible scenarios[2]:
Shut Down, Task Manager, Work Offline.

Shut Down

In a Shut Down world political leaders decide that the uncertainty of climate change is too large a risk and therefore severely limit all emission sources by 2020 (globally emissions are brought down such that greenhouse gas concentrations are stabilised at around 450 ppm). This includes all liquid fuel transport and fossil fuel power stations and is driven by strong legislation on emission sources as well as strong legislation governing the behaviour of individuals. A massive capital investment is made to deploy all known technologies including a large role out of new nuclear as well as significant investments in wind and geothermal. Limited emissions are allowed for critical industrial processes (to be phased out over time). In this scenario the risk of climate change is mitigated and little adaptation is needed.

Task Manager

In a Task Manager world political leaders recognise the risk of dangerous climate change and decide to scale-back emissions in order to make the transition to a low climate risk economy as smooth as possible. Every country takes on strong emission reduction targets with developed countries agreeing to targets in the current round of negotiations (coming into force by 2012) which would be met mainly through efficiency measures and developing countries agreeing to targets in the subsequent round of negotiations (which should conclude by 2020). These targets are guided by science and result in no net emissions by 2050 (greenhouse gas concentrations are stabilised at around 550ppm). This would require a global emission reduction target of at least 50% by 2050 over 2000 levels (implying between 60 and 90% reductions for developed countries). By 2100, the global economy is based on a fully electrified, hydrogen and renewable system. Significant climate impacts will still be seen and strong adaptation measures are put in place including flood defences, changes in agricultural practices and infrastructure protection from extreme weather events.

[2] We do not include population controls in these scenarios as we see this area as very politically difficult to achieve any type of agreement

Work Offline

In a Work Offline world no political agreement is reached at the international level (or very limited voluntary agreement). Each country implements efficiency measures for economic reasons and a limited investment is made into renewable technologies, mainly due to energy security concerns. However, emissions continue to rise at their current rate with efficiency measures not meeting the growth of the global economy and feedback loops in the climate system results in runaway climate change. Large capital investment is made into adaptation measures with large scale movements of infrastructure out of flood plains and the construction of more extreme weather resilient buildings. Local sourcing of agriculture is increasingly important as food crops fail in certain regions and global food prices soar. Water availability becomes increasingly problematic leading to large hydro-storage projects being implemented. There is a much larger risk from regional and global conflicts as a result of the increased pressure on resources and nation states become increasingly isolated and unconnected.

The Task Manager scenario is our preferred way forward because we do not wish to run the risks of large scale global conflicts in Work Offline and the potential of a large negative economic impact from a sudden change in energy resource in Shut Down. The rest of this report will examine key aspects of the requirements in achieving this vision. Although the requirements for this scenario are currently achievable any delays will significantly hamper and potentially destroy the chance of this succeeding.

Task Manager: Delivering efficiency by 2020?

By 2020, society will need to be highly efficient and have the right frameworks and support structures in place to start rapidly deploying new technologies that will have, by then, completed full-scale demonstration. Climate risk will need to be built into the daily decision-making process and strong adaptation measures for our physical infrastructure will be in place. Most developed countries should have achieved approximately 30% reductions in emissions, a large part of which will have been from efficiency measures.

Each year, an estimated $200-250 billion is invested in energy-related infrastructure to replace existing capital stock and meet ever-rising demand (and another $1.5 trillion is spent on energy consumption). It has been estimated that $170 billion annual investment in efficiency measures will result in annual savings in energy costs of $900 billion by 2020[3]. The International Energy Agency (IEA) has estimated that for every $1 spent on efficiency, $2 is saved on electricity supply. In addition, an increasing amount of research indicates that significant savings can be made today by companies investing in efficiency measures[4], however, business decisions, as with political decisions, are currently incredibly short-term. For example, the potential for efficiency savings in Russia is estimated at 45% of primary energy across a variety of sectors including construction, manufacturing, transport and fuel production. This potential saving equates to more natural gas than Russia currently exports.

Large-scale efficiency gains are possible in infrastructure, transport and manufacturing. However, even with a high price on usage, projections for future demand remains relatively unaffected in the majority of academic models. For example a price on carbon only affects demand slightly. The current ratio used is 0.05: a 10% increase in fuel price translates into a 0.5% decrease in demand. This figure is likely to get smaller as people become wealthier. Therefore, efficiency gains will increasingly need to be driven by standards and regulations as well as carbon pricing.

The largest efficiency gains are to be found in the way we construct and use our buildings, and includes many energy intensive technologies being replaced by 'passive' technologies such as natural lighting and ventilation. This will be increasingly important as the need to adapt our buildings to a new climate is felt.

Non-domestic new-build rates are very dependent on economic development within each sub-sector of an economy. Typical rates may be in the region of 1% of existing stock, but this will often be associated with

[3] McKinsey Global Institute, The case for investment in energy productivity, 2008

[4] See, for example, The Climate Group, Carbon Down, Profits Up

rebuilding on land which was previously built on. Demolition rates can typically be in the order of half the new build rate. However, as various sectors of an economy grow, the new-build rate can be far higher. So, for example, service sub-sector buildings may replace industrial buildings. A balance needs to be found between the demolition of existing stock that is never going to be economically attractive to improve to the required standard of performance, and its replacement with new improved stock. Because demolition and building themselves produce carbon, the standard of the new building needs to have a carbon payback.

Domestic stock tends to have a much longer economic lifecycle; typical demolition rates are around 0.1%, implying 1,000 years are needed to replace them all. This figure is distorted because much stock that has been built has yet to reach an age whereby demolition is inevitable, however a 100-year life is not at all unusual for domestic stock, 5 times longer than that of non-domestic stock. In these circumstances, improvements are more likely to come through refurbishment than demolition and new build. Additionally, the ratio of embodied carbon to operational carbon is much higher for typical residential stock, again supporting their improvement rather than demolition and replacement.

In addition to the efficiency savings that can be made, investments in infrastructure should also be seen as an opportunity for growth. Green refurbishment could generate a global industry that matches the size of the current construction sector. Governments will play a key role in creating this green growth by driving through efficiency measures in the public estate (schools and hospitals in particular).

Task Manager: Delivering a transition by 2050?

By 2050, the world should be well on the way to developing a fully renewable-based and climate resilient infrastructure. However, we will need interim measures to ensure that 'the lights stay on', but these measures still need to deliver the global emissions reduction targets. Therefore, there is likely to be a need for an increased interim use of nuclear power in the current developed countries until alternative renewable based technologies and infrastructure becomes available at a level necessary for total adoption.

Most importantly, governments around the world will have put in place strong regulatory frameworks that increasingly support the move to a fully electrified infrastructure (with improved energy storage potentially including hydrogen fuel which takes its supply from renewable technologies deployed in the most appropriate environment). For example, Europe will have opened up its national grids to create a super-grid and be putting in place new technologies on energy storage. These sources will include concentrated solar power from North Africa, tidal power from Spain and the UK, wind power from Scandinavia and the UK and hydro power from the Alps. These solutions will not be fully deployed by 2050 without substantial financial support.

Carbon emissions from the transport sector should decrease significantly over the next 40 years. Efficiency should improve dramatically (by at least half) with the increased use of hybrid technologies, and the introduction of fully electric cars (possibly through the use of hydrogen fuel cells), but demand will also increase, particularly driven by the growth in emerging markets. At present replacement rates, a new electric car would take at least twenty years to completely penetrate the market and so the sooner models (and the infrastructure that is needed to support them) are available, the better. In addition short-haul air travel should be replaced by electric, high-speed, rail (where the electricity can be supplied from renewable sources). New transport systems in emerging economies should be developed to be wholly reliant on new electricity infrastructure.

In developing countries, improving access in urban and rural areas, upgrading national transmission grids, developing efficient power-trade arrangements, promoting off-grid renewable power supply systems and promoting sustainable household fuel will all lead to a more efficient infrastructure. This process would need to be supported by the Multilateral Development Banks and donor governments as well as through developing

Solar thermal collector, Font-Romeu, France

new markets in those countries which will then allow business to invest directly. In essence, the developing countries should have leapfrogged developed countries in implementing a renewable-based economy by 2050.

Even with significant emissions reductions by 2050, it is unlikely that without significant financial support the scale of transformation achieved will be sufficient to avoid major climate change impacts. Therefore, in parallel to these developments, national and global frameworks for disaster risk management will need to be put in place. Estimates show that for every $1 spent on preparing for disasters, $7 is saved in post-disaster recovery. A key element to this is access to water and water storage.

Task Manager: Achieving a vision by 2100?

By 2100, the world's economy should be based entirely on renewable technologies and will be fully climate resilient. To achieve this, the distribution of energy around the world will need to be based on electricity.

It is important to note that there will be competing interests. The majority of these will be political and linked to short term security of supply. For example, oil sands (over mature oil wells), are 20% worse in lifecycle emissions than conventional oil recovery, but are available in significant quantities in Canada and are becoming economic. Oil shale (pre-mature oil wells) will become economic over the next decade and is therefore likely to be developed over the next 30-40 years. The US has 75% of the known oil shale reserves (amounting to twice the current oil reserves from conventional wells). It is difficult to see, how within current 'business as usual' ,the transformational changes needed to electrify the global economy will occur faster than the incremental changes needed to develop these wells. What is needed is strong policy measures to support a different pathway. In addition, the relative abundance of coal is likely to result in an increased deployment of coal power stations and coal-to-liquid fuel technologies unless political action is taken.

Therefore, society needs to make a conscious decision about the direction it is heading and invest in key areas of the economy. One particular technology that needs significant investment over the next few decades to enable us to retain a high quality of life is energy storage. This involves a range of possible solutions that already exist, from pumped water storage (for example in Dinorwig, Wales), compressed air storage and ground source heat pumps, to novel 'batteries' (both centralised and distributed) that can store significant amounts of energy over long periods. To support this deployment, there will also need to be a revolution in the way products are powered and in the management of the power grid. Many products will need to be able to cope with variable power and have dynamic demand management so that all aspects of the power grid are supporting each other.

The substitution of energy carriers has traditionally taken 100 years, if not longer (this happened with coal, oil and now gas). The substitution of the market share of infrastructure also occurs on a similar timescale (e.g. rail, roads etc). It is possible to develop a new renewable economy in that timescale, but we need to start now.

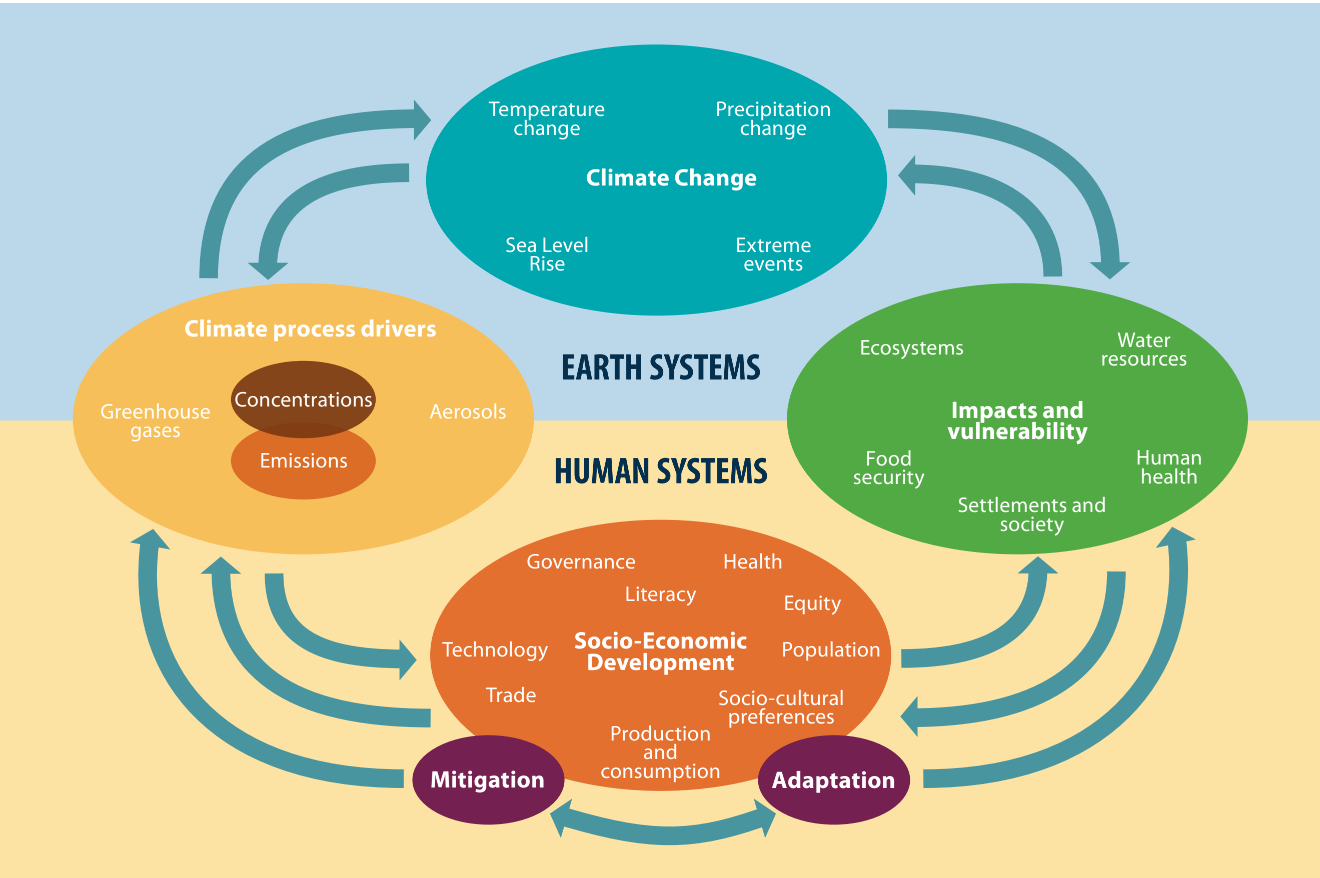
It should be noted that while some new technologies may be required to deliver a fully electrified and renewable economy, it is possible to achieve most of this scenario in a much shorter timescale. If government and business decide today that this is what they will deliver, and lay out a clear vision, then all indications show that the capital required and society 'buy-in' that is needed will be there. It will be a massive job and whether we achieve the full transformation by 2050, or we go through a transition and get there by 2100 (with the appropriate and necessary additional adaptation costs), the new green-growth era of our society offers us a very exciting opportunity.

Climate Science and Impacts

Background
Since the publication of the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report (TAR) in 2001, it has been possible to evaluate development pathways and global emissions scenarios. This chapter gives an overview of the recent scientific updates given in the IPCC Fourth Assessment Report (AR4), published in 2007, together with a review of possible impacts[5].

The IPCC Fourth Assessment Report (AR4) in particular noted that the "warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level".

Eleven of the last twelve years (1995-2006) rank among the twelve warmest years ever recorded since global surface temperatures were first measured in 1850. Although the temperature increase is global, larger increases have been recorded at high northern latitudes and land regions have experienced faster warming than the oceans. Average Northern Hemisphere temperatures between 1950 and 2000 were higher than during any other 50 year period in the last 500 years and the highest in at least the past 1,300 years.



Schematic framework representing anthropogenic drivers, impacts of and responses to climate change, and their linkages. From IPCC, 2007.

[5] Where the IPCC assesses uncertainty quantitatively one of the following likelihood ranges are used to express the assessed probability of occurrence: *virtually certain* (>99%); *extremely likely* (>95%); *very likely* (>90%); *likely* (>66%); *more likely than not* (>50%); *about as likely as not* (33-66%); *unlikely* (<33%); *very unlikely* (<10%); *extremely unlikely* (<5%); and *exceptionally unlikely* (<1%). In this chapter we use facts that the IPCC deems as having a higher than 66% likelihood.

Consistent with this warming are rising sea levels (which since 1961 have globally risen at a rate of 1.8mm/year and since 1993 at 3.1mm/year) and observed decreases in snow and ice extent. Satellite data obtained since 1978 have shown that the annual average Arctic sea ice extent has shrunk by 2.7%/decade, with larger decreases of 7.4%/decade during summer.

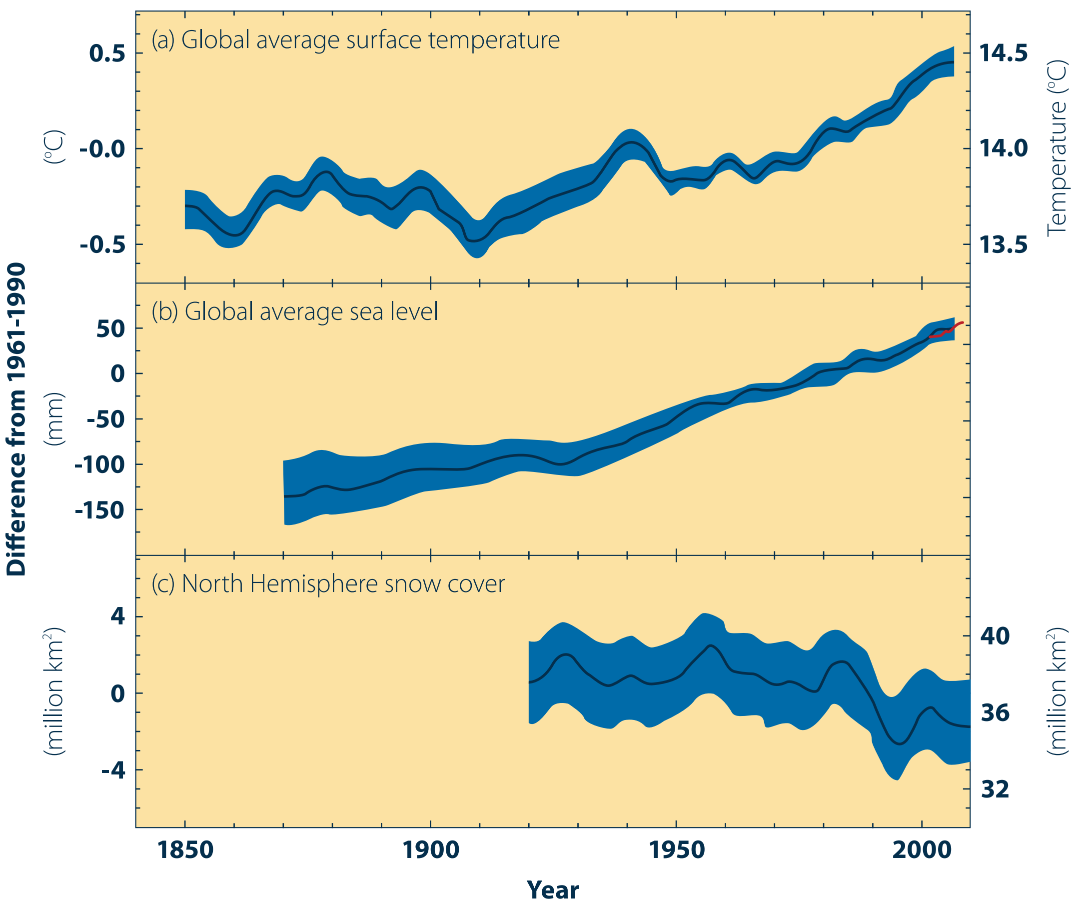
Precipitation has also changed from 1900 to 2005, with increases in eastern parts of North and South America, northern Europe and northern and central Asia but decreases in the Sahel, Mediterranean, southern Africa and parts of southern Asia.

Overall, observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes – particularly temperature increases – and these impacts are accelerating.

What may have affected the climate system?

Any natural perturbations in the concentration of atmospheric greenhouse gases and aerosols, land cover and solar radiation will alter the energy balance of the climate system. In addition, as a result of anthropogenic (man-made) activity since 1750, global atmospheric concentrations of carbon dioxide (CO_2, 379ppm[6] in 2005), methane (CH_4, 1774ppb in 2005) and nitrous oxide (N_2O) have significantly increased, and are now far higher than the pre-industrial values determined from ice cores over the

Changes in temperature, sea level and Northern Hemisphere snow cover



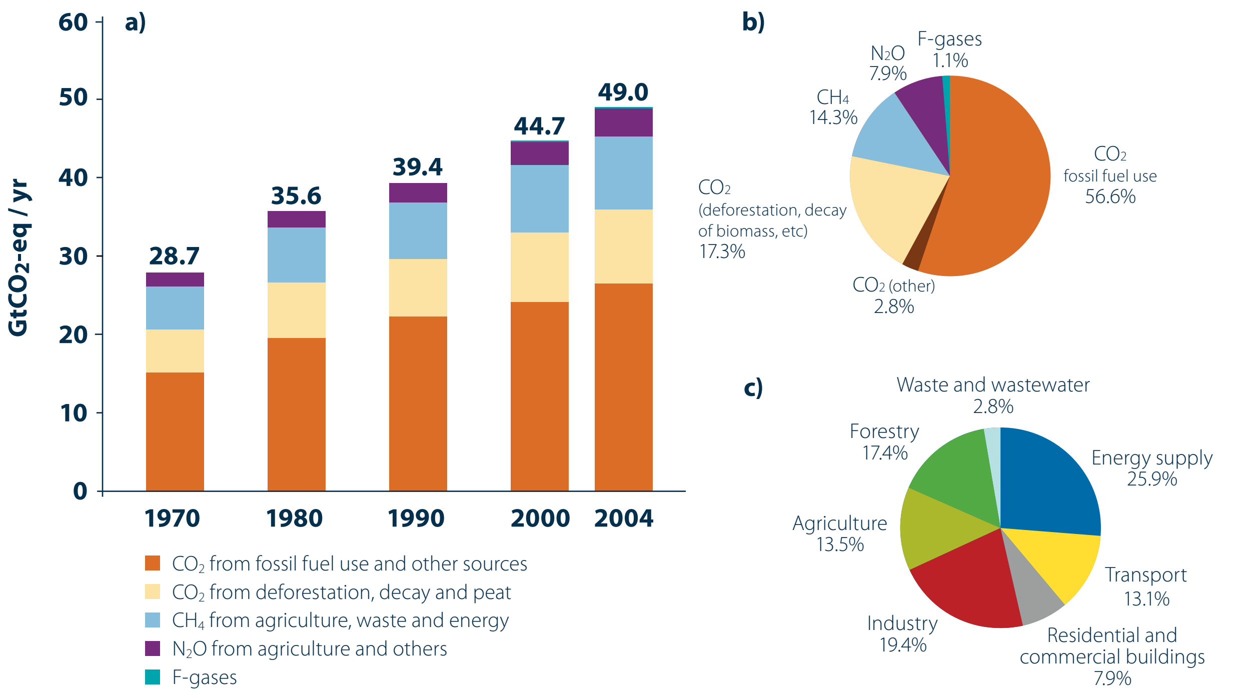
Observed changes in (a) global average surface temperature; (b) global average sea level from tide gauge (blue) and satellite (red) data and (c) Northern Hemisphere snow cover for March-April. All differences are relative to corresponding averages for the period 1961-1990. Smoothed curves represent decadal averaged values while circles show yearly values. The shaded areas are the uncertainty intervals estimated from a comprehensive analysis of known uncertainties (a and b) and from the time series (c). From IPCC, 2007.

[6] Greenhouse gas concentrations in the atmosphere are measured in ppm (parts per million) and ppb (parts per billion). Very often an average of all greenhouse gases is used as quoted as a CO_2 equivalent concentration.

last 650,000 years. Annual CO_2 emissions have grown by ~80% between 1970 and 2004 and greenhouse gas concentrations now stand at approximately 430ppm CO_2 equivalent (rising by 2ppm per year).

It has often been suggested that these changes to the climate may have occurred naturally as a result of solar and volcanic activity, however, recent research using highly sophisticated atmospheric models has clearly shown that this is not the case, as observed patterns of warming and their changes are only simulated by models that include anthropogenic activity. In particular, spatial agreement between regions of significant warming and locations of significant observed changes in many physical and biological systems, consistent with warming, are not due solely to natural variability.

Global anthropogenic GHG emisions



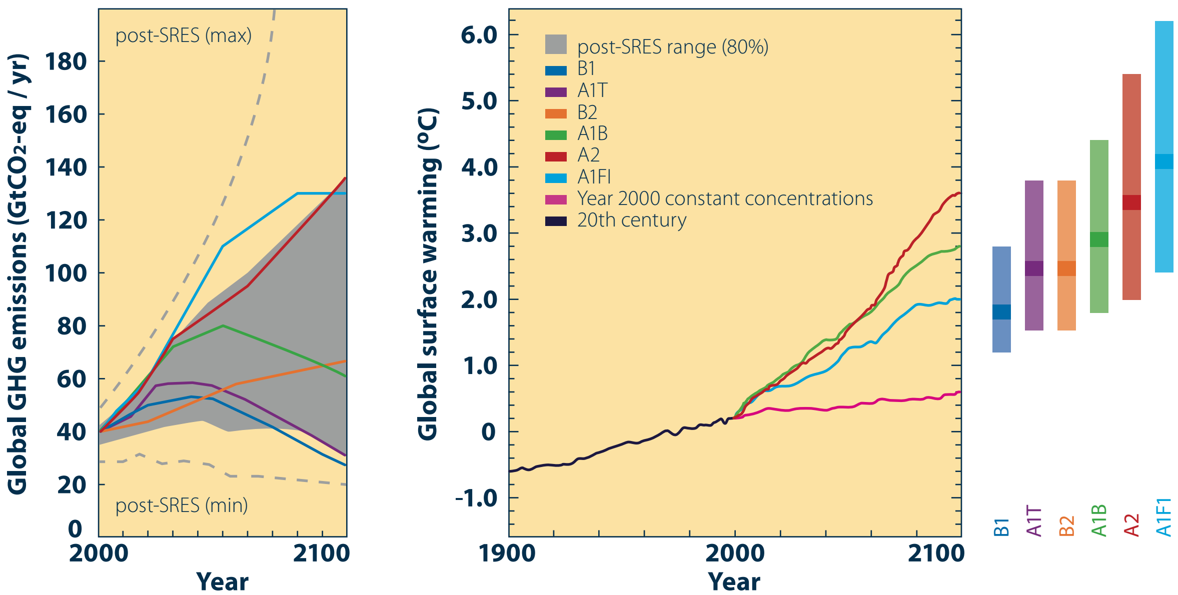
(a) Global annual emissions of anthropogenic greenhouse gases from 1970 to 2004 [includes only carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydroflurocarbons (HFCs), perfluorocarbons (PFCs) and sulphurhexafluoride (SF_6), whose emissions are covered by the United Nations Framework Convention on Climate Change (UNFCCC).] (b) Share of different anthropogenic greenhouse gases in total emissions in 2004 in terms of carbon dioxide equivalents (CO_2-eq). (c) Share of different sectors in total anthropogenic greenhouse gas emissions in 2004 in terms of CO_2-eq. From IPCC, 2007.

Where are we heading?

Even with current climate change mitigation policies and related sustainable development practices, global greenhouse gas emissions will continue to increase over the coming decades. Indeed, the IPCC Special Report on Emissions Scenarios (SRES, 2000) expects between 2000 and 2030 an increase in greenhouse gas emissions globally by 25 to 90%, with the main contributor to global energy being fossil fuels until at least 2030. The continued rate of greenhouse gas emissions would cause further warming and induce changes to the global climate system during the 21st century that would be larger than those observed during the 20th century. If the concentrations of all greenhouse gases and aerosols had remained constant at 2000 levels then a climate warming of 0.1ºC/decade would have been expected for the next two decades, however for the range of SRES emissions scenarios a warming of ~0.2ºC/decade is projected over the same period.

The uncertainty between the scenarios is not an uncertainty in the science, but an uncertainty in the response that society will have to this issue over the next century. The

Scenarios for GHG emissions from 2000 to 2100 (in the absence of additional climate policies) and projections of surface temperatures



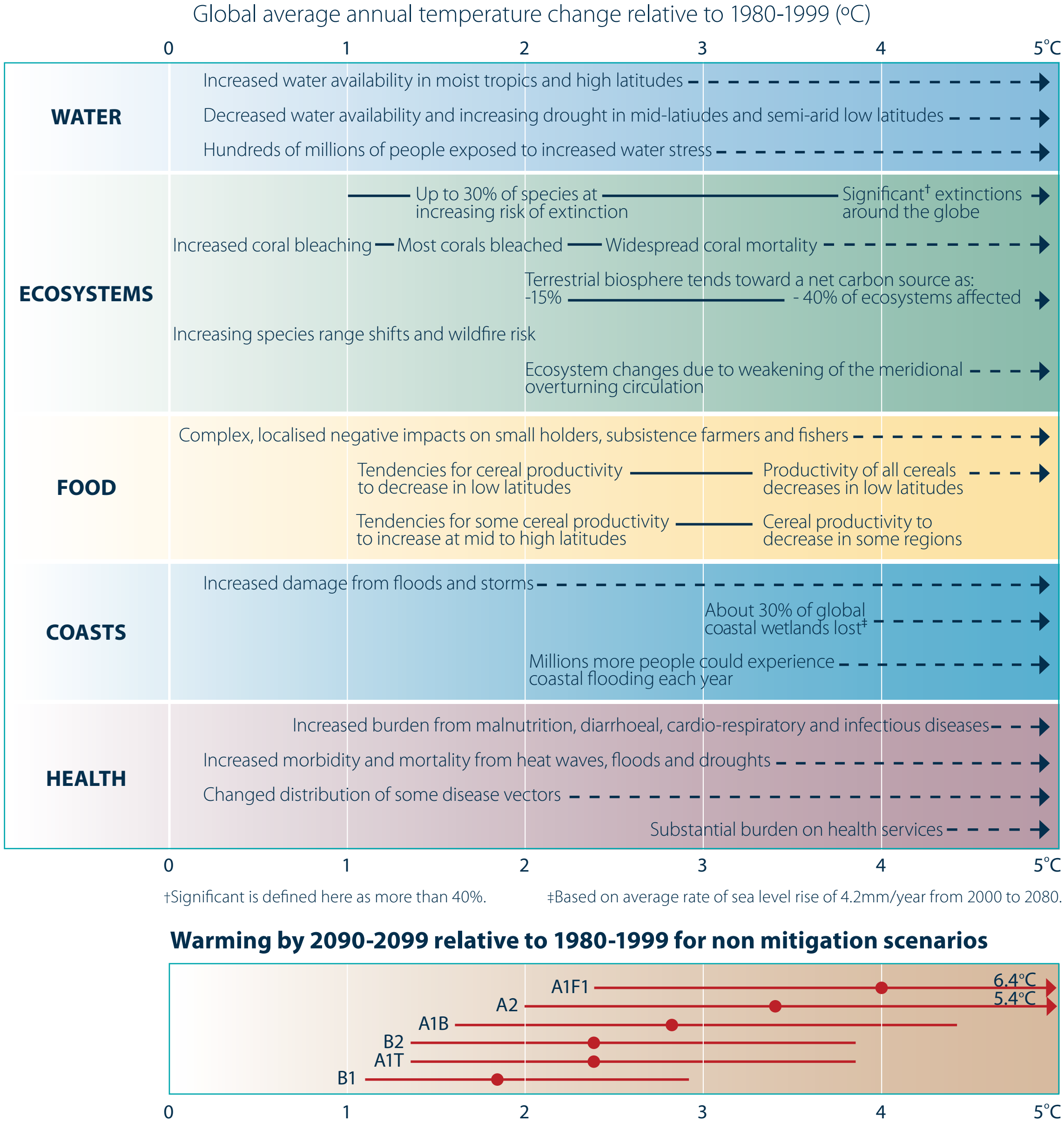
Left panel: Global greenhouse gas emissions ($GtCO_2$-eq) in the absence of climate policies: six illustrative SRES marker scenarios (coloured lines) and the 80th percentile range of recent scenarios published since SRES (post-SRES, grey shaded area). Dashed lines show the full range of post-SRES scenarios. The emissions include CO_2, CH_4, N_2O, and F-gases (fluorinated greenhouse gases). Right panel: Solid lines are multi-model global averages of surface warming for scenarios A2, A1B and B1, shown as continuations of the 20th-century simulations. The pink line is not a scenario, but is from the Atmosphere-Ocean General Circulation Model (AOGCM) simulations where atmospheric concentrations are held constant at 2000 values. The bars at the right of the figure indicate the best estimate and the likely range assessed for the six SRES marker scenarios at 2090-2099. All temperatures are relative to the period 1980-1999. From IPCC, 2007.

difference between the highest temperature scenario and lowest is down to the speed by which we put in place mitigation technologies and the right set of policies that deliver a low climate risk economy.

The uncertainty within the individual scenarios results from variability in the model calculations when determining the strength of the climate-carbon feedback – the climate sensitivity. This is a measure of how much warmer the climate gets as a result of an increase in greenhouse gas concentration. Scientists are trying to develop models that give us a better understanding of climate sensitivity, for example, what the impact of warming is on natural terrestrial and ocean uptake (or sequestration) of atmospheric CO_2. In particular, our current understanding of potential feedback loops is limited (this includes, amongst others, how quickly ice sheets will melt, changes in ocean circulation patterns and potential melting and release of frozen greenhouse gas stores). Indeed, most recent measurements show that scientific models are consistently underestimating the climate sensitivity as well as underestimating the growth in greenhouse gas emissions from man-made activities.[7]

[7] See for example, NASA observations of Arctic sea ice melt (http://earthobservatory.nasa.gov/Newsroom/view.php?old=2004042316880) or the Carnegie Institute's studies on ocean chemistry (http://www.sciencedaily.com/releases/2008/12/081211141832.htm)

Examples of impacts associated with global average temperature change (impacts will vary by extent of adaptation, rate of temperature change and socio-economic pathway)



Examples of impacts associated with projected global average surface warming. Upper panel: Illustrative examples of global impacts projected for climate changes (and sea level and atmospheric CO_2 where relevant) associated with different amounts of increase in global average surface temperature in the 21st century. Lower panel: Dots and bars indicate the best estimate and likely ranges of warming assessed for the six SRES marker scenarios for 2090-2099 relative to 1980-1999. From IPCC, 2007.

In determining what constitutes 'dangerous anthropogenic interference with the climate system' value judgements will need to be made. For example, based on the projected impacts of different temperature rises, the European Commission has adopted 2°C as its target for avoiding dangerous climate change.

The scientific community can support informed decisions on this issue, and the IPCC TAR gave five 'reasons for concern' as a viable framework with which to consider key vulnerabilities associated with climate-sensitive systems. These 'reasons' have been assessed within the IPCC AR4 as being stronger than previously considered by the IPCC TAR, with many risks identified with higher confidence. Indeed some risks are now projected to be larger or to occur at lower increases in temperature. Not only this, but our understanding of the relation between impact and vulnerability (including the ability to adapt to impacts) has improved, due to more precise identification of the circumstances that make systems, sectors and regions especially vulnerable, and growing evidence of the risks of very large impacts on multiple-century timescales.

CO_2-eq concentration (ppm)	Global mean temperature increase above pre-industrial at equilibrium, using 'best estimate' climate sensitivity (°C)	Peaking of CO_2 emissions (year)	Change in global CO_2 emissions in 2050 (% of 2000 emissions)
445-490	2.0-2.4	2000-2015	-85 to -50
490-535	2.4-2.8	2000-2020	-60 to -30
535-590	2.8-3.2	2010-2030	-30 to +5
590-710	3.2-4.0	2020-2060	+10 to +60
710-855	4.0-4.9	2050-2080	+25 to +85
855-1130	4.9-6.1	2060-2090	+90 to +140

Scenario predictions from IPCC projecting levels of required emissions reductions to ensure we remain within a certain temperature range increase (70% likelihood). Current levels of CO_2-eq are approximately 430ppm.

Appropriate mitigation efforts can delay, reduce or even avoid many climate impacts and, together with investment over the coming decades, will have a large impact on the opportunity to achieve lower climate stabilisation levels. In contrast, delaying emissions reductions will significantly constrain future opportunities to achieve lower climate stabilisation levels and will increase the risk of more severe climate change impacts. If we are to achieve stabilisation of greenhouse gas levels in the atmosphere then emissions will need to peak and decline thereafter. The lower the stabilisation level necessary to avoid significant climate change, the more quickly the peak and decline would need to occur. As an example, for the lowest mitigation scenario category assessed by the IPCC AR4, emissions would need to peak by 2015 (and decline thereafter).

The impact of climate change will result in net annual costs, which will increase as global temperatures increase. Peer-reviewed estimates (as reported in the Working Group II report of IPCC) of the net economic costs in 2005 of damages from climate change (aggregated across the globe and discounted to the specified year) were on average US$12 per tonne of CO_2 (with a range from ~100 estimates of -$3 to +$95 per tonne of CO_2). This range is mainly due to assumptions regarding climate sensitivity, response lags, treatment of risk and equity, economic and non-economic impacts, inclusion of potentially catastrophic losses and discount rates, and will only increase with time.

Any choices regarding the scale and timing of greenhouse gas mitigation will involve balancing the economic costs of more rapid emissions reductions today against the medium-term and long-term climate risks of any delay into the future.

What might we expect?

The IPCC AR4 states that "the altered frequencies and intensities of extreme weather, together with sea level rise, are expected to have mostly adverse effects on natural and human systems… Anthropogenic warming and sea level rise would continue for centuries due to the time scales associated with climate processes and feedbacks, even if greenhouse gas concentrations were to be stabilised… Anthropogenic warming could lead to some impacts that are abrupt or irreversible, depending upon the rate and magnitude of the climate change".

Access to food, water, health and the use of our surrounding environment is under threat from climate change. The effect could be disastrous. Typical examples include rising sea levels; ocean acidification; changes in crop production; and increased frequency of heat waves, storms and other extreme weather events. Not only this, but the consequences of climate change will increase disproportionately with increased warming, with higher temperatures increasing the likelihood of abrupt and large-scale changes that may result in significant regional changes, migration and conflict. In tropical regions, the combined effect of climate change on increases in the frequency of heat waves and crop pest numbers, together with decreases in water

Climate change phenomenon	Likelihood based on projections for 21st century using SRES scenarios	Examples of major projected impacts			
		Food production; living environment	Water	Health	Society
Warmer over most land areas with fewer cold days and nights	**Virtually certain** that there will be a warming of the most extreme days and nights each year (>99% probability of occurrence)	Increased yields in currently colder environments; decreased yields in warmer environments	Impact on water resources relying on snow melt; effect on some water supplies	Reduced human mortality from decreased cold exposure	Reduced energy demand for heating; increased demand for cooling; declining city air quality; reduced disruption to transport from snow and ice; impact on winter tourism
Increased frequency over most land areas of warm spells/heat waves	**Very likely** (90-99% probability of occurrence)	Reduced yields in warmer regions from heat stress; increased danger of wildfires	Increased water demand and water quality problems	Increased human mortality from heat stroke	Reduction in quality of life for people in warm regions without appropriate housing; impacts on elderly, very young and poor
Increased frequency of heavy precipitation events over most areas	**Very likely** (90-99% probability of occurrence)	Damage to crops; soil erosion, inability to cultivate land due to waterlogged soil	Adverse effect on surface and ground water quality; contamination of water supply; water scarcity may be relieved	Increased risk of death, injuries, and infectious, respiratory and skin diseases	Disruption of settlements, commerce, transport and society due to flooding; pressures on infrastructure and loss of property
Increased drought-affected area	**Likely** (66-90% probability of occurrence)	Degradation of land; lower crop yields; increased mortality of livestock; increased danger of wildfires	Increased spread of water stress	Increased risk of food and water shortage; increased risk of water- and food-borne diseases	Water shortages for settlements, commerce and society; potential for population migration
Increased intense tropical cyclone activity	**Likely** (66-90% probability of occurrence)	Crop damage; uprooting of trees; damage to coral reefs	Power outages; disruption of public water supply	Increased risk of death, injuries and disease	Disruption by winds and floods; insurance withdrawal for high-risk areas; potential for population migration; loss of property

Climate change phenomenon	Likelihood based on projections for 21st century using SRES scenarios	Examples of major projected impacts			
		Food production; living environment	Water	Health	Society
Increased incidence of extreme high sea levels (highest 1% of hourly values of observed sea levels at a given station and for a given reference period)	**Likely** (66-90% probability of occurrence)	Salinisation of irrigation water, estuaries and fresh water systems	Decreased availability of fresh water due to salt water intrusion	Increased risk of death and injury by drowning in flood water	Trade-off in cost between coastal land protection and land-use relocation; potential for population migration; loss of property

Examples of possible impact of climate change based on projections to the mid- to late-21st century. The impacts do not include any changes or developments to adaptive capacity. Based on IPCC, 2007 AR4 WG II.

supplies and native pollinators, could lead to substantially larger declines in food production than might have be expected through the individual effects alone.

The ultimate consequence of climate change will be dependent upon the interactions between physical impacts and socio-economic factors. For example, economic growth is expected to reduce vulnerability to climate change with an increase in society's ability to adapt, whilst population growth will result in a reduction in the available resources per person.

The array of potential adaptive responses available to society is extensive and ranges from the technological, through the operational (including behavioural and managerial) and into the political arena. Although many of the initial impacts can be effectively addressed through adaptation, the available options for adaptation decrease, and associated costs increase, with increasing climate change.

Extreme weather

With more heat waves and fewer cold weather events, together with increased frequency of severe floods, droughts and storms, climate change is likely to increase the damage costs due to extreme weather events, and could significantly impact on lives and livelihoods. This is particularly evident in the Indian subcontinent where the economy and infrastructure is intrinsically linked with the monsoon, to the extent that any fluctuations in the strength of the monsoon can result in significant flooding or drought, with major implications for the rural farming communities. In the USA, a 2-3°C temperature rise will lead to increased hurricane intensities leading to a doubling in the costs due to infrastructure damage.

Water

Water is a critical ingredient for sustainable growth and poverty reduction[8]. Globally ~70% of all freshwater is used for crop irrigation and food production; ~22% is used in manufacturing and energy production; with only ~8% used for drinking, sanitation and recreation[9]. The impact of climate change is expected to be felt most strongly through changes in the world's distribution of water together with seasonal and annual variations.

As the water cycle intensifies due to

[8] Grey, D. and Sadoff, C. 'Water for growth and development' in 'Thematic documents of the IV World Water Forum', Mexico City: Comision Nacional del Agua, 2006.

[9] World Water Development Report 'Water: A Shared Responsibility', World Water Assessment Programme, New York: United Nations, 2006.

climate change, billions of people will be affected. Some will see increases in water availability whilst others will see water shortages. With altering patterns of water availability both droughts and floods will become more severe, with more rain at high latitudes and less rain in the already dry subtropics. Currently dry regions such as the Mediterranean and parts of South America and Southern Africa may experience further reductions in the availability of water. The Hadley Centre predicts that the proportion of land which experiences severe droughts may increase from ~10% currently to ~40% for a temperature increase of 3-4°C, and IPCC, 2007 suggests that by 2020, in Africa, 75-250 million people could be exposed to increased water stress due to climate change. However, in parts of South Asia, Northern Europe and Russia, increases in water availability is likely. Increases in river flows are not necessarily beneficial, as rivers may flood more frequently[10] and as there may be insufficient storage to hold the additional water throughout the drier seasons[11].

Food

The production of food, which occupies 40% of land area, is particularly sensitive to changes in temperature, rainfall and the onset of extreme weather events. Agriculture currently accounts for ~24% of world production, with ~22% of the global population employed in this area, although for those who live on less than $1/day approximately 75% of people rely on agriculture for their livelihood[12].

Whilst crop production at high latitudes is likely to benefit from a moderate warming (2-3°C), lower levels of warming are expected to lead to declines in yield in tropical regions where agriculture is already close to critical temperature thresholds. These effects will be felt most strongly across Africa and Western Asia (including the Middle East), where crop yields may decrease by 25-35% (depending upon the extent of carbon fertilisation) for a temperature increase of 3-4°C[13]. In parts of Central America and Africa, which rely on maize-based crops, substantial declines in crop yields are expected since maize, unlike many other crops, is less responsive to carbon fertilisation resulting from increased levels of carbon dioxide. If crop production moves towards higher latitudes then the costs and population movements required to provide this adaptation could be extremely disruptive.

In China, climate change between 2020 and 2080 is expected to decrease land productivity by 1.5-7.0% in irrigated regions and by 1.1-12.6% in rain-fed regions. Declining crop yields could also potentially increase the number of people at risk of hunger in Africa by up to 25% for temperature increases of 2-3°C, and up to 70% for temperature increases greater than 3°C, in areas where declines in yields are greatest, dependence on agriculture the highest and the ability to purchase food limited.

Oceans

A direct implication of rising carbon dioxide levels is the impact on ocean acidification (as increased levels of carbon dioxide are dissolved in seawater), with its major effects on marine ecosystems. Ocean acidification has significant consequences for fish stocks and can therefore further impact on the availability of food (~15% of the world's population rely on fish as their primary source of protein). Ocean acidification has the potential to disrupt marine ecosystems irreversibly by inhibiting the growth of corals and damaging plankton which are crucial to the ocean's food chain.

Current evidence suggests that the pH (the measure of acidity) of the ocean has already fallen by 0.1 due to carbon dioxide emissions and is projected to fall by up to 0.5 in the next 100 years. This level is probably lower than at any point for hundreds of millennia and, more importantly, the rate of change is much greater than at any time over this period (giving oceans less time to adapt to the changing acidity).

Health

The health of the world's population has

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[10] Milly, P., Wetherald, R., Dunne, K. and Delworth, T., 'Increasing risk of great floods in a changing climate', Nature, 415, 2002.

[11] Arnell, N., 'Climate change and water resources' in Schellnhuber, H.J., Cramer, W., Nakicenovic, N., Wigley, T. and Yohe, G.(Eds.), Avoiding Dangerous Climate Change, Cambridge University Press, 2006.

[12] Bruinsma, J. (Ed.), World Agriculture: Towards 2015/2030: An FAO Study, Earthscan Publications Ltd, 2003.

[13] Stern, N., The Economics of Climate Change, The Stern Review, Cambridge University Press, 2007.

improved significantly, with the average life expectancy increasing by 20 years since the 1960s. In parts of Africa, however, life expectancy has fallen recently due to HIV/AIDS[14]. Climate change will further amplify differences in health between the rich and the poor. It is estimated by the World Health Organisation (WHO) that since the 1970s climate change has resulted in over 150,000 deaths/year through increases in diarrhoea, malaria and malnutrition, with the potential to reach 300,000 deaths/year by 2030[15].

People in urban slum areas are particularly exposed to disease, with poor air quality, limited access to clean water and heat stresses. Although in northern mid-high latitudes any increases to temperature resulting from climate change will reduce cold-related winter deaths, in some tropical regions the temperatures may already be at the maximum levels of human tolerance. By the 2050s, the UK Climate Impacts Programme, 2002 predicts that increasing temperatures could result in around 20,000 less winter cold-related deaths in the UK per annum; on the other hand, rising summer temperatures are expected to increase heat-related deaths from 800 to 2,800/year on average. This will obviously have an impact on UK health provision and human behaviour. In addition, the influence of increased heat-wave frequency and high levels of air pollution in cities will become increasingly dangerous. The 2003 severe heatwave over Europe increased the summer temperatures by up to 5ºC and brought major drought to the region, with 35,000 additional deaths (Earth Policy Institute: www.earth-policy.org/Updates/Update29.htm), reduced agricultural productivity, increased frequency of wildfires and severely disrupted energy supplies.

Changes in temperature and rainfall will impact on mosquito distributions (the area covered by and abundance of), which will obviously affect the potential for malaria. Much of the increase in malaria will occur in Sub-Saharan Africa, with some research suggesting that malaria may decrease in parts of West Africa due to a decrease in. local rainfall.

Extreme weather events such as droughts and floods may also impact on health through changes in the water cycle. Long-term droughts will increase the chances of biomass fires (e.g. forest fires) resulting in an increase in pollutants which may cause respiratory problems, whilst the growth of infectious fungal spores due to flooding may bring with it outbreaks of water-borne diseases such as cholera.

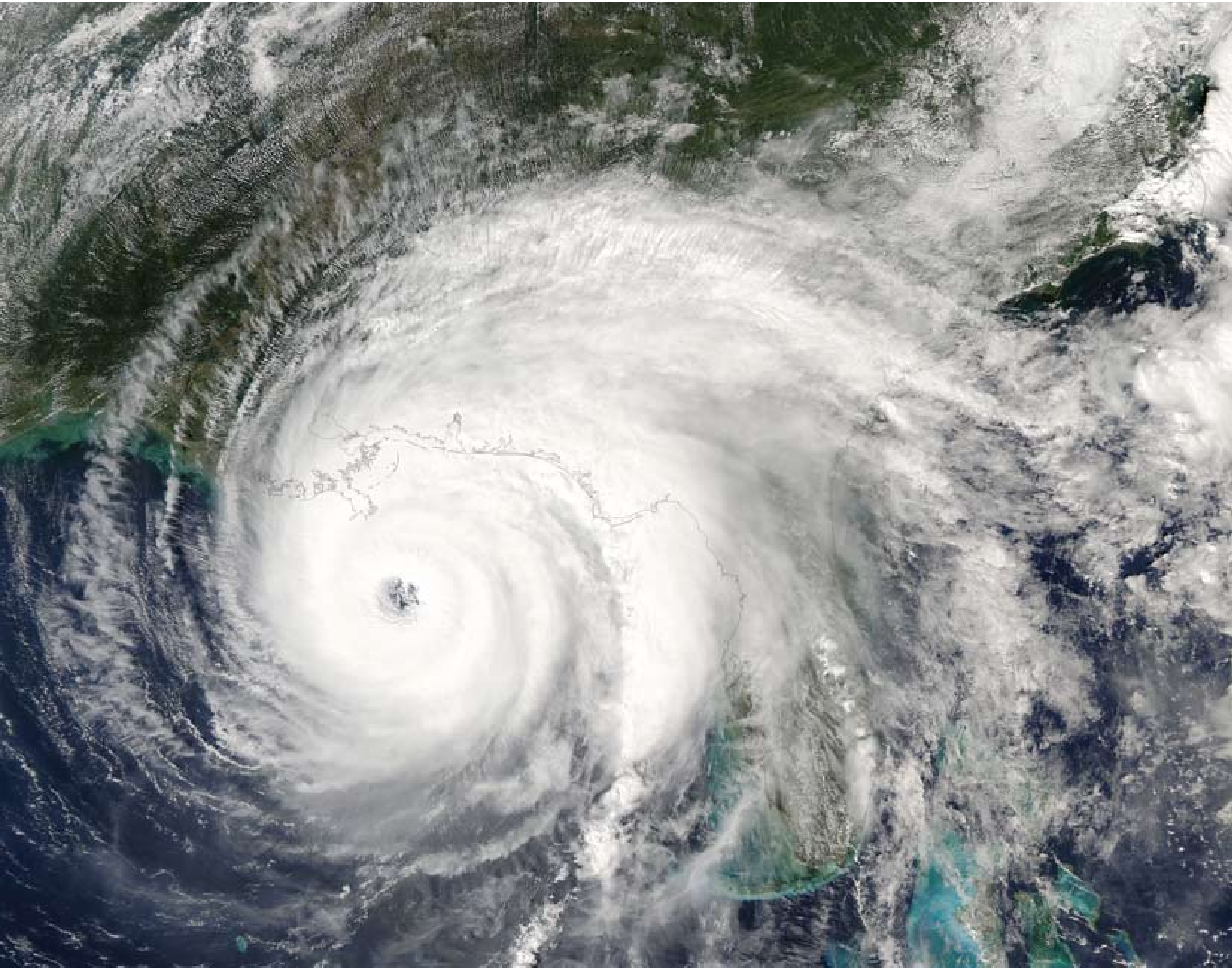
Sea level

A rise in the world's sea level will impact significantly on coastal areas. These areas are some of the most densely populated in the world, with critical infrastructure such as power plants and industrial facilities. At present more than 200 million people live on coastal floodplains less than 1m above current sea levels. In Bangladesh, for example, 25% of people live on coastal floodplains[16]. Furthermore, 22 of the world's top 50 major cities are at risk of flooding from coastal surges, including Buenos Aires,

[14] McMichael, A., Campbell-Lendrum, D., Kovats, S. et al. 'Global climate change', in Ezzati. M et al. (Eds.), Comparative Quantification of Health Risks: Global and Regional Burden of Disease Due to Selected Major Risk Factors, Geneva: World Health Organisation, 2004.

[15] World Health Organisation, WHO/UNEP Health and Environment Linkages Initiative, WHO, Geneva, 2006.

[16] Ali, A., 'Vulnerability of Bangladesh coastal region to climate change with adaptation options', Dhaka, Bangladesh Space Research and Remote Sensing Organisation, 2000.



Aerial view of Hurricane Katrina off the coast of America

Calcutta, Hong Kong, Karachi, London, Miami, Mumbai, New York, Shanghai, St Petersburg and Tokyo[17].

In general, South and East Asia (e.g. Bangladesh, parts of China, India and Vietnam) are most vulnerable due to the large number of inhabitants living in low-lying coastal regions, but millions will also be at risk around the coast of Africa. In the Caribbean and Indian and Pacific Oceans, many small island states are acutely threatened. The risks are further enhanced in the Caribbean where more than 50% of the population lives less than 1.5km from the shore.

The number of people currently forced to leave their homes due to environmental disasters and a scarcity of natural resources is almost as many as are forced to leave due to political, religious and ethnic oppression. Indeed, some estimates suggest that 2% of the projected global population may be environmental refugees by 2050[18].

Living environment

Our delicate ecosystem has already been directly affected by climate change. Since the 1970s species have on average moved polewards by 6km/decade, and seasonal activities (e.g. flowering or egg laying) have been occurring several days earlier each

[17] Munich Re, 'Megacities – Megarisks', Munich Re Group, Munich, 2005.

[18] Myers, N. and Kent, J. 'Environmental Exodus: An Emergent Crisis in the Global Arena', The Climate Institute, Washington D.C., 1995.

decade[19,20]. Overall, temperature increases of 2°C are expected to contribute to the extinction of ~15-40% of species[21].

In the USA, 'ghost forests' are becoming increasingly common with standing dead trees killed by salt water intrusion. These ghost forests are particularly prevalent in southern New Jersey, Maryland, Louisiana and North Carolina[22].

The Arctic will be particularly affected by increased temperatures with polar bears and seals sensitive to the substantial loss of sea ice. Over the Amazon, reduced rainfall would result in a dying back of the rainforest, the region with the highest levels of biodiversity in the world.

For many species, climate change will be too rapid to withstand, for others migration will be the only option. Areas set aside for environmental conservation will no longer provide suitable climate habitats for native species. Other pressures from human activities such as crop production and pollution, especially if current practices are continued, will further contribute to the environmental strains.

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[19] Root, T., MacMynowski, D., Mastrandrea, M. and Schneider, S., 'Human-modified temperatures induce species changes', Proceedings of the National Academy of Sciences, 102, 2005.

[20] Parmesan, C. and Yohe, G., 'A globally coherent fingerprint of climate change impacts across natural systems', Nature, 421, 2003.

[21] Thomas, C., Cameron, A., Green, R. et al., 'Extinction risk from climate change', Nature, 427, 2004.

[22] Environment Protection Agency, 'Coastal Elevations and Sensitivity to Sea Level Rise'.

Policies and the State of Politics in 2009

Background

Since 1824, when the greenhouse effect was first described by Joseph Fourier, scientists have been trying to understand the dynamics of an ever-changing atmosphere and how this affects the long-term weather on Earth. In 1896, the Swedish chemist Svante Arrhenius first proposed the idea that man-made emissions could lead to additional heating, but it was not until the late 1950s that measurements by Charles Keeling confirmed the increase in atmospheric carbon dioxide (CO_2) levels that had been predicted.

With increased scientific understanding of the underlying processes behind climate change, pressure in the political community grew until the first World Climate Conference was held in 1979, when it seemed that there was a prevailing political momentum towards finding a solution. Indeed another pressing environmental issue, that of the depletion of the ozone layer (creating the 'ozone hole'), led to a series of high-level political negotiations which secured the Montreal Protocol in the mid-1980s. This protocol governs the use of ozone-depleting hydrocarbons and it is estimated that the ozone layer will recover by 2050 if the agreement is adhered to.

Similarly a series of political negotiations were set up around the issue of climate change, in particular the establishment of the Intergovernmental Panel on Climate Change (IPCC) in 1988. However, it took until 2005 to get an international protocol agreed that governed the greenhouse gases.

1970	**Earth Day:** April 22nd, USA
1979	**1st World Climate Conference,** Geneva
1988	**Intergovermmental Panel on Climate Change (IPCC)** set up by World Meteorological Organization (WMO) and United Nations Environment Program (UNEP) **Dr James Hansen**, NASA Goddard Institute for Space Studies, delivers testimony to U.S. Senate
1990	**IPCC:** first assessment on the state of climate change
1992	**Earth Summit:** United Nations Conference on Environment and Development, Rio de Janiero, attended by 172 countries
1995	**UNFCCC COP1,** Berlin **IPCC report** states that "the balance of evidence suggests a discernible human influence on global climate"
1997	**UNFCCC COP3, Kyoto Protocol** – industrialised countries agree to cut their emissions of six key greenhouse gases by an average of 5.2%
2005	**Kyoto Protocal becomes a legally binding treaty,** following ratification by Russia
2007	**UNFCCC COP-MOP 3,** Bali **Former US Vice President Al Gore** and the **IPCC** jointly win the Nobel Peace Prize
2008	**UK Climate Change Bill:** adopted **EU Energy Package:** adopted **GS Summit, Italy:** report of the Hokkaido Process **US Presidential elections:** Barack Obama elected **UNFCCC Cop14,** Poznan (Poland)
2009	**UNFCCC COP15,** Copenhagen: **comprehensive agreement?**

The history of climate change politics

2009: capturing the momentum?

Twenty years after the establishment of the IPCC there is an increasing urgency about taking action to tackle climate change. As the scientific understanding has moved on it has become increasingly difficult for politicians, business groups and other organisations to oppose the need to take action. The majority of discussions are now centered on how to take action rather than whether action should be taken at all.

In 2009, just prior to being elected, US President Barack Obama said "To finally spark the creation of a clean energy economy, we will double the production of alternative energy in the next three years." Specifically Obama said, "We will modernize more than 75 percent of federal buildings and improve the energy efficiency of two million American homes, saving consumers and taxpayers billions on our energy bills." "In the process, we will put Americans to work in new jobs that pay well and can't be outsourced, jobs building solar panels and wind turbines; constructing fuel-efficient cars and buildings; and developing the new energy technologies that will lead to even more jobs, more savings, and a cleaner, safer planet in the bargain."

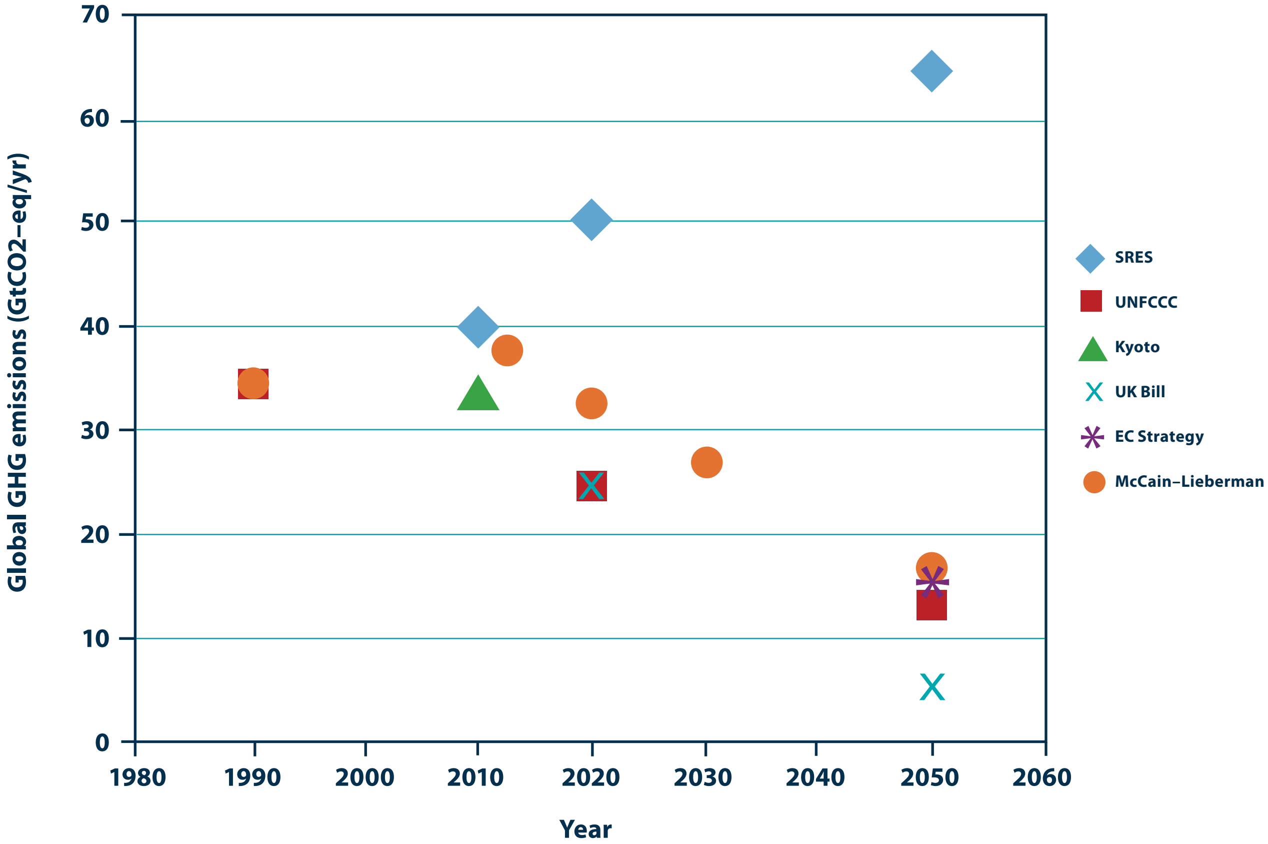

Figure highlighting the different levels of ambition (scaled to global emissions reductions) from various proposals for emissions reduction targets. The IPCC's Special Report on Emissions Scenarios (SRES) is shown under a 'business as usual' growth for emissions and is compared to the various proposals under discussion at the United Nations and elsewhere.

As can be seen in the figure above, there is very good agreement that deep emissions reductions are needed by 2050 – representing a 60% cut from 1990 emissions for developed countries. However, there is increasing evidence that this will not be enough and there are calls for an 80% cut (or higher).

Whichever long-term targets end up being agreed at local, national and international levels, they represent a significant change over business as usual and a major transformation in society. This change is often compared to a new industrial revolution (although some commentators refer to it as two or three industrial revolutions in less than half the duration of the last one).

Here we set out some of the current policies that are in place as these give us a platform on which to build real momentum.

The Kyoto Protocol

The Kyoto Protocol came into force in early 2005 following Russia's ratification. It is a protocol of the United Nations Framework Convention on Climate Change (UNFCCC) and, as of May 2008, 182 countries have ratified it, with the notable exception of the United States. Countries ratifying the protocol are split into Annex I (developed) and Non-Annex I (less-developed).

The protocol commits the Annex I countries to limit their emissions by, on average, a reduction of 5.2% below their 1990 level over the period 2008-2012. Some individual countries have limits that are above their 1990 level, which take into account their level of development and per capita emissions levels.

The targets are set as national-level commitments although countries are permitted to achieve those targets by purchasing carbon credits (emissions reductions) under mechanisms that have been set up including the Clean Development Mechanism (CDM) and Joint Implementation (JI). The Clean Development Mechanism allows Annex I countries to buy the emissions reductions in Non-Annex I countries (for example, by Europe investing in an energy-efficient power plant in China) while the Joint Implementation mechanism allows Annex I countries to invest in other Annex I countries in a similar way. The CDM market is currently valued at approximately $7 billion.

How countries implement and manage their particular targets is left open.

The Kyoto Protocol sets out emissions targets up until 2012. Intensive negotiations are currently underway as part of the United Nations Conference of the Parties (COP) under the UNFCCC process, in the hope of agreeing a further protocol that would set out a new phase of climate change targets beyond 2012. The UNFCCC process is intended to reach agreement by the December 2009 COP meeting in Copenhagen, Denmark.

Region	Emissions targets relative to 1990 levels
European Union, Switzerland and most Central and East European states	8% reduction
Canada	6% reduction
Hungary, Japan and Poland	6% reduction
New Zealand, Russia and Ukraine	stabilise emissions
Australia	increase emissions by up to 1%
Norway	8% increase
Iceland	10% increase

Kyoto emissions reduction targets for 2012

European Commission: Strategy for Energy and Climate

The European Commission published its proposed energy and climate change strategy in early 2007 and it was passed in late 2008. It includes a commitment to reduce greenhouse gas emissions by 20%, compared to 1990 levels, by 2020. However, it also included the provision to increase this target to 30% if there was an international agreement within this time. It also indicated that Europe would seek to achieve a 50% global emissions reduction target under the United Nations negotiations (this equates to between 60-80% reductions for developed countries). The EU also set out plans for 20% of all energy to come from renewables by 2020. This is an ambitious target as it was set on energy rather than electricity and therefore includes heating and fuel. It has also now officially recognised carbon capture and storage as a mitigation technology.

The European Union set up the Emissions Trading Scheme (EU-ETS) in 2005. Phase 1 of

United Nations building, Geneva

the scheme covered CO_2 emissions from 'major' industrial emitters between 2005 and 2008. This accounted for approximately half of the EU's CO_2 emissions and in 2007 the scheme had a traded value of $50 billion. The scheme allowed Member States to set a limit on the annual emissions from their industrial emitters (the National Allocation Plans) through a process of predicting where they thought the emissions would be and then applying a reduction to these emissions. Unfortunately a number of these predictions were too high and therefore the price of the emission allowances (EUA) towards the end of Phase 1 went to almost zero (there was a large over-supply of emission allowances). In Phase 2 (2008-2012) the European Commission has been stricter on the Member States in their National Allocation Plans and rejected all but one (the UK's) in the first round. The price of allowances in the current phase is therefore much more robust and is approximately 20 euros per tonne of CO_2.

The new energy and climate change strategy further strengthened the EU-ETS. The EU-ETS is to be expanded to include all greenhouse gases as defined under the Kyoto Protocol and a new centralised cap will be set (as opposed to 27 national caps in Phase 1 of the scheme). There are also proposals to move to auctioning of credits and to include aviation.

China: National Climate Change Programme

Some recent estimates put China as the world's largest emitter of CO_2. However, as it also has a sixth of the world's population this means its per capita emissions are well below those of developed countries. It is also one of the world's most rapidly developing economies, and as such, its emissions are growing strongly as demand for energy increases. China is also likely to see significant impacts from climate change and is playing an important role in the international negotiations.

Its own National Climate Change Programme outlines plans for a 20% improvement in energy efficiency by 2010 (over 2006) and a doubling of the use of renewable energy by 2020. However, this is not a limit on absolute emissions – if the economy grows by more than 20% in that time, which it is predicted to do, then the total emissions will grow.

UK: Climate Change Act

The UK Climate Change Act was first published in March 2007. It became law in November 2008 and requires the UK to cut emissions by 2050 by 80% over 1990 levels with a target of between 26% and 32% by 2020. These targets currently include international aviation and shipping but the Government retains the right to exclude them if this can be justified by the end of 2012. It makes the UK the first country to set a long-range binding reduction target into law. The Act also committed the UK Government to carry out a UK Climate Change Risk Assessment that will inform all parts of government about the risks of climate change to help set priorities for adaptation programmes and to make sure other policies reflect the potential risks and opportunities.

An independent Committee on Climate Change, as well as an Adaptation Sub-Committee, has been set up to provide advice and oversee the implementation of the Climate Change Bill. For example, in October 2008 the Committee recommended the 2050 emissions reduction target to be increased from 60% to 80%. The Climate Change Bill also includes enabling legislation that allows new regulations to be put in place that will help the UK achieve these targets.

California: Global Warming Solutions Act, AB 32

California's Global Warming Solutions Act came into force in September 2006 and requires California's greenhouse gas emissions to be reduced to 1990 levels by 2020. This Act also sets up requirements around reporting and monitoring and includes legislation that would allow California to implement new regulation that will ensure these targets are met.

To support this Act, Governor Schwarzenegger has highlighted the need for technology changes to take the lead in achieving these emissions limits. He has supported several initiatives that are intended to help innovation in renewable technologies and energy efficiency such as a Low Carbon Fuel Standard (announced in 2007) and the Million Solar Roofs Plan (announced in 2006). In addition, California is investing heavily in technology solutions.

Africa: National Adaptation Programmes of Action

Twenty-two African countries have submitted National Adaptation Programmes of Action (NAPAs) to the UNFCCC. These countries are Benin, Burkina Faso, Burundi, Cape Verde, Comoros, Djibouti, Eritrea, Guinea, Lesotho, Madagascar, Malawi, Mali, Mauritania, Niger, Democratic Republic of Congo, Rwanda, Sao Tome, Principe, Senegal, Sudan, Tanzania, Uganda and Zambia. NAPAs provide a country with a process for identifying priority actions for adaptation measures in the face of climate change. They include land use changes, coastal erosion and storm protection, disaster risk reduction and the strengthening of early warning systems (for major weather events). A number of projects have now been submitted for funding to the Global Environment Facility (GEF) under the UNFCCC. However, the GEF facility, which includes several different funding mechanisms (such as the Least Developed Countries Fund and the Strategic Priority on Adaptation Fund), amounted to less than $50 million per year between 2001 and 2006. A new fund, the Adaptation Fund, has been set up from a 2% levy on the CDM credits and could reach $400 million by 2012 but is not yet operational[23].

2009: a new mood in climate politics?

The Kyoto Protocol had been ratified by all major economies when it came into force except for Australia and the USA. However, as was seen above, this did not necessarily signify a complete rejection by those countries of the need to take action. Indeed, California has taken on board stricter emissions reduction targets than anywhere else.

United States of America: President Obama

With the election of Barack Obama to the US Presidency there is potential for a new momentum of change on climate change. President Obama has already indicated his support for an emissions reduction target of 80% below 1990 levels by 2050. A market-based cap-and-trade system, with all credits auctioned, seems a likely first step.

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[23] Africa Partnership Forum, Climate Challenges to Africa: A Call for Action

President Obama is committed to engaging fully with the UNFCCC. He has proposed to increase federal investment in clean energy research, development and deployment by $150 billion over ten years including retrofitting of buildings and energy storage technologies. He has also proposed increasing efficiency standards across a range of products into buildings and transport.

Australia: The Garnaut Review

In late 2007, with the election of a new government, Australia signed up to the Kyoto Protocol. In fact some commentators have signalled that the election was partly won on the differing environmental policies of the two main parties.

A review of policies in Australia to tackle climate change was published in 2008. The Garnaut Review stated that Australia should enter the international negotiations with a willingness to take on emissions reduction targets over 2000 levels of 25% by 2020 and 90% by 2050. It should also commit significant capital to research, development and commercialisation of low emissions technology.

In addition Australia is currently in the planning phase of an emissions trading scheme that could be launched in 2010. If it is launched by this date then it would come into force under the Kyoto compliance period.

Policy Requirements

Background

While developing a coherent policy framework that will deliver the low climate risk economy required under the Task Manager scenario, we need to keep in mind the scale of the change. At the moment a lot of money and time is being spent on incremental efficiency and in this report we have outlined the need for at least a factor of 4 reduction in current emissions by developed countries (which actually implies a factor of 20 reduction per unit of GDP given the expected growth over the same timescale). The International Energy Agency has estimated that investments of over US $1 trillion are needed annually until 2050 on both energy supply and demand sides to cut global emissions by half.

For business, certainty of delivery is key. The policy changes that need to be implemented are levers to support and drive forward the change that is needed, and that business is ready to make. The changes must be set up from the beginning by a government-business partnership.

To that end, all of the businesses interviewed during the research for the TCM agree that they will:

- Support work to set and achieve national and global emissions targets;
- Support government action, including regulation, to ensure targets are met;
- Work with policy-makers nationally and internationally to help develop and maintain a progressive policy framework, including mitigation and adaption plans;
- Support the development and deployment of new technologies.

It is important to consider at each stage how the changes will be implemented. The majority of the changes will be developed and delivered at a local level. Therefore, it is important for politicians to engage at all levels, and the international policy should be set up to enable national strategies, which in turn enable local strategies. This engagement includes delivering both the framework and resources needed.

As has been discussed previously in the TCM, policy makers have already delivered a price on carbon through the Clean Development Mechanism (CDM) as well as regional prices through trading schemes such as the European Emissions Trading Scheme (EU-ETS). However, here we argue strongly that this is only the start of the process.

Capacity building is key over the next few years. A change of this scale requires new policies and markets to be set up in every region of the world, and to deploy the scale of technology-change that is called for requires a substantial workforce capable of doing this. Therefore any agreement needs to include support for developing the skills needed to deliver on-the-ground change.

Policy type	2009-2012	2012-2020	2020-2050
Emissions reduction targets	Developed countries agree to binding 2020 targets and indicative 2050 targets.	Less-developed countries agree to voluntary targets.	All countries have agreed 2050 targets with national governments implementing emissions reduction pathways.
Carbon price	All developed countries should implement a cap-and-trade scheme with full auctioning.	Global framework set up linking existing carbon markets. Border taxes changed to avoid undermining carbon markets.	Less-developed countries should develop carbon markets (potentially by linking through CDM regional programmes).
Forward procurement	Targets set in advance for government procurement contracts over 2012-2020 period, including vehicle standards and white goods.	Targets set for building efficiency standards to encourage the creation of ESCOs (energy service companies) in developed countries.	Efficiency and energy standards in all government contracts globally.
Standards and regulation	Change/merge regulators to have more of a systems view; Ensure planning authorities are streamlined to reduce costs of implementation.	Increased mandatory efficiency standards following forward procurement commitments by governments; Include better 'closed system' (cradle-to-cradle) regulations.	Use of the Japanese 'top-runner' standards to encourage more innovation in product design; Carbon sink regulations fully embedded; Electricity grids opened up.
Subsidy reform	Examine and reform all forms of subsidy to ensure driving appropriate behaviour change (e.g. VAT on energy efficiency measures should be removed).	Feed-in tariffs redeployed as technologies become cost effective.	Continuous monitoring of subsidies and their impact. Subsidies shift from technology sources to electricity infrastructure.
Support for discovery and demonstration	Increased spend on research and development.	International funding schemes to ensure global efforts are coordinated.	Support for demonstration of fully electrified and renewable economy.
Technology transfer	Reform of Clean Development Mechanism (CDM) to be programmatic (launch in 2012).	Substantial investments in multilateral funds for demonstration and deployment of technologies in emerging and less developed countries.	
Behaviour change	Governments should invest in information campaigns and education; Introduction of 'avoidable' tax and incentives to drive customer behaviour.	Create new market incentives for companies to be able to capture long-term value in service offerings.	

Land rights	Dialogue between land owners and government on carbon stored in soil.	Development of REDD (Reducing Emissions from Deforestation and Degradation) markets through capacity building in forest regions.	Regulatory framework implemented for carbon in soil and conserved forest stocks.
Adaptation	Development of international arrangement for collecting and sharing climate data; Full examination of changes in risk for access to food and water; Investment into adaptation measures that reduce risk to an insurable level.	Management plan for changes in healthcare and ecosystem conservation implemented.	Process set up to continually monitor and assess changing climate risks.
Carbon disclosure	Encourage voluntary standards for carbon disclosure.	Implement mandatory global standards for climate risk disclosure by companies.	

Summary of the key policy areas and timescales to deliver a factor-4 reduction in emissions.

Creating frameworks for delivery?

To enable serious work to begin on implementing policies that will drive business decisions, a clear long-term commitment by governments is needed. This global deal, under the United Nations Framework Convention on Climate Change (UNFCCC) process, should be agreed as soon as possible. It should include a global emissions reduction target of at least 50% by 2050 relative to a baseline of 2000. This target should be based on the latest available science. Developed and less-developed countries need to take on specific targets over this period. In particular a new framework for 2012-2020 should be agreed and include:

- Developed countries' emissions reduction targets: 25-40% target by 2020 (on 2000 baseline) and indicative targets of 80-95% by 2050;
- Less-developed countries' emissions reduction targets: voluntary inclusion to 2020, then targets set for 2050, under the overall 50% global target, based on a capacity to achieve.

A global framework should include:

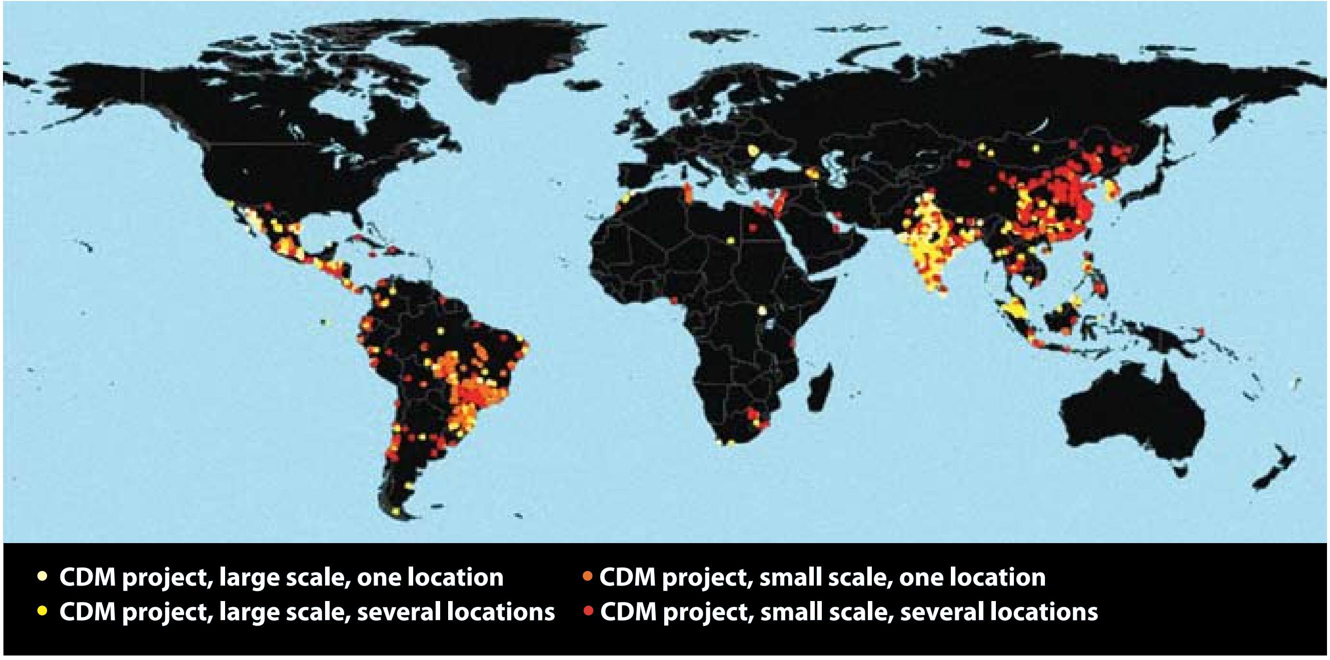
- Finance/trading mechanism for linking carbon markets in different regions;
- Technology transfer and investment framework;
- Requirement for national mitigation and adaptation plan.

To support adaptation a clear, long-term international arrangement for collecting and sharing climate data is required. This will need substantial investment in accurate national and regional forecasting of future weather and catastrophe patterns. Governments at domestic and all international levels can then assess their climate-related risk exposure and pool their analyses, as well as making them publically available.

The UNFCCC process should look at the requirements for the development of new, or redevelopment of existing, international institutions that can support the delivery of these mechanisms. These institutions will be key to sharing technologies and best practice as well as adaptation strategies in each of the key climate impact areas such as water, food and health globally.

For example, the Multilateral Development

Banks have a long track record in providing policy advice to less-developed country governments on energy market developments and removing market barriers. There should be a growing emphasis on helping less-developed countries create markets that can link into the global carbon markets such as the CDM. The World Bank Group needs to move countries 'up' the chain to allow private sector investment into these regions. With open markets and clear opportunities for investment, intellectual property rights will become less of an issue (the majority of the 'value' in clean technology is in the deployment and implementation of that technology rather than in a patent).



Source: UNFCCC, CDM Project Locations, http://cdm.unfccc.int/Projects/MapApp/index.html

Current location of Clean Development Mechanism (CDM) projects around the globe, showing that it is mainly the emerging economies rather than the less-developed economies that are currently benefiting from this system.

To increase capacity to respond to CDM opportunities, a reform of the CDM is required. The ability to 'package up' different project-based initiatives into regional or programmatic initiatives (for example, a less-developed country will be able to offer efficiency gains for its entire energy-supply sector) will ease a lot of the bureaucratic burden associated with measurement and authentication, and should be offered alongside project-based CDM opportunities where individual businesses can partner on particular technologies and sites. For example, in West Africa gas flaring projects on oil exploration sites could be bundled together to allow for efficiency savings within a new CDM methodology. Within developed countries, the flow of investment into a new CDM should be encouraged through their carbon markets. Bilateral agreements between countries could also be set up through the CDM regional initiatives. The revenue from auctioning of credits on carbon markets could be used to fund these bilateral agreements.

Particular technology and market issues that are difficult to manage locally should also be included in an international agreement. This includes shipping, aviation and carbon sinks. The Reduced Emissions from Deforestation and Degradation (REDD) proposals should be implemented as soon as possible. REDD should be implemented through an initial phase of international government support to develop the required measurement and monitoring mechanisms in the forest regions, as well as mechanisms for transfer of funds within those regions (funding for this phase could possibly be provided through the issuance of long-term government bonds). Once the mechanisms are in place, REDD carbon credits should have a clear mechanism for linking into the other carbon markets. Conserved forest carbon stocks (and not just avoided deforestation) should be looked at over the longer term.

With an international framework in place, national and regional governments then need to implement specific mechanisms to deliver on their emissions targets or commitments. A national target should be broken down into sector-specific targets linked to governmental responsibility. (These are not industry sectors but government department sectors, for example, transport, industry and agriculture.) These targets should be set in the same way as government budgets – each department would take ownership of their allocated budget and produce a vision on how best to achieve those targets. Each department would then have a responsibility to look at all legislation within its control and how it impacts on climate change. However, there does need to be an independent government focus that can oversee these budgets (such as the finance ministries do for the financial budget).

What role for carbon pricing?
A carbon price is an essential, but not sufficient, tool in the fight against climate change. It delivers clear accounting mechanisms for management decisions and generates revenue from efficiency measures but it will not overcome market inertia and is not transformational. A carbon price needs to be implemented as broadly as possible with any exclusions limited to necessity only. A price can be delivered as a carrot (credits) or a stick (tax).

Most technology solutions do not implicitly 'need' a carbon price, but the price facilitates their early adoption and speeds-up market penetration. Currently, carbon prices are at most 10% of the total energy price. Most energy efficiency measures will pay for themselves, and once clean technologies are cost competitive the normal market mechanisms will kick in and provide a return on investments. However, two areas do require a price on carbon: carbon capture and storage and forest protection. There is no other reason to implement these two products without a price (apart from preventing future losses from climate impacts).

Where you apply the price is very important. For example, a price on fuel at the forecourt may reduce car usage slightly; a price on the carbon content of the discovery of fuel may drive a move to alternative lower carbon sources; while a price on the efficiency of cars (possibly through road tax) could drive the development of new types of vehicles.

To deliver a price on carbon, heavy industry prefers the flexibility of cap-and-trade schemes rather than a direct carbon tax. A cap-and-trade scheme is a market-based mechanism whereby governments set a cap (limit) on the allowed emissions by organisations defined as being governed by that scheme, and those organisations are given (or sold) allowances to emit up to that limit. The organisations under the scheme are then allowed to trade their allowances with each other on an open market so that the lowest cost emissions reduction solutions can be found. These schemes have the 'certainty' of achieving the reduction target that is set and allows market flexibility to implement the cheapest solutions to deliver those reductions. However, some direct taxation, or incentives, in certain circumstances may be better. Certain project-based investments (such as carbon capture and storage) require more certainty over the carbon price before investments will be made and certain sectors or activities (such as smaller businesses) do not have the resources to be active in cap-and-trade schemes.

Within cap-and-trade schemes, centralised caps should be used and these caps should cover all sectors. Within those caps full auctioning should be used to ensure the real carbon price is embedded into business decision-making. Full auctioning can generate revenue which can be used to support innovation, cooperation with developing countries (see CDM above) as well as offset tax reductions in other areas that in turn support economic growth. Full auctioning will also reduce the need for windfall taxes which create investment uncertainty in the high carbon sectors. However, some countries will need to reform certain regulated sectors to allow companies to pass on the costs of carbon to customers.

There will be a need to treat certain sectors differently to manage 'leakage' and discussions on this issue should be started immediately. Leakage occurs where a particular sector is open to competition from high carbon competitors from outside the cap-and-trade region that can undercut the cost of products because they are not subject to a carbon price. This could be addressed through allowing some free allocations in the cap-and-trade scheme to those sectors, state aid (obtained from revenue generated through full auctioning) or through border adjustments. However, border adjustments (taxes on imports or credits on exports) are politically very difficult and would need to be implemented in close partnership with the World Trade Organisation and have clear limitations on which products are included, with any adjustments having limited lifetimes. Analysis shows that leakage only impacts sectors accounting for 1-2% of Gross Domestic Product in countries such as the UK or Germany (predominantly cement, aluminium and steel) although countries who have borders with regions outside of the trading scheme could suffer more leakage (for example, electricity generation for Eastern European countries).

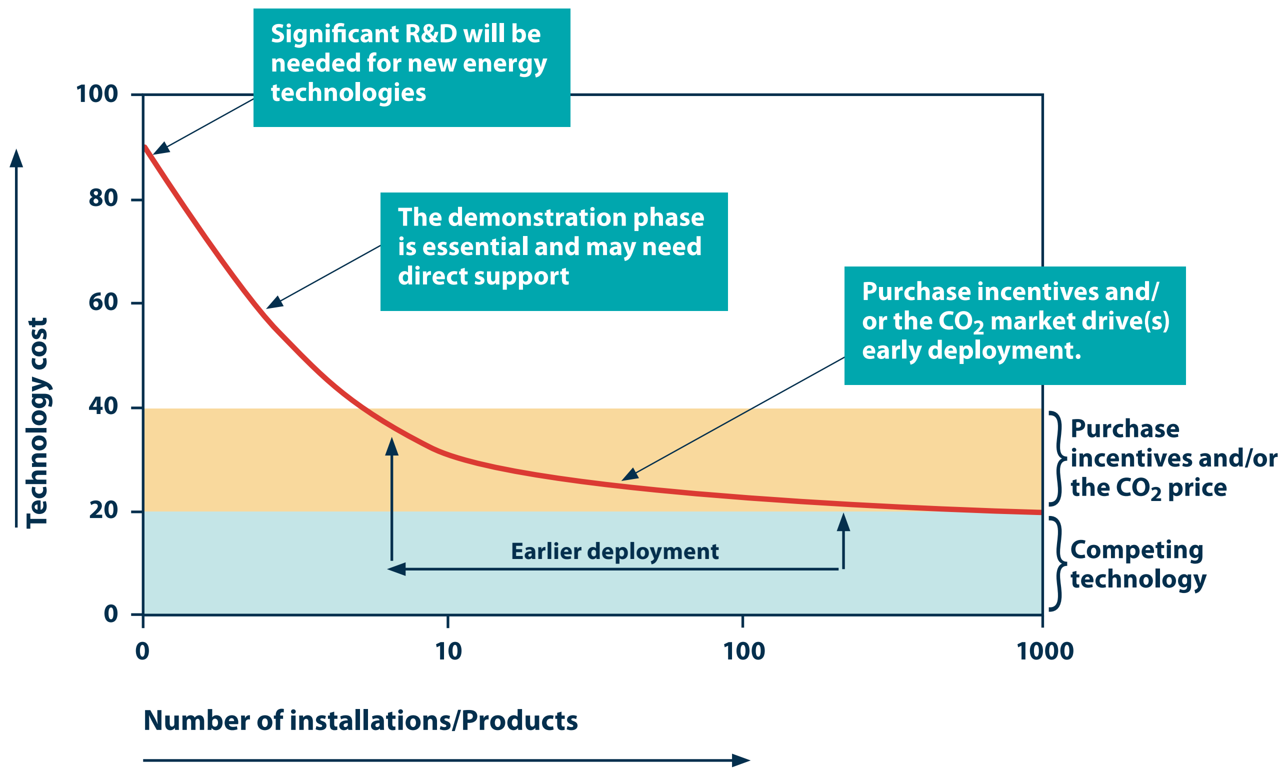
How can we deploy new technologies?
It is clear that a carbon price will deliver a business focus on climate change, but will not in itself be sufficient to ensure the transformational change that is needed. Therefore, a set of other policy mechanisms are needed to support the carbon price.

When designing regulation to support the deployment of new technologies it is important not to pick 'winners'. Rather than designing support for a particular technology it is much better to define a 'goal' for a particular sector or issue (for example, defining a 10% carbon content reduction for fuel over its lifetime is better than a 10% biofuel commitment). However, government has many tools that it can use to reduce the risk for businesses in investing in new technology areas and we outline some of those tools in this section.

New technologies have a three-stage process until they can reach their full potential for emissions reductions:

1. Discover and develop;
2. Demonstrate;
3. Deploy.

The cost of a particular technology will usually reduce as it progresses through these three stages. For example, as manufacturing capabilities are scaled-up, the cost of reproducing individual products are reduced



Technology cost through deployment lifecycle showing impact of carbon price (or purchase incentives)

	Power generation	Transport	Infastructure
Discover and develop	Support for infrastructure (e.g. grids and pipelines)	Support for advanced fuel development	Urban planning decisions
Demonstrate	Fiscal support for large-scale CCS (carbon capture and storage) demonstrations	Public transport infrastructure	Encouraging radical design
Deploy	'Cap-and-trade' and CCS rules and recognition	Vehicle efficiency standards	Efficiency standards (appliances, air conditioning)

Examples of government tools that could be used to ensure technologies are fully deployed.

through increased efficiency, and new innovations offer extra cost saving. A carbon price ensures that a new technology becomes cost-competitive earlier with the existing technology it is trying to replace. However, while new technologies often find support for the discovery phase, and the market will take over in the deployment phase once the costs are competitive, there is a 'valley-of-death' in between these two phases where it is difficult to get funding and support (either from business or government) to ensure that a technology can reach phase three.

To further support the deployment of technologies, there needs to be clearer communications between governments, business and researchers (and across the different disciplines within research). Therefore, we would encourage governments to support the development of 'Deployment' agencies which would bring together these three sectors. This could also allow academic research to be delinked from short-term business needs and blue-sky research can be given a space to explore what is needed over the long term.

Forward procurement

An important part of the decision-making process within business associated with investing in new technology areas is whether there will be market demand for that new product. One of the strongest tools in government's armoury is not direct regulation, but purchasing power. Governments in most countries form a substantial part of the financial activity of that country. By using their buying power, governments can demonstrate a commitment to the market to purchase a particular standard of technology, and thereby create the market pull that can help certain technologies overcome the 'valley-of-death'.

Forward procurement commitments, where a government gives an indication to the market that it will only purchase a particular product if it meets certain standards in the future, gives this type of reassurance to business. For example, governments could commit to a certain standard of efficiency in its vehicle fleet over the next three years. If European governments committed to only purchasing cars with emissions of 100g/km by 2015 (compared with a proposed regulatory target of 120g/km by 2012-2015), the car industry would see this as a clear commitment to a marketplace and would respond accordingly. In fact, once this market is established it would be much easier to then introduce a mandatory target, industry-wide, of 100g/km by 2020, as proposed by some European countries. Some research has indicated that the higher the targets, the more innovation business will respond with, and with lower cost technologies.

Government should also use the public sector infrastructure (such as schools, hospitals and government buildings) to stimulate the creation of energy service companies (ESCOs). By tendering for contracts to manage the energy efficiency and climate resilience of public sector buildings, companies will be created that can then respond to this demand. These ESCOs, in partnership with the public sector, will have a guaranteed customer (the government) as well as having the additional incentive of selling carbon savings into the trading markets and developing expertise in climate adaptation.

Standards and regulations

When making purchase decisions, customers are not always driven by rational decision-making processes. For example, if return on investment were the primary reason for a purchase, this would mean that every household in Europe would have a condensing boiler rather than a savings account. Some obvious policy solutions may not always deliver the desired outcome and it is important to work with people's behaviour and decision-making processes.

Where consumer behaviour can be influenced (for example, with white goods), an energy efficiency certification system should be implemented. This certification system should be followed by regulation similar to the Japanese 'top-runner' process – whereby the future minimum standards are based on current best-performing products, giving industry enough time to innovate and meet those increasing standards. The system of ever increasing standards should be used to phase out old technologies and it is important to set clear timescales for this. Energy efficiency certification can also be used to embed long-term 'carbon value' into a product. For example, energy efficiency certification, coupled with a forward look at increasing mandatory efficiency standards, may provide some property value accrual for capital expenditure on efficiency, and make it more likely that building owners will invest in these measures to ensure the value of their property remains high.

In the next few years governments will need to look again at the role of regulatory authorities and planning authorities. In a transformational change process, delaying change can be very costly. It can currently cost more to deploy a solution than it does to develop it because of the process of planning applications and regulatory approval. While it is very important to keep stringent rules and regulations around planning and deployment, the urgent need to implement large-scale solutions has to be streamlined if we are to have any chance of success in tackling climate change.

International and national targets need to be considered at local levels, and while not overwriting local concerns, a national plan for deployment of technology solutions can be used to demonstrate the need for particular solutions to be utilised in particular regions. Very often planning laws are sufficient to deliver on the necessary change but the interpretation of the law is often confused. Therefore, it is also important to ensure better implementation of existing laws.

Planning regulations for urban development mainly focus on the land allocated to housing (including density requirements and transport links). Planners usually look at three models for growth of the urban environment:

- Increasing compactness (not allowing any expansion of the urban sprawl);
- Unconstrained growth (market led dispersal);
- Planned extensions (guided developments).

Using planning laws to constrain growth or to try and influence the behaviour of people to ensure lower emissions is very difficult, and early indications from research carried out by the University of Cambridge show that, in developed countries, constraining the growth makes, at best, a 5% change in emissions but can have a significant impact on the economics of a region. This is because what you can do as 'new' is very limited (at most 20-30% of infrastructure in a developed country city is likely to be replaced). Even with the most radical policies you don't get significant changes. People in highly compact areas travel less distance but at slower speeds and so any savings are usually cancelled out. Therefore, planning regulations should be used to ensure that individual buildings are as energy efficient as possible but that the overall infrastructure remains as flexible as possible so that new technologies which are developed later on can easily be retrofitted where needed.

There needs to be a better system for regulation of utilities. In particular there is a need to merge regulators where there are competing agendas. For example, the water and energy industries, which will be increasingly dependent on each other over the next few decades, should not be regulated by separate authorities with separate agendas. By bringing these two sectors (and the waste sector) closer together, there would be a vested interest in maximising the efficiency of the system, including the distribution of electricity, heating, cooling, water and waste. Regulated monopolies (or semi-monopolies) should also be given more ability to retain profit from innovation to encourage the large utilities to invest more in research and development.

For the electricity sector there also needs to be a focus on market design. In particular, how new technologies or sites can be linked on to the grid needs to be examined, to ensure that renewables can be deployed as rapidly as possible. In the short term, the legal requirements associated with outage should be examined. By increasing the amount of outage acceptable on a grid (for example, by allowing 2 hours of permissible outage per year rather than 0.5 hours) there will be much less need for standby generation and resilience which will reduce the electricity costs significantly allowing for further investment into alternative technologies.

Regulation for closed-loop products should be improved. For example, over the next two or three years governments should be setting up a system for diagnostic and defect detection in products (such as steel) that can be reused at end of life. A regulatory system which allows for end-of-life products to be reintegrated into the manufacturing system should be implemented. This 'cradle-to-cradle' concept needs to be incorporated across all sectors so that by 2050 companies no longer sell 'stuff' but lease it to us for their lifetimes. For example, an aircraft manufacturer can lease the metal in a plane to operators and at the end of life take the metal back and reuse it in new aircraft. Both 'carrots' and 'sticks' will be needed to fully realise the potential for 'cradle-to-cradle' and should build on current regulations such as the European Waste Electrical and Electronic Equipment Directive (WEEE).

In addition, new regulation will be needed associated with the creation of markets or technology sectors. For example, a clear long-term legal system associated with stored carbon (from carbon capture and storage plants – CCS) is required now. While this system does not need to be operational until 2020 (when CCS will start to become deployable at scale) governments need to clearly state what that system will look like and how the value in captured carbon will be managed and included in any carbon markets. In addition, the carbon markets need to be put in place for as long as the full duration of a typical storage site's operation (15-20 years for geological storage in depleted oil wells) and the 'ownership' of the credits created in storing carbon and the liabilities over potential leaks following the operational period need to be clarified. For example, government should take over the long term liabilities of such sites once the long term storage has been demonstrated.

Subsidy reform

Government subsidies play a useful role in developing new markets and in deploying new technologies into markets. However, they can also distort markets and result in unintended consequences and very often encourage investment to maximise subsidy rather than maximise intended outcome. The International Energy Agency's World Energy Outlook 2006 examined energy subsidies in 20 non-OECD (Organisation for Economic Co-operation and Development) countries. They found the total value of subsidies to be over US $200 billion in 2005. Almost 80% of these subsidies were estimated to be on fossil fuels. An energy subsidy delivers a particular fuel source to the market cheaper than it would otherwise be and is usually put in place to benefit consumers by lowering prices.

A 'good' subsidy can ensure early uptake of cleaner technologies and move markets quicker than they would otherwise, in order to deliver a very much more rapid transition to a low climate risk economy. For example, feed-in tariffs on electricity supply encourage the uptake of low carbon energy sources by guaranteeing a price above market rates for electricity generated from those sources. Feed-in tariffs are better than sector targets (for example, obligations on energy suppliers to deliver a certain percentage of their supply from a particular source). Feed-in tariffs give more of an incentive to innovate and reduce the costs of technologies and encourage a more rapid uptake, while obligation targets will deliver exactly what they ask for – a certain percentage of energy from a certain source.

Government intervention	Example	How the subsidy usually works		
		Lowers cost of production	Raises price to producer	Lowers price to consumer
Direct financial transfer	Grants to producers	•		
	Grants to consumers			•
	Low-interest or preferential loans	•		
Preferential tax treatment	Rebates or exemptions on royalties, sales taxes, producer levies and tariffs	•		
	Tax credit	•		•
	Accelerated depreciation allowances on energy-supply equipment	•		
Trade restrictions	Quotas, technical restrictions and trade embargoes		•	
Energy-related services provided directly by government at less than full cost	Direct investment in energy infastructure	•		
	Public research and development	•		
	Liability insurance and facility decommissioning costs	•		
Regulation of the energy sector	Demand guarantees and mandated deployment rates	•	•	
	Price controls		•	•
	Market-access restrictions		•	

From Reforming Energy Subsidies, United Nations Environment Programme, 2008

In Spain, for example, feed-in tariffs were introduced in 1997 and varied according to the particular technology being deployed (prices were set based on the needs of various technologies to achieve cost competitiveness with existing technologies). These tariffs have been the main driver for a rapid expansion of the renewables industry in Spain, which is now one of the world leaders in wind and solar power. However, there are many issues with feed-in tariffs and when implementing such a system clear mechanisms for removing the subsidy in time (a sunset clause) are needed up front as well as certainty over how the subsidy will function throughout its lifetime. While refocusing subsidies to increase the use of low carbon technologies, the pro-poor subsidy – especially in countries with little or no welfare state – must not be eroded.

Certain subsidies currently drive behaviour which is counter to tackling climate change. While these sometimes derive from good motivations, governments should take a holistic approach to the economy. For example, coal mining in Germany received 2.5 billion euros in subsidy in 2007 to protect employment in that sector. In the UK, Value Added Tax (VAT) is charged on retrofitting buildings but not on new builds and therefore it can be cheaper to rebuild a property rather than implement energy efficient and adaptation measures into an existing building. All governments should examine current direct or indirect subsidies to make sure they are driving the behaviour change that is desired.

Support for discovery and demonstration

All of the regulations and policy measures outlined above will encourage the deployment of new technologies through the creation of market pull. For certain emissions reduction strategies there is also a need to support the discovery and development of new technologies. This is because the uncertainty in developing certain new technologies that require significant and prolonged investment is too large to justify capital expenditure under 'normal' business models. Therefore, direct support from government is needed in these areas. Current estimates show that 0.01% of GDP is spent on renewable energy research in developed countries (total spending on research is approximately 2% of GDP in those countries). This is inadequate.

For example, blue skies research that focuses on a 2100 vision of a completely electrified and renewable society should be encouraged and supported. This will include supporting the design of new technologies that can run on variable voltage, products that can be remotely switched off during peak periods to offset demand and dynamic distributed storage solutions that can smooth out electricity demand. There is also a need to explore further adaptation measures such as drought- or heat-resistant crops which will be needed as climate change impacts are felt.

Government support is also needed at the demonstration phase for certain large-scale technologies that require significant capital investment. While clarity around the legal system for managing stored carbon (see above) will certainly help create a justification for investment in carbon capture and storage, the costs associated with deploying this technology are very large and some uncertainty still remains given that payback periods will be over a very long timescale. Therefore support for pilot plants is urgently needed, and governments should encourage close collaboration between power companies with expertise in managing emissions and companies that can provide the technical expertise in distributing and pumping gases underground (such as oil companies). However, governments should allow companies to develop the best economic models for carbon capture and storage and not dictate particular solutions.

Technology transfer

To ensure technology is used globally as quickly as possible, a mechanism for technology transfer should be implemented under a global framework. Intellectual property rights issues for large scale clean technology are less important than the costs associated with deploying new technologies, and therefore funding should be directed at increasing the capacity of emerging and less-developed economies for demonstration and diffusion of these technologies. Funding should be made more available through mechanisms such as CDM as outlined previously as well as from direct sources such as The World Bank Climate Investment Funds (for example, the Clean Technology Fund). These funds should place emphasis on projects which can create new enabling and regulatory environments. In addition there should be a review of import and export taxes (in both developed and less developed countries), especially for those technologies that require more rapid deployment.

In addition, existing border taxes may need to be changed so that they do not undermine carbon markets and carbon prices. For example, import and export taxes, or regulations that impose restrictions on the movement of technology or electricity in power grids across national or regional borders, should be changed to ensure new low carbon technologies are cost competitive wherever they are deployed.

For smaller scale energy storage and energy efficient products a robust intellectual property system will support the innovation of these products as it protects the value that can be gained. However, a strong supporting financial system will be needed to encourage the deployment of these technologies as rapidly as possible around the world.

Particular technologies such as carbon capture and storage and technology regimes, such as those that can deal with flaring of gas in oil exploration, require incentives on the ground to be able to produce the necessary infrastructure and local capacity for implementation.

Can we encourage behaviour change?

The simplest way to ensure behaviour change is through 'choice editing': banning products and services that are undesirable. Encouraging behaviour change through national campaigns to make particular types of behaviour undesirable in society can take many years (such as recent moves to make smoking socially unacceptable or previous drives to discourage drink-driving). Therefore, 'choice-editing' is a vital part in encouraging behaviour change in the timescales demanded by climate change, and as discussed in the previous section, this can be implemented in a way that will encourage innovation and new product design.

In certain circumstances, certification or standards will not drive customer behaviour (or will not drive it fast enough). Therefore, extra regulation will be needed and empowering people is important. For example, while vehicle efficiency standards are important (there is some evidence that efficiency standards encourage manufacturers to promote more efficient vehicles through their advertising) they will not change customer behaviour when it comes to the use of vehicles (as the price differential based on vehicle efficiency standards is small). Increasing fuel costs (through carbon pricing), or charging road users will have an impact on customer behaviour but it is important that any increase in the cost of private transport is accompanied by an increase in the availability, affordability and usability of public transport.

The customer must be able to see any cost increase as an avoidable tax (they can decide to get on public transport to avoid a road congestion charge) and these taxes should not replace existing taxes as they should be short lived (as behaviour is changed this source of tax revenue will reduce). If they are given more self control over their environment, a choice is made available (public transport must be simple and cost effective to use), the information they need to make choices is accessible, and incentives to change are put in place, they are more likely to behave differently.

Therefore the two elements of behaviour change are:

- Information (education and incentives);
- Standards (mandatory).

One of the most effective and quickest step changes in building efficiency should come from behavioural change; if we switched off equipment, maintained it better, replaced inefficient with more efficient, and tolerated slightly higher summer building temperatures and cooler winter temperatures we would accrue significant benefit. To encourage this behaviour change, business models need to be changed so that business is incentivised to work with their customers and provide the information they need to make these changes. Currently, utility profits are derived from volume sold. Regulators should look at new models for utilities and allow partnerships between utilities and other sectors (such as mortgage companies) who can link efficiency savings to other products offered to the customer.

However, with any changes in behaviour it is important to note the 'rebound effect'. Any efficiency savings that a customer will make may be used to pay for an increased amenity and will therefore increase demand, and potentially emissions, elsewhere. Therefore, policies will need to be designed carefully to take this into account.

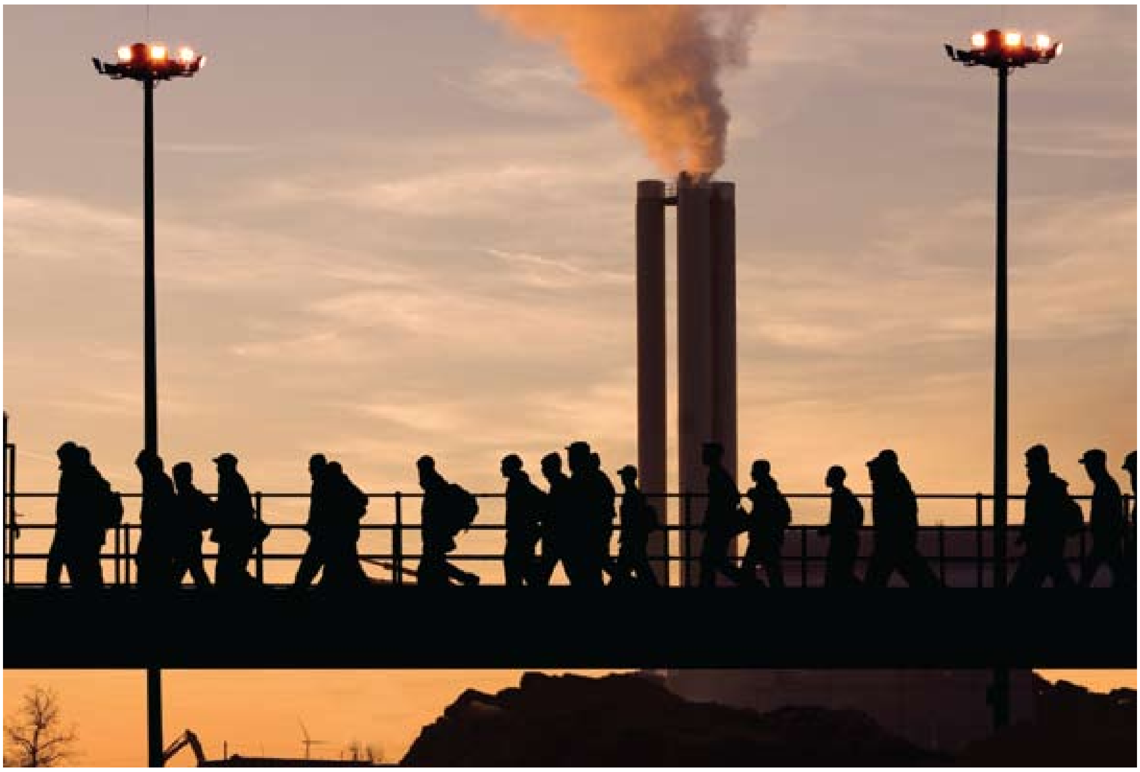
Who has the responsibility for carbon?

Carbon that is already captured is often ignored when considering climate change. However, ensuring that the carbon remains captured is a vital part of the transformational change. 90% of terrestrial carbon is stored in soil and systems are needed to ensure that it remains in the soil. The two key issues associated with land-use changes resulting in the release of carbon are agriculture and deforestation. The UNFCCC process should incorporate a market to avoid deforestation (the REDD mechanism) as soon as possible.

A key driver for land use change is the growing world population and the increasing demand for food. There is a question over the property rights of carbon in soil – whom does it belong to? A similar issue has existed in the past, associated with other pollutants in soil. The introduction of agri-environment schemes in the UK saw a shift away from farmers being paid not to pollute, to a voluntary period where farmers in Sites of Special Scientific Interest (SSSIs), and more recently other areas, being paid for taking positive actions relating to conservation.

But does this impose costs and on whom? Is any loss of carbon acceptable? If you own carbon do you have a duty to protect this? In terms of tackling this problem a benchmark needs to be set (a benchmark of 50ml of nitrogen in water was set to tackle nitrate pollution) – then who has responsibility needs to be worked out. Linking reduced carbon emissions from all sources into existing carbon markets through a scheme such as REDD should be pursued as soon as possible.

To take forward carbon stock management, and building on the Land Use, Land-Use



Change and Forestry (LULUCF) section of the Kyoto Protocol, policy frameworks will need to include how to establish baselines and ensure additionality (so that land owners are encouraged to preserve existing carbon stocks while not undermining the need to reduce carbon emissions across the economy). It will also need to incorporate the complexity of having a large number of small landowners who will need to take part in such a scheme, and therefore linking all LULUCF activities, in particular conserved carbon stock, into existing cap-and-trade markets may not be the best solution. A dialogue needs to be started between governments and land owners to provide information on what is needed and how to work in partnership to deliver sensible management mechanisms for carbon in agriculture.

How do we protect current systems?

While it is anticipated that significant, and rapid, progress can be made on introducing new technologies and encouraging behaviour change that will mitigate climate change, there will still be a significant need to manage climate risks. In particular water management, land management and migration issues should be included in national and regional adaptation strategies. It will be increasingly difficult for adaptation strategies to be implemented at national levels, and increased cooperation and dialogue between countries is to be encouraged, especially those countries with shared resources.

National adaptation plans should include a thorough analysis of the changes in food and water availability (in particular taking into account projected population increases). They should include an analysis of which mitigation activities could also be used for adaptation – such as reforestation and watershed management for protection against floods. In addition they will need to examine the changing demands, and investment requirements, of the healthcare system, the emergency services and ecosystem conservation, all of which will have big impacts as a result of changing weather patterns (see the Climate Science and Impacts chapter).

A particularly important part of adaptation within a low climate risk economy will be the provision of insurance services to ensure that when climate-related events occur, business and customers can rebuild infrastructure and recover from these events. In order for insurers to play their fullest role in helping customers around the world to manage these growing risks, governments must make adequate investments in adaptation measures to ensure those risks remain manageable and insurable. This is particularly important when offering insurance products to the previously uninsured or uninsurable (in both developed and less-developed economies).

How can we finance the future?

With the current fiscal stimulation packages being put in place as a response to the global financial crisis it will be important that this investment supports the long term development of the economy and underpins this transformational change.

The current creation of value is through debt and interest repayment. This is based on infinite limits, and environmental externalities are not included in any decision-making process. To help with investment decisions mandatory disclosure of climate risk should be phased in to ensure climate value is embedded in long-term company value. This will encourage organisations to view climate risk within their current risk analysis processes which include other global issues such as currency fluctuations. In addition, financial flows in carbon markets (and the links between carbon markets and between regions and countries with and without carbon markets) need to be regulated. The embedding of long-term stable investment opportunities (through the creation and embedding of long-term stable carbon markets and climate risk monitoring) is the only way to ensure that climate risk is managed throughout the economic system.

It is vital to ensure that private capital is utilised to finance the transformational change needed. Understanding how private capital is deployed and the decisions that are associated with investments is essential. For example, it is not sufficient for a particular technology to appear to be profitable over the long term but it must also overcome the hurdle rate – the accept/reject threshold for determining if an investment will be made by a particular company – usually derived from typical risk/return profiles for the existing products and services.

A much wider discussion between the finance community and the public sector than has happened to date is needed. In particular the public sector has to deliver the capacity, regulatory framework and infrastructure needed to support new technologies when they are ready to be deployed. This public-private partnership is the only way to ensure we deliver a low climate risk economy.

Technological and Behavioural Change

Background

The 2008 WWF Living Planet Report bleakly confirms that globally, we are currently using 30% more natural resources than the Earth can produce.[24] At this present rate of consumption, by 2030 we will need the equivalent of two planets in order to sustain ourselves. Ecosystem collapse on a mass scale, including rapid biodiversity loss, water shortages, deforestation, and climate change, is the direction in which we are heading. With only one planet to live on, the urgency with which we need to address this 'overshoot' and change course should be apparent. Technology and technological transfer has a major role to play in maximising efficiency and minimising greenhouse gas emissions for the energy sector. However, remaking our world in the image of sustainability needs to go beyond techno-fixes or isolated solutions at the edges of present methods of working. It requires a total overhaul of the way that we build, move around, produce, manufacture, consume, manage land, and grow our food – or, to put it another way, it requires a fundamental shift in *why we do things*, *how we do things* and *the way in which we think about doing things.*

To successfully implement sustainable solutions with the goal of optimizing conditions for human development over time, a thoughtful approach to communicating goals, objectives and responses needs to be developed. The issues our society faces today are highly technical. Climate change is an accepted reality, although the specific consequences are still unknown. The requirements of people, now and in the future, demand that we completely integrate not only aesthetic and scientific factors, but the real needs and desires of people: their senses, their emotions and their diverse identities.

Sustainability can perhaps best be thought of as being a political issue which has design and technical attributes. In this context, it can be considered that there are four critical stages to shifting from one paradigm to another.

1. **Be clear about the nature of the problem or opportunity.** There is a tendency to focus on attributes, rather than fundamentals, because the attributes are often more intuitively obvious. For instance we are highly focused now on climate change mitigation, adaptation and in some cases resilience. However, climate change is an attribute of the more fundamental issues of energy, resource use and population growth and even population growth is a function of available energy resources. How we value available resources, price them, choose to use them, share them, and so on drives the climate equation. Design can be considered to be an attribute of the more fundamental issue of energy because energy issues shape possibilities about location, mobility and building form itself. One needs to ask "If we were willing and able to fold all of the now external costs of energy into a true pricing would that in itself make design more effective?" That is not to say that design and technology are not critical elements in solving energy problems.

> "In the long run, men hit only what they aim at, so they better aim at something high."
>
> Henry David Thoreau

[24] WWF, Living Planet Report 2008, http://assets.panda.org/downloads/living_planet_report_2008.pdf

2. **Get the necessary stakeholders to agree that the problem or opportunity needs to be addressed.** It can be all too easy for professionals to propose solutions to problems that stakeholders either do not think need addressing or are of lower priority than other issues. Part of this is the result of not getting the question right. Part is what is referred to as 'the tyranny of experts' where the public is expected to simply defer to the intellectual superiority of others when experience is clear that this is often flawed. And part is a failure to appreciate and incorporate the wisdom of the masses when they are provided unbiased information that is accessible to them, not just to the experts. This is not to suggest that majority must rule. The literature is clear however that if trusted institutions and individuals are not convinced that the problem at hand is a priority then the majority will withhold their permission to act.

3. **Know what to do to solve the problem and be honest with the public about levels of confidence and limits to the potential impacts of actions.** There can be greater confidence (and influence) in addressing attributes of problems rather than fundamentals. Design can go a long way towards addressing aspects of some problems, but it cannot address the fundamentals. The fundamentals are political.

4. **Those in positions of power choose to act on the permission granted by stakeholders.** Without this conventional wisdom we will make much less progress than would otherwise be possible. The choice to act differently is a risk management issue – political risk, financial risk, resource management risk. Good design and good science can help reduce the risk of different courses of action. More fundamental however are culture, nostalgia, aspiration, fear and what Frances Bacon described as the preference for truths that we would rather believe.

Unless the basic human issues above can be aligned with what people would rather were true, then design and technological solutions will not be embraced at the rate that they need to be embraced.[25]

This next section will briefly discuss, in theoretical terms, what the concepts of Integration and Design might mean for a transformation in our mindset as a precondition for change. It will also look at what integrated thinking might mean for values and ethics, as an underpinning driver of psychological and social change. We will then move on to look at what applying this new type of thinking might mean practically for the large-scale problem areas of infrastructure and mobility; manufacture and consumption; and agriculture, land economy and carbon sink management. What kind of wins can be achieved through the application of integrative design thinking?

Focusing primarily on how theory can inform practice, it is acknowledged that a detailed and full-breadth discussion of the solutions to these massive subject areas is beyond the scope of this report. What TCM aims to do, however, is to provide a model for change and to inform wider policy debates by providing a framework for action. Therefore, key proposals for practical implementation are put forward with the aim of stimulating further discussion and thought, and in the long-term, building up a portfolio of ideas for action as they emerge.

The second half of this chapter will give an overview of the status of energy supply technologies we are currently using, namely fossil fuels, before exploring the various technologies that exist in helping us to transition over to a low climate-risk economy. It will outline each existing technology's potential to contribute to greenhouse gas reductions, flagging up key issues for further consideration and providing an overview of current global utilisation.

[25]

"We cannot solve problems by using the same kind of thinking we used when we created them."

Albert Einstien

What is in our toolkit to reduce carbon demand?

As Einstein's oft-quoted maxim states: 'We cannot solve problems by using the same kind of thinking we used when we created them.' Industrial thought processes have created industrial production processes. These operate in a fundamentally linear manner: Input–Process–Output, or Resource–Process–Waste. Natural resources are mined for conversion into desired or needed goods, the process of which produces effluents and 'waste', which end up either dumped or reincorporated into our ecological systems (air, water, land, other species), often as toxins, whilst the product itself often ends up being thrown away. Presently every year we throw away over half a trillion tonnes of 'stuff'; less than 1% of the materials and energy used to produce this stuff is actually embodied within it, whilst the same minimal percentage of these products are still in use 6 months after their sale.[26] This 'cradle-to-grave' system has been the result of erroneous thinking and reductive logic that views natural materials as an infinite 'resource' to be 'used', humans as separate from the Earth's natural ecosystems, and 'waste' as a legitimate and unavoidable end result.

The trouble with this is that all these assumptions are simply untrue, and the concepts that spawned them, premised on the belief that all this would serve human progress and improve material standards of living, are outdated and defunct. We also want to improve standards of living and pursue progress, but the nature of this pursuit has radically changed. Technology should find its place amongst society – as a tool for improving human life in the pursuit of sustainability, rather than a set of systems controlling and defining our options in life. Thus, with sustainability as the central criterion for evaluating design – be it for a product, an industrial process, a transport system – the success and merit of each should depend on the contribution that design makes to positive transformational change.

While this is the biggest challenge humanity has ever faced – it can also be seen as the most exciting and stimulating opportunity ever to present itself, should we accept it as such. The motivation for innovation, inventiveness, re-inventiveness, creative thinking, and imagination, has never been so compelling. As Paul Hawken, author of *The Ecology of Commerce*, stated 15 years ago: 'Industrialism is over, in fact; the question remains how we organise the economy that follows. Either it falls in on us, and crushes civilisation, or we reconstruct it and unleash the imagination of a more sustainable future into our daily acts of commerce.'[27] Steps have been made since then, but transformational change is still to come. Integrative thinking and a 'new design mentality'[28] are the essential ingredients for this reconstruction.

Integration

'Integrative' thinking, or holistic/systems thinking, frames the world in terms of a web of inter-related and interdependent faculties and processes. It recognises and values complexity, tolerates uncertainty, and rejects the reductionism of simple cause-and-effect models and the illusory silos that too often separate disciplines and areas of knowledge and expertise into stand-alone parts. No longer can 'economy', 'society', and 'ecology' occupy separate realms – industry, social well-being and ecological awareness co-exist in a complex, interconnected system in which each aspect interacts and impacts on the other. Integration requires the mutual consideration of global and local, present and

[26] Lovins, L. H., 'Rethinking Production', Chapter 3 in The Worldwatch Institute, State of the World: Innovations for a Sustainable Economy, 25th Anniversary Edition, Washington D.C., The Worldwatch Institute, 2008, http://www.worldwatch.org/files/pdf/SOW08_chapter_3.pdf, p.32

[27] Hawken, P., The Ecology of Commerce, New York: HarperCollins, 1993 p.212

[28] Hawken, P., Lovins, A. B., Lovins, L. H., Natural Capitalism, New York: Back Bay Books / Little, Brown and Company, 2000 p.62

future, theory and practice, universal and context-specific. Our problems, whether they are to do with energy, waste, water, mobility, or psychological wellbeing, are interrelated and mutually reinforcing, or perhaps undermining.

Our solutions, therefore, should identify areas where these problems coincide and offer multifunctional, cohesive remedies. This means adopting a truly interdisciplinary approach to all stages of problem-solving – decision-making, planning, design, construction and/or implementation, assessment, even education – involving teams of diverse contributors from across disciplines to form a truly integrated knowledge network and platform for action. Too often problems are tackled from a one-dimensional angle, involving only experts in directly related fields, thereby maintaining the silos that falsely separate perspectives. This results in flawed solutions that are unable to deal with complexity.

Design

Approaching problems with a 'design mentality', as Paul Hawken, Amory Lovins and L. Hunter Lovins in *Natural Capitalism* describe it, is the key to solving them.[29] Currently 80% of the environmental impact of products, services and infrastructure is determined at the design stage.[30] Too often, 'design' here follows a technocratic approach which focuses on short-term and isolated end-of-line results without thought for wider implications. Design for sustainability, on the other hand, focuses on long-term solutions that connect up all the dots, changing what *is*, to what is *preferred*.

In this context then, to 'design' means, in the first instance, holding in mind an intention to create in a particular manner or form and for a particular purpose. In the second instance, it is about acknowledging and consciously reflecting on the connections between things and incorporating the three-dimensional aspect of time. Design is thus the opposite to purposelessness, randomness, lack of complexity and short-sightedness. The importance of design to creating a low climate risk economy is emphasised by the fact that current systems are resulting not in order, but in chaos. Climatic, economic, social and biological systems are in spiraling decline. Systems are not working cohesively but are instead at odds and in conflict with one another. The resulting global 'order' is not a product of intent but one of mindlessness – of separately fashioned systems, economic, social, ecological – misaligning with one another to produce emergent dissonance. Nobody has 'designed' the current discord, (although we have undoubtedly accepted it as a status quo), and if they had it could only be classified as an extremely 'bad' design.

'Good design', however, requires both rethinking and integrative thinking. In 2008, the UK Design Council published their latest national strategy and delivery plan, identifying 'good design' to be design that a) solves problems and b) is sustainable.[31] This definition of 'good design' points up the failures of current methods of industrial design that do not factor in sustainability criteria and are governed by technical and internally oriented success measures. It thereby highlights the recognition of the need for a dramatically new impetus for design – one that is stimulated by perceived problems rather than simply by design for design's sake. This involves joining creativity with innovation and delivering value as a 'quantifiable benefit' measured in economic, social and environmental terms.[32]

Increasingly the inspiration for sustainable design based on integrative thinking is being found in nature. It is apparent that natural ecosystems are ingeniously self-regulating, dynamic, resilient, stable and productive. Design is an inherent and automatic property of nature, whilst sustainable design for human systems must be aligned and compatible with this biological design if they are to co-exist. Thus integrative 'ecological design' should comprehend and reflect natural patterns and systems, starting from the perspective

[29] ibid

[30] Thackara, J., In the Bubble: Designing in a Complex World, Cambridge, Mass: MIT Press, 2006 p.1

[31] UK Design Council, The Good Design Plan, 2008 http://www.designcouncil.org.uk/en/Design-Council/1/What-we-do/The-good-design-plan/

[32] ibid, p.9

that to live as resourcefully and efficiently as possible means to take inspiration from nature itself – the most efficient, resourceful and intelligent whole system-of-parts in existence. A number of leading thinkers and organisations are seriously advocating and researching developments into this new trajectory as a must for sustainable growth. This must be accepted as a broad vision first, rather than an immediately available solution – much research still needs to be done. But it is the scale of vision that is impressive – if we are to aim high, vision is an imperative.

Vision

The first basic vision that has been derived from nature is the concept of 'Zero Waste', taking example from the fact that in biological systems there is no such thing as 'waste', only an endless cycle of nutrients and energy. One organism's waste is another one's food. The 'Zero Waste' movement, which advocates the creation of circular industrial systems that reuse as much waste as possible just as in nature, was first put forward by PhD student and Zero Waste Systems Inc founder Paul Palmer in the mid-1970s. Recently it has gained prominence spawning a global network of communities promoting zero-waste practices.[33]

The term 'waste equals food' was used by Paul Hawken in *The Ecology of Commerce* and later taken up by architect William McDonough and scientist Michael Braungart in their 2002 book *Cradle to Cradle: Remaking the Way We Make Things*.[34] Here they put forward what they called a 'Cradle-to-Cradle' model for industrial processes – a cyclical system that operates in opposition to the dominant 'cradle-to-grave' model of linear systems, but according to the system of nutrients and metabolisms found in nature where there is no such thing as 'waste'. They illustrate their argument, beginning with a cherry tree that 'makes many blossoms and fruit to (perhaps) germinate and grow…But the extra blossoms are far from useless. They fall to the ground, decompose, feed various organisms and microorganisms, and enrich the soil. Around the world, animals and humans exhale carbon dioxide (CO_2), which plants take in and use for their own growth. Nitrogen from wastes is transformed into protein by microorganisms, animals, and plants. Horses eat grass and produce dung, which provides both nest and nourishment for the larvae of flies. The Earth's major nutrients – carbon, hydrogen, oxygen, nitrogen – are cycled and recycled. Waste equals food.'[35]

McDonough and Braungart separate out two categories of 'nutrients' present in today's material flows – 'biological nutrients', useful for the biosphere, and 'technical nutrients', useful for the 'technosphere', or the system of industrial processes.[36] But their vision of an industrial system modelled on nature goes beyond the idea of no waste, envisioning a system whereby human processes in the technosphere actually contribute a net benefit back into the system, providing a new meaning for 'growth'. Thus a second vision that has been derived from nature is that just as in natural systems, where the cherry tree offers numerous positive effects for other species, our designs can incorporate asset creation where possible, deepening ecological, cultural and economic wealth. Their vision of a 'new design assignment' of an 'eco-effective', rather than merely 'eco-efficient', world looks like this:[37]

- Buildings that, like trees, produce more energy than they consume and purify their own waste water;
- Factories that produce effluents that can be used as drinking water;
- Products that, when their useful life is over, do not become useless waste but can be tossed on to the ground to decompose and become food for plants and animals and nutrients for soil; or, alternatively, that can be returned to industrial cycles to supply high-quality raw materials for new products;
- Billions, even trillions, of dollars' worth of materials that accrue for human and natural purposes each year;

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[33] See http://www.zerowaste.org/

[34] Hawken, P., The Ecology of Commerce 1993; McDonough, W., and Braungart, M., Cradle to Cradle: Remaking the Way We Make Things, New York: North Point Press, 2002

[35] McDonough, W., and Braungart, M., Cradle to Cradle, p.92

[36] ibid, p.93

[37] ibid, p.90-1

- Transportation that improves the quality of life while delivering goods and services;
- A world of abundance, not one of limits, pollution and waste.

McDonough has worked with Ford, Nike, Herman Miller and with Chicago public bodies to implement Cradle-to-Cradle principles (C2C). In 2003, GreenBlue set up a Sustainable Packaging Coalition with industry giants, such as Dow Chemicals, Alcoa, Coca-Cola, Hewlett-Packard, Pepsi, Starbucks, TetraPak, Estee Lauder and many others, as an ongoing working group dedicated to implementing C2C principles to packaging.[38] These ideas are gradually making it into the mainstream, not just as vision, but as practice.

A further key visionary in this field is Janine Benyus, who in 1997 formed the concept of 'biomimicry' – the idea that all human design challenges can learn from and be solved by looking to the 3.8 billion years of research and development experience available in biological systems.[39] These systems are highly efficient, imaginative and successful. She suggests that human systems should mimic organisms in a mature ecosystem that:[40]

1. Use waste as a resource;

2. Diversify and cooperate to fully use the habitat;

3. Gather and use energy efficiently;

4. Optimise rather than maximise;

5. Use materials sparingly;

6. Don't foul their nests;

7. Don't draw down resources;

8. Remain in balance with the biosphere;

9. Run on information;

10. Shop locally.

A website listing 'Nature's 100 Best Innovations', supported by UNEP and IUCN, gives examples of such innovative projects as self air-conditioned structures inspired by termites nests, harvesting water from fog like a beetle, creating adhesive glue from mussels and self-assembling glass inspired by sea sponges.[41]

'Permaculture', or 'permanent agriculture', offers a similar proposal from the perspective of agriculture in particular, but distinguishes itself by concentrating not only on the individual sustainability of practices, processes and products, but on the wider sustainability of the relationships between elements of a system and deliberate spatial design. Coined by Australian Right Livelihood Award winner, Bill Mollison, and David Holmgren in the 1970s, permaculture describes itself as the 'conscious design and maintenance of agriculturally productive ecosystems' based on observation of how the components of natural ecosystems interact.[42] Taking a Lovelockian view that life is fundamentally cooperative, those who promote permaculture believe that by examining and thinking about the way in which parts interact, we can better understand how 'dissonance or harmony in life systems and society is achieved.'[43] As such, it is a more sophisticated approach to organic gardening, which is a technical rather than holistic theory.

However, permaculture is not limited to agriculture alone – it has also been applied when thinking about the built environment, legal, economic, and social systems, and even to ethical systems. The portmanteau has quickly extended itself to include 'permanent culture' as a core vision, in recognition that social systems, or human systems, have an integral role to play in a

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[38] Sustainable Packaging Coalition, http://www.sustainablepackaging.org/

[39] Benyus, J., Biomimicry: Innovation Inspired by Nature, New York: Quill, William Morrow, 1997

[40] ibid, p.254

[41] Nature's 100 Best, http://www.n100best.org/list.html

[42] Bell, G., The Permaculture Way: Practical Steps to Create a Self-sustaining World, East Meon, Hampshire, UK: Permanent Publications, 2004, p.5

[43] Mollison, B., Permaculture: A Designers' Manual, Victoria, Australia: Tegari Publications, 1988, p.2

truly sustainable world. Permaculture has spawned a global following, with notable examples in Cuba, Australia, the USA and many developing countries. In 2001, the United Nations High Commission on Refugees published a report positively examining the potential of using permaculture in refugee-camp situations.[44]

Whatever the object of analysis, beneficial design is the fundamental objective. The philosophy behind it is 'one of working with, rather than against, nature; of protracted and thoughtful observation rather than protracted and thoughtless action; of looking at systems in all their functions, rather than asking only one yield of them; and of allowing systems to demonstrate their own evolutions.'[45] Permaculture promotes multifunctional integration of all elements in a system, resulting in a design that can accept flexibility and progressive contributions as a continually evolving process. It stresses that 'Every component of a design should function in many ways. Every essential function should be supported by many components.'[46] This results in design that is polycultural, rather than monocultural, and ultimately self-regulating. The aim is to create a system where each component 'serves the needs, and accepts the products, of other elements.'[47] From this emerges the maxim that 'Pollution is an output of any system component that is not being used productively by any other component of the system. [External Energy or] Extra Work is the result of an input not automatically provided by another component of the system.'[48] Both pollution and external energy/extra work are viewed as unnecessary results of an incompletely designed or unnatural system. Minimum inputs (resources) for maximum yields (products and behaviours) is the golden aim.

David Holmgren has laid out the following 12 Permaculture Principles: [49]

1. **Apply self-regulation and accept feedback** – we need to discourage inappropriate activity to ensure that systems can continue to function well.

2. **Catch and store energy** – by developing systems that collect resources when they are abundant, we can use them in times of need.

3. **Creatively use and respond to change** – we can have a positive impact on inevitable change by carefully observing, and then intervening at the right time.

4. **Design from patterns to details** – by stepping back, we can observe patterns in nature and society. These can form the backbone of our designs, with the details filled in as we go.

5. **Integrate rather than segregate** – by putting the right things in the right place, relationships develop between those things and they work together to support each other.

6. **Observe and interact** – by taking the time to engage with nature we can design solutions that suit our particular situation.

7. **Obtain a yield** – ensure that you are getting truly useful rewards as part of the work that you are doing.

8. **Produce no waste** – by valuing and making use of all the resources that are available to us, nothing goes to waste.

9. **Use and value diversity** – diversity reduces vulnerability to a variety of threats and takes advantage of the unique nature of the environment.

10. **Use and value renewable resources and services** – make the best use of nature's abundance to reduce our consumptive behaviour and dependence on non-renewable resources.

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[44] UNHCR Environmental Services Section, and the Southern Alliance for Indigenous Resources (SAFIRE), Permaculture in Refugee Situations: Handbook on Sustainable Land Management: A Refugee Permaculture Handbook, 2001 http://postconflict.unep.ch/liberia/displacement/documents/UNHCR_SAFIRE_Permaculture_Refugee_Situations.pdf

[45] Mollison, B., Permaculture: A Designers' Manual, p.3

[46] ibid, p.36

[47] ibid, p.37

[48] ibid, p.38

[49] Holmgren, D., Permaculture: Principles and Pathways Beyond Sustainability, Holmgren Design Services, 2003

11. Use edges and value the marginal – the interface between things is where the most interesting events take place. These are often the most valuable, diverse and productive elements in the system.

12. Use small and slow systems – small and slow systems are easier to maintain than big ones, making better use of local resources and producing more sustainable outcomes.

The other aspect that distinguishes permaculture from alternative ecological design theories, is its fundamental ethical basis. Bill Mollison in his book *Permaculture: A Designer's Manual* sets out three basic principles that underpin action, premised on respect for the diversity of life, cooperation and equity: [50]

1. Care of the Earth: provision for all life systems to continue and multiply;
2. Care of people: provision for people to access those resources necessary to their existence;
3. Setting limits to population and consumption: by governing our own needs, we can set resources aside to further the above principles.

The overall emphasis is on an ethic of responsibility which manifests itself in beneficial design. Mollison sees the uncontrolled disorder of current systems as a result of immutable, unresponsive rules and 'our own stupidity and lack of personal responsibility to life'[51]. Just as industrial production processes are outdated in the face of today's challenges, so too are industrial ethics. Mollison takes a Darwinian view of ethics as a continually evolving and adapting code of conduct which either help or hinder our survival. Rigid human behaviours and beliefs that centre round scarcity, brute competition and individualism are damaging when applied to the ecological reality of constantly changing, cooperative, interdependent and abundant ecosystems. Rather, our ethics must evolve as our understanding matures of the way in which the world operates, and how as a species we need to operate in order not only to survive but also to improve standards of living.

Whilst the parameters of this text do not here permit a detailed discussion on the role of ethics and values in transformational change, it is important to note that in order for our actions to answer the complex challenges we face, a more responsible and socially oriented impulse or motivation is demanded. Ethics can often provide the social cohesion for concerted action and change the incentives behind why things are done at all. It is not only our technical and physical infrastructures that require rethinking and redesigning, but, if we are to take the integrated approach seriously, our social and psychological constructs also need redefining in terms of meanings, aspirations, values and interactions.
This redefinition would not be through coercion, but via a new integrated ethics that recognises the interdependent and interconnected nature of our world.

How to make things stick? The psychology of design – the human element

We have seen what kinds of visions exist for a human society based on ecological design. But how can we ensure that implementing such visions will be successful? How can we make these new designs and systems appealing – how can we make them work? Whilst a new ecological ethics is essential, constructing a new ethical basis for action is a slow process. We need to act now! Often people, or 'consumers', respond to other motivators, such as cost, social benefit, status, and self-image, long before they act from a sense of morality. Understanding and harnessing human psychology is essential to ensure good design successfully takes to the market. Therefore, good design must keep the human element in focus – the desires and psychological aspects of people must be kept in mind if design is to be truly beneficial. Good design connects ideas, innovation and the market to create products or services that become 'practical or attractive propositions for customers or users.'[52]

Every product or service has a social

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[50] Mollison, B., Permaculture: A Designer's Manual, p.2

[51] ibid, p.1

[52] UK Design Council, The Good Design Plan, p.9

component. How we interact and respond to products and services influences the way in which we use them, and whether we use them at all. Quite often the time lag between a new design innovation and the point at which that innovation catches on in the market can take as much as several decades. If we are to design sustainable solutions to our everyday problems and redesign our human systems, this process needs to be radically sped up. To do this we need to ensure our design speaks to both individuals and communities in an appealing and ergonomic fashion by making central the question 'why do people use things?' and 'why do they not use other things?' If we can make things usable, useful, and desirable by harnessing people's desires and then by redefining them to encourage ecological lifestyle choices, then we are half way to creating both a more humanly efficient and more sustainable world.

What does it mean for design to be human-oriented? Firstly, it must mean regarding people holistically – not just as 'users' or 'consumers' who passively receive objects and are delivered 'to'. Rather, human beings, in all their complexity of dreams, desires, fears, and pleasures, must be treated as cognitive and responsive elements of a people-product system. People interact – they do not just simply react. People prefer simplicity, communicability, and aesthetics over complicatedness, mechanical indifference, and functional austerity. For example, the company Philips found that 65% of Americans said 'they have lost interest in purchasing a technology product because it seemed too complex to setup or operate.'[53] From this emerges a second central factor – human-oriented design must speak to our emotions for two reasons: to make products and services more attractive and useable; and to begin the work of shaping and influencing behaviour towards lifestyle sustainability.

In *Emotional Design: Why we love (or hate) everyday things*, Donald Norman, a cognitive scientist, explains that human reactions to design exists on three levels: at a visceral level – or the level of appearance; at a behavioural level – the pleasure and effectiveness of use; and at a reflective level – how the object impacts on our self-image and sense of satisfaction.[54] For a design to be successful it must excel at all levels. In particular, products, or indeed services, that are attractive and provide pleasure, enjoyment, or meaning, are more likely to be successful, because science has demonstrated that these actually work better. Norman explains: 'attractive things make people feel good, which in turn makes them think more creatively. How does that make something easier to use? Simple, by making it easier for people to find solutions to the problems they encounter.'[55] By tapping into human emotions, we can both increase the appeal of a product or service, by, for example, making it fun to use, and begin to change people's behaviour by challenging their expectations. If taking public transport becomes more enjoyable than driving to work every day, people will likely change their behaviour. As Norman says, 'Technology should add more to our lives than the improved performance of tasks: it should add richness and enjoyment.'[56] Why should design be boring or stiflingly utilitarian?

Advertisers have long capitalised on the emotional drivers behind product purchases and desire creation to successfully market their wares. But the question 'what is a product for?', in terms of its social and meaningful contribution, has rarely been asked. According to Jonathon Chapman, this has resulted in a flooding of the market of useless and non-beneficial 'things'.[57] Starting from the shameful fact that 25% of vacuum cleaners, 60% of stereos and 90% of computers all still functioning when they are thrown away, Chapman argues that their only failure was their inability to engage empathy with their users.[58] He criticises 'industrial' or 'technocratic' design for being extremely narrow and limiting in its exploration of the range and intensity of human experiences, engendering wasteful cycles of 'desire and frustration within

[53] Coleman, R., From Margins to Mainstream: Why Inclusive Design is Better Design, London: Royal College of Art, 2006 http://www.hhc.rca.ac.uk/CMS/files/ErgSocLecture06.pdf, p.21

[54] Norman, D. A., Emotional Design: Why We Love (Or Hate) Everyday Things, New York: Basic Books, 2004, p.19

[55] ibid

[56] ibid, p.101

[57] Chapman, J. Emotionally Durable Design: Objects, Experiences and Empathy, London: Earthscan, 2005

[58] ibid, p.20

consumers by delivering only short-lived glimpses of progress.'[59] If we are to reduce the flows of material waste that are the result of this cycle of disappointment, he argues, we must make a radical about-face design turn and develop more 'emotionally durable design' that engages with human empathy and emotional interaction in order to create lasting relationships with things, making them less likely to be discarded.[60]

Equally, Christiaan de Groot argues that interacting with the 'technocratic and de-personalised environment' where technology has almost eradicated the need for conscious human intention by making anything possible without requiring human empowerment, has resulted in a 'reactionary mindset that hankers after meaningful content, mystery and emotion.'[61] In his view, commercial design has commoditised both the act of design and its products in attempting to objectively control branding, product identity and style trends. This has resulted in 'small incremental design changes and little actual product differentiation'.[62] de Groot argues that it is precisely this lack of meaningful content that, in the West, is spurring a 'profound cultural shift' towards a 'society that expects more from its objects' and one that is searching for more value and meaning in life.[63] Corporations, he argues, are being forced to reassess their core values and their long-term strategies to reflect this shift, making them 'active participants of change rather than the stoic arbiters of consumer culture.'[64] Thus human-oriented design for sustainability must not only reflect 'consumer culture', but must begin to shape and cajole it to more meaningful ends.

In addition to meeting individual emotional needs and desires, human-oriented design must, thirdly, also mean designing for the positive enhancement of social interaction and community. John Thackara argues that we need to structure community back into society through collaborative design and a shift to an emphasis on services and systems, rather than on increasing technocracy and the proliferation of objects that separate.[65] He identifies an increasing shift in the market to a service-based economy, where people are choosing to use rather than to own. Car-sharing and lift-sharing schemes are examples of this shift. Encouraging service-oriented systems that are demand-responsive can help foster collaboration and interaction between people, as well as reduce consumption of material goods. Additionally, he emphasises the need to design with us rather than for us – an approach supported by the UK Design Council in their programme 'Designs of the time' (Dott), which encouraged local communities to come up with design solutions to local issues and challenges.[66] Community-based design can be a way of meeting diverse needs within specific communities as well as a way of empowering people, providing them with a sense of ownership, engagement and control over local systems.

Finally, then, empowering people with control over their own environment and actions is an important element of human-oriented design. Donald Norman, in *The Design of Future Things*, expresses his exasperation with the trend in modern technology towards 'intelligent design' that aims to take increasing control over your environment, by treating you as a passive component in an expert design.[67] Cars that park themselves without your input, houses that are geared to self-regulate themselves without consulting the inhabitant, fridges that monitor your dietary intake by a series of shrill sounds – these are examples of

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[59] ibid, p.16

[60] ibid

[61] de Groot, C., 'Experiencing the Phenomenological Object', http://www.nowherefoundation.org/knowledge/DevelopingaPracticeofCo-Creation/1999-Experiencing-ThePhen-Object.pdf, p.1

[62] ibid

[63] ibid

[64] ibid

[65] Thackara, J., In the Bubble: Designing in a Complex World

[66] See UK Design Council, Dott (Designs' of the time) http://www.designcouncil.org.uk/en/Design-Council/1/What-we-do/Our-activities/20-reasons-to-go-to-Dott/

[67] Norman, D. A., The Design of Future Things, New York: Basic Books, 2007

how he sees the future of design eventually designing out human agency. While he recognises the value of such mechanisms up to a point, he points out that 'intelligent systems have become too smug…[T]hey need to be socialised; they need to improve the way they communicate and interact and to recognize their limitations. Only then can they be truly useful.'[68] Human frustration with controlling or uncontrollable machines is anti-social and, finally, disempowering. Putting the user in central control, thereby making it more attractive, as we saw, makes it more likely for a design to be successful. 'Bad design disables; Good design enables'.[69]

Integrated human-oriented design in practice

Infrastructure and mobility

Infrastructure refers to the physical and technical structures and systems that support society. Roads, power grids, buildings, water-supply systems, waste-management systems and transport networks are all examples of our infrastructures. The built environment itself is responsible for about one-third of primary global energy demand[70], accounting also globally for about 30-40 % of material resource consumption, 30-40 % of waste production, 50% of all fresh water consumed and 30-40 % of greenhouse gas emissions.[71]

Currently, infrastructure and mobility systems are often created around centralised, large-scale, fixed, top-down systems where decision-making is vested in the hands of a few authorities and the environment is relegated to a separate category of consideration. Sustainable infrastructure, on the other hand, recognises that infrastructure, the environment, and people are inextricably linked, impacting continually on one another. Decentralised, distributed, local, open, flexible and responsive systems, where control is handed over to communities or individuals, are far more stable and efficient. Our physical infrastructure must be seen from wider perspective – as contributing to our social and psychological well-being, enhancing and sustaining our communities, biological diversity and ecological stability, and providing essential services for poverty alleviation and green growth. Approaching this vital sector from an integrative-design perspective could mean the following:

- In the **planning** stages, stakeholders and multidisciplinary professionals, such as architects, landscape designers, construction workers, engineers, contractors, building owners, and end-use representatives, follow the 'Whole Building Design' process, whereby they come together to examine the project objectives from multiple perspectives in a 'design charette' (an intense period of design activity), and continue to work together throughout the project to assess and evaluate the project from all angles.[72]

- **Energy efficiency** measures related to building materials (e.g. reusing and using locally sourced, sustainable, and durable materials), reducing energy consumption levels, and 'creating more value with less impact' or 'doing more with less'[73] – creating multifunctional structures that increase 'service intensity' whilst decreasing material resource use and the need for separate systems as well as fostering cooperation, collaboration and sharing – are the foundations of design.

- Designing, building, or retro-fitting **eco-homes**, which start to take on the characteristics of civil infrastructure, becoming almost self-sufficient in their ability to power themselves on renewable fuels, capture, store and recycle water, treat waste flows, and use 'smart' metering or Intelligent Building technology to regulate energy consumption and maintain optimum living conditions using the minimum of resources. Buildings that are highly energy-efficient, make the most of passive solar heating, natural ventilation, natural cooling systems and daylight, and use local and

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[68] ibid, p.9

[69] Coleman, R., From Margins to Mainstream, http://www.hhc.rca.ac.uk/CMS/files/ErgSocLecture06.pdf

[70] IPCC, Special Report on Emissions Scenarios, Cambridge, UK: Cambridge University Press, 2000

[71] The Norwegian Universtiy of Science and Technology, Sustainable Infrastructure Project, http://www.ntnu.no/sustainability/crucial

[72] Whole Building Design, Whole Building Design Guide, 2008 www.wbdg.org/wbdg_approach.php

[73] http://www.wbcsd.ch/web/publications/eco_efficiency_creating_more_value.pdf

natural materials where possible, are attractive and fun to live in. They can offer a net positive contribution to environmental and human health, for example through the use of green roofs which provide habitats for wildlife and reduce the heat island effect, and are also buildings that deliver financial dividends, in the form of energy savings, improved worker productivity, fewer sick days, and reduced maintenance costs.[74]

- **Commercial buildings** are considered for their functional purpose – e.g. school, hospital, office – and designed around their community provision. The objectives of 'Whole Building Design' are in concert with each other: accessibility, aesthetics, cost-effectiveness, functionality/operational performance, historic and cultural preservation, productivity of occupants, security/safety, and environmental performance.[75] Buildings take on multi-functional purposes – as usable spaces and as, for example, providers of shade, air pollution and CO_2 absorbers, wildlife habitat providers (e.g. green roofs) and places of aesthetic beauty.

- In relation to the **spatial design** of cities, intensifying and diversifying zones so that goods and services are in close proximity to the people who need them, employing brownfield sites to regenerate urban centres rather than continuing the expansion of urban sprawl, and establishing localised transport hubs, will contribute to the fostering of community and reduce the need for long-distance travel. Green spaces constitute at least 20% of cities' surface area. Elements of infrastructure are thought of from a systems perspective – in relation to their contribution to sustainability and social inclusivity (their service), rather than simply their basic, reductionist function as a 'road' or 'building'.

- For **transport modes**, a number of key changes occur. Current dominance of road transport for passengers and freight (around 70%) is switched particularly to emphasise high-speed electrified rail networks, combined transport, or waterborne transport. Public transport, car-sharing, smart on-demand 'public cars', and increased use of communications technology, together with the regionalisation of production, and a focus on service provision will reduce the volume of traffic and the need to travel. Ultra fuel-efficient, hybrid-electric, or electric (hydrogen) vehicles offer cleaner personal mobility options. Cycling and walking are compellingly promoted and encouraged, supported by better provision of facilities and safety. Partnerships between mobility businesses are developed, resulting in, for example, the 'dematerialisation' of freight transport, such as in Kassel, Germany where ten delivery firms worked in partnership to coordinate and bundle deliveries for distribution by a neutral carrier.[76] Air travel is reduced considerably since the need for business travel is decreased through the use of telecommunications and electronic systems; high-speed rail offers comfortable, affordable, attractive options for international travel, eliminating the need for short-haul flights.

- **Mobility systems** become multi-functional and dynamic, offering solution synergies. For example, research conducted at the University of South Australia is looking into 'water-sensitive urban design' which could integrate transportation corridors with rainwater harvesting facilities using permeable pavements designed for enhanced water quality treatment and rainwater tank storage below the pavement surface.[77] Trial demonstration projects of noise barriers on highways doubling as solar collectors

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[74] Birkeland, Dr J., 'Designing Cities to Reverse Environmental Impacts', CSIRO Sustainability Network, May 2005, pp.1–4

[75] Whole Building Design, Whole Building Design Guide, www.wbdg.org/wbdg_approach.php

[76] Ness, D. A., 'Sustainable Infrastructure: Transport, Energy & Water – Doing More With Less by Applying Eco-efficiency Principles', CSIRO Sustainability Network, October 2006, pp.1–9

[77] Shackel, B., Ball, J., Mearing, M., 'Using Permeable Eco-paving to Achieve Improved Water Quality for Urban Pavements', Proceedings of the 7th International Conference on Concrete Block Paving (PAVE AFRICA 2003), 12th-15th October 2003, http://www.psparchives.com/publications/our_work/stormwater/lid/paving_docs/Permeable%20Paver%20WQ%20Treatment-%20Ball%202003.pdf

are found in Europe and Japan, with the possibility of directly heating neighbouring buildings under exploration. A 'smart road' concrete road system, known as 'ModieSlab', has been equipped with a number of technologies to act simultaneously as a noise reducer, solar energy collector, an efficient drainage system, an intelligent traffic control and, in the future, to offer electronically guided traffic.[78] 'Smart networks' involving Transport Information Monitoring Environments (TIME), offer congestion detection and projection, car-park status information, bus arrival time displays, empty taxi location, and support for emergency services.[79]

- **Water systems** are arranged in a nested hierarchy, involving systems of tanks, houses, clusters of houses, sub-catchments and catchments, backed up by larger scale systems where beneficial, dealing with all forms of water originating on or imported on to a site, such as via rain, spring, bore, stream, or town water, wastewater, irrigation water, and environmental water. These replace large-scale water supply and sewerage systems in most localities, while reducing the cost and increasing the effectiveness of stormwater and pollution control systems (particularly relevant to developing countries).[80] Wastewater, or greywater, is reused on-site for flushing or garden irrigation; on-site water harvesting techniques and rainwater storage systems are set up, particularly in developing countries. Improving the efficiency of distribution systems and ensuring effective preventative maintenance is key – much easier and cheaper to do on smaller-scale, distributed, community-based systems.

- **Waste flows** are diverted to form closed-systems where 'waste' is reused as a 'resource' or raw material. This could be in the form of energy from waste, such as municipal or sewage wastes. Arup describes the example of the Danish industrial town of Kalundborg where 'the oil refinery provides the coal-fired power station with its treated wastewater for use in its cooling process. In return the power station supplies the waste steam for use in the oil refining process. This waste steam is also used to supply 20,000 households with heating. Waste gases from the refinery are reused by the power station and by Gyproc, a company which makes plasterboard. Gyproc purchases waste material from the power station in the form of Gypsum. Other partners include a local fish farm, commercial greenhouses and a chemicals company.'[81]

Manufacture and consumption

Industry is the largest energy user in the world, accounting for 37% of global demand.[82] Of this demand, about half is driven by production of only five key materials: cement, steel, aluminium, plastic and paper.[83] Wood is a sixth key area, and requires significant research as it could provide an alternative to some of the above. In terms of consumption, developed countries account for only 22% of the world's population, yet consume 60% of the world's industrial raw materials.[84] Globally, we generate between 8-10 billion tonnes of waste each year, including 1.4 billion tonnes of municipal waste.[85] With population

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78 Holdsworth, Bill, 'The Smart Concrete Road', Concrete, March 2002, http://www.allbusiness.com/manufacturing/nonmetallic-mineral-product-manufacturing/1152128-1.html

79 Bacon, J., Beresford, A.R., Evans, D., Ingram, D., Trigoni, N., Guitton, A., Skordylis, A., Transport Information Monitoring Environment (TIME) Project, Cambridge University and Oxford University. For info see: http://www.comlab.ox.ac.uk/sensors/publications/Bacon_CCNC2007.pdf

80 Fox, J., 'Re-patterning Civilisation: Nested Self-Organising Water Systems', CSIRO Sustainability Network, June 2006 pp.1–14

81 Greitschus, J. (ed.) Arup, 'Drivers of Change' series, Waste: Technological Waste, Industrial Symbiosis 07, 2008

82 Bernstein, L., Roy, J., Delhotal, K.C., Harnisch, J., Matsuhashi, R., Price, L., Tanaka, K., Worrell, E., Yamba, F., Fengqi, Z., 'Industry' in Metz, B., Davidson, O.R., Bosch, P.R., Dave, R., Meyer, L.A., (eds) Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press, 2007, p.449

83 Baumert et al, Navigating the Numbers, Boston: World Resources Institute, 2005

84 Baker, E., Bournay, E., Harayama, A., and Rekacewicz, P., 'Vital Waste Graphics', in collaboration with the Basel Convention, GRID-Arendal, UNEP, and DEWA-Europe, October 2004 http://www.grida.no/_res/site/file/publications/vital-waste/wastereport-full.pdf

85 The StEP Initaitive, http://www.step-initiative.org/

expected to be in the region of 10 billion by 2030 and economic growth in emerging economies developing apace, projected demand for steel and aluminium alone is expected to double by 2050. At best, energy efficiency measures could deliver 30-50% improvements, resulting in no net reduction in emissions. Both the nature of how we manufacture products (supply) and how we use and consume them (demand) needs to radically change.

Closed-loop systems and zero waste measures, together with a shift towards a service-based economy and life-cycle assessment of product design and production are necessary in the shift to sustainability. Approaching this sector from an integrative-design perspective could mean the following:

- Beginning with **product design** – full Life-Cycle Assessments that assess development, material production, processing, product fabrication, distribution, consumer use, and end-of-life disposition are fully taken into account, and efficiency measures and waste reduction or circulation opportunities are identified.[86] Choices at the design stage determine 80-90% of the products environmental impact.[87]

- Focusing on **cradle-to-cradle systems** and **energy demand** as a starting point encourages us to think beyond efficiency of primary production and more about the efficiency of end-of-life recycling and reuse as well as ways in which to optimise material use by making the same product using less material. For example, even in the face of doubled demand, if two-thirds of steel and aluminium scrap were reused without melting, and the energy of forming and fabricating were halved, the 2050 carbon emissions reduction target of 60% could be achieved.[88]

- Products are deliberately made for easy or **'Active Disassembly'** and reuse – for example, mobile phones could be dumped into a 'tumble dryer' at their end-of-life, which would heat them to a trigger temperature whereby they disassemble into separately useable components.[89]

- Products are made with materials with **low-embodied energy** that are **designed to be reused,** which means innovating in the choice of material for manufacture. Additionally, **products reuse materials** that have previously entered into our waste stream and are accumulating in the biosphere. For example, tyres, 650 million-1 billion of which are scrapped every year, are broken down into a substance called rubber crumb which can be reused to make shock absorbent surfaces for playgrounds, the rubber backing for carpets and floor tiles, and can be mixed with asphalt to make road surfaces.[90] Concrete materials can be made from non-recyclable polymer wastes.[91]

- To encourage these trends, **take-back systems** and **Extended Producer Responsibility** laws are implemented which require companies to take responsibility for the end-of-life stage of their product and allow consumers to return them for sorting and recovering. For example, laws in Germany and Austria require packaging producers to take back and reuse or recycle packaging, resulting in increased recycling and reuse almost straight away.[92] This principle should be extended from small-scale consumer products to large-scale industrial products including aircraft frames or cement 'blocks'.

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[86] Business for Social Responsibility, Aligned for Sustainable Design: An A–B–C–D Approach to Making Better Products, May 2008, p.5

[87] Lovins, L. H., 'Rethinking Production', p.32

[88] Allwood, J.M., 'Step Change Material Efficiency for Steel and Aluminium', Application for ESPRC Leadership Fellowship, University of Cambridge, February 2008

[89] Active Disassembly Research Ltd, http://activedisassembly.com/index3.html

[90] Greitschus, J., (Ed), Arup, 'Drivers of Change' series, Waste: Technological Waste 10, 2008

[91] AZoMaterials, 'Sandplast Project Develops New Production of Concrete Materials Using Recycled Polymer Waste', May 2008 http://www.azom.com/news.asp?newsID=12104

[92] Greitschus, J., (ed.), Arup, 'Drivers of Change' series, Waste: Political Waste 22, 2008

- A shift to a **de-materialised product-service oriented economy** focuses on the fulfilment of needs (intangible human value) rather than of wants (tangible goods), resulting in a reduced need for material products. People require, for example, mobility, entertainment, comfort, and information, rather than, specifically, personally owned cars, DVDs, appliances or newspapers. The shift is away from traditional manufacturing of owned 'goods' that incur substantial costs in terms of raw materials, labour and capital equipment for mass-production, towards knowledge-based or high-tech consumed-on-the-spot 'services', where costs are highest in the product development stage, and a single master product can be mass-reproduced for the market.[93] Companies see themselves more in terms of service-provision that includes maintenance and recycling services, rather than manufacturing companies. Four main types of product-service systems are encouraged: **'result services'**, which sell a result rather than a product, for example Interface's EverGreen lease carpet system; **'shared utilisation services'**, which aim to increase utilisation of the material parts of a system through product sharing, for example shared household appliances or car-sharing; **'product life-extension services'**, which aim to substantially increase the life of products through maintenance, repair, reuse and recycling; and **'demand-side management'**, which involves designing least-cost methods of supplying a demand, for example for heating or lighting.[94]

Agriculture, land economy and carbon sinks

Since 1950, global agricultural production has increased by 60% due to industrial farming practices. However, more than 850 million people still suffer from chronic hunger and we have vast soil erosion, water pollution, and biodiversity loss.[95] Current farming practices are based on energy-intensive outputs that are heavily dependent on pesticides, fertilisers, and other agro-chemicals based on fossil fuels. In the US, 20% of all fossil fuels used go towards agricultural production.[96] Other features of industrial crop agriculture include large-scale monocultures, use of specialised hybrid seeds designed to favour large-scale distribution, use of genetically engineered or modified crops (GMOs) designed for large-scale production, large-scale irrigation, heavy mechanisation, and then high levels of energy spent on packaging, processing, refrigerating and transporting food.

These practices have contributed massively to water and air pollution, soil degradation and erosion, and global warming, due mainly to release of previously stored carbon from soil by poor land management practices, including intensive tillage, irrigation and use of fertilisers as well as the cultivation of former grasslands, forests and wetlands. During the period between 1850 and 1990, 50% of CO_2 increases were a result of land-use change, mainly due to agriculture.[97]

Livestock farming in particular has been highlighted as a major contributor to global environmental degradation. Livestock farming accounts for 40% of global agricultural Gross Domestic Product (GDP).[98] According to the UN Food and Agricultural Organization (FAO) report *Livestock's Long Shadow*, it is a major contributor to a range of negative environmental impacts such as global warming, land degradation, air and water

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[93] Organisation for Economic Cooperation and Development (OECD), 'The Service Economy', for the Science and Technology Industry, Business and Industry Policy Forum Series, 2000 http://www.oecd.org/dataoecd/10/33/2090561.pdf, p.10

[94] Roy, R., 'Sustainable Product-Service Systems', Futures 32, 2000, pp.293–297

[95] The Food and Agricultural Organisation (FAO), 'The State of Food and Agriculture: Paying Farmers for Environmental Services', FAO Agriculture Series No.38, 2007 ftp://ftp.fao.org/docrep/fao/010/a1200e/a1200e00.pdf

[96] Food and Water Watch, 'Fossil Fuels and Greenhouse Gas Emissions from Industrial Agriculture', Fact Sheet, November 2007, http://www.foodandwaterwatch.org/food/factoryfarms/dairy-and-meat-factories/climate-change/GreenhouseGasIndustrialAg.pdf[74] Greitschus, J., (Ed), Arup, 'Drivers of Change' series, Waste: Technological Waste 10, 2008

[97] Melchett, P., 'One Planet Agriculture – the Strengths and Weaknesses of Organic Food and Farming', PPT presentation at the Soil Association Annual Conference, January 2007 http://www.soilassociation.org/Web/SA/saweb.nsf/ed0930aa86103d8380256aa70054918d/88439715590911808025738a00581864/$FILE/conference_melchett.pps#307

[98] FAO, 'Livestock's Long Shadow: Environmental Issues and Options', 2006 ftp://ftp.fao.org/docrep/fao/010/a0701e/a0701e.pdf

Design for eco-city, Dongtan, China (Arup)

pollution, and loss of biodiversity.[99] It is estimated that livestock farming accounts for 18% of total world greenhouse gas emissions, pushing it ahead of the transport sector, including 37% of total anthropogenic methane emissions.[100] It also accounts for more than 8% of global human water use, mainly for the irrigation of feed crops as well as being the largest sectoral source of water pollutants.[101]

On top of this, livestock farming has had a negative impact on biodiversity with farm animals (including poultry but excluding fish and invertebrates) now making up two-thirds of terrestrial vertebrates by weight, with most of the rest being humans and only 3% wildlife.[102] Livestock production has encroached into biodiversity hotspots and ecologically fragile regions, with 23 of Conservation International's 35 'global hotspots for biodiversity' – characterised by serious levels of habitat loss – affected by livestock production.[103] This is highly unsustainable. Yet at current rates of increase, meat and milk production is expected to more than double between 2000 and 2050.[104] This means that the environmental impact per unit of livestock production needs to be cut by half, just to avoid increasing the level of damage beyond its present level.[105] Additionally, demand for food in general by 2030 is expected to be double 1990 levels, with 2.5-3fold increases in the poorest countries.[106] To support this growth, the planet would need to cultivate a billion more hectares of arable land, roughly the area of Brazil.[107]

In particular, such demands on land have already resulted in the loss of vast areas of forest and rainforest, particularly in the Amazon, where 70% of previously forested land is occupied by pastures.[108] Deforestation is a major cause of climate change, accounting for 20% of global

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99 FAO, 'The State of Food and Agriculture'

100 ibid

101 ibid

102 FAO, 'Livestock's Long Shadow'

103 World Society for the Protection of Animals, 'Eating our Future: The Environmental Impact of Industrial Animal Agriculture', November 2008 http://www.wspa-usa.org/download/140_eating_our_future_nov_08_.pdf, p.12

104 ibid

105 FAO, 'Livestock's Long Shadow".

106 Daily, E., Ehrlich, P. et al, 'Global Food Supply: Food Production, Population Growth and the Environment', Science, 281 (5381) August 1998 pp.1291 – 1292 http://www.sciencemag.org/cgi/content/full/281/5381/1291

107 Fischetti, M., 'Growing Vertical', Scientific American, Special Issue: 'Energy vs. Water', 18(04), 2008, p.74

108 FAO, Livestock's Long Shadow, p.21

greenhouse gas emissions. Forests, as well as peatlands, wetlands, grasslands and soil, form important carbon sinks. There is thus huge potential to increase carbon sequestration in these areas, through, for example, reforestation programmes, controlled savannah burns, improved forest fire management, and shifts to sustainable agricultural practices. Agriculture employs more people and uses more land and water than any other human activity, and more than 2 billion people's livelihoods depend directly on it. Its potential, therefore, for contributing to proper and sustainable resource and land management is overwhelming. Approaching agriculture, land economy and carbon sinks, or more generally land management, from an integrated design perspective could mean the following:

- Thinking about farming in an integrated approach means returning to a view of farming as an **ecosystem stewardship** activity, rather than farms as a unit of specialised production. Carbon management is an essential component.

- **Regenerative agriculture** replaces destructive agribusiness practices with an emphasis on **organic farming** methods and no-till agriculture that build root systems and rebuild soil organic matter, in particular mychorrizha funghi, to lock carbon away.[109] Relationships between animals and crops are re-established, as well as those between cover crops and food crops. Organically managed soils can convert carbon from greenhouse gases into a food-producing asset in order to create rich soil that supports healthier plants and is more naturally resistant to droughts, pests, and diseases – something we will see more of in a climate stressed world. Studies from the leading organic farming research centre in the USA, The Rodale Institute, claim that organic systems showed a 30% increase in soil carbon over 27 years, compared to no increase, and even depletion, in petroleum-based systems over the same period.[110] Therefore, if regenerative agriculture was practiced on the 4.5 billion hectares of global arable land, up to 40% of our current CO_2 emissions could be sequestered with no decrease in yields or profits, together with a reduction of fossil fuel use by 33%.[111]

- **Conservation agriculture** becomes mainstream – this emphasises minimising soil disturbance, maximising soil surface cover by managing crops, pastures, and crop residues, and stimulation of biological activity through crop rotations, cover crops and integrated nutrient and pest management. Farmers are recognised for their contribution to sustaining ecosystem services, including the national and international implementation of policies that recognise the value of conservation agricultural practices to ecosystem services.

- Emphasis is on **locally produced food** as much as possible to reduce the number of food miles required to transport it.

- **Urban agriculture** is introduced that is responsive to the daily demand of local consumers. This could also involve 'vertical farms' in tall glass buildings in the centre of cities. Dickson Despommier, from University of Columbia, advocates the use of indoor agriculture in urban centres run on renewable energy and irrigated through the use of municipal wastewater. Hydroponic and aeroponic food-growing methods would be utilised. The need for energy-intensive machines and practices as well as pesticides is eliminated. Food can also be grown on building rooftops and city gardens. According to Despommier, a 30-storey farm that covered a city block in New York could feed 50,000 people year-round.[112]

- The concept of **'yield'** evolves to reflect the health of the ecosystem from which the yield is obtained and the benefit to human society. Conventional econometric understandings of 'yield' are usually

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[109] LaSalle, T. J., and Hepperly, P., 'Regenerative 21st Century Farming: A Solution to Global Warming', Rodale Institute, 2008 http://www.ifoam.org/growing_organic/1_arguments_for_oa/environmental_benefits/pdfs/Rodale_Research_Paper_Regenerative_Agriculture.pdf [110] ibid, p.2

[111] ibid, p.1

[112] Fischetti, M., 'Growing Vertical', Scientific American, pp.74–9

understood in terms of the weight or number of a single product produced per hectare. However, **sustainable yield**, or the 'system yield', must be understood in terms of its ecological impact, its nutritional value, and the sum total of surplus energy that is 'produced by, stored, conserved, reused, or converted by the design. Energy is in surplus once the system itself has available all its needs for growth, reproduction and maintenance.'[113]

- Encouraging the growth of **fair-trade** products ensures that developing country farmers are receiving a fairer deal and are able to spend more time and resources to pursuing the environmental protection mandate of the label, thereby breaking the link between poverty and environmental damage.[114]

- Policies to help developing countries in particular to **reduce or avoid deforestation** such as the UN REDD programme (Reduced Emissions from Deforestation and forest Degradation) are implemented with particular emphasis on including and empowering **indigenous forest communities** to ensure their success and effectiveness.[115]

- Large-scale sustainably managed **reforestation** programmes are under way, particularly in the tropics where their biophysical affects are enhanced by cloud formation to further reflect sunlight. Reforestation in boreal regions, however, is thought to have limited benefits due to the replacement of large areas of reflective snow with dark canopies.[116] These programmes could perhaps be supported by the UN Joint Implementation mechanism or the Clean Development Mechanism.

- Improved management and **reduction of unnatural forest fires** results in reduced rates of deforestation. Improving forest fire predictions, risk assessments and our understanding of natural ecological fire regimes will contribute to successful forest management that is compatible with sustainable practices.[117]

What is in our toolkit to reduce carbon intensity?

History has shown that technological advancements have resulted in both progress and problems. Arguably, nuclear weapons, agrochemicals and the internet have contributed to both our security and instability. It is our rapid and intensive burning of fossil fuels that is causing the greenhouse effect and climate change. On the other hand, an ever-growing portfolio of alternative energies and new technologies presents us with the vital tools for change, that used correctly and with understanding, could transform our civilisation as we know it.

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113 Mollison, B., Permaculture: A Designer's Manual, p.18

114 Transfair, USA, 'Environmental Benefits of Fair Trade Coffee, Cocoa and Tea' http://uhfairtrade.org/files/env.ben_coffee.cocoa.tea.pdf

115 According to the Rainforest Foundation of Norway and the US-based Rights and Resources Initiative and based on past experience in Brazil, indigenous people need to be included in the development and monitoring of climate plans and investments at the national and international level if they are to be successful. They advocate the Four Foundations for Effective Investments in Climate Change:
1) Recognise rights – establish an equitable legal and regulatory framework for land and resources.
2) Prioritise payment to communities – ensure that benefits and payments prioritise indigenous and local communities, according to their potential role as forest stewards.
3) Establish independent advisory and auditing processes to guide, monitor and audit investments and actions at national and global levels.
4) Monitor more than carbon to keep track of the status of forests, forest carbon, biodiversity and impacts on rights and livelihoods. Secure a role for indigenous peoples in monitoring of emissions, making full use of their knowledge of the state of forest ecosystems, something which could be particularly relevant to keep track of forest degradation. See: 'Forest People's Rights Key to Reducing Emissions from Deforestation', ScienceDaily, 20th October 2008, http://www.sciencedaily.com/releases/2008/10/081015110238.htm

116 e! Science News, 'Tropical Forest Sustainability: A Climate Change Boon', 13th June 2008 http://esciencenews.com/articles/2008/06/13/tropical.forest.sustainability.a.climate.change.boon

117 WWF, 'Forest Fires', Position Paper, January 2002 http://assets.panda.org/downloads/po5fires.pdf

The following table summarises the main large-scale technologies that can be used to lower the carbon intensity of our energy production.

Technology	Pros	Cons
Carbon Capture and Storage (CCS) for fossil fuel power stations	• CCS could reduce power plant emissions by as much as 80-90%. • A number of commercial projects have demonstrated tightness of storage.	• Uncertain risks concerning leakages and induced seismicity. • Uncertainties surrounding security of storage. • Complex unresolved legal issues. • Huge costs.
Wind power	• Relatively mature technology. • Energy potential is enormous. • Capable of producing cheap and competitive energy. • Can be used in conjunction with other technologies and with energy storage back-up. • Offshore resources more consistent.	• Not suited to all regions of the world – need wind speeds of at least 10mph. • Land availability hampers development. • Intermittent – cannot guarantee steady supply. • Offshore developments more expensive and risky.
Solar power	• Photovoltaic (PV) cells can be used in both small-scale and large-scale applications and can be retrofitted. • Offer on-site energy generation so are suitable for off-grid, community use. • Concentrated PV systems offer the potential of significantly boosting PV efficiency. • Concentrated Solar Power (CSP) can produce large amounts of energy using a relatively small area of land. • CSP is expected to reduce the costs of solar energy generation by 20%, and is expected to become competitive with fossil fuel prices as global capacity increases.	• PV cells offer intermittent supply and are only suitable in the sunniest regions of the world, or for small, niche appliances. • PV cells are expensive and operate at low efficiency ratios. • CSP in the short-term is expensive to implement. • It is a relatively immature technology, but, so far, has proved successful in those large-scale commercial projects that have deployed it.
Biomass	• Biofuels widely available anywhere and integrates well with current infrastructure. • Relatively cheap to produce. • Second generation biofuels could be more sustainable and require lower agricultural inputs. • Third generation biofuels offer high-yielding energy production, but are in the development stages. • Biogas offers a way to convert wastes into energy in a decentralised system. • Does not require large capital investment to set up. • Can be used in remote rural locations, particularly in developing countries, as an alternative fuel for cooking. • Can offer a solution for municipal waste management.	• Studies show that often more energy is required to produce first generation biofuels than they then provide. • Many studies point to the negative environmental impacts of biofuels, such as deforestation and nitrogen pollution impacts, as well as question the greenhouse gas emissions savings. • Evidence shows that biofuel production has contributed to the rise in food prices.

Geothermal energy	• Offers far lower or zero-carbon emissions as opposed to fossil fuels. • Can be used as a base-load or scaled-back (small) supply. • Enhanced Geothermal Systems (EGS) offer the potential of harnessing hard-to-reach and previously untapped geological heat resources that are in huge abundance. • Ground-source Heat Pumps have a high Coefficient of Performance ratio and are one of the most efficient cooling and heating systems on the market with very low carbon emissions. • Offer a cheap supply of energy.	• Requires careful management to avoid depletion. • Only directly available to those regions situated on tectonic plate boundaries or on the Pacific 'Ring of Fire'. • EGS requires high capital investment and is only in the first phase of commercial operation. • Potential risks from earthquakes mean that EGS systems must be located in suitably remote/non-urban regions. • For ground-source Heat Pumps the effect of withdrawing heat from soil and sub-soil not yet fully understood.
Wave power	• Wave energy potential huge; technologies are diversifying and continually under development. • Commercial projects have been constructed with more underway.	• Geography a key determining factor. • Intermittent supply, including seasonal variability. • Requires high capital investment and ongoing maintenance, with survivability a key issue.
Tidal power	• Tidal range technology is reliable and predictable, can offer base-load power supply. • Tidal stream is potentially much cheaper to run and much kinder to marine environment than tidal range. • Much simpler to engineer and run than wave power. • Far wider applicability than tidal range worldwide, although sites are still restricted by certain requirements.	• Only 20 regions worldwide identified as suitable locations for a tidal power plant. • Huge capital investment required for large-scale infrastructural projects. • Environmental impacts as yet not fully understood. • Initial investments are high. • Technology yet to be proven on a large-scale.
Hydroelectric power	• Extensively proven and mature technology. • Cheap (in the long-run) and reliable source.	• Large-scale hydropower responsible for the mass displacement of millions of people and can cause large-scale environmental damage and some evidence points to increased emissions. • Huge initial investment required for huge infrastructure project involving flooding of huge areas of land and often diversion of rivers. • In light of future climate change impacts causing decreased water supply, the number and location of suitable sites is due to change and potentially decrease.
Nuclear power	• Proven technology. • Reliable base-load supply. • Offers lower-emissions energy as an interim solution to energy security issues. • Production costs are relatively low in comparison to fossil fuels once the plant is in operation.	• Major issues concerning waste management/disposal, proliferation, and social acceptance have not yet been solved. • Health concerns unresolved. • Highly capital intensive to build, also requiring ~10 years to complete before it goes online. • Uranium ore is a finite fuel, with stores in depletion.

Fossil fuels

Fossil fuels are hydrocarbons that over millions of years have formed in the top layer of the Earth's crust. They are a non-renewable energy source made from the preserved remains of organisms, such as phytoplankton and zooplankton, that over geologic time have chemically altered to produce oil, natural gas, and coal. In 2005, the US Energy Information Administration found that 86% of primary energy production came from burning fossil fuels.[118] Burning fossil fuels produces around 21.3 billion tonnes of CO_2 per year, with natural processes only absorbing half that amount, resulting in a net increase of 10.65 billion tonnes of atmospheric CO_2 a year, contributing massively to global warming and climate change.[119]

Crude oil

Crude oil, or petroleum, is a naturally occurring, flammable liquid found in rock formations, consisting of a complex mixture of hydrocarbons and other organic compounds. After crude oil is extracted from the ground it is transported to a refinery by a pipeline, ship or barge, where it is separated into different usable petroleum products, such as gasoline (petrol), diesel, heating oils, jet fuel and liquefied petroleum gases. But it is not only fuels that are made from crude oil – many of our consumer and chemical products have their origins in this form, such as ink, crayons, bubble gum, dishwashing liquids, deodorant, spectacles, records, tires, ammonia, medicines, fertilisers, pesticides and plastics. However, 84% of crude oil is transformed into energy-rich fuels.[120]

According to the US Geological Survey (USGS), in 2004 the world's proven reserves of conventional oil stood at 1.7 trillion barrels, over half of which are found in the Middle East.[121] 'Proven' reserves is the term used to describe oil fields that have already been discovered but not yet pumped out. 'Undiscovered' oil, on the other hand, is oil whose existence has not yet been confirmed by drilling, but is strongly suggested by geological markers. Again, according to the USGS, undiscovered oil amounts to around 900 billion barrels.[122] Adding these figures of proven and undiscovered oil together totals 2.6 trillion barrels. Paul Roberts, author of *The End of Oil*, does the maths; assuming that world oil consumption remains at around 80 million barrels a day and continues to grow at the rate of 2% a year, a 2.6 trilllion-barrel reserve brings us to peak oil production in around 2030.[123]

Of course, 'proven' estimates are often exaggerated for political ends, whilst 'undiscovered' estimates are also questionable. But world oil demand is projected to increase by 37% on 2006 levels, from 86 million barrels a day to 118 million barrels per day by 2030, due in part to rising transportation demands, and growing demands from emerging economies, such as China and India.[124] Harry J. Longwell, Director and Executive Vice President of Exxon Mobil Corporation, explains that half the daily volume needed to meet projected demand by 2010 is not on production today.[125]

'Peak oil' has been the subject of much debate and discussion. Demand for oil is increasing for a number of reasons. The first as we have just mentioned is the economic growth of emerging economies. China has seen oil consumption grow 8% per year since 2002, doubling over the decade 1996-2006.[126] It is now the second largest oil consumer after the US, although it consumes only half that of the US.[127] US and Chinese demand is, however,

[118] US Energy Information Administration (EIA), International Energy Annual 2005, 'World Energy Overview 1995-2005' http://www.eia.doe.gov/iea/overview.html

[119] US EIA, 'Greenhouse Gases, Climate Change and Energy', May 2008 http://www.eia.doe.gov/bookshelf/brochures/greenhouse/Chapter1.htm

[120] US EIA, Energy Kid's Page, May 2008, http://www.eia.doe.gov/kids/energyfacts/sources/non-renewable/oil.html#Howused

[121] Roberts, P., The End of Oil, London: Bloomsbury Publishing Ltd, 2004, p.48

[122] ibid

[123] ibid

[124] BBC News, 'World Oil Demand 'To Rise By 37%'', 20th June 2006, http://news.bbc.co.uk/1/hi/business/5099400.stm

[125] Longwell, H.J., 'The Future of the Oil and Gas Industry: Past Approaches, Future Challenges', World Energy, 5(3), 2002 http://www.worldenergysource.com/articles/pdf/longwell_WE_v5n3.pdf, p.101

[126] US EIA, 'International Petroleum (Oil) Consumption', http://tonto.eia.doe.gov/country/index.cfm

[127] ibid

increasing at roughly the same level – around 3-3.6 million barrels a day.[128] Other emerging economies also make it on to the top 15 list of oil consumers – India is 6th, Brazil 8th, and Mexico 11th.[129] Population growth and the resultant increased pressure on agricultural productivity is also putting pressure on oil reserves.

Oil is becoming increasingly more difficult to extract. The peak in oil discovery has already occurred – back in the 1960s at almost 60 billion barrels per year.[130] Today, we discover around one barrel of oil for every four we consume.[131] The world is turning more and more to the exploration of previously off-limits territory, like that of the Alaskan Arctic, and to more unconventional sources – such as oil shale, heavy crude oil, and tar sands – more difficult and more expensive to extract and refine. They are also much more environmentally damaging, requiring far larger amounts of energy to extract and more intrusive and destructive methods of extraction. According to the Wall Street Journal, recovering heavy crude oil, for example, releases up to three times as much greenhouse gas as a conventional barrel of oil.[132] Many of the identified unconventional oilfields, such as the Orinoco Belt in Venezuela and oil sands in the forests of Northern Canada, sit under ecologically fragile areas of the world.

As world oil prices rise, however, unconventional sources become more appealing. Record prices experienced round the world this past year have been a result of surging demand, refinery shortages, and increased security costs. As prices have smashed records, going up to almost $150 a barrel in July 2008, the cost-competitiveness of unconventional oil and alternative energy sources has increased. However, with prices crashing back down five months later (due mainly to the economic crisis) to a four-year low – at around $40 a barrel in December 2008 – the volatility surrounding oil prices does little alone to boost steady investment into alternatives, but much to add to the instability of our politically and economically sensitive world. As Paul Roberts' prescient book *The End of Oil* concludes, 'The longer we wait to start moving toward a new energy system, the harder it will be to make any kind of orderly, progressive transition.'[133]

Natural gas

Natural gas is a combustible gaseous fossil fuel consisting primarily of methane, but also containing significant quantities of heavier hydrocarbons such as ethane, propane, butane, and pentane, which are removed before consumer use, as well as CO_2, nitrogen, helium and hydrogen sulphide (H_2S). Fossil natural gas in associated form is found in oil fields, in non-associated form either dissolved or isolated in natural gas fields, and in coal-beds as coal-bed methane. Before natural gas can be used as a fuel, it must undergo extensive processing to remove almost all materials other than methane. Natural gas can be used in gaseous form or can be transformed into liquid form – as liquefied natural gas (LNG) and liquefied petroleum gas (LPG) – which makes it easier to transport. It can also be compressed to increase its energy density, as compressed natural gas (CNG).

Natural gas contributes almost 25% to the total world energy consumed.[134] It is considered the least environmentally damaging fossil fuel as it releases the lowest amount of CO_2 per unit of energy. According to the industry, it emits 30% less greenhouse

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[128] BP, Statistical Review of World Energy, June 2008, http://www.bp.com/liveassets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2008/STAGING/local_assets/downloads/pdf/statistical_review_of_world_energy_full_review_2008.pdf

[129] ibid

[130] Longwell, H.J., 'The Future of the Oil and Gas Industry', p.102

[131] Aleklett, K., 'The Oil Supply Tsunami Alert', Association for the Study of Peak Oil&Gas (ASPO) http://www.peakoil.net/Aleklett/Oil_Market_Tsunami_Alert.pdf

[132] Duarte, J., 'Peak Oil: A Shattered Myth?' from 'Canadian Tarsands: the Good, the Bad, and the Ugly', March 2006 http://www.rigzone.com/news/article.asp?a_id=30703

[133] Roberts, P., The End of Oil, p.306

[134] United Nations Conference on Trade and Development (UNCTAD), InfoComm, Market: Natural Gas Reserves, http://www.unctad.org/infocomm/anglais/gas/market.htm

gases than an equivalent amount of oil and just under 45% less than coal.[135] However, its main component is methane – one of the most potent greenhouse gases with 23 more times the radiative forcing impact (the change in net irradiance at the lowest of the Earth's atmospheric layers) per kilogram on the climate system of a kilogram of CO_2 over a 100-year period.[136] Putting natural gas into perspective, it contributes 15% of total anthropogenic global methane emissions, in comparison with 8% contribution from coal and a 1% contribution from oil.[137]

However, natural gas has other environmental benefits over its fossil fuel cousins – emitting far less NO_X (nitrogen oxides) and virtually no mercury or sulphur dioxide (SO_2), reducing the amount of toxic sludge created when burning oil or coal. Natural gas can be used in a process of 'reburning' where it is injected into coal or oil fired boilers, resulting in NO_X emissions reductions of 50-70%, and SO_2 emissions reductions of 20-25%.[138] Cogeneration systems that produce both heat and energy simultaneously, thereby increasing efficiency of energy generation systems and industrial boilers, are preferably run on natural gas. Furthermore, natural gas fired Combined Cycle Generators that capture normally wasted heat energy after initial electric generation and reuse it to generate more electricity can be up to 60% more efficient in contrast with oil and coal generators, which only reach 30-35% efficiency[139] (modern supercritical coal can achieve higher efficiency).

Viewing natural gas through the IPCC CO_2 stabilisation scenarios, it does have a potential role to play on the initial path towards emissions decline. Decreasing coal use while increasing natural gas use is expected to be an effective strategy through the 'emission peak'. However, even the International Petroleum Industry Environmental Conservation Association (IPIECA) concludes that after the peak, as emissions reduction requirements become more stringent, these actions will become insufficient and natural gas would have to be used in conjunction with carbon capture and storage (CCS) or replaced by non-carbon energy sources.[140]

Furthermore, like oil, natural gas is also expected to reach a peak in production, although less is known about the timescale of gas as it is a much less mature technology to oil. Consumption of natural gas has doubled over the last 30 years, and is expected to more than double by 2020, particularly in developing countries due to a shift away from oil and coal to natural gas in response to rising demand for electricity and increasing oil prices.[141]

World estimated proved natural gas reserves are about 6,186 trillion cubic feet with almost 75% located in the Middle Eastern and Eurasian regions. Russia, Iran and Qatar together accounted for about 57% of world natural gas reserves in January 2008. The US Energy Information Administration remains optimistic that the rate of discovered reserves in comparison with the rate of increasing consumption remains stable, pointing to

[135] Naturalgas.org, US Natural Gas Supply Association, 'Natural Gas and the Environment', http://www.naturalgas.org/environment/naturalgas.asp#greenhouse/ http://www.unctad.org/infocomm/anglais/gas/market.htm

[136] International Petroleum Industry Environmental Conservation Association (IPIECA), 'Natural Gas as a Climate Change Solution: Breaking Down the Barriers to Methane's Expanding Role', September 2006 http://www.ipieca.org/activities/climate_change/downloads/workshops/26sept_06/Report.pdf

[137] ibid

[138] Naturalgas.org, US Natural Gas Association, 'Natural Gas and the Environment'

[139] ibid

[140] IPIECA, 'Natural Gas as a Climate Change Solution', p.1

[141] US EIA, 'Natural Gas', International Energy Outlook 2008, http://www.eia.doe.gov/oiaf/ieo/nat_gas.html

the US Geological Survey World Petroleum Assessment report of 2000, which estimated that a volume of about 60% of current reserves is yet to be discovered.[142] However, there are many who argue that the global peak of natural gas is already in sight – within about 20 years time – particularly as oil prices force nations to turn more and more to natural gas as a substitute.[143]

Coal

Coal is a hydrocarbon made when plant remains are preserved in mud and water from oxidation and biodegradation over millions of years thereby sequestering carbon. Coal is a combustible sedimentary rock that is extracted from the ground by underground or open-pit mining. It contains mostly carbon and hydrogen but also sulphur and is classified by the different content of carbon and impurities (lignite or brown coal is the lowest quality while anthracite coal is the highest quality).

Coal is the largest source of fuel for worldwide electricity generation and the single largest contributor to global carbon emissions – the main cause of global climate change. World consumption of coal is in the region of 6.2 billion tonnes annually, about one third of this produced by China.[144] In 2005, 63% of coal was shipped to electricity producers, 34% to industrial consumers, and the majority of the remaining 3% went to the residential and commercial sectors.[145] In 2008, coal was the fastest growing fuel in the world for the fifth consecutive year, rising by an above-average 4.5% globally, more than two-thirds of which was accounted for by China.[146] Coal is widely available, and unlike oil and natural gas, can be found in almost every country around the world, with recoverable reserves in around 70 countries.[147] At current production levels, proven coal reserves are expected to last around 133 years – more than twice as long than either oil or natural gas.[148] Widespread availability and longevity are perhaps the reason why, according to the US Energy Information Administration, coal's share of total world energy consumption is projected to increase to 29% by 2030.[149]

In addition, a typical 500-MW coal-fired power plant requires vast amounts of water to produce energy (both for cooling and steam generation). While a large part of the water used can be seawater, or can be part of a closed cycle, about 8.5 billion litres – enough water to support a city of around 250,000 people – is extracted each year from nearby water systems to create steam for turning the turbines.[150]

The World Coal Institute claims that energy efficiency and new technologies can drastically reduce the negative impacts of coal, although many of these are still only under development or in the research stage, and technology transfer particularly to developing countries is needed.[151] 'Clean coal' technologies, such as coal washing to remove impurities and unwanted matter in order to make it burn more efficiently, constructing gasification plants that do not burn coal directly, and using various methods to remove pollutants, such as using 'wet scrubbers' to remove sulphur dioxide (SO_2), or using specially designed burners that minimise the formation of nitrogen oxides, are being put forward as a means of improving coal's environmental impact.[152]

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[142] ibid

[143] Bentley, R.W., 'Global Oil and Gas Depletion: An Overview', Energy Policy 30 (2002), pp.189 – 205, http://www.oilcrisis.com/bentley/depletionOverview.pdf

[144] ZHCommodities, http://www.zhcommodities.com/commodities-portal

[145] US EIA, 'Coal', International Energy Outlook 2008 http://www.eia.doe.gov/oiaf/ieo/coal.html

[146] BP, Statistical Review of World Energy

[147] World Coal Institute, 'Coal Facts 2008', http://www.worldcoal.org/pages/content/index.asp?PageID=188

[148] ibid

[149] US EIA, 'Coal', International Energy Outlook 2008

[150] Union of Concerned Scientists USA, 'Environmental Impacts of Coal Power: Water Use', 2008, http://www.ucsusa.org/clean_energy/coalvswind/c02b.html

[151] World Coal Institute, 'Environmental Impacts of Coal Use', http://www.worldcoal.org/pages/content/index.asp?PageID=127

[152] BBC News, 'Clean Coal Technology: How It Works', 28th November 2005, http://news.bbc.co.uk/1/hi/sci/ tech/4468076.stm

In particular, a favoured 'clean coal' technology is the use of carbon capture and storage (CCS), which the World Coal Institute identifies as providing the greatest potential for reducing CO_2 emissions from coal-fired plants by 80-90%.[153]

Carbon capture and storage

Carbon capture and storage, or CCS, also known as carbon sequestration, is the technology that aims to capture CO_2 emissions from large point sources, such as fossil-fuel power plants, and permanently store it away from the atmosphere. The IPCC in their 2005 report on the topic claim that CCS used on a conventional power plant could reduce CO_2 emissions by 80-90% in comparison to a plant without CCS technology.[154]

There are three different types of CO_2 capture systems: post-combustion, pre-combustion and oxyfuel combustion.[155] Post-combustion capture systems are used to capture CO_2 from part of the flue gases, for example in the natural gas processing industry. Post-combustion will be the most widely-relevant method of capturing CO_2 from our stationary combustion power plants. New Integrated Gasification Combined Cycle (IGCC) power stations, where coal is first converted into gas, can use pre-combustion technology. Pre-combustion technologies are used in fertiliser manufacturing and hydrogen production. This system is more costly and elaborate, but the higher concentrations of CO_2 in the gas stream and the higher pressure make the separation easier. Oxyfuel combustion (burning oxygen with gaseous fuel) is in the demonstration phase, using high purity oxygen.

Pipelines are the preferred and most tried-and-tested method of transporting large amounts of CO_2 over distances up to 1000km.[156] For smaller amounts or for larger distances ships can be used, at a potentially lower cost.[157] The three main options for CO_2 storage are gaseous storage in deep geological formations, liquid storage in deep ocean masses, and solid storage as mineral carbonates.

The UK Government has focused its research and development efforts into geological storage, which it says is the most environmentally viable and cost-effective method.[158] The process involves capturing CO_2 and injecting it into rock layers via a choice of three storage methods – in depleted or near-depleted oil or gas fields, deep saline aquifers (porous rock layers containing salty water deep underground) or in unminable coal seams. CO_2 is captured as a gas and then compressed and/or cooled in order for it to be transported by pipeline. The CO_2 is then 'injected' into a permeable rock layer, which acts as a seal to trap and store the gas. CO_2 can also be reacted with water in rock pore spaces to immobilise it chemically. The key question for CCS, in terms of its mitigation effectiveness, is the ability of geological structures to retain the CO_2 over hundreds of thousands of years without 'leakage'.

In relation to the different storage options in geological structures, coal seam storage is at the earliest stage of development. According to the UK report, we have greatest understanding of storage in oil and gas fields and saline aquifers. Oil and gas fields have demonstrated their ability to retain buoyant fluids below ground over long periods. But extraction may have damaged their 'tightness', and may also have weakened the rock structures that contain it. However, injecting CO_2 into depleted oil and gas fields has been successfully practised for many years in the form of 'acid gas' – a mixture of CO_2, hydrogen sulphide (H_2S) and other byproducts of oil and gas exploitation and refining.[159] In 2001,

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[153] World Coal Institute, 'Environmental Impacts of Coal Use', http://www.worldcoal.org/pages/content/index.asp?PageID=127

[154] Mert, B., Davidson, O., de Coninck, H., Loos, M., and Meyer, L. (eds.), IPCC Special Report on Carbon Dioxide Capture and Storage, Cambridge: Cambridge University Press, 2005

[155] ibid

[156] ibid

[157] ibid

[158] Parliamentary Office of Science and Technology (POST), 'Postnote: Carbon Capture and Storage (CCS)', March 2005 (238), http://www.parliament.uk/documents/upload/POSTpn238.pdf

[159] Herzog, H., Golomb, D., 'Carbon Capture and Storage from Fossil Fuel Use', Massachusetts Institute of Technology, http://sequestration.mit.edu/pdf/enclyclopedia_of_energy_article.pdf, p.5

nearly 200 million cubic metres of acid gas was injected into formations across Alberta and British Columbia at more than 30 different locations as a form of disposal.[160]

Saline aquifers do not have proven 'tightness', but a more than decade-long project in the Norwegian North Sea – the Statoil Sleipner project – has so-far shown that the injected gas stays in place.[161] Saline aquifers may offer the greatest potential for CCS due to the fact that these reservoirs are widespread and have the largest volumes of space.[162] More research into what percentage of these aquifers are suitable for CO_2 storage, how to ensure geologic formation tightness, and what the potentials are for large CO_2 releases needs to be undertaken. The biggest human risks associated with geologic storage are the potential impacts of leaks, slow migration and accumulation, and induced seismicity (earthquake risks).

Storage in deep ocean masses is by either injecting the CO_2 directly in liquid form into the ocean water column at intermediate depths (1,000-3,000m) or deeper than 3,000m, where liquid CO_2 becomes heavier than seawater and so drops to the seabed to form a 'CO_2 lake'.[163] The ocean is by far the largest sink for anthropogenic CO_2, already containing 40,000 gigatonnes of CO_2 (GtC), compared to only 750 GtC in the atmosphere and 2200 GtC in the terrestrial biosphere.[164]

However, ocean storage runs the real risk of acidifying the oceans and there are many groups who directly oppose these moves due to concern over ecological and marine damage. The OSPAR Commission, for example, which guides international cooperation on the protection of the marine environment of the North-East Atlantic, together with the International Marine Organisation (IMO) have legally ruled out placement of CO_2 into the water-column of the sea and on the seabed, because of the potential negative effects.[165, 166] They state that studies indicate that with a 'business as usual' scenario, by the year 2100 the pH of the surface mixed layer of the ocean could decrease by more than 0.3 units and by 2250 by 0.7 units, creating a lower pH than that known to have been experienced in at least the last 20 million years.[167] The impacts of such a radical change on marine life are unimaginably far-reaching. Instead, the OSPAR Commission and the IMO favour geologic storage, including storage beneath the seabed, arguing that these offer the most secure and attractive option for CO_2 storage in the short-term.[168]

Mineral storage via the reaction of metal oxides with CO_2 to form stable carbonates is still only in the immature research phase. The reaction is naturally very slow and so needs to be thermochemically enhanced to speed up the process. This is very energy intensive and costly. It is estimated that mineral storage would require a power plant to produce 60-180% more energy in order to create the necessary conditions for the chemical reactions to take place.[169] The attractions of this method, however, lie in the fact that once converted, CO_2 is permanently locked away in a stable form, while the possible materials that can be used in the process include not only abundant silicate rocks but also industrial residues,

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160 ibid

161 Statoil, 'Carbon Dioxide Storage Prized', 18th December 2000, http://www.statoil.com/statoilcom/SVG00990.NSF?OpenDatabase&artid=01A5A730136900A3412569B90069E947

162 Herzog, H., Golomb, D., 'Carbon Capture and Storage from Fossil Fuel Use', p.6

163 ibid, p.5

164 ibid, p.7

165 The Convention for the Protection of the Marine Environment of the North-East Atlantic (the OSPAR Convention), OSPAR.org, 'New Initiatives on CO2 Capture and Storage and Marine Litter', 28th June 2007, http://www.ospar.org/content/news_detail.asp?menu=00600725000000_000002_000000

166 The International Maritime Organisation (IMO), 'CO2 Sequestration FAQ', http://www.imo.org/Environment/mainframe.asp?topic_id=1548

167 ibid

168 ibid

169 Mert, B. et al (eds.), IPCC Special Report on Carbon Dioxide Capture and Storage

such as slag from steel production or fly ash. However, studies on mineral sequestration are as yet unable to thoroughly report on the potential costs and impacts or large-scale feasibility of this technology.

Other options for CCS exist. Alternative methods under experimentation include capture by microalgae for biofuel; ocean fertilisation with limiting nutrients such as iron to stimulate the growth of marine phytoplankton, which absorb CO_2 and then fall to the bottom of the ocean; utilisation of CO_2 as a raw material in chemical and industrial processes, such as to make vulcanised rubber, polyurethane foam and polycarbonates (this method is limited, however, with estimated world commercial use at less than 0.1GtC equivalent); the use of CO_2 in Enhanced Oil Recovery and Enhanced Coal Bed Methane Recovery processes, which can provide added revenues to the industries whilst recycling CO_2, although not permanently storing it; and afforestation to enhance the uptake of CO_2 by the terrestrial biosphere.[170]

Further issues include economic costs, public perception, diffusion and transfer of technology to developing countries and regulatory aspects. Currently, there exist no uniform guidelines to regulate CCS projects nationally or internationally. Unresolved legal issues that could impact on the long-term success and particularly the environmental integrity of CCS projects include issues surrounding accountability, long-term stewardship, property rights, storage-well design standards, and how to account for CO_2 in international and national greenhouse gas inventories, including measuring leakages and carbon pricing.[171]

Renewable energies

Renewable energy is the term used to define different types of energy derived from resources, such as wind, water, sun, tides and geothermal heat, that are naturally replenished and non-finite, i.e. potentially infinite. These are found in the natural world and harnessed by the use of technology to produce heat and/or electricity for human use. Currently, renewables represent only 5% of global power capacity and 3.4% of global energy generation.[172] However, 2007 saw the largest ever investment into renewable energy capacity of over $100billion.[173]

Wind power

Wind power is energy generated by the use of wind turbines. The rotor blades of the turbines are connected to a generator through a shaft, which is turned by the force of the wind to create electricity.

With massive investment over the past decade or so, wind turbines are a relatively mature and global technology, now topping 100GW (gigawatts) of production worldwide[174] (the equivalent to around 90 average-sized coal-fired power stations) and offering electricity for as little as 0.03 Euros per kilowatt-hour – competitive with today's fossil fuel prices.[175] Since the turn of the century, wind generation has increased more than five-fold. Germany is the current global frontrunner with 7% of its energy generated by 19,460 turbines.[176] However, the US is catching up, as are Spain, India and China, which has doubled its capacity every year since 2004 and aims to generate 30GW of electricity by wind power by 2020. Today, one in every three countries generates a portion of its electricity by wind.[177] In 2007 wind power attracted 43%, or

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[170] Herzog, H., Golomb, D., 'Carbon Capture and Storage from Fossil Fuel Use', pp.10–11

[171] US Department of Energy (DOE) and the National Energy Technology Laboratory (NETL), 'International Carbon Capture and Storage Projects: Overcoming Legal Barriers', June 2006 http://www.netl.doe.gov/energy-analyses/pubs/ccsregulatorypaperfinalreport.pdf

[172] Worldwatch Institute, Renewables 2007 Global Status Report, Renewable Energy Policy Network for the 21st Century, http://www.worldwatch.org/files/pdf/renewables2007.pdf, p.8. [NB: figure excludes large hydro-power which itself was responsible for 15% of global power generation.]

[173] ibid

[174] Finfacts News, 'Global investment into renewable energy surged to almost $150billion in 2007 despite financial market turmoil: Europe still leads', 2nd July 2008, http://www.finfacts.ie/irishfinancenews/article_1014084.shtml

[175] Vestas, Management Report 2004, http://www.vestas.com/Default.aspx?ID=200&q=management+report+2004

[176] German Wind Energy Association (BWE), 'Wind energy in Germany', http://www.wind-energie.de/en/wind-energy-in-germany/

[177] Dorn, J.G., 'Global Wind Power capacity reaches 100,000 Megawatts', Earth Policy Institute, 4th March 2008, http://www.earth-policy.org/Indicators/Wind/2008.htm

$US 50.2 billion, of the total invested globally into renewable energies that year.[178]

Forecasts for this industry remain optimistic. The Global Wind Energy Council is expecting a further 155% growth in the global market by 2012, expanding wind's total global energy production from just over 1% in 2007, to around 3% – or about 250GW.[179] But a 2006 Stanford University study looks even further, claiming that, based on locations with annual average windspeeds of over 6.9m/s at 80m alone, the worldwide potential for onshore wind power generation is estimated at 72TW (terawatts), or 54,000Mtoe (Million Tonnes of oil Equivalent), of electricity per year – five times the total amount of electricity generated globally today.[180] However, this assumes 6 turbines per square km for 77m-diameter, 1.5 MW-turbines on roughly 13% of the total global land area, (which could also be used for compatible uses such as agriculture) – that's an area slightly bigger than the size of South America.[181]

Land use and availability is clearly a major barrier. Studies have shown that certain areas of the world are more suitable for wind farm developments thanks to higher average wind speeds (the power derived from wind is proportional to the cube of the wind speed). The areas of the world with most potential are the US, Northern Europe on the North Sea coast, the southern tip of South America, parts of East Asia, and areas in Australia and New Zealand. Constraints on where to place wind farms are not only limited by wind speeds and altitude, but also rule out urban areas and must consider current land-use of rural areas, such as for nature reserves. Some studies insist that wind farms should only be placed where 'dual land-use' is facilitated – e.g. for agriculture. Public reservations about the noise and visual impact of wind farms, and concern over the affect on birdlife and other wildlife, have impacted heavily on planning

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[178] Finfacts News, Global investment into renewable energy surged to almost $150billion in 2007 despite financial market turmoil: Europe still leads'

[179] Global Wind Energy Council, 'Global wind energy market to reach 240GW by 2012', 27th March 2008, http://www.gwec.net/index.php?id=30&no_cache=1&tx_ttnews%5Btt_news%5D=143&tx_ttnews%5BbackPid%5D=4&cHash=773fe52939

[180] Archer, C.L., Jacobson, M.Z., 'Evaluation of Global Wind Power', Working Paper: Stanford University, USA, http://www.wind-energie.de/fileadmin/dokumente/Themen_A-Z/Potenzial%20der%20EE/Stanford_global_winds.pdf

[181] ibid

applications. Wind farms should only be developed in well-positioned territories where the load factor (the ratio of the net amount of electricity generated to the net amount which it could have generated if it were operating at its net output capacity) is over 30% to make them economically viable (although this is dependent on the price of electricity). An average wind speed of 13 miles per hour is considered a good wind resource. Some available wind turbines will generate about 1,400kWh per year with a 13mph resource. However, little energy is produced below 10mph.[182]

Even as wind turbine technology is swiftly developing, with advancements in blade design and size and material build already moving forward apace (there are currently 126m-diameter turbines operating at 5MW capacity, and are expected to develop 260m-diameter turbines at 20MW capacity by 2020, but economic factors put this under question), the variability of wind speeds mean that wind power cannot always guarantee a steady supply of energy, and neither will it always deliver maximum output. A 1MW turbine will only deliver 1MW during high winds, which are never guaranteed and difficult to predict, although forecasting is improving. A wind farm's 'capacity' may be just 45% in high-wind regions, but is more generally closer to 33%, which means that in order to get 100MW of power closer to 250MW of new turbines need to be installed.[183] Wind is unsuitable as a base-load supply, and needs to be backed up by other sources or deployed in a smart grid system which does not require a base-load supply. Currently these have been fossil fuels.

However, as an example, the EU is currently studying plans put forward by Greenpeace to create a North Sea transnational wind-powered offshore electricity grid that would connect up more than 100 northern European wind farms in a self-stabilising connection, backed up by Scandinavian hydropower that can be switched on to supplement demand. Such a grid would supply seven North Sea countries with enough electricity to power 70 million homes.[184] Other types of 'smart-grid' and 'dynamic demand' options, focused on the consumer-end of energy demand, are also under investigation, which would enable power grids to be more flexible, responsive, adaptive and self-balancing, enabling wind to perhaps play a bigger role.

Other recent technological advancements in energy storage are also providing ways in which to stabilise the electricity flow from intermittent sources such as wind. Batteries capable of recharging when surplus energy is available and then of storing large amounts of energy in chemical form can be connected up to wind farms. A 2MW vanadium flow battery with an energy capacity of 12MWh is due to be installed next year at Sorne Hill wind farm in Ireland, costing $6.3million.[185] Another alternative is to use 'compressed-air energy storage' (CAES). Energy generated by wind is used to compress air, stored underground in salt domes or aquifers. The air is then released, feeding it into a gas turbine to handle peak demand. The turbine is still gas-fuelled, but uses up to 50% less fuel due to the alternative use of wind power to compress the air in the first instance. However, the EC is researching into advanced CAES plants that would consume no natural gas at all. Current CAES plants cost around $600-$700 per installed kilowatt to build and are almost economic when compared to coal-fired power stations which cost $476 per kilowatt to build.[186]

In order to get around the problem of variable wind speeds, together with the limits of land availability, offshore wind farms are of increasing interest. Offshore wind potential is, again, theoretically considered to be able to offer around double the global current energy consumption. Higher and more constant average wind regimes at sea together with

[182] Sandia National Laboratories, Photovoltaic Systems Research and Development, 'Hybrid Power Systems – Issues and Answers', http://photovoltaics.sandia.gov/docs/Hybook.html

[183] Roberts, P., The End of Oil, p.202

[184] The Guardian.co.uk, 'Greenpeace's grid plan: North Sea grid could bring wind power to 70m homes', 4th September 2008, http://www.guardian.co.uk/environment/2008/sep/04/windpower.renewableenergy

[185] NewScientist.com, 'Renewable Energy: Will the Lights Stay On?', New Scientist, 8th October 2008, http://www.newscientist.com/article/mg20026771.600-renewable-energy-will-the-lights-stay-on.html

[186] ibid

less turbulence and wind shear are a decisive advantage. Installation and maintenance costs are much larger, however, and operational and construction difficulties are a problem, such as only being able to build or carry out maintenance during calm weather. However, costs are expected to fall, as happened with onshore wind, as capacity increases. There are a total of 24 operational offshore wind projects worldwide at the moment – all in Europe – with another 6 already under construction and due to be completed in the next 2 years (when almost half of the worldwide total will be in the UK). They are usually built in generally shallow water of no more than 30m in depth. They can be sited in places of greater depth, but at current technological rates, the British Wind Energy Association (BWEA) states this is highly expensive and un-economical. Overall, offshore wind developments are hampered by a lack of capital investment due to high risk on returns.

Solar power

Solar power is electricity or heat generated directly from the sun's rays. The total amount of energy irradiated from the sun to the Earth's surface is 10,000 times our global energy consumption.[187] Solar power technology attempts to harness some of that energy, and transfer it into electricity and/or heat for human use. There are two main methods currently deployed: photovoltaic cells, which absorb sunlight via semiconducting materials, such as silicon, and convert it into low-voltage direct current electricity; and thermal solar power, which generates electricity from the heat produced by sunlight.

Photovoltaic (PV) cells

PV cells can be used at a wide range of scales, from single cells powering small hand-held devices such as calculators, to ground-based arrays covering miles of deserts, providing 10MW of energy. They can be integrated into building surfaces, such as roof tiles, glass panels and walls, and can also be retro-fitted, but at a higher cost. In 1995, Japan announced an ambitious programme to subsidise and install millions of rooftop PV systems for homeowners. Two years later, Germany implemented a similar law led by its Green Party. Between 1995 and 2002 the number of PV systems installed every year leapt from 80MW of total power to 500MW.[188] In 2007, global production of PV cells increased by over 50%, bringing cumulative global installations of PVs to over 9,500MW.[189] It is currently the fastest-growing energy technology in the world.

However, PV cells have similar drawbacks to wind. They provide intermittent power – only when the sun is shining – and do not store energy (although they can be connected to battery storage systems). They are thus more suitable for sunny regions of the globe where sunlight hours are longer and more consistent. Any site that receives more than 1,800 kilowatt hours per year of solar insolation (a measure of solar radiation energy received on a given surface area in a given time) is considered a good site for a PV system.[190] However, contrary to popular belief, PV cells actually work better in colder temperatures. Their limited applicability to temperate zones are therefore related to shorter sunlight hours, lower sun angles and greater cloud cover, and not heat.[191] The output of a PV cell is reduced to around 5-20% of its full capacity under cloudy conditions.[192]

For these reasons, many argue that in most areas of the world, PV cells are most suitable and cost-effective in small products and certain niche appliances, such as stand-alone parking meters, street lights, traffic lights, vending machines and public telephones, which would lower energy demand but

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187 Greenpeace, 'Solar Thermal Power: 2020 Exploiting the Heat from the Sun to Combat Climate Change' October 2003, http://www.greenpeace.org/raw/content/international/press/reports/solar-thermal-power-2020.pdf

188 Roberts, P., The End of Oil, p.194

189 Worldwatch Institute, 'Another Sunny Year for Solar', May 2008 http://www.worldwatch.org/node/5449

190 Sandia National Laboratories, Photovoltaic Systems Research and Development, 'Hybrid Power Systems – Issues and Answers'

191 ABS Energy Research, SPV 2007 Solar Photovoltaic Report, Edition 5 2007, http://www.absenergyresearch.com/cmsfiles/reports/Solar-Photovoltaics-Report-2007.pdf

192 ibid

would not supply energy to the grid, as well as when integrated into new build, requiring changes in building regulations to incentivise capital expenditure. Additionally, thanks to the fact that they operate as on-site generation devices, capable of supplying energy at the point of consumption, PV cells can be utilised very effectively in remote, off-grid areas and communities, where access to electricity is limited, particularly in developing countries. However, costs at the moment are high (around $US 3-5/watt – but bearing in mind they originally cost around $40,000/watt[193]) due to the use of expensive raw materials in manufacture, such as high-grade silicon and copper, although new investments in cheaper, more efficient alternatives, such as thin-film PVs (TFPVs) and Copper indium diselenide PVs (CIS) are underway. But these are very much regarded as technologies for the future.

Efficiency and cost are thus the two main factors limiting PV cell use. They are, commercially, at best between 14-19% efficient, but some operate at a rate as low as 5% efficiency, although this is improving all the time. The most efficient 'multijunction' cells, at somewhere between 30-40% efficiency (the highest recorded efficiency claim was made by the company Spectrolab testing its 'Ultra-Triple-Junction' high efficiency solar cell in 2006 at 40.7%), are upwards of 100 times more expensive to manufacture due to low-volume output and the use of rare materials.[194] However, ways to 'boost' solar efficiency are being explored, with new 'concentrator systems' rapidly becoming cost-competitive. These increase light intensity using lenses or mirrors to focus sunlight on a small area of the PV cell, boosting sunlight intensity by as much as 500 suns. IBM reported in May 2008 to have tested a Concentrated Photovoltaic (CPV) system capable of concentrating 2,300 suns, or 230watts/cm^2.[195]

In 2009, construction is to start on a mega-scale CPV power station in Victoria, Australia, part-funded by the Australian government in collaboration with the Australian company Solar Systems, at a cost of $AUS 450million. It is expected to provide 154MW of energy and to switch on in 2010. By 2011, New Mexico will be the home of the world's largest solar power plant, covering 1,300ha and producing 300MW of energy. Other such large-scale 'solar parks' exist in Spain, Germany, South Korea and Portugal[196], with other countries, mainly in Europe, soon to follow suit.[197] CPV may be developing rapidly for such on-the-ground projects, but are currently not suitable for rooftop applications – which represent 90% of current PV demand.[198]

An alternative way to use PV cells is to create a Hybrid Power System (HPS) that combines with other forms of renewable energy, such as wind, or with diesel or gas-fired engines and that is connected to an acid-fuel cell, or more recently, hydrogen fuel-cell battery, to store energy.[199] This type of system is considered most economical and suitable for remote, off-grid locations or stand-alone systems, such as on islands or village-scale mini-grids, where costs of grid extension are prohibitive and fossil fuel prices dramatically increase due to restricted and distant access.[200]

Solar thermal power

Solar thermal energy is different to photo-voltaic electricity in that it uses the sun's heat to heat water, which then can be used to raise the temperature of buildings or power electricity generators by steam. It uses direct sunlight, so is suitable only for the sunniest

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[193] Schaeffar, J., Real Goods: Solar Living Sourcebook, Gabriola Island, BC Canada: New Society Publishers, 2005, p.45

[194] RenewableEnergyWorld.com, 'Solar Cell Breaks the 40% Efficiency Barrier', 7th December 2006 http://www.renewableenergyworld.com/rea/news/story?id=46765

[195] Physorg.com, 'IBM Research Unveils Breakthrough in Solar Cell Technology', 15th May 2008, http://www.physorg.com/news130086323.html

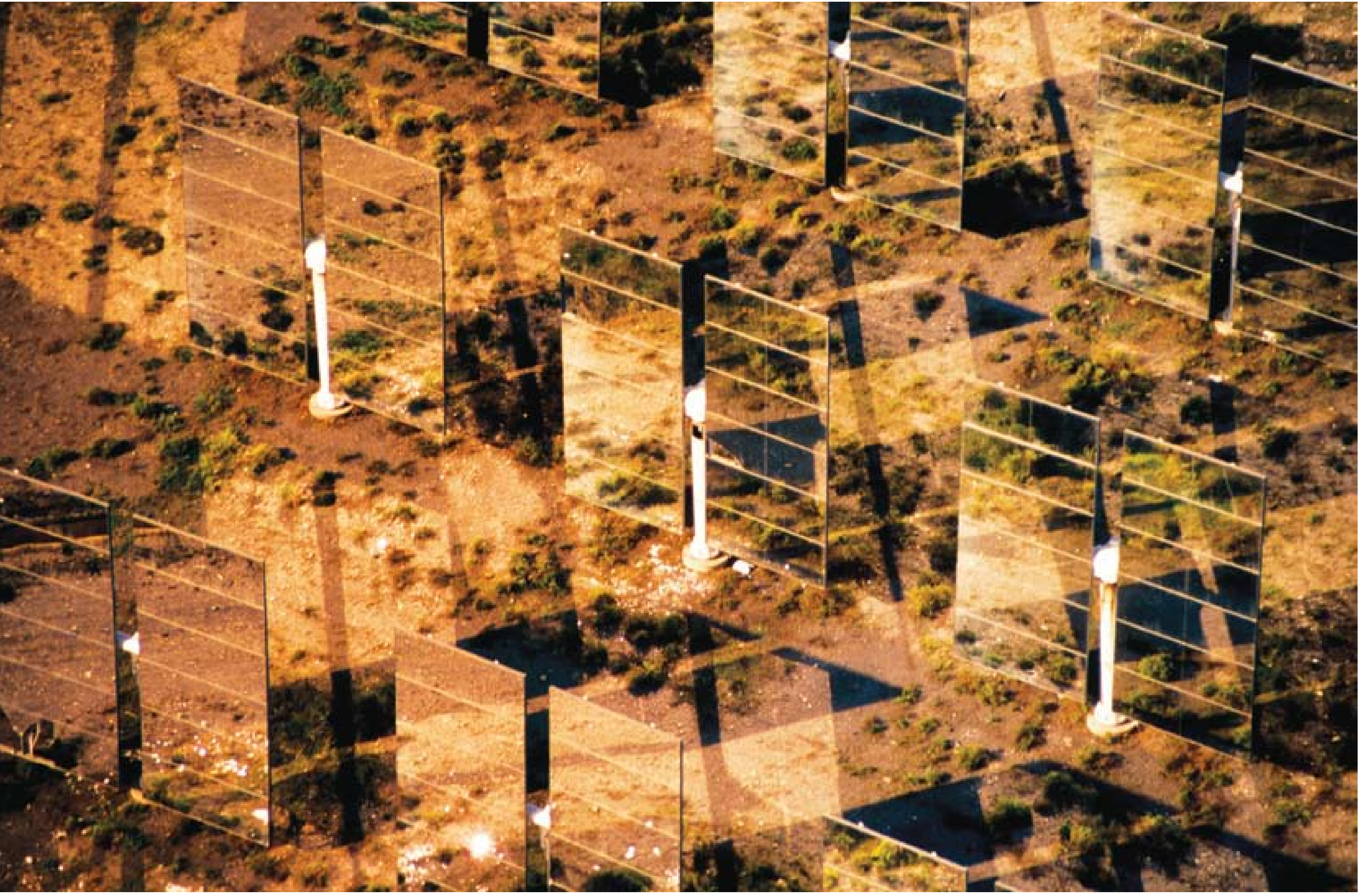
[196] T Ecoworldly.com, 'World's 13 Biggest Solar Energy Plants', 5th March 2008, http://ecoworldly.com/2008/03/05/worlds-7-biggest-solar-energy-plants/ y/docs/solar_dish.pdf

[197] Pvresources.com, 'Large-Scale Photovoltaic Power Plants: Cumulative and Annual Installed Power Output Capacity', Annual Report 2007: Revised Edition April 2008, http://www.pvresources.com/download/AnnualReport2007.pdf

[198] Taggart, S., 'CSP: Dish Projects Inch Forward', Renewable Energy Focus, 9(4), 2008, pp.52–4

[199] Sandia National Laboratories, Photovoltaic Systems Research and Development, 'Hybrid Power Systems – Issues and Answers'

[200] The Euro-Mediterranean Renewable Energy Partnership (HY-PA), INCO Specific Support Action, First Periodic Activity Report, July 2006, http://www.hy-pa.org/Publications/2006/Annex1-2-HYPA-Report0607-RTDRequirements.pdf



regions of the world. Suitable sites should offer annually at least 2,000 kilowatt hours (kWh) of electricity per square metre of sunlight, whilst the best sites offer more than 2,500kWh/m^2.[201] The best sites are thus areas of savannah, arid desert, semi-deserts, bush, and steppes. Therefore the most promising areas are south-western USA, Central and South America, Africa, the Middle East, the Mediterranean countries of Europe, Iran, Pakistan and the desert regions of India, the former Soviet Union, China and Australia. In 2005, China, India and Japan had a 75% share of the market, but as this relatively new technology has grown, it has spread wider afield.[202] In many parts of the world, 1km^2 of land is enough to generate 100-200GWh of electricity per year using solar thermal technology.[203] This is equivalent to the annual production of a 50MW conventional coal or gas-fired power plant.[204]

Until recently, solar thermal has been exploited mainly on a small-scale; for domestic uses such as cooking, and for building applications, such as heating space or water. The market for such low-tech solar thermal cookers and water heaters is huge, as are their economic, social and environmental benefits. In poorer countries, energy used for cooking is the bulk of all energy consumption – in some cases, up to 80%.[205]

Larger scale solar thermal projects are now also being developed. This is largely thanks to Concentrated Solar Power (CSP) technology, which uses the same

[201] Greenpeace, 'Solar Thermal Power: 2020 Exploiting the Heat from the Sun to Combat Climate Change'

[202] ABS Energy Research, STP 2005: Solar Thermal Power: CST Concentrated Solar Energy, Edition 1, 2005, http://www.absenergyresearch.com/cmsfiles/reports/Solar-Thermal-Power-Report-2005.pdf

[203] Greenpeace, 'Solar Thermal Power: 2020 Exploiting the Heat from the Sun to Combat Climate Change'

[204] ibid

[205] Burkhardt, H., 'Feasibility of Solar Cooking and its impact on Conservation of Forests', presented at the Roundtable on Forestry, 22nd September 2006, University of Toronto, http://www.ihtec.org/fileadmin/archives/IHTEC/documents/Solar_Cooking_impact_on_forests060920.doc

mechanisms we saw in CPV systems. Direct solar radiation is collected and concentrated using mirrors or lenses and tracking devices to focus a large area of sunlight into a small beam. The concentrated light is then used as a heat source for conventional power plants, for example through a steam or gas turbine or Stirling engine. Current CSP technologies include parabolic trough power plants, solar power towers, parabolic dish engines, and linear 'Fresnel' reflector systems. Each concentration method is capable of producing high temperatures and correspondingly high thermodynamic efficiencies, but they vary in the way they track the sun and focus light. All CSP technologies can be hybridised with fossil fuels and/or other renewable energies.

The parabolic trough system works by using cylindrical parabolic mirrors to capture and focus the sun's radiation. Several of these collectors are installed in rows about 100m long and the total solar field is composed of many such parallel rows.[206] The resulting energy is used to heat thermal oil, which is pumped through an absorber pipe. The heated oil then passes through a heat exchanger that in turn creates steam to drive a steam turbine.[207] The trough system is the most mature of all CSP technologies, with 354MW connected to the Southern Californian grid since the 1980s, involving 2km^2 of trough collectors. These plants supply around 800kWh annually at a cost of 10-13 UScents/kWh.[208] Costs are expected to decrease to between 4.3-6.2 UScents/kWh as thermal energy storage systems are developed, technological efficiencies improve and as plant volume increases, combined with good market incentives for making renewables cost-competitive.[209] Hybrid developments of trough plants combined with gas-fired combined cycle plants – ISCCS (Integrated Solar Combined Cycle Systems) – which back up the solar output using natural gas – are expected to reduce the costs to 6 UScents/kWh in the near future, and 5 UScents/kWh in the long term.[210]

A new system using Fresnel lens technology, developed with the help of research scientists at the Fraunhofer Institute for Solar Energy Systems in Freiburg, Germany, offers lower cost solar concentrating ability in comparison with parabolic troughs. While the basic system is the same as that of parabolic troughs, the design is simpler and cheaper. Instead of using the giant parabolic mirrors that require expensive high-precision optical elements, the Fresnel lens systems uses rows of flat reflectors that simulate a curved mirror by varying the adjustable angle of the individual rows of mirrors in relation to the absorber pipe. The reflectors are made using standard glass mirrors – similar to a bathroom mirror – making the raw materials very inexpensive and opening up the possibility to produce these key components in low-cost countries. Whilst the curved shape of the parabolic mirrors makes them around 15% more efficient than the Fresnel reflectors, the team behind their development expects that Fresnel-based CSP will decrease solar thermal generation costs by the same percentage.[211, 212] In addition, the closer arrangement of mirrors using the Fresnel system requires less land and provides a partially shaded, potentially useful space underneath, which could be used for horticulture.[213]

Another type of CSP technology relatively

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206 VGB Power Plants 2001, Brussels, 'Solar Power – Photovoltaics or Solar Thermal Power Plants?', October 2001, http://www.volker-quaschning.de/downloads/VGB2001.pdf

207 RenewableEnergyWorld.com, 'Ahead of the Curve? Fresnel Technology in CSP', 8th April 2008, http://www.renewableenergyworld.com/rea/magazine/story?id=52024

208 Greenpeace, 'Solar Thermal Power: 2020 Exploiting the Heat from the Sun to Combat Climate Change' http://www.dlr.de/tt/Portaldata/41/Resources/dokumente/institut/system/projects/TRANS-CSP_Full_Report_Final.pdf

209 National Renewable Energy Laboratory, 'Executive Summary: Assessment of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecasts', October 2003, http://www.nrel.gov/csp/pdfs/35060.pdf

210 Greenpeace, 'Solar Thermal Power: 2020 Exploiting the Heat from the Sun to Combat Climate Change'

211 RenewableEnergyWorld.com, 'Ahead of the Curve? Fresnel Technology in CSP'; and PureEnergySystems.com 'Fresnel Reflectors Bring Solar Price Down', 13th July 2007 http://pesn.com/2007/07/13/9500481_Fraunhofer_Institute_Fresnel_Solar/

212 Solar Power Group (SPG), 'SPG Welcomes Maan Ferrostaal Power Industry GmbH as New Shareholder', 5th July 2007 http://www.spg-gmbh.com/news.asp?news_id=11

213 Greenpeace, 'Solar Thermal Power: 2020 Exploiting the Heat from the Sun to Combat Climate Change'

new to the market is solar power towers, or central receivers. These are considered to hold an advantage over the parabolic trough systems in also being capable of generating electricity at a cheaper cost in the long-term.[214] Solar-power towers, or 'heliostat' power stations, use moveable computer-controlled mirrors, or 'heliostats', to focus sunlight on to a tower-mounted heat-exchanger. Air or molten salt transports the heat, and a gas or steam turbine drives an electrical generator that transforms the heat into electricity. In a molten-salt solar power tower, liquid salt at 290°C (554°F) is pumped from a 'cold' storage tank through the receiver where it is heated to 565°C (1,049°F) and then on to a 'hot' tank for storage. When power is needed from the plant, hot salt is pumped to a steam generating system that produces superheated steam for a conventional Rankine cycle turbine/generator system. From the steam generator, the salt is returned to the cold tank where it is stored and eventually reheated in the receiver. With thermal energy storage, these towers can potentially operate for 65% of the year without the need for back-up, whilst being able to meet peak-demand capacity during daylight hours.[215]

March 2007 saw the inauguration of the world's first central receiver, and Europe's first commercial CSP plant, with a peak capacity of 11MW in Seville, southern Spain.[216] It is expected, that as the technology matures, capacities of up to 400MW will be feasible.[217] The US National Renewable Energy Laboratory estimates that by 2020, electricity could be produced from solar power towers for between 3.5-5.5 UScents/kWh,[218] whilst Chicago-based consultants Sargent and Lundy estimate it as low as $0.04 cents/kWh.[219] Since large amounts of water and land are required for solar power towers, building locations are important to consider for environmental and economic reasons.

Solar dish/engines use a mirror array to reflect and concentrate incoming direct sunlight to a receiver, in order to achieve the temperatures required to efficiently convert heat to electricity. Of all solar technologies, dish/engine systems have demonstrated the highest solar-to-electric conversion efficiency (31.25%), but are still relatively immature as a technology.[220] The modularity of dish/engine systems allows them to be deployed individually for remote applications, or grouped together for small-grid (village power) or end-of-line utility applications. Depending on the system and the site, dish/engine systems require approximately 1.2-1.6ha of land.[221]

Two large-scale solar-dish projects are currently under development – and all eyes are on the outcomes to determine the future viability of solar thermal dishes. The first is a planned 500MW capacity instalment of 30,000 11.5m 'SunCatcher' dishes situated on 6,500 acres of desert in the Imperial Valley, east of San Diego in California by Arizona-based company Stirling Energy Systems Inc.[222] The company, together with Sandia National Laboratories, broke a world record when they achieved the highest energy conversion efficiency rate of 31.25%.[223] Construction of this mega-project is due to start in 2009. The project will be the largest CSP project in the world, and the most

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[214] National Renewable Energy Laboratory, 'Executive Summary: Assessment of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecasts'

[215] SolarPACES, CSP Technology: 'Solar Power Tower', http://www.solarpaces.org/CSP_Technology/docs/solar_tower.pdf

[216] Renewable Energy UK, 'First European Solar Power Tower: Europe's First Concentrated Solar Powee Tower Opens in Spain', 4th May 2007, http://www.reuk.co.uk/First-European-Solar-Power-Tower.htm

[217] SolarPACES, CSP Technology: 'Solar Power Tower'

[218] National Renewable Energy Laboratory, 'Executive Summary: Assessment of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecasts'

[219] Taggart, S., 'Hot Stuff: CSP and Power Tower', Renewable Energy Focus, May/June 2008, pp.51–54

[220] SolarPACES, CSP Technology: 'Solar Dish Engine' http://www.solarpaces.org/CSP_Technology/docs/solar_dish.pdf

[221] ibid

[222] See http://www.stirlingenergy.com/projects/solar-two.asp

[223] Sandia National Laboratories, 'Sandia, Stirling Energy Systems Set New World Record for Solar-to-Grid Conversion Efficiency 31.25%: Efficiency Rate Topples 1984 Record', 12th February 2008, http://www.sandia.gov/news/resources/releases/2008/solargrid.html

expensive – costing $1billion.

The second project is located in Southern Australia and is being developed by Wizard Power.[224] Combining traditional CSP with an innovative ammonia-based thermal storage system, Wizard claims it will be able to generate power 24 hours a day, as soon as the end of 2009.[225] The dishes to be used for the venture, which have been under development at Australia's National University for 20 years, are the size of two-storey houses, and Wizard claims they can concentrate the sun nearly 1,500 times.[226]

Altogether, the CSP technologies are expected to decrease solar power generation costs by 20%, once 400MW of capacity is installed, and once 5,000MW is reached, it is believed that this type of solar generation will be competitive with fossil fuel prices.[227] An ambitious plan to supply 15% of Europe's electricity by 2050 via a trans-national CSP grid connecting the Middle East and North Africa (MENA) with the European Union (EU), was put together in 2006 by the Institute of Technical Thermodynamics at the German Aerospace Centre (DLR), commissioned by the German Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety. It proposes importing 60TW/y of solar power energy by 2025 over a distance of around 300km from the South via an interconnected grid of alternating current (AC) and high voltage direct current (HVDC) transmission technologies, rising to a potential 700TW/y by 2050. It is considered that high solar irradiance in MENA and low transmission losses of 10-15 % will yield a competitive import solar electricity cost of around 0.05€/kWh.[228] A similar plan for North America was modelled on the DLR report by the US Department of Energy in 2007.[229]

A further study on the potential to use CSP technology for seawater desalination in MENA was also conducted by the DLR in 2007. Combining these two studies, a white paper was presented to the European Parliament at Brussels in 2007 by the Club of Rome and the Trans-Mediterranean Renewable Energy Cooperation (TREC), entitled 'The DESERTEC Concept for Energy, Water and Climate Security'. The paper draws up plans for a $400 billion (over the next 30 years) EUMENA (Europe, the Middle East and North Africa) supergrid connection of desert CSP plants and other renewables, such as wind, hydropower, biomass and geothermal, with back-up from fossil fuels. This supergrid would power most of Europe's energy use and meet two-thirds of MENA's energy needs, using 80% renewable energy by 2050, all on a land area of only 1% of the total land of EUMENA – the equivalent land used at present for transport and mobility in Europe.[230] DESERTEC was intended not only to provide energy, but also water and security, while reducing harmful CO_2 emissions and promoting peaceful relations and cooperation between the countries.[231] It is presented as the 'least-cost option for clean and sustainable energy' and calls on EU and MENA governments to create the necessary legal and financial framework to stimulate the required investment. The EU asked TREC to provide more specifics for the proposal in November 2007.

Air-source heat pumps

Air-source heat pumps use the outside air as a heat source or heat sink to heat or cool a building. There are two types: air-to-air

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[224] See http://www.wizardpower.com.au/images/wizarddownloads/aestannouncementpressrelease.pdf

[225] Taggart, S., 'CSP: Dish Projects Inch Forward'

[226] ibid

[227] Greenpeace, 'Solar Thermal Power: 2020 Exploiting the Heat from the Sun to Combat Climate Change'

[228] German Aerospace Center (DLR) and the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, 'Trans-Mediterranean Interconnection for Concentrating Solar Power: (TRANS-CSP) Final Report', June 2006, http://www.dlr.de/tt/Portaldata/41/Resources/dokumente/institut/system/projects/TRANS-CSP_Full_Report_Final.pdf

[229] US Department of Energy, 'DLR TRANS-CSP Project Applied to North America', presented at the 2007 Parabolic Trough Technology Workshop, Golden, Colorado, 8th March 2007, http://www.nrel.gov/docs/fy07osti/41422.pdf

[230] Trans-Mediterranean Renewable Energy Cooperation (TREC), 'Clean Power From Deserts: The DESERTEC Concept for Energy, Water and Climate Security', November 2007 http://www.trec-uk.org.uk/reports/TREC_Whitebook_final.pdf

[231] Gramling, C., 'Desert Power: A Solar Renaissance', Geotimes.com, April 2008, http://www.geotimes.org/apr08/article.html?id=feature_solar.html

systems that provide warm air, which is circulated to heat the building, and air-to-water systems, that heat water to provide heating to a building through radiators or underfloor heaters. The system runs on electricity, but it has a Cooefficient of Performance (CoP) of 3 or 4 – meaning that for every 1kW of energy put in, 3-4kW of energy is produced in the form of hot water/air.[232] In this way, air-source heat pumps have a typical efficiency of 300-400% compared to a resistance heater and are 140-185% more efficient than using a gas-fired conventional boiler.[233] Other benefits of air-source heat pumps, which are more efficient than ground-source heat pumps, are that they require no civil ground works, such as laying of pipes – they can simply be retro-fitted into an urban home and connected up to conventional radiators. They take up as much space as an air-conditioning unit and can extract heat from temperatures outside that are as low as -15°C.[234]

Ocean thermal energy conversion

Ocean thermal energy conversion, or OTEC, exploits the temperature difference that exists between deep and shallow water in oceans to produce electricity via a heat exchanger. Oceans are the largest solar heat energy collectors and storage systems on the planet – covering 70% of the Earth's surface. On an average day, 60 million km^2 of tropical seas absorb an amount of solar radiation equal in heat content to about 250 billion barrels of oil. If less than one-tenth of one percent of this stored solar energy could be converted into electric power, it would supply more than 20 times the total amount of electricity consumed in the US on a single day.[235] Some experts believe that using OTEC technology could provide as much as 10GW of baseload power generation, especially for tropical island communities.[236]

OTEC is a relatively advanced technology. In May 1993, an open-cycle OTEC plant at Keahole Point, Hawaii, produced 50,000 watts of electricity during a net power-producing experiment. This broke the record of 40,000 watts set by a Japanese system in 1982. It neither requires solar energy collectors nor energy storage facilities, making their continuous operation possible. In October 2008, the US Department of Energy granted $1.2million to Lockheed Martin to 'demonstrate innovative technologies to enable ocean thermal energy power generation.'[237] Under the agreement, Lockheed Martin will 'demonstrate a cold water pipe fabrication approach using modern fiberglass technology and recent low-cost composite material manufacturing methods at prototype and pilot plant scales.'

OTEC also has benefits of use for aquaculture, desalination, hydrogen production, chilled-soil agriculture, and mineral extraction. However, its use is limited to areas where temperature differentials are greater than 20°C at a depth of no more than 1000m – so generally within latitudes of 20° above or below the equator.[238]

Biomass energy

Energy from biomass refers to solid, liquid or gas fuel derived from living and recently dead organic (plant or animal) matter, such as timber, manure or specially grown crops.

Biomass materials absorb CO_2 from the atmosphere via photosynthesis when they

[232] The Energy Saving Trust, UK, 'Generate Your Own Energy: Air-Source Heat Pumps' http://www.energysavingtrust.org.uk/Generate-your-own-energy/Types-of-renewables/Air-source-heat-pumps
[233] MacKay, D., Sustainability – Without the Hot Air, Cambridge: UIT Cambridge, 2009, p.151
[234] The Energy Saving Trust, UK, 'Generate Your Own Energy: Air-Source Heat Pumps'
[235] US National Renewable Energy Laboratory, 'Ocean Thermal Energy Conversion: What is Ocean Thermal Energy Conversion?' http://www.nrel.gov/otec/what.html
[236] ibid
[237] McDermott, M., 'Ocean Thermal Energy Conversion: Renewable Ocean Power and Air-Conditioning Research Receives Federal Funding', Treehugger.com, 10th October 2008, http://www.treehugger.com/files/2008/10/ocean-thermal-energy-conversion-renewable-energy-air-conditioning-research-lockheed-martin-receives-federal-funding.php
[238] US National Renewable Energy Laboratory, 'Ocean Thermal Energy Conversion: Plant Design and Location', http://www.nrel.gov/otec/design_location.html

grow, making them a carbon sink. When they are burnt to produce heat or electricity, they release this carbon back into the atmosphere, theoretically creating a continuous and neutral cycle. Unlike fossil fuels, which also have their origins in ancient biomass, the carbon released from biomass today forms part of the current natural fixed carbon cycle, which normally remains in a stable state. Biomass energy can be converted into liquid transportation biofuels, such as bioethanol or biodiesel, as well as into methane gas, or 'biogas'. It can also act as a direct source of heat and electricity via combustion. Biomass energy is not a new form of energy – it has been used for centuries, and is the fourth-ranked source of primary energy consumed after oil, coal and gas. Interest in mass-scale use, particularly in the developed world, however, has only very recently cropped up, driven by concern over global warming, rising oil prices, and energy security.

Biofuels

The production and use of biofuels – mainly ethanol based on cereals and sugar crops, and biodiesel based on vegetable oils such as rapeseed or canola oil – has grown rapidly over the past few years and is expected to further double in the decade to come.[239] Global biofuel production has tripled from 4.8 billion gallons in 2000 to about 16.0 billion in 2007.[240] The US and Brazil remain the largest ethanol producers with 48% and 31% respectively of global ethanol output in 2007, while the European Union accounts for about 60% of global biodiesel production.[241] But biofuels currently still provide only 3% of global fuel supply for transportation.[242]

Theoretically, biofuels appear to be a readily and widely available emissions-free fuel, with the added benefit that they integrate well with our current fuel distribution infrastructure. As with other renewables, the theoretical potential of biomass energy is enormous. Of the approximately 100,000TW of solar energy flow that reach the Earth's surface, an estimated 4,000TW reach the world's 1.5 billion hectares of existing crop lands.[243] If modern biomass technologies could achieve only a 1% energy conversion efficiency, these existing crop lands could in theory yield 40TW of usable energy flow, or more than three times the current global primary energy consumption.[244]

Ted Patzak from the University of California, Berkeley explains in his paper presented to the 20th Round Table OECD discussion on Sustainable Development of Biofuels in September 2007, that due to the Earth's natural and physical mechanisms, which means ecosystems cannot sustain net mass outputs of materials for more than a few years, the 'mining' of biomass energy would result in the inevitable final exhaustion and depletion of mineral stocks, soils and clean water.[245] Studies have questioned the economic, environmental and energy efficiency impact of biofuels, particularly in comparison with fossil fuels.[246]

The first question concerns their energy balance – whether or not they provide more energy than they use to be produced. Academics from Cornell University and the University of California claim that, based on all the fossil energy inputs in US sugarcane

[239] de la Hamaide, S., 'Global Biofuel Output to Soar in Next Decade-Report', Planetark.org, 30th May 2008, http://www.planetark.org/dailynewsstory.cfm/newsid/48562/story.htm

[240] Coyle, W., 'The Future of Biofuels, A Global Perspective', Amber Waves, The Economic Research Service/USDA 5(5), November 2007

[241] OECD, Biofuel Support Policies: An Economic Assessment: Executive Summary, 2008 http://www.oecd.org/dataoecd/56/60/41256075.pdf

[242] Coyle, W., 'The Future of Biofuels, A Global Perspective'

[243] InterAcademy Council, 'Biomass' in Lighting the Way: Toward a Sustainable Energy Future, October 2007, http://www.interacademycouncil.net/CMS/Reports/11840/11928/11943.aspx

[244] ibid

[245] Patzak, T. W., 'How Can We Outlive Our Way of Life?', paper prepared for the 20th Roundtable on Sustainable Development of Biofuels: Is the Cure Worse than the Disease?, September 2007, http://petroleum.berkeley.edu/papers/Biofuels/OECDSept102007TWPatzek.pdf

[246] Pimental, D. and Patzak, T. W., 'Ethanol Production: Energy and Economic Issues Related to U.S. and Brazilian Sugarcane', National Resources Research, 16 (3), September 2007 http://www.springerlink.com/content/a073n47122rwk007/fulltext.pdf

conversion processes, a total of 1.12kcal of ethanol is produced per 1kcal of fossil energy expended. In Brazil a total of 1.38kcal of ethanol is produced per 1kcal of fossil energy expended.[247] A University of Minnesota study says that ethanol made from corn yields only 25% more energy than the energy invested in its production, whereas biodiesel made from soybeans yields 93% more.[248] The type and method of producing biofuel gives varying results.

Another important factor to consider in assessing biofuels' sustainability, is their contribution to greenhouse gas emissions reductions. Studies are wide-ranging and conflicting, suggesting both net increases and decreases to greenhouse gas emissions from biofuels. A number suggest that corn ethanol production, relative to gasoline, provides 12-19% greenhouse gas emissions savings.[249]

Many recent studies criticise past greenhouse gas emissions assessments, including the Swiss study, for being too simplistic, based on old data, or underestimating, or simply not factoring in, 'indirect' emissions in a full-scale 'life-cycle assessment' (LCA).[250] 'Well-to-wheels' LCAs are meant to examine not only the combustion but also the production and processing of the feedstock into fuel from cradle to grave. Acknowledging the complexity of the matter, researchers point to the need for more complex models of assessment and further study. As evidence accumulates, it appears that with regards to both greenhouse gas emissions and to aggregate environmental costs, biofuels may well be failing the sustainability test.

As an example, Crutzen et al in the journal Atmospheric Chemistry and Physics, suggest that all past studies have seriously underestimated the increase in use of nitrogen-based fertilisers to grow fuel crops, which they found would simply replace or worsen current fossil fuel contributions to global warming by releasing greater amounts of nitrogen dioxide (NO_2) into the atmosphere.[251] A 2008 University of California study by Mark Delucchi also expresses great concern over the methods and scope of most LCAs in relation to biofuels' greenhouse gas emissions.[252] Delucchi accuses most LCA analyses of not seriously considering or taking into account broader issues such as land-use change, infrastructure, the nitrogen cycle, water cycle and water albedo impacts (the extent to which water diffusely reflects light from the sun), CO_2-equivalency factors (how much global warming a given type and amount of greenhouse gas may cause with reference to a functionally equivalent amount of CO_2), economic effects of policies, omitted climate impacts, and other factors, resulting in outcomes that do not bear resemblance to real-world scenarios.[253]

Concern over deforestation and food crops

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[247] ibid

[248] Hill, J., Nelson, E., Tilman, D., Polasky, S., Tiffany, D., 'Environmental, Economic and Energetic Costs and Benefits of Biodiesel and Ethanol Biofuels', PNAS, 25th July 2006, http://www.pubmedcentral.nih.gov/picrender.fcgi?artid=1544066&blobtype=pdf

[249] Polasky, S., 'Biofuels and the Environment', Environment Roundtable, University of Minnesota, 6th May 2008, http://environment.umn.edu/events/Biofuels%20and%20Environment%205.2008%20Polasky.pdf

[250] See Scharlemann, J.P.W., and Laurence, W.F., 'How Green are Biofuels?', Science 319, January 2008; Searchinger, T., et al, 'Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change', Science Express 319, February 2008, pp.1238-1240; Crutzen, P.J. et al, 'A Global View of N20 Impact on Net GHG Savings from Crop Biofuels: LCA Comparisons', Biofuels in the Midwest: Chicago II, September 2008; DeLucchi, M.A., 'Lifecycle Analyses of Biofuels' Draft Report, Institute of Transportation Studies, University of California, Davis, May, 2006; Farrell et al, 'Ethanol Can Contribute to Energy and Environmental Goals', Science, 311 (5760), January 2006

[251] Crutzen, P.J. et al, 'A Global View of N20 Impact on Net GHG Savings from Crop Biofuels: LCA Comparisons', Biofuels in the Midwest: Chicago II, September 2008 http://www.wilsoncenter.org/events/docs/Arvin%20Mosier.pdf

[252] DeLucchi, M.A., 'Lifecycle Analyses of Biofuels' Draft Report, Institute of Transportation Studies, University of California, Davis, May, 2006 http://www.its.ucdavis.edu/publications/2006/UCD-ITS-RR-06-08.pdf

[253] ibid

converted for fuel use are two central factors that have blackened biofuels' image in recent years. It is of crucial importance that biofuels do not compete for land, particularly with forests, in the context of global deforestation and biodiversity loss, nor with food crops, particularly when looking at the shortage of world food reserves, current world food prices, and global population projections.

Deforestation is an important global concern since it is the third largest source of greenhouse gas emissions worldwide.[254] Biofuels' contribution to this devastation is increasingly prominent. Friends of the Earth have highlighted, as an example, that palm oil plantations have been responsible for 87% of deforestation in Malaysia, whilst also displacing millions of hectares of forests in many other parts of the world – in Indonesia, Thailand, Myanmar, and Papua New Guinea.[255] A Dutch consultancy, Delft Hydraulics, published a report which showed that every tonne of palm oil produces 33 tonnes of CO_2 emissions – or 10 times as much as petroleum.[256]

By contrast, reforestation has been proffered as a far more beneficial activity and use of land, than is growing biofuels in terms of mitigating climate impacts. A study published in the journal Science in August 2007, and taking a 30-year view, claims that 'In all cases, forestation of an equivalent area of land would sequester two to nine times more carbon over a 30-year period than the emissions avoided by the use of the biofuel. Taking this opportunity cost into account, the emissions cost of liquid biofuels exceeds that of fossil fuels.'[257] Converting rainforests, peatlands, savannas, or grasslands to produce food-based biofuels in Brazil, Southeast Asia,

[254] WWF, Deforestation and Climate Change, November 2007 http://assets.panda.org/downloads/intro_factsheet_27nov07_lr.pdf

[255] Friends of the Earth, 'The Oil for Ape Scandal: How Palm Oil is Threatening Orang-utan Survival', September 2005, http://www.foe.co.uk/resource/reports/oil_for_ape_full.pdf, p.13

[256] Monbiot, G., 'If We Want to Save the Planet, We Need a Five-year Freeze on Biofuels', The Guardian, 27th March 2007 http://www.gla.ac.uk/media/media_30528_en.pdf

[257] Righelato, R., Spracklen, D.V., 'Carbon Mitigation by Biofuels or by Saving and Restoring Rainforests?' Science, (317), 17th August 2007, http://www.sciencemag.org/cgi/reprint/317/5840/902.pdf

and the US was found by a University of Minnesota report to create a 'biofuel carbon debt' by releasing 17 to 420 times more CO_2 than the annual greenhouse gas reductions these biofuels provide by displacing fossil fuels.[258]

Growing biofuels is therefore not necessarily the most rational action when thinking about trying to reduce greenhouse gas emissions, particularly when land is converted for use. As demand for biofuels increases, there is a real danger that expansion will be driven into carbon sinks such as forests, wetlands, and grasslands, triggering the release of previously stored carbon, thereby resulting in a net increase in greenhouse gas emissions in the name of alternative fuel. Emissions resulting from land-use change are vast, accounting for 20% of all carbon emissions.[259]

In a similar vein, the 'food versus fuel' debate highlights the risk of diverting crop yields, such as maize, sugar cane, corn, vegetable oil or palm oil (first generation biofuels), from food consumption use to energy use, as happened in 2007, when due to oil price rises, one-quarter of the US corn harvest was diverted towards biofuel production. In July 2008, a World Bank policy research working paper concluded that recent large-scale increases in biofuel production in both the US and EU, driven by government subsidies and mandates, was the most important factor behind the rapid escalations in global world food prices since 2002, pushing them up by 75%.[260] Similarly, the IMF estimated that increased demand for biofuels has accounted for 70% of the increase in maize prices and 40% of the increase in soybean prices.[261]

There are of course other factors at play in global food price rises, including increasing demand from emerging markets, changes in world food consumption patterns, and oil price rises. But many reports concur that increasing biofuel production is a leading cause, particularly when viewed in relation to government policies and incentives that have created a highly distorted market for biofuels. US Federal subsidies alone for ethanol production amount to $7billion a year, or around $1.90 per gallon.[262] Bearing in mind that biofuels account for only 3% of total global fuel supply for transportation, in 2007, biofuel production accounted for nearly half of the worldwide increase in consumption of principal food crops, with total support from OECD countries amounting to $13–15billion.[263] The scale of government financial backing is all the more problematic when we consider that, according to a group of scientists and economists from the University of Minnesota, even if all US corn and soybean production was dedicated to biofuels, it would only meet 12% of gasoline demand and 6% of diesel demand.[264] In April 2008, the UN Secretary General, Ban Ki-Moon, called for a review of global biofuel policies after significant pressure and criticism from within UN agencies on the matter.[265]

Combining the concerns over deforestation,

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258 Fargione, J., Hill, J., Tilman, D., Polasky, S., Hawthorne, P., 'Land Clearing and the Biofuel Carbon Debt', Science 319 (5867), February 2008, pp.1235-1238 http://www.sciencemag.org/cgi/content/abstract/1152747

259 Polasky, S., 'Biofuels and the Environment'

260 Mitchell, D., 'A Note on Rising Food Prices', Policy Research Working Paper 4682, The World Bank, Development Prospects Group, July 2008, http://www-wds.worldbank.org/servlet/WDSContentServer/WDSP/IB/2008/07/28/000020439_20080728103002/Rendered/PDF/WP4682.pdf

261 Lipsky, J., 'Commodity Prices and Global Inflation' at the Council on Foreign Relations, New York, 8th May 2008, http://www.imf.org/external/np/speeches/2008/050808.htm

262 'Food Prices, The Economist, 6th December 2007, http://www.economist.com/displaystory.cfm?story_id=10250420

263 OECDObserver.org, 'Biofuels', OECD Observer (267), May-June 2008, http://www.oecdobserver.org/news/fullstory.php/aid/2594/Biofuels.html

264 Hill et al, 'Environmental, Energetic and Economic Costs and Benefits of Biodiesel and Ethanol Biofuels', Proceedings of the National Academy of Sciences, USA, 103 (30), 2006, http://www.pnas.org/content/103/30/11206.abstract?ijkey=a4 87c3831ae6939a9bb711a8c0e82a72a227fe48&keytype2=tf_ipsecsha

265 Borger, J., 'UN Chief Calls for Review of Biofuels Policy', The Guardian, 5th April 2008, http://www.guardian.co.uk/environment/2008/apr/05/biofuels.food

land-use change and use of food crops, supporters of biofuels have been encouraging research and development into 'second generation' biofuels. Whereas 'first generation' biofuels are those produced from feedstocks such as seeds or grains, for example wheat, fermented to produce bioethanol, or sunflower seeds, pressed to produce vegetable oil which can be used as biodiesel; 'second generation' biofuels are fuels made from almost any and all plant material or 'lignocelluloses'. This includes non-food elements of crops, such as stems, leaves and husks, crops not grown for food purposes, such as switch grass, jatropha, miscanthus, as well as straw, municipal waste and industry waste, such as woodchips or fruit skins and pulp from fruit pressing. Some studies have found that second generation biofuels deliver larger greenhouse gas emissions savings in comparison with first generation fuels, as well as providing the benefits of being able to grow them on marginal and abandoned agricultural land, or use up waste biomass, reducing the need for, and environmental costs of, waste disposal.[266] In addition these studies point to lower agricultural input requirements (less fertiliser, pesticide and energy), lower water use, and lower-input energy to convert to fuel.[267]

However, there is much continued dialogue and study within the scientific community concerning which biofuels hold the greatest potential in terms of output, cost effectiveness, and environmental footprint, and so there is still much debate and uncertainty concerning these claims. Closer investigation into their many impacts is needed. What is certain is that if their benefits are not to become moot, clear guidelines on sustainable planting and harvesting must be implemented. For example, it is important that soil fertility and erosion is not worsened by the excessive removal of agricultural residues, so often erroneously termed agricultural 'waste'. Second generation biofuels are still in the developmental stages and not yet commercially available, apart from in a few cases. If they are to be marketable, they need to overcome a number of technical and economic obstacles, including research gaps, further development and standardisation of production processes, and current high costs. At the moment, there is no technology available that can produce them on a commercial-scale.[268]

In addition to second generation biofuels, are so-called 'third generation' biofuels made from algae. According to the US Department of Energy, algae yields 30 times more energy per acre than land crops such as soybeans.[269] Advantages of 'algoil' also include its ability to be grown in almost any enclosed space, even in harsh, salty environments, as well as the massively reduced area required for its growth. It has also been suggested that they can be grown in sewages and next to smokestacks to act as pollutant absorbers, whilst also providing fuel. Again however, despite theoretical promises, much research and development needs to be undertaken into 'algaculture' if it is to live up to its potential as there are currently no large-scale projects in operation.

Biogas

Biogas is produced from the anaerobic (without oxygen) biological breakdown of organic matter, such as livestock manure and other wastes. Biogas is primarily made up of methane (CH_4) and CO_2, with small amounts of water vapour, hydrogen sulphide (H_2S), carbon monoxide (CO) and nitrogen also present.

Biogas is a way of converting wastes into energy. It is a highly effective form of off-grid energy generation. The United Nations Development Programme (UNDP) in their 1997 report *Energy after Rio*: *Prospects and Challenges*, cited biogas as one of the most useful decentralised sources of energy supply.[270] Biogas plants do not require large capital investment for set-up, and

[266] POST, Transport Biofuels, Postnote 293, August 2007, http://www.parliament.uk/documents/upload/postpn293.pdf

[267] Hill et al, 'Environmental, Energetic and Economic Costs and Benefits of Biodiesel and Ethanol Biofuels'

[268] Dickie, A., 'Biofuels Sustainability: a UK Perspective', Renewable Energy Focus 8(6), November-December 2007, pp.59-61

[269] Hartman, E., 'A Promising Oil Alternative: Algae Energy', Washington Post, 6th January 2008, http://www.washingtonpost.com/wp-dyn/content/article/2008/01/03/AR2008010303907.html

[270] UNDP, Reddy, A.K.N., Williams, R.H., Johansson, T.B., (eds.), Energy After Rio: Prospects and Challenges, UNDP/BDP Energy and Environment Group, 1997, http://www.energyandenvironment.undp.org/undp/indexAction.cfm?module=Library&action=GetFile&DocumentAttachmentID=1867

they offer environmental benefits as well as solutions to waste management and disposal. The plants also yield good quality sludge fertiliser, creating biogas fuel or electricity as an additional bonus. This has been the driving force behind large biogas programmes in a number of developing countries.

Biogas generators have had an up-and-down history. China began widespread implementation in 1975 under the slogan 'biogas for every household'. 1.6 million biogas digesters were installed in the first few years, but, due to low-quality design and manufacture, by the mid 1980s only half of these were still in use.[271] However, a revamp of technology and a renewed programme resulted in 15 million households using biogas by the end of 2004.[272] Similarly in India, a too-rapid biogas programme was rolled-out initially in the 1990s, which ran ahead of the country's research and development capacity for more efficient and reliable designs. However, renewed interest and improved design together with government subsidies, have meant that by the end of 2004, 3.67 million biogas units had been installed.[273] These success stories have been replicated in countries such as Nepal, Vietnam, Cambodia, and Sri Lanka.

The Nepalese Biogas Support Programme is widely seen as an international model for large-scale success, providing about 1 million people, or 4% of the population, with fuel for cooking, lighting, and sanitation provisions for toilets.[274] The biogas digesters replace firewood as the traditional fuel for cooking, improving health conditions and releasing time, especially for women, for other economic activities. The Nepalese programme was also supported by the Clean Development Mechanism (CDM). In 2006, an Indian programme developed by the Appropriate Rural Technology Institute aimed to encourage the use of compact biogas digesters for domestic cooking through the use of food wastes, rather than animal or human.[275] This new type of digester was innovative in terms of its size, no bigger than a household refrigerator, and its accessibility, overcoming cultural obstacles.

In the developed world, biogas is also being put to use. The benefits of anaerobic digestion are being rediscovered by farms in Wisconsin, USA, which leads the country in the number of operating dairy farm digesters that produce electricity and heat from cow manure and other organic materials. According to a report which brings together 17 case studies from across the state of Wisconsin, published in October 2008, a typical anaerobic digester with a 300kW biogas-fuelled generator can produce enough electricity to power around 224 average Wisconsin homes, whilst the annual environmental benefits were found to be the equivalent to offsetting nearly 2,460 tonnes of CO_2 from being released into the atmosphere.[276] The UK Department for Trade and Industry (DTI) initially ran a farm-scale biogas programme in the 1980s, with 200 plants built. But as oil prices came back down, interest diminished. Now, in a similar energy security climate, interest has been renewed with seven biogas plants integrated into farm waste management systems in Scotland.[277] There is a large programme in Germany, encouraged by high feed-in tariffs

[271] Institute of Science in Society, 'Biogas Bonanza for Third World Development', 20th June 2005, http://www.i-sis.org.uk/BiogasBonanza.php

[272] ibid

[273] van Nes, W.J., 'Asia Hits the Gas: Biogas from Anaerobic Digestion Rolls-out Across Asia', Renewable Energy World, January-February 2006, pp.102-111, http://www.unapcaem.org/Activities%20Files/A01/AsiaHitsTheGas.pdf

[274] The Ashden Awards for Sustainability, 'Domestic Biogas for Cooking and Sanitation', Biogas Sector Partnership, Nepal 2005, http://www.ashdenawards.org/files/reports/BSP%20Nepal%202005%20Technical%20report.pdf

[275] The Ashden Awards for Sustainability, 'Compact Digester for Producing Biogas from Food Waste', Appropriate Rural Technology Insitute, India, 2005, http://www.ashdenawards.org/files/reports/ARTI%20India%202006%20Technical%20report.pdf

[276] Kramer, J., Wisconsin Agricultural Biogas Casebook, July 2008, http://www.focusonenergy.com/files/Document_Management_System/Renewables/2008BiogasCaseStudy.pdf

[277] The Ashden Awards for Sustainability, 'Biogas', http://www.ashdenawards.org/biogas

Geothermal power plant, Svartsengi, (near the Blue Lagoon) Iceland

for electricity generated on farms, with about 3,500 farm-scale plants installed.[278] There is also keen interest in Scandinavia, with buses and even a small train running on biogas in Sweden.

Municipal Solid Waste (MSW) incinerators, which convert waste originally meant for landfill into energy for heat or electricity through combustion, are frequently a contentious battleground between councils and local communities. It is often put forward as a means of managing increasing waste flows, and redirecting waste away from landfill, which is responsible for producing large amounts of the potent greenhouse gas methane. But burning MSWs still releases greenhouse gases and ash, and many environmental campaigners argue against it on the grounds that it encourages the persistent disposal of waste and causes health problems.

Geothermal energy

Geothermal energy is energy extracted from the hot water and steam below the Earth's surface. Geothermal resources range from those found in shallow ground to those several miles below the Earth's surface, and even further down to the extremely hot molten rock, or magma. Wells over a mile deep can be drilled into underground reservoirs to tap steam and very hot water that can be brought to the surface for use in a variety of applications.

The three main types of geothermal plants are dry steam, flash steam, and binary. Dry and flash steam plants release some CO_2 and other gases into the air, whilst binary systems, which account for about 15% of all systems, produce virtually no emissions of CO_2 or other gases.[279] However, in comparison with fossil fuels, which release between 0.5-1.1kg of CO_2 per kWh, geothermal emissions of CO_2 are only in the range of 0.01-0.4kg/kWh[280], with the added possibility of capturing.

Since geothermal plants work 24 hours a

[278] ibid

[279] Jacobson, M., 'Review of Solutions to Global Warming, Air Pollution, and Energy Security', The Energy Seminar, Stanford University, October 2008, p.5, http://www.stanford.edu/group/efmh/jacobson/0810EnergySeminar.pdf

[280] Barbier, E., 'Geothermal Energy Technology and Current Status: an Overview', Renewable and Sustainable Energy Review (6), 2002, p51.

day, they can be used as base-load power supplies, and can be scaled to suit large energy projects or small. Alongside biomass, however, geothermal energy is the only other renewable energy that requires careful management to avoid depletion. If heat is extracted at a rate faster than the Earth replenishes that heat, eventually the site will cool down. Geothermal energy is converted to provide electricity from power stations, and for direct use in providing hot water for bathing and swimming, for aquaculture and agriculture, to heat buildings, and for industrial uses, such as product drying and warming. Whether it is used for electricity or for heating and cooling depends on the underground temperature.

Geothermal heat in the upper six miles of the Earth's crust contains 50,000 times as much energy as is found in all the world's oil and gas reserves combined. Despite this abundance, only 9300MW of geothermal generating capacity have currently been harnessed worldwide, with a growth-rate of only 3% a year over the past decade.[281] Half the world's generating capacity is concentrated in the US and the Philippines, with Mexico, Indonesia, Italy, and Japan accounting for the majority of the remainder. A total of 24 countries now convert geothermal energy into electricity. The Philippines, with geothermally generated power supplying 25% of its electricity, and El Salvador, at 22%, are the leaders.[282] In addition to this, roughly 10 times the amount converted to electricity, around 100,000MW of energy, is used directly in over 70 countries to heat homes and greenhouses and as process heat in industry.[283] In Japan, geothermal energy is used directly to provide hot water for baths, in Iceland, to heat homes, and in Russia to heat greenhouses.[284]

The main limitations for geothermal energy are geographic. In order to generate electricity from geothermal resources, access to high temperature reservoirs is required. Few countries in the world have magma close enough to the Earth's surface to generate electricity economically. The few countries with accessible geothermal resources are those situated around the Pacific 'Ring of Fire', or along major tectonic plate boundaries where volcanoes and earthquakes are concentrated. Geothermal power plants are generally built where hydrothermal reservoirs are located within a mile or two below the Earth's surface, and as such are site-specific and unevenly distributed. However, a new technology, called Hot Dry Rock Geothermal Energy (HDR), or Enhanced/Engineered Geothermal Systems (EGS), aims to make use of the vast stores of heat-energy in the Earth's crust currently inaccessible by conventional technologies that rely on naturally-occurring water-bearing, hot permeable rocks by creating 'man-made' reservoirs.

Enhanced geothermal systems

HDR generates electricity by pumping high pressure water down a borehole into hot granite rock 3-10km below ground. The water travels through fractures in the rock, capturing the heat of the rock until it is forced out of a second borehole as very hot water, which is converted into electricity using either a steam turbine or a binary power plant system. All of the water, now cooler, is injected back into the ground to heat up again in a closed loop. Hot dry rock heat stores are much more widely distributed and so offer a geothermal potential to many countries where conventional resources are absent. Even in those areas where good conventional geothermal resources exist, there is usually a much greater volume of heated rock than can be exploited with current techniques.[285] A 2006 Massachusetts Institute of Technology (MIT) report, estimated that tapping just 2% of the total EGS resource between 3-10km below the surface of the USA could supply more

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[281] Brown, L.R., 'Turning to Renewable Energy', Plan B 3.0, Washington D.C.: Earth Policy Institute, 2008, p.252

[282] ibid

[283] ibid

[284] ibid

[285] European Commission, 'Geothermal Energy: Key Advantgaes of Enhanced Geothermal Systems', http://ec.europa.eu/research/energy/nn/nn_rt/nn_rt_geo/article_1134_en.htm

than 2,500 times the country's total annual energy use.[286] In Australia, the estimated thermal energy stored in EGS resources was considered to be 7,500 times Australia's annual energy consumption.[287] Even with margins for overestimation, the resources are clearly abundant.

EGS technology has been proved in several prototype projects around the world, and is now in commercial operation or development in Germany, the USA and Australia. Reflecting the steady development of the technology, in August 2008, Google announced investment of $10m into EGS, whilst the Australian government announced AUS$50m of funding.[288] In July 2008, the US Department of Energy granted $43m for research and development into EGS.[289] As interest mounts, and carbon taxes and green tariffs come into force, costs of electricity generation are expected to fall. At present, costs are between 10 UScents/kWh and $1/kWh, depending on the depth of the hot rock and the terrain's geologic structure, but these could eventually fall to around 4 UScents/kWh, which compares very favourably to gas at 8 UScents/kWh and to solar at 31 UScents/kWh. At present, however, investment costs are high and the next stages of development are yet to be completed.

An additional concern refers to seismicity, or earthquake risks. In December 2006 and January 2007, three earthquakes measuring over 3 on the Richter scale – not big enough to cause structural damage, but strong enough to be felt by residents – shook the Swiss town of Basel, which sits atop a historically active faultline. It turned out that the cause was the injection of cold water deep beneath the Earth, which attempted to fracture the hot, unstable rocks found below to create another EGS. The project came to a halt as a result, and showed the importance of siting these projects appropriately. Experts however say that induced seismicity is not likely to be a major stumbling block for EGS technology if plants are located away from large population centres.[290]

Ground-source heat pumps

A decidedly more economical and direct method to exploit geothermal heat resources that does not require proximity to high temperature reservoirs is the use of geothermal heat pumps (GHPs) to heat or cool buildings. Geothermal, or ground-source, heat pumps take advantage of the stored heat in the Earth. At a depth of 2m, the temperature of soil in most of the world's regions remains stable between 7°C and 21°C.[291] GHPs use the Earth as either a heat source, when operating in heating mode, or a heat sink, when operating in cooling mode. They operate in a similar way as a refrigerator, which extracts heat from the inside to keep food cool and expels, in this case, waste heat from behind. In the same way, GHPs extract heat from the ground and use it to heat internal space.

They come in two main configurations – ground-coupled (closed loop) and groundwater (open loop) systems, which are installed horizontally and vertically, or in wells and lakes. The type chosen depends upon the soil and rock type at the installation, the land available and/or if a water well can be drilled economically or is already on site.[292]

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[286] Massachusetts Institute of Technology, The Future of Geothermal Energy: Impact of Enhanced Geothermal Systems (EGS) on the United States in the 21st Century, 2006 http://www1.eere.energy.gov/geothermal/pdfs/future_geo_energy.pdf

[287] Wyborn, D., Somerville, M., Bocking, M., and Murray, A., 'Australian Hot Dry Rock Geothermal Energy Potential and a Possible Test Site in the Hunter Valley', International Journal of Rock Mechanics and Mining Sciences and Geomechanics Abstracts, 32(8), 1995, p.375

[288] Jha, A., 'Green Energy from Hot Rock Technology Gets Double Boost'

[289] Moresco, J., 'Next-Gen Geothermal Power Heats Up $43m', Redherring.com, 6th October 2008, http://www.redherring.com/Home/25165

[290] Biello, D., 'Deep Geothermal: The Untapped Energy Source', Environment360, 23rd October 2008, http://e360.yale.edu/content/feature.msp?id=2077

[291] Kyriakides, R., The Energy Age, London: Genersys, 2006, p.124

[292] Curtis, R., Lund, J., Sanner, B., Rybach, L., Hellström, G., 'Ground-source Heat Pumps – Geothermal Energy for Anyone, Anywhere: Current Worldwide Activity', World Geothermal Congress 2005, http://www.sanner-geo.de/media/1437.pdf, p.2

In the ground-coupled system, a closed loop of pipe, placed either horizontally (1-2m deep) or vertically (50-70m deep) is placed in the ground and a water-antifreeze solution is circulated through the plastic pipes to either collect heat from the ground in the winter or reject heat to the ground in the summer. The open loop system uses groundwater or lake water directly in the heat exchanger and then discharges it into another well, into a stream or lake, or on the ground (for example for irrigation), depending upon local laws.[293] The heat is utilised via a heat distribution system, which consists of underfloor heating or radiators for space heating, and in some cases, water storage for hot water supply.[294] The energy-saving benefit of geothermal heat pumps is measured by its Coefficient of Performance, or the ratio of heat output to work input, which, according to the Energy Savings Trust, is between 3 and 4, sometimes greater, meaning that for every unit of electricity used to pump the heat, 3-4 units of heat are produced,[295] making them one of the most efficient heating and cooling systems on the market.

The International Energy Agency (IEA) have recognised that GHPs alone could cut global CO_2 emissions by 6% (increasing to 16% as the technology improves), making them one of the largest contributors to emissions reductions by an application of a single technology currently on the market.[296] In a similar vein, in 2004 the World Energy Council, on conducting a lifecycle analysis on a number of renewable technologies, found that for heating technologies, GHPs had the second lowest lifetime carbon emissions after wood chips.[297] Rapidly expanding recognition of these facts is evidenced by GHPs' status as one of the fastest growing applications of renewable energy in the world, with annual increases of about 10% in 30 countries over the past decade, and with present worldwide capacity estimated at 10,100MWt (thermal), or 16,470GWh of energy use.[298] GHPs are generally installed as isolated units for individual homes or buildings, but can be connected up and used as part of a district heating system, like those found in Sweden.

[293] ibid

[294] The Energy Saving Trust, UK, 'Generate Your Own Energy: Ground-Source Heat Pumps', http://www.energysavingtrust.org.uk/Generate-your-own-energy/Types-of-renewables/Ground-source-heat-pumps

[295] ibid

[296] IEA, Heat Pump Centre Newsletter, 'Heat Pumps – Better by Nature: Report on the 7th IEA Heat Pump Conference' 20(2), 2002, http://www.pac.ch/dateien/N2002.pdf

[297] Curtis, R. et al, 'Ground-source Heat Pumps – Geothermal Energy for Anyone, Anywhere: Current Worldwide Activity'

[298] ibid

A potential problem for GHPs is that the effect of withdrawing heat from the soil and subsoil has not been thoroughly researched. Robert Kyriakides, author of The Energy Age, says that heating and cooling over an extended period is likely to alter the soil properties, in particular its moisture content, potentially resulting in ice forming underground and other unforeseen environmental damage.[299] For this reason, Dave MacKay states that air-source heat pumps, although less efficient, may be more applicable to dense urban areas, where there is not enough land to store the amount of energy and heat required for all to use ground-source heat pumps.[300]

Wave power

Wave power harnesses energy from the motion of ocean waves, caused by wind. Waves embody vast amounts of energy, in some cases 70MW/km of wave front are experienced.[301] The World Energy Council have estimated that wave energy holds 2TW of usable energy[302], providing 15-20 times more available energy per square metre than either solar or wind.[303] It is the harvesting of this energy that is difficult. The highest concentration of wave power can be found in the areas of the strongest winds, between latitudes 40 degrees and 60 degrees in both the northern and southern hemispheres, on the eastern sides of the oceans.[304] There are literally thousands of different methods and designs of wave energy conversion (WEC), with research and development expanding all the time, but the main types of WECs can be classified under two generic types: turbine-types and buoy-types.

Turbine-types use a turbine as the energy converter. The most mature example of this is the oscillating water column (OWC), which consists of a partially submerged, hollow cylinder below the water line fitted with a piston connected to a floating buoy that pumps air as it rises and falls and so drives water through a turbine to generate power. These can be placed either on the shoreline or near the shore. An example of this kind of device is the Limpet (Land Installed Marine Powered Energy Transformer), designed and built by Wavegen and researchers from Queen's University, Belfast, and located off the coast of Scotland on the Isle of Islay. It was commissioned in 2001 and feeds 500kW of power into the island's electrical grid. Less common than the OWC is the 'overtopping device', which works much like a hydroelectric dam. A collector funnels the waves into a hydroturbine, which then generates electricity. These can also be placed on the shoreline or near the shore. A Danish company called Wave Dragon has created such a device and successfully trialled a prototype, with plans to construct the world's largest WEC demonstration project off the coast of Wales and to build a 50MW commercial 'Wave Energy Park' off the Portuguese coast.[305]

Buoy-type WECs, or 'point absorbers', which harvest energy from the sea from all directions, but at one point, use a mechanical or hydraulic system in a linear or rotational motion to drive electric generators. The power is transmitted to shore via an underwater cable. Point absorbers can be floated on or below the water surface away from the shoreline. The most common types are the tube-type and the float-type. An example of a buoy-type WEC is the 'Power Buoy' developed by Ocean Power Technologies, who recently completed the first phase of a 1.25MW commercial-scale buoy-type wave park on the northern coast of Spain – the first of its kind in Europe. It went live in September 2008.[306]

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[299] Kyriakides, R., The Energy Age, London: Genersys, 2006, p.126

[300] MacKay, D., Sustainable Energy – Without the Hot Air, p.152

[301] Currie, R., Elrick, B., Ioannidi, M., and Nicolson, C., 'Renewable Energy in Scotland: Wave Power', Energy Systems Research Unit at the University of Strathclyde, UK, http://www.esru.strath.ac.uk/EandE/Web_sites/01-02/RE_info/wave%20power.htm

[302] Thopre, T.W., 'A Brief Review of Wave Energy', produced for the UK Department for Trade and Industry, May 1999, http://www.mech.ed.ac.uk/research/wavepower/Tom%20Thorpe/Tom%20Thorpe%20report.pdf

[303] Clement, A. et al, 'Wave Energy in Europe: Current Status and Perspectives', Renewable and Sustainable Energy Reviews (6), 2002, p.406

[304] Kyriakides, R., The Energy Age, p.156

[305] Wave Dragon, http://www.wavedragon.net/index.php?option=com_frontpage&Itemid=1

[306] McDermott, M., 'The Tide's Rising for Wave Power: power Buoys Installed off the Spanish Coast', treehugger.com, 23rd September 2008, http://www.treehugger.com/files/2008/09/power-buoy-wave-power-project-spain.php

Another way of classifying WECs is to do so by positioning. Shoreline devices, or so-called 'first generation' techniques, can be placed on the sea bottom or in shallow water. They are much easier and cheaper to install and maintain due to proximity. The OWC is a major class of shoreline device.[307] Shoreline resources, however, are much smaller than in deep water positions, providing only one-quarter of the energy resource available in deep-water, due to friction, earlier breaking of large waves and other factors.[308] In some areas, this can be offset by refraction and reflection to create energy-focused 'hot-spots', but generally speaking, lack of suitable sites and the impact on coastal landscapes makes shoreline development unattractive. Near-to-shore devices are deployed in water depths of between 10-20m, 100m or up to a number of kilometres away from the shore. These depths are suitable for large, bottom-standing devices that are moored to the sea-bed in order to exploit wave motion fully.

Offshore devices in deep waters and open sea offer the most promising conversion of wave energy for electricity generation. Due to the harsh environments experienced at these locations, survivability is a key issue, as is maintenance and installation ability. Mooring systems need careful design to avoid damage or deactivation. Offshore exploitation is more suitable for large-scale projects such as wave farms that can justify expenditures and exploit available capacity more effectively.[309] One such project, using a unique type of WEC, has recently made headlines as the world's first commercial-scale machine to generate electricity for the grid from offshore wave energy, and the first WEC to be used in a commercial wave farm project. The Pelamis wave farm opened in September 2008 off the coast of Portugal. The Pelamis is a 'hinged contour device' consisting of connected floater sections that move in relation to each other as waves pass. As the articulated joints bend with the waves, they drive hydraulic pistons which in turn power turbine generators. The Pelamis wave farm has an installed capacity of 2.25MW, which is enough to meet the average electricity demand of more than 1,500 Portuguese homes. A second phase of the project plans to increase the installed capacity from 2.25MW to 21MW using a further 25 Pelamis machines. A similar project was announced for Scotland in February 2007, which will take the lead as the world's largest wave farm with an installed capacity of 3MW using four Pelamis machines. Funding of £4m was provided by the Scottish Executive as part of a £13m package for marine power in Scotland.

A further development marks the beginnings of a UK wave power industry. The establishment of a 'wave hub' 10 miles off the coast of Cornwall in the UK, planned for Spring 2010, plans to bridge the gap between research and development and full-scale production by providing the means to offer large-scale and commercial testing of WECs.[310] The hub is a wave farm research project which proposes to connect up four different types of WECs to a kind of 'socket' sitting on the seabed. The hub will be connected to the mainland via a cable which will transfer the generated electricity to the national grid, expected to be 20MW. The four WECs to have been granted leases are the Pelamis, sponsored by WestWave (a joint venture between E.ON and Ocean Prospect); US company Ocean Power Technologies' 'Power Buoy'; Norwegian company Fred Olsen Ltd's unique multiple point-absorber system; and the final WEC, under negotiation, is potentially Oceanlinx – an OWC developed by an Australian company with the same name.[311] The

[307] Thorpe, T.W., 'An Overview of Wave Energy Technologies: Status, Performance and Costs', November 1999, http://www.waveberg.com/pdfs/overview.pdf

[308] The UK Department for Business, Enterprise and Regulatory Reform (BERR), 'Wave Energy: Technology Description', Sustainable Energy Technology Route Maps, http://www.berr.gov.uk/files/file15410.pdf

[309] Polinder, H., and Scuotto, M., 'Wave Energy Converters and their Impact on Power Systems', IEEE Explore, http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=01600483

[310] RenewableEnergyWorld.com, 'Wave Hub for Ocean Energy', 17th February 2005, http://www.renewableenergyworld.com/rea/news/story?id=22626

[311] The British Wind Energy Association, 'Wave Hub Seeks More Developers', 8th February 2006, http://www.bwea.com/media/news/wavehub.html

Barrage Plant, Rance Estuary, Brittany, France

estimated cost of the project is £28m, but the amount that the project will generate for the economy is expected to be £27m a year.[312]

Progress is being made in the wave power industry, but there are currently no clear winners. There are still major difficulties that wave-power technologies must face. Designs suitable for small, frequent waves are not suitable for large, infrequent waves, making weather, geography and location a key determining factor. Wave power has high seasonal variability and the amount available is different in different parts of the world. Another problem is that wave farms must be built to withstand storms and freak, giant waves, making them expensive to build and creating design challenges in relation to survivability and reliability. Institutional factors, like planning constraints, grid connection possibilities and costs, and health and safety parameters in some countries, can create additional obstacles. Environmental impacts, such as on marine life, coastal erosion, and noise pollution, must also be considered and are not yet fully understood.[313]

Tidal power

Tidal power is a form of hydropower that exploits the natural ebb and flow of coastal tidal waters, caused mainly by the interaction of the gravitational fields of the Earth, moon and sun, to produce electricity and other usable forms of energy.

Some estimates put potential tidal energy contributions at 1mGWh per year, or about 5% of worldwide electrical generation.[314] But practically, this is difficult to exploit for technical and economic reasons. However, the reliable predictability and scale of tides in some parts of the world makes them an attractive renewable energy option. There are two distinct methods for harnessing tidal power: tidal range and tidal stream technologies.

Tidal range power

Tidal range technology exploits the natural twice daily ebb and flow of tides through the building of 'barrages' or dams that are installed across a tidal bay or estuary. When there is a sufficient difference in the height of water on either side of the dam, the gates are opened and the pressure that is created causes water to flow through turbines, turning a generator to produce electricity. The predictability and reliability of tides makes this kind of power generation attractive. The longest running example of a barrage plant

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[312] RenewableEnergyWorld.com, 'Wave Hub for Ocean Energy'

[313] Thorpe, T.W., 'An Overview of Wave Energy Technologies'

[314] Palmer, J., 'The Tide is Turning', New Scientist, Special Issue: Renewable Energy, 11th October 2008, p.35

can be found straddling the Rance estuary in Brittany, France. The plant, run by French electric giant EDF, has been in operation since 1966 and provides an average 70MW of power at a cost of 0.20€/kWhr – less than the company's average electricity costs.[315] Similar projects, but on a much smaller scale, are in operation in Canada, Russia and China. South Korea is currently building the world's largest tidal power plant at Sihwa Lake, 25km south-west of Seoul.[316] It is scheduled for completion in 2009 and will have a capacity of 254MW. However, these figures are a fraction of what Russia has planned for its tidal capacity. One project on the Mezenski Bay on the White Sea will provide a massive 15GW of energy, whilst in the far east of the country, an 8GW plant is planned in the Tugurski Bay to power nearby industry.[317]

Despite these developments, such projects have limited applicability. Only 20 regions worldwide have been identified as possible locations for tidal power stations.[318] This is due to the fact that suitable sites require high tidal ranges and concentrated large tides and that geographically, not many sites offer a suitable location for construction. Huge capital investment is also required for such a large-scale infrastructure project that can take decades to complete. For example, the proposed Severn barrage spanning the Severn estuary in the UK, which enjoys the world's second-highest tidal range, after the Bay of Fundy between Maine and Nova Scotia, between 7-14m[319], is expected to cost upwards of £15billion and take about 12 years to complete. In 2007, the UK government launched a two-year feasibility study following a report published by the Sustainable Development Commission (SDC) that examined the potential of a Severn barrage. It analysed the economic, social and environmental impacts of such a large-scale project, coming out in overall support but with a number of provisos, focused on public ownership and environmental protection.

A new form of tidal range power to enter the mix is offshore tidal power, or tidal lagoons. Built of material such as loose rock, sand, and gravel, the self-contained lagoons hold water at high tide and then release that water back to the open sea at low tide through conventional hydroelectric turbines to generate power. They then repeat that cycle at high tide by refilling the lagoon. Situated a mile or more out to sea, the structures are barely visible and look like a rocky shoreline or island. This also means that the environmental impacts associated with the building of barrages that block off and alter the shoreline are avoided. Friends of the Earth, Cymru, claim that lagoons would generate twice as much power per square mile impounded at the Severn estuary than a barrage and could extract about 25-40% more energy from two-thirds of the impounded area.[320]

The world's first tidal lagoon project has been proposed to be built at Swansea Bay in Wales by a company called Tidal Electric (TEL).[321] An independent consultancy, Atkins Consultants Ltd, conducted a feasibility study on the project and came out in support of the proposal.[322] TEL estimate the cost of the project to be £81.5m and that it will generate power at a cost of £0.035/kWh. A study conducted on behalf of the UK Department for Trade and Industry and Welsh Development Agency however, concluded that the costs would be as much as £234m, with an estimated annual energy output of £0.172/kWh with an 8% discount rate – much higher than the costs associated with barrage

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315 ibid

316 ibid

317 ibid

318 Hammons, T.J., 'Tidal Power', Proceeding of the IEEE 8(3), March 1993, http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=00241486

319 BERR, 'Severn Tidal Power Q&A', URN 08/586, http://www.berr.gov.uk/files/file43809.pdf

320 Friends of the Earth Cymru, 'A Severn Barrage, or Tidal Lagoons? A Comparison', Briefing January 2004, http://www.foe.co.uk/resource/briefings/severn_barrage_lagoons.pdf

321 Tidal Electric Ltd, 'Technology: Tidal Lagoons', http://www.tidalelectric.com/Tidal%20Lagoons.htm

322 Tidal Electric Ltd, 'Feasibility Study for a Tidal Lagoon in Swansea Bay: Executive Summary', September 2004, http://www.tidalelectric.com/Web%20Atkins%20Executive%20Summary.htm

developments.[323] They also disagreed on the predicted energy output and put a heavy question mark over the scheme's development.

Tidal stream power

In recent years, technologies have been taking off that can exploit the ocean currents, or tidal streams, beneath the surface of the sea. Tidal stream technology is potentially far cheaper and kinder to the marine environment, although there is some debate about this, whilst initial investments are again high.[324] In addition, in comparison to wave technology, tidal stream systems are much simpler to engineer as they are based on well-understood and researched concepts. In essence they resemble a wind farm, by using turbines to generate electricity, but under water.

In comparison with barrages, tidal stream technologies have a far wider applicability with a greater number of potential sites worldwide, although these are still limited to sea areas with high enough average tidal current velocities to make projects cost-effective.[325] In practice, locations are needed with mean spring peak tidal currents faster than 4–5 knots (2-2.5m/s), or the energy density will be inadequate to allow an economically viable project.[326] Such locations are found at 'pinch points', where natural water flows are concentrated between obstructions, such as at the entrances to bays and rivers, around rocky points, headlands, or between islands or other land masses. They also require sufficient sea-depths for large turbine installation, a relatively uniform seabed to minimise turbulence and loss of velocity, and a relatively nearby on-shore grid connection point to ensure costs remain reasonable.[327] A 1995 EC-supported study found that 106 locations in European waters were suitable for tidal stream energy exploitation with an aggregate capacity amounting to over 12000MW; capable of yielding some 48TWh of electrical energy per annum.[328]

Despite a number of small commercial projects already in operation worldwide, such as in Norway and the US, the technology is yet to be proven on a large scale. In August 2008, the UK company Marine Current Turbines, opened the world's present largest grid-connected tidal stream system harnessing the fast-flowing tidal currents in Strangford Lough, Northern Ireland.[329] The 'SeaGen Tidal System', designed and built by the company, which operates using twin axial flow rotors to drive a generator 18-20 hours a day, provides 1.2MW of energy and is a technological leader in its field. A follow-up project is planned off the Welsh coast to provide 10.5MW. In March 2008, British company, Lunar Energy, signed a £500m deal to build the world's largest tidal stream plant yet – a 300-turbine farm that will provide 300MW of renewable energy off the South Korean coast by 2015.[330] The same company has teamed up with E.ON to build a multi-million pound 8MW project off the Welsh coast, anticipated to be in operation by 2010.[331] The UK appears to be leading in marine renewable technology, with 30 marine technology developers based here, compared to 15 in the rest of Europe.[332] Perhaps this is

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[323] Leach, P., Baker, C., Walbancke, J., 'Tidal Lagoon Power Generation Scheme in Swansea Bay', UK Department for Trade and Industry and Welsh Development Agency, April 2006, http://www.berr.gov.uk/files/file30617.pdf

[324] Palmer, J., 'The Tide is Turning'

[325] Charlier, R. H., 'A 'Sleeper' Awakes, Tidal Current Power', Renewable and Sustainable Energy Reviews 7, 2003, pp.515–529

[326] Fraenkel, P.L., 'Tidal Current Energy Technologies', Marine Current Turbines Limited, Ibis 148, pp.145-151, 2006, http://www3.interscience.wiley.com/cgi-bin/fulltext/118619866/PDFSTART

[327] Fraenkal, P.L., 'Power from Marine Currents', Proceedings of the Institution of Mechanical Engineers, 216(A:J), Power and Energy, 2002 http://journals.pepublishing.com/content/786mr5h30g8r2100/fulltext.pdf

[328] Fraenkel, P.L., 'Tidal Current Energy Technologies'

[329] Jha, A., 'First Tidal Power Turbine Gets Plugged In', The Guardian, 17th July 2008 http://www.guardian.co.uk/environment/2008/jul/17/waveandtidalpower.renewableenergy

[330] Lunar Energy, 'British Firm Announces World's Largest Tidal Power Development', 11th March 2008 http://www.lunarenergy.co.uk/newsDetail.php?id=14

[331] E.On, 'E.On and Lunar Energy to Build One of the World's Leading Tidal Power Stations', 15th March 2007, http://pressreleases.eon-uk.com/blogs/eonukpressreleases/archive/2007/03/15/363.aspx

[332] Lynas, M., 'The Power to Save Britain', 7th March 2008, http://www.marklynas.org/2008/3/7/the-power-to-save-britain

because the UK has the best tide and wave energy resources in the world, with access to 10% of global tidal resources, with its extensive coastline, and geographic and hemispheric positioning amidst fast-flowing currents.[333] The Carbon Trust estimates wave and tidal power could provide as much as one-fifth of UK electricity.[334]

Elsewhere, projects are also appearing, with investment growing in India, New Zealand and China. Plans to expand current exploitation into deep oceans and large rivers, rather than just tidal estuaries, are also underway. A team of researchers at Florida Atlantic University is investigating ways in which energy can be captured from the 8billion gallons per minute flow of the Gulf Stream – one of the world's most energy-dense ocean currents.[335] A prototype 20km turbine is being tested. Energy could also be extracted from river currents. For example, the 8-knot current of the river underneath the Golden Gate Bridge in San Francisco could provide all the bridge's needs for electricity.[336] River Current Turbines (RCTs) are in parallel development alongside tidal technologies and operate on the same principles as tidal stream turbines, but are usually smaller, based on a floating system that can be easily placed in a river channel.[337] Costs are expected to be much lower and considering high global population proximity to rivers, could offer significant contribution to the renewable energy mix, particularly for developing countries. However, RCTs are still in their infancy and there are many questions left unanswered, including lack of sufficient datasets for identifying suitable locations and uncertainties surrounding the economics.[338]

Hydro-electric dam, Indonesia

One uncertainty that all current turbine technologies share is their unknown environmental impact. The interference caused to marine life, such as the impact on fish stocks and marine mammals, is not known, although it is thought that it should be minimal, since the turbine rotation pace is relatively slow compared to, say, wind turbines or boat propellers, and wildlife is quick to adapt to such changes. The UK Environment Agency also highlights that the impact on seabeds, in terms of water flow and sediment transfer is, as yet, unknown, and stresses the importance of continued research and impact assessments in all these areas.[339] So far, however, environmental impact assessments on pilot and current

333 Eccleston, P., 'Tidal Power Scheme to Launch in Scotland', The Telegraph, 29th September 2008, http://www.telegraph.co.uk/earth/main.jhtml?xml=/earth/2008/09/29/eatidal129.xml

334 The Independent on Sunday, 'The Rise of British Sea Power', 23rd March 2008, http://www.independent.co.uk/environment/green-living/the-rise-of-british-sea-power-799630.html

335 Jacquot, J.E., 'Gulf Stream's Tidal Energy Could Provide as Much as a Third of Florida's Power', Treehugger.com, 5th December 2007, http://www.treehugger.com/files/2007/12/gulf_streams_wave_energy.php

336 Charlier, R. H., 'A 'Sleeper' Awakes, Tidal Current Power'

337 Khan, M. J. et al., 'River Current Energy Conversion Systems: Progress, Prospects and Challenges', Renewable and Sustainable Energy Reviews (12), 2008, p.2182

338 ibid

339 UK Environment Agency, 'Generating Electricity from Tidal Power', Position Statement, November 2004, http://www.environment-agency.gov.uk/static/documents/Research/ca233genelecfinal_2_930392.pdf

projects indicate that overall effects appear to be low – noise pollution is minimal, no known pollutant leaks have occurred, and the seabed appears unaffected.[340]

Hydroelectric power

Hydroelectricity is generated through the use of the gravitational force and kinetic energy of falling or flowing water. For a reliable supply of water, dams are usually built to create reservoirs, which act as a battery, storing water for later use in electricity production, and also for irrigation, and industrial and domestic use. Fast-flowing water released from dams turns turbines which generate electric power.

Hydroelectric power is the most widely used form of renewable energy, in 2006 accounting for one-fifth of global electricity production and 63% of all renewable energy production.[341] World production of hydroelectricity has grown steadily by about 2.3% per year on average since 1980, with predicted growth rates of 2.4-3.6% per year until 2020.[342] The highest growth rates are expected to be in developing or industrialising countries with high but not yet exploited hydropower potentials, e.g. parts of Eastern Europe, while for Western Europe only a 1% annual increase is estimated.[343] China has the world's largest installed capacity of 145GW, almost twice as much as the next largest hydroelectric producer, Canada, which has 89GW, followed by Brazil (69GW) and the US (291GW).

There are three forms of hydroelectric power: impoundment, involving the construction of a dam across a river to create a reservoir; a diversion – or run-of-river scheme – where a portion of the river is channelled through a canal; and pumped storage systems, which are energy-storage facilities that pump water from a lower to upper reservoir in times of peak demand.[344] The initial two can be further classified as large-scale hydropower (LHP), defined by the EU as producing over 10MW of power, and small-scale hydropower (SHP), generating less than 10MW.

Large-scale hydropower

Large-scale hydroelectric power has been heralded as a cheap, clean and reliable energy resource capable of meeting high demand and providing base-load electricty capacity. However, there is considerable debate about the sustainability of LHP stations, due to growing criticism of their environmental and social impacts, and not least in light of climatic changes and decreasing water supplies. Landscape destruction, ecosystem damage, and even increased greenhouse gas emissions are some of the environmental issues associated with this type of hydroelectric power in particular, whilst according to the World Commission on Dams, large-scale dam-building has been responsible for the worldwide displacement of between 40-80 million people[345], particularly indigenous communities, in the pursuit of energy for 'development', making dams the single largest cause of displacement among development projects.[346]

The building of a dam is a huge and expensive infrastructure project, involving the flooding of huge areas of land and the frequent diversion of rivers. By the end of the 20th century, 45,000 large dams (over 15m high) together with 800,000 smaller dams had been built worldwide[347], obstructing 65% of fresh water flows to the oceans.[348]

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[340] Fraenkel, P.A., 'Tidal Current Energy Technologies'

[341] Renewable Energy Policy Network for the 21st Century (REN21), Renewables Global Status Report: 2006 Update, http://www.istp.murdoch.edu.au/ISTP/seminars/hohmeyer06/globalstatus_renewables.pdf

[342] ibid

[343] Lehner, B. et al., 'The Impact of Global Change on the Hydropower Potential of Europe: a Model-Based Analysis', Energy Policy (33), 2005, pp.839–855

[344] The Renewable Energy Centre, 'Hydroelectric Power', http://www.therenewableenergycentre.co.uk/hydroelectric-power/

[345] World Commission on Dams, Dams and Development: A New Framework for Decision Marking, Nov 2000 Report, London: Earthscan Publications, 2000, p.102

[346] Thukral, E. G., ed., Big Dams, Displaced People: Rivers of Sorrow, Rivers of Change, London: Sage Publications, 1992, p.10

[347] World Commission on Dams, Dams and Development

[348] Wu, J. et al, 'The Three Gorges Dam: An Ecological Perspective', Frontiers in Ecology and the Environment, June 2(5), pp.241-248

The Three Gorges Dam in China is the largest dam in the world, expected to come into full operation in 2011, taking 17 years to complete. The total area of the reservoir is approximately 58,000km^2, flooding 632km of land, including 13 cities, 140 towns, 1,350 villages and 1,300 archaeological sites, and displacing 1.14 million people, although this number is set to rise to more than 5 million as further 'resettlement' is required as the project expands.[349] As a result of the dam construction, biodiversity loss has rapidly increased, such as the functional extinction of the Yangtze river dolphin; it has also caused increased water pollution, due to a decrease in the river's flushing capacity, and land erosion. Plant, aquatic, and terrestrial wildlife are predicted to be highly adversely affected.

In addition to this, studies have questioned the contribution of hydroelectric power to greenhouse gas emissions reductions. The first accusation that hydroelectric reservoirs can actually cause increased greenhouse gas emissions was levelled in 1993 by Rudd et al.[350] The build up of decomposing organic matter in still-water, man-made reservoirs causes the release of methane into the atmosphere, whilst land-use change and the flooding of large areas of natural forest, peatland, and soil, causes the loss of important carbon sinks and the release of other greenhouse gases. The construction of a dam interferes with the natural flow of the carbon cycle, and, for example, can disrupt the flow of carbon into ocean sinks.[351]Carbon emission from dam construction, involving the displacement of large volumes of material, such as rock, gravel and sand from blasting, can also contribute significant amount of CO_2 emissions from cement manufacture and transportation.[352]

Combining these criticisms, attacks have been made on the Clean Development Mechanism (CDM) for providing funds in the form of carbon credits for the building of hydropower plants around the world.[353] In 2007, hydropower plants represented as much as a quarter of all CDM projects in the pipeline, becoming the most popular CDM technology, most of these in China. However, a report published at the UNFCCC Bali negotiations in 2007, by non-governmental organisation (NGO) International Rivers called 'Failed Mechanism', revealed that most applications for credits were not 'additional' schemes, but those already in progress looking for extra revenue, resulting in the effective subsidisation of hydropower developers by the UN.[354] Since Bali, third party validators have agreed that projects applying for CDM status more than one year after having taken their investment decision should not qualify for CDM status, and as of July 1st 2008, Certified Emissions Reductions for hydropower projects are no longer listed on the European Carbon Exchange.

Climate change impacts on hydropower projects are a further uncertainty (although this is also true when considering the impact of climate change on wind power and power stations that require water for cooling or steam generation). Increased concern over water resources in a changing climate put question marks on the feasibility

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[349] Debatty, R., 'Flotsam, Jetsam, and the Three Gorges Dam', WorldChanging.com, 9th December 2007, http://www.worldchanging.com/archives/007682.html

[350] Rudd, J.W.M., Harris, R., Kelly, C.A., and Hecky, R.E., 'Are Hydroelectric Reservoirs Significant Sources of Greenhouse Gases?', Ambio 22(4), pp. 246-248.

[351] Secretariat of the World Commission on Dams, 'Workshop on Dam Reservoirs and Greenhouse Gases (Part III): Final Minutes', Montreal, Quebec: 24th-25th February, 2000, http://www.dams.org/docs/kbase/thematic/tr22pt3.pdf

[352] Svensson, B., 'Greenhouse Gas Emission from Hydroelectric Reservoirs: A Global Perspective', in dos Santos, M.A. and Rosa, L.P. (eds.) Global Warming and Hydroelectric Reservoirs. Proceedings of the International Seminar on Greenhouse Fluxes from Hydro Reservoirs & Workshop on Modelling Greenhouse Gas Emissions from Reservoirs at Watershed Level, Rio de Janeiro, Brazil: 8th – 12th August, 2005, COPPE/UFRJ, Eletrobrás

[353] Davies, N., 'Power Firms Accused of Emissions Trade Cheating', The Guardian, 3rd December 2007, http://www.guardian.co.uk/environment/2007/dec/03/climatechange.greenpolitics1

[354] Haya, B., 'Failed Mechanism: How the CDM is Subsidising Hydro Developers and Harming the Kyoto Protocol', International Rivers, November 2007, http://internationalrivers.org/files/Failed_Mechanism_3.pdf

and effectiveness of hydroelectric projects. Changes in the quantity and timing of river runoff, together with increased reservoir evaporation, will have a number of effects on the production of hydroelectric power and could stress output severely. These include impacts upon the ability of the electricity supply system to meet average and peak demands, which in turn could affect financial returns on high capital investments, impacting on debt-repayments in developing countries in particular.[355] A 2005 study from the German University of Kassel analysing the impact of global climate changes on hydroelectric power potential in Europe alone, concludes that 'severe future alterations in discharge regimes have to be expected, leading to unstable regional trends in Europe's hydropower potentials.'[356] What must be recognised about LHP is that it will continue to be a large and important component of the renewable energy mix due to its current dominance and maturity. Therefore, ensuring its relative sustainability is crucial.

Small-scale hydropower

SHPs systems are often cited as offering a more environmentally friendly, lower-cost renewable energy option than LHPs. SHPs are usually 'run-of-river' systems where water from a stream, river, or canal is diverted through a turbine which generates electricity. Any dam or hydraulic structure, such as a weir, is small, and generally little or no water is stored, making it relatively unobtrusive. There is no universal definition of what 'small' entails, although 10MW or less is the most broadly accepted measure worldwide. However, in China, the definition officially stands at 25MW, whilst in North America it is 30MW. 'Micro-hydro' refers to projects generating 500kW or less.

In 2005, SHP installations rose by 8%, bringing global capacity to 66GW.[357] The majority of this growth was in China (38.5GW), followed by Japan (3.5GW) and the US (3GW).[358] The advantages of SHP are its lower cost, reliability and flexibility. It can respond quickly to demand changes and be tailored to the needs of the end-use market. Plants can be designed and built within one or two years, requiring quite simple construction. Output is consumed near the source, eliminating the need for long transmission lines and making it particularly suitable for rural, off-grid developments, or to power individual industrial plants.[359]

There is some debate however on their environmental impact, with some arguing that SHPs are just as bad as LHPs in terms of ecological symptoms, such as biodiversity loss due to migratory passage obstruction.[360] Others claim that with proper design and planning, such as the incorporation of special fish passage or fish diversion systems and the minimising of the total flow diverted, environmental impacts can be minimised.[361] Again, uncertainty requires greater research and investigation.

Pumped storage

Pumped storage is not a means of energy generating but a means of energy storage. Stored energy in the form of water is pumped from a low elevation to high elevation reservoir powered by low-cost off-peak electricity, for example overnight. During high demand the stored water is released to turn turbines. Pumped storage systems use more energy than they contribute, but they are the largest capacity form of grid energy storage currently available.

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[355] Harrison, G.P., Whittington W.H., Gundry, S.W., 'Climate Change Impacts on Hydroelectric Power', Energy Systems Group at the School of Engineering and Electronics, The University of Edinburgh, http://www.see.ed.ac.uk/~gph/publications/GPH-Upec98.pdf

[356] Lehner, B. et al, 'The Impact of Global Change on the Hydropower Potential of Europe'

[357] REN21, Renewables Global Status Report: 2006 Update

[358] ibid

[359] Dragu, C., Sels, T., 'Small Hydropower, State of the Art and Applications', Department of Electrical Engineering, Katholieke Universiteit Leuven, Belgium, http://www.esat.kuleuven.ac.be/electa/publications/fulltexts/pub_737.pdf

[360] Janssen, R., 'The Biological Cost of Hydropower', Coalition Clean Baltic, 2002:2 http://www.ccb.se/documents/TheBiologicalCostofHydropower.pdf

[361] Ickes, B.S., Wlosinksi, J.H., Knights, B.C., Zigler, S.J., 'Fish Passage Through Dams in Large Temperate Floodplain Rivers: An Annotated Bibliography', U.S. Geologic Survey, June 2001 http://www.umesc.usgs.gov/documents/reports/2001/fish_passage_bibliography.doc

One such plant exists in Dinorwic, Wales, with the fastest response time to high demand of any such plant in the world, capable of supplying 1320MW in 12 seconds.[362] The system is housed in man-made caverns in the mountain, with natural lakes at the top and bottom. Pumped storage systems could also be used in conjunction with tidal lagoons, as well as being directly connected with wind turbines to form a reliable and energy efficient power supply.[363]

Nuclear power

Nuclear power is a form of technology designed to extract energy from atomic nuclei via controlled nuclear reactions. Nuclear energy is released by the splitting (fission) or merging together (fusion) of the nuclei of an atom or atoms.

The most common method of nuclear energy extraction is nuclear fission. Utility-scale reactors heat water to produce steam, which is then harnessed to drive a turbine to produce electricity. Nuclear power produces 16% of the world's electricity use (25% in OECD countries), and provides 6.3% of total global energy. 85% of this capacity can be found in the USA, France, Russia, the UK, Korea and India.[364] The USA provides 19% of its electricity through nuclear power, making it the biggest producer of nuclear energy, but France produces the highest percentage of its electrical energy from nuclear: 78% in 2007. In 2007, the IEA reported that there are 443 reactors in operation in 31 different countries around the world, representing 370GW of power.[365]

The majority of existing power plants are 2nd generation Light Water Reactor (LWR) plants, built in the 1970s and 80s.[366] These have accumulated more than 5,000 reactor-years of operation time, making them the most well-established and mature nuclear power plant technology.[367] Third-generation power plants were developed in the 1990s for improved safety, security and efficiency. Several of these have been built, mainly in East Asia. Fourth generation reactors (GEN-IV) are currently in development and are not expected to enter the market until at least 2030. These include three fast reactor concepts cooled by liquid lead, sodium or gas (LFR, SFR, GFR), and three thermal reactor concepts cooled by very high-temperature helium (VHTR), molten-salt (MSR), and supercritical water (SCWR). GEN-IV plants are all designed with the stated aim of improving safety, minimising long-life radioactive waste production, improving proliferation resistance and reducing costs.[368]

However, huge doubts surround these claims and the viability of future nuclear power in general. Nuclear power is perhaps the most contentious of all energy options, with heated debate as to its safety, sustainability, effectiveness (in terms of greenhouse gas emissions reductions), security, and costs. With many nuclear plants approaching the end of their lifespan, discussions around the future role of nuclear power have been prominent in political and media circles. Environmentalists themselves have been split in the debate, some, such as James Lovelock and Jared Diamond, arguing that nuclear power is the only option in the face of mitigating climate change; others, such as Zac Goldsmith and leading NGOs such as Friends of the Earth and Greenpeace, stressing that nuclear power only creates further problems to do with radioactive waste disposal and nuclear weapons proliferation and is fundamentally unsustainable.

According to the International Energy Agency (IEA), winning this argument is essential if nuclear power is to expand to

[362] The Green Party, 'It Works!', GreenEnergyWorks.org, http://greenenergyworks.org.uk/itworks.htm
[363] MacKay, D., 'Enhancing Electrical Storage by Pumped Storage in Tidal Lagoons', Draft 1.8, Cavendish Laboratory, University of Cambridge, March 2007, http://www.inference.phy.cam.ac.uk/sustainable/book/tex/Lagoons.pdf
[364] IEA, 'Nuclear Power', IEA Energy Technology Essentials (4), March 2007, http://www.iea.org/textbase/techno/essentials4.pdf
[365] ibid
[366] ibid
[367] Guldner, R., 'Potential of Light Water Reactors for Future Nuclear Power Plants', World Nuclear Association Annual Symposium, 3rd-5th September 2003, http://www.world-nuclear.org/sym/2003/pdf/guldner.pdf
[368] IEA, 'Nuclear Power'

its projected electricity generation share of 19-22% by 2050.[369] If the key nuclear issues of waste management, proliferation and social acceptance are not addressed, the 2006 Energy Technology Perspectives report predicts that nuclear power is unlikely to expand and its electricity share in 2050 could drop to only 7%. A 2003 MIT study backs this claim, stating that if nuclear is to have a large stake in the future energy mix, four critical problems must be overcome: high relative costs in comparison with fossil fuels; safety issues related to health and the environment; unresolved challenges in the management of nuclear waste; and concern over the security risks of proliferation.[370]

After the Chernobyl accident in 1986, public concerns over the safety and security of nuclear reactors as well as the impact of nuclear power on health and the environment came to the fore. The 2006 International Atomic Energy Agency (IAEA) Chernobyl Forum report, that brought together bodies such as UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation), WHO (World Health Organization), the World Bank Group, UNEP (United Nations Environment Programme), UNDP (United Nations Development Programme), the UN-OCHA (United Nations Office for the Coordination of Humanitarian Affairs), and the FAO (Food and Agriculture Organization) places the number of associated thyroid cancer cases at 4,000, with total cancer mortality rates projected to increase only a few percent owing to Chernobyl-related radiation exposure.[371] It concludes that 'For the most part, [the population surrounding Chernobyl was] exposed to radiation levels comparable to or a few times higher than the natural background levels, and future exposures continue to slowly diminish as the radionuclides decay. Lives have been seriously disrupted by the Chernobyl accident, but from the radiological point of view, generally positive prospects for the future health of most individuals should prevail.'[372] This report has been attacked for being partial and understated by groups such as Greenpeace and the German affiliate of International Physicians for the Prevention of Nuclear War, who in their reports claim that the Chernobyl Forum report misrepresented its own research and failed to look at the broader impacts.[373] Here estimated mortality figures are in the region of over 200,000 deaths, with thyroid cancer rates projected at as much as 50,000 cases.[374]

Without getting caught up in the wide-ranging debate about Chernobyl, what can be deduced from this case study is that health effects are difficult to measure and quantify and that a considerable amount of uncertainty surrounds the health impacts of nuclear radiation. Even the IAEA report states that: 'It is impossible to assess reliably, with any precision, numbers of fatal cancers caused by radiation exposure due to the Chernobyl accident – or indeed the impact of the stress and anxiety induced by the accident and the response to it. Small differences in the assumptions concerning radiation risks can lead to large differences in the predicted health consequences, which are therefore highly uncertain.'[375]

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[369] IEA, Energy Technology Perspectives, 2006: Scenarios & Strategies to 2050, IEA, http://www.iea.org/textbase/nppdf/free/2006/etp2006.pdf

[370] Ansolobhere, S. et al, The Future of Nuclear Power, Massachusetts Institute of Technology (MIT), 2003, http://web.mit.edu/nuclearpower/pdf/nuclearpower-full.pdf

[371] The Chernobyl Forum, 'Chernobyl's Legacy: Health, Environmental and Socio-Economic Impacts and Recommendations to the Governments of Belarus, the Russian Federation and Ukraine', The Chernobyl Forum 2003-2005, http://www.iaea.org/Publications/Booklets/Chernobyl/chernobyl.pdf

[372] United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), 'The Chernobyl Accident: UNSCEAR's Assessments of the Radiation Effects', http://www.unscear.org/unscear/en/chernobyl.html#Health

[373] Yablokov, A., Labunska, I., and Blokov, I., (eds.) 'The Chernobyl Catastrophe: Consequences on Human Health', Greenpeace, the Netherlands, 2006, http://www.greenpeace.org/raw/content/international/press/reports/chernobylhealthreport.pdf; and Pflugbeil, S., Paulitz, H., and Clau?en, A., 'Health Effects of Chernobyl: 20 Years After the Catastrophe', German Affiliate of the International Physicians to Prevent Nuclear War and the German Society of Radiation Protection, 2006 http://www.ippnw-students.org/chernobyl/IPPNWStudy.pdf

[374] ibid

[375] The Chernobyl Forum, 'Chernobyl's Legacy', p.7

Health concerns will never be fully resolved, but they play a part in public resistance and lack of acceptance of risk in the nuclear debate. It is the level of uncertainty associated with nuclear, unlike other renewable energies (if nuclear can be placed in this category), which is perhaps the main issue. A key lesson to be learnt from Chernobyl is that public perception of risks is usually very different to government or industry perceptions, resulting in a lack of common understanding.

For many, a further unacceptable uncertainty lies in the issue of nuclear waste and the risks associated with terrorism and nuclear weapons proliferation. Although the amount of waste in comparison with coal, for example, is very small, the potency and delicate requirements of its handling is much more significant. At present, each country is responsible for managing and disposing its own radioactive waste. But no country in the world has a strategy in place for permanently disposing of spent fuel and other radioactive wastes.[376] At the moment our so-called 'waste legacy' is in temporary or permanent storage, and research into permanent disposal methods is under operation alongside plans for new-build plants. Expanding our nuclear capacity without a serious and viable plan for nuclear waste disposal is not only unethical but also risky.

The most popular current proposal is for 'geologic' disposal, where waste is sealed hundreds of metres below ground in chambers blocked off through specially engineered barriers and natural geologic structures.[377] A proposed site at Yucca Mountain in Nevada, USA, has been under consideration for two decades, but the discovery of more water at the site than anticipated has led to the Nuclear Regulatory Commission withholding its approval. Identification and approving of geologic sites can be a major barrier. The new nuclear reactor under construction in Finland is the first in the world to incorporate permanent high-level waste disposal research facilities underground. The Onkalo project at the Olkiluoto plant will test the disposal technology in actual deep underground conditions, with the hope that with government approval, the first canisters of waste can be deposited in 2020. The estimated date for completion, when access routes would be sealed, would not be until 2130.[378]

Alongside this must be consideration of the security risks and implications. The link between nuclear power and nuclear weapons proliferation arises from the fact that the highly enriched uranium and plutonium used as reactor fuels are also the principal ingredients of nuclear weapons and other nuclear explosive devices. The Swedish Nobel Prize winning physicist, Hannes Alven, has described the civil atom and the military atom as 'Siamese twins'. As it stands, under the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) and IAEA monitoring and inspection measures, any declared non-weapon state can legally acquire reactors and nuclear fuel cycle facilities and can stockpile large quantities of nuclear weapons-usable material as long as they can point to potential 'peaceful uses'.[379] The increasing use of mixed-oxide fuel (MOX) that produces reactor-grade plutonium through the reprocessing of spent nuclear fuel in facilities such as the THORP plant in Sellafield in the UK, creates increased security risks due to the impossibility of guaranteeing that these weapons-grade materials are not diverted or stolen to make weapons. An Oxford Research Group study on the security of nuclear power concludes that not only is the 'risk of plutonium being diverted for a clandestine state programme extremely serious in itself, but as the plutonium-MOX economy grows, the risk of plutonium finding its way to a terrorist group

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[376] Deutch, J.M., Ernest, J.M., 'The Nuclear Option', Scientific American, 295(3), September 2006, http://web.mit.edu/chemistry/deutch/policy/80TheNuclearOption2006.pdf

[377] ibid

[378] ibid

[379] Cochran, T.B., Paine, C.E., Fettus, G., Norris, R.S., and McKinzie, M.G., 'Position Paper: Commercial Nuclear Power', National Resources Defence Council, USA, October 2005, http://www.nrdc.org/nuclear/power/power.pdf, p.9

Nuclear power plant, Bavaria

dramatically increases with it.'[380] Attacks on nuclear facilities themselves, especially if they grow in number, is also an enhanced security risk.

One solution proffered to improve nuclear power security risks related to fuel reprocessing is to abandon closed-fuel cycle systems that reuse spent fuel and opt for open-fuel cycle systems only, which send all plutonium waste into storage. MIT professors John Deutch and Ernst Moniz, who formed part of the research team behind the 2003 report back this solution, but cite the future possibility of using an 'advanced closed cycle' that would dramatically reduce waste in the long-term.[381] However, the National Academy of Sciences in the US, after assessing the Department of Energy's research into advanced fuel cycles under the Global Nuclear Energy Partnership (GNEP) programme, that had the goal of accelerating the elimination of fuel reprocessing systems that separated out plutonium, concluded that 'the state of knowledge surrounding the technologies for achieving the goals of the GNEP is still at an early stage.'[382]

A further significant uncertainty exists in the marketplace. A wide range of estimates exist on the costs of building new nuclear power plants. As with most renewables, the capital costs of new nuclear represent the majority of the total cost of generation and are extremely high – typically about 70% of the base-load cost.[383] Taking a recent construction example, a plant in Finland, Western Europe's first new reactor in a decade, is being built at an expected cost of £2.25billion, although there have been serious delays predicted to cause the project to go 25% over-budget. In relation to this, equivalent capacity gas and coal-fired power stations are much cheaper to build, between £800million-£1billion.[384]

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[380] Barnaby, F., and Kemp, J., (eds.), 'Secure Energy? Civil Nuclear Power, Security and Global Warming', Oxford Research Group, March 2007, http://www.oxfordresearchgroup.org.uk/publications/briefing_papers/pdf/secureenergy.pdf

[381] Deutch, J.M., Ernest, J.M., 'The Nuclear Option'

[382] Committee on Review of DOE's Nuclear Energy Research and Development Program, National Research Council, 'Review of DOE's Nuclear Energy Research and Development Program', Washington D.C.: National Academies Press, 2008, http://books.nap.edu/catalog/11998.html

[383] The Royal Academy of Engineering, The Costs of Generating Electricity, London: The Royal Academy of Engineering, 2004, http://www.countryguardian.net/generation_costs_report2.pdf, p.43

[384] BBC News, 'Q&A: The Costs of Nuclear Energy', 10th January 2008, http://news.bbc.co.uk/1/hi/business/7180539.stm

An interdisciplinary MIT study, which was a result of a 2-year analysis of a comprehensive range of different studies on the matter, came out with an average total cost for new-build nuclear plants, excluding interest during construction, but including decommissioning costs, of £1,150 per kW for the base case.[385] The Royal Academy of Engineering supports this assessment, adding an uncertainty level of ±25%.[386]

Whilst capital costs are high, production costs (fuel, operation and maintenance costs) for nuclear plants are much lower than for fossil fuel stations. Whereas fuel costs make up 27% of the overall production costs of nuclear power plants, fuel costs for coal, natural gas and oil make up more than 75% of their production costs. Nuclear plants require refueling every 18-24 months at an average cost of 0.47c/kWh, and are not susceptible to fuel-price volatility like gas and oil-powered plants.[387] Even taking this into consideration, the MIT report concluded that nuclear power only becomes cost-competitive when carbon costs are internalised, such as through a carbon tax or cap-and-trade scheme, whereupon costs for fossil fuels, such as gas and coal, start to rise sharply, but nuclear costs remain the same as they are considered a carbon-neutral energy source. With a sufficient carbon price, nuclear power could start to be competitive, especially as fossil fuel prices continue to rise. However there are still questions over costs of decommissioning and waste disposal.

But treating nuclear power as a carbon neutral energy source is not without its problems. It is understood that an operating plant has near-to-zero carbon emissions, but it is the secondary processes, such as construction, transport, mining and processing of uranium ore, waste storage, and finally decommissioning, that contribute to nuclear power's carbon footprint. The Sustainable Development Commission (SDC)'s 2006 position paper on *The Role of Nuclear Power in a Low Carbon Economy* concluded that overall, based on analysis of construction and fuel-cycle, the emissions associated with nuclear power production are still relatively low, with an average of 16g/kWh for nuclear, compared with 891g/kWh for coal and 356g/kWh for gas.[388] But this does not take into account decommissioning and waste disposal emissions, which are difficult to quantify. Concern over the use of low-grade uranium ore, which requires greater levels of energy inputs to be enriched for use, have also been raised[389], though some studies say that even with this increased energy input, the carbon output of nuclear remains comparatively low.[390]

In 2005, a joint report by the OECD Nuclear Energy Agency and the IAEA on uranium reserves concluded that at current rates of demand, uranium stores are sufficient to last another 85 years, with fast reactor technology expected to increase this to 2,500 years. With global predicted growth of nuclear capacity of between an additional 22-44%, demand for uranium would mean stores would last only 350 years.

Perhaps the key question, is how much would nuclear power contribute to greenhouse gas emissions reductions if it were to be employed? Taking the UK alone, the SDC reports that if nuclear plants are displacing carbon-intensive fossil fuel plants, such as coal or gas-fired plants, then emissions savings are large in comparison – but if nuclear displaces a low carbon technology such as wind, there may be no

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385 Ansolobhere, S. et al, The Future of Nuclear Power

386 The Royal Academy of Engineering, The Costs of Generating Electricity

387 Nuclear Energy Institute, 'Nuclear Statistics: Costs: Fuel, Operation and Waste Disposal', http://www.nei.org/resourcesandstats/nuclear_statistics/costs/

388 Sustainable Development Commission, SDC Position Paper: The Role of Nuclear Power in a Low Carbon Economy, London: Sustainable Development Commission, 2006, http://www.sd-commission.org.uk/publications/downloads/SDC-NuclearPosition-2006.pdf

389 Greenpeace, UK, 'Nuclear Power – Increasing Carbon Emissions', 11th November 2005, http://www.greenpeace.org.uk/blog/climate/nuclear-power-increasing-carbon-emissions

390 World Nuclear Association, 'Comparative Carbon Dioxide Emissions from Power Generation', http://www.world-nuclear.org/education/comparativeco2.html

emissions savings.[391] The emissions savings in terms of fossil-fuel replacement are something in the order of a 4% cut in emissions on 1990s levels if current nuclear capacity is simply replaced (10GW), and an 8% cut if nuclear capacity is doubled.[392]

Hydrogen fuel

Hydrogen fuel is not an energy source but an energy carrier. Energy carriers, e.g. electricity, move energy in a usable form from one place to another. The advantage of hydrogen is that it can be stored in large quantities although the cost of storage is currently very high. It is made as a byproduct of chemical processes, and can be produced from a number of different resources, for example water, fossil fuels or biomass.

Hydrogen as an energy carrier has the advantage of being storable in large quantities and can be produced from almost any energy source to provide almost any energy service.[393] 1kg of hydrogen has about the same energy capacity as 1US gallon of gasoline, making it a very light energy carrier.[394] However, per unit of volume hydrogen contains only 30% the energy of natural gas.[395]

The reason hydrogen is not an energy source is that it is found as a free element only in trace amounts and so is mostly bound into a compound, such as in water (H_2O), in fossil fuels, and in all plants and animals. It therefore requires separation via the use of a variety of primary energy sources such as wind, solar, geothermal, hydropower, biomass, nuclear and fossil fuels, and serves as a means by which these sources can be stored, transported by truck or pipeline, and utilised in a fuel cell, turbine or engine to generate electricity with water as the main byproduct in combustion.[396] Currently, hydrogen is mainly used in industrial applications, with ammonia production accounting for 62.4% of total global consumption in 2001, oil refineries accounting for 24.3% and methanol production for 8.7%.[397]

The two main methods used globally for separating hydrogen are the thermal method and chemical method. A third, biological, method is currently being researched and developed. About 97% of worldwide hydrogen is produced through 'steam-reforming', or via the thermal method, using natural gas and other fossil fuels as the primary energy source. Presently, 40% of hydrogen is produced from natural gas, 30% from heavy oils and naphtha, 18% from coal, 4% from electrolysis and about 1% from biomass.[398] Steam-reforming splits the hydrocarbons in a catalytic conversion in the presence of high temperature steam (800-900°C). During the catalytic split, a product called 'syngas' is created, which mainly consists of methane and carbon monoxide. In the second step, or the 'shift reaction', carbon monoxide from the syngas is transformed into CO_2 and hydrogen, via a reaction catalysed by iron oxide. Thus in this process, a by-product is CO_2, and along with other gases released during production and distribution processes, such as natural gas lost to the atmosphere, this form of hydrogen production is not wholly climate-friendly. Based on a life-cycle assessment (LCA) of natural-gas based

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[391] Sustainable Development Commission, SDC Position Paper: The Role of Nuclear Power in a Low Carbon Economy

[392] ibid

[393] Lovins, A. B., 'Twenty Hydrogen Myths', Boulder, Colorado: The Rocky Mountain Institute, February 2005 https://www.rmi.org/images/other/Energy/E03-05_20HydrogenMyths.pdf, p.5

[394] Lovins, A.B., 'Hydrogen: The Future of Energy', Rocky Mountain Institute Quest for Solutions, Public Lecture, Given Institute, Aspen, Colorado, 6th August 2003, http://www.rmi.org/images/other/Energy/E03-15_H2FutureOfEnergy.pdf

[395] ibid

[396] The Hydrogen Association, 'Hydrogen Fact Sheet: The Hydrogen Economy', 2008, http://www.hydrogenassociation.org/general/factSheet_economy.pdf

[397] Spath, P.L., Mann, M.K., 'Life Cycle Assessment of Hydrogen Production via Natural Gas Steam Reforming', Golden, Colorado: US National Renewable Energy Laboratory, 2001, http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/27637.pdf, p.3

[398] Das, D., Khanna, N., Veziro?lu, T.N., 'Recent Developments in Biological Hydrogen Production Processes', Chemical Industry and Chemical Engineering Quarterly 14(2), 2008, http://www.ache.org.rs/CICEQ/2008/No2/02_3001_2008.pdf

hydrogen production, for every 0.66MJ of hydrogen produced, 1MJ of fossil fuels must be consumed.[399] The use of carbon sequestration facilities has been proffered as a way to ensure that a move to a large-scale hydrogen economy will contribute to emissions reductions.

The chemical method of hydrogen separation, however, involves no emissions. Here hydrogen is produced via the process of electrolysis, which passes an electric current through water in an ionic transfer device to separate the water back into its hydrogen and oxygen components. France uses its abundance of nuclear power as its most common method of producing hydrogen, but methods harnessing solar, wind, hydropower and biomass have also been developed.[400] Determining the environmental impact of hydrogen depends very much upon the production methods used. One LCA carried out by the International Association of Hydrogen Energy found that using photovoltaic energy to produce hydrogen has the worst environmental performance compared to other feedstocks, including natural gas, due to the manufacturing processes involved and the low efficiency levels.[401] Natural gas steam reforming, however, came second from the bottom, due to the release of CO_2, sulphur dioxide and methane in the process. The study concluded that wind, hydropower and solar thermal energy offered the most environmentally friendly methods of production and that such renewable systems offer the best prospects in terms of sustainable growth.[402]

The biological process of separating hydrogen, or 'biohydrogen', is also far more environmentally benign, being operated at lower temperatures and atmospheric pressure and thus requiring far less energy input. Hydrogen can be extracted from biomass and algae. It is also found naturally, although in temporary form, as a byproduct of several biochemical reactions caused by microbes, mainly in anaerobic fermentation. Some microorganisms can also produce enzymes that can produce hydrogen from water if an external energy source, such as sunlight, is present.[403] Biohydrogen production capitalises on these natural processes. The four main processes involved in the biological method are: water bio-photolysis, photo-fermentation, dark fermentation and hybrid systems.[404] However, there are currently no commercial-scale applications in existence, and biohydrogen is still demonstrable only in the lab. It is therefore difficult to define the practical application of biohydrogen developments. Studies have shown that at current levels, biohydrogen systems do not provide enough hydrogen to power even a 1kW fuel cell on a continuing basis.[405] Further research and development, as well as more integrated research with engineer fuel-cell developers is required in order to meet the challenges of scale-up.

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[399] Spath, P.L., Mann, M.K., 'Life Cycle Assessment of Hydrogen Production via Natural Gas Steam Reforming', p.23

[400] The Hydrogen Association, 'Hydrogen Fact Sheet: Hydrogen Production Overview', 2008, http://www.hydrogenassociation.org/general/factSheet_production.pdf

[401] Koroneos, C., Dompros, A., Roumbas, G., Moussiopoulis, N., 'Life Cycle Assessment of Hydrogen Fuel Production Processes', International Journal of Hydrogen Energy (29), 2004, p.1,450

[402] ibid

[403] Das, D., Khanna, N., Veziro?lu, T.N., 'Recent Developments in Biological Hydrogen Production Processes

[404] ibid

[405] Levin, D. B., Pitt, L., Love, M., 'Biohydrogen Production: Prospects and Limitations to Practical Application', International Journal of Hydrogen Energy (29), 2004, pp.173–185

Organisational Change Case Studies

Background

As has been outlined in this report, the scale of the change that is required in today's society to respond to the challenge of climate change is transformational. The current flow of 'value' through our economic system is inadequate for capturing long-term trends and 'externalities'. Therefore a new approach to measuring and managing the externalities is required. Business is starting to develop new ways of responding to the challenge including developing new business models and opportunities.

It is possible to look at the different levels of response by business as follows:[406]

- **Response level 1: core-business focused.** Organisations with a short-term focus do not see that the issue has much relevance to them at all.
- **Response level 2: stakeholder responsive.** Organisations that recognise the need to understand and comply with a complex and rapidly changing set of rules, regulations and financial instruments, while keeping up-to-date with customers' needs and corporate policy.
- **Response level 3: efficient management.** Organisations that manage their operations, to quantify and prioritise issues, put in place common sense and effective management programmes for improvement.
- **Response level 4: breakthrough projects.** Organisations that identify creative innovations and put in place the conditions for a strategic response.
- **Response level 5: strategic resilience.** Organisations that are more able to put in place programmes to ensure their resilience in what is likely to be a very different and fast-changing future.
- **Response level 6: the champion organisation.** Organisations that go further and seek to lead wider social change to slow and reverse climate change.

This chapter brings together some examples of current initiatives by business. While none of these address the full transformational change required to tackle climate change, they highlight the direction that business is taking to respond to the challenge. It is the role of policy makers to ensure that the momentum behind this change leads to true transformation in the next few years. In particular, we examine government-business partnerships; a new move in the finance and legal communities to incorporate climate risk in their decision making; and some examples of new opportunities, risks and responses by business.

- **Government-business partnership**
  - Bremen Initiative: economic regeneration
  - Curitiba: integrated urban transport
- **Reducing the financial and legal risk**
  - Kivalina: suing big energy
  - Kohlberg Kravis Roberts: private equity and the environment
- **New opportunities, risks and responses by business**
  - Merrill Lynch: carbon credits and forest conservation
  - Wal-Mart: sustainable supply chains
  - Holcim: natural disaster relief

The business drivers behind each of these changes are complex and involve a combination of external pressures, leadership, business culture and innovation. However, it is clear that these transformations have occurred when the companies in question have stopped trying to find the 'answer' elsewhere and have decided to take a leadership

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[406] Proposed in Alexander Ballard Ltd and Hampshire County Council (2008), Adaptation Capacity Benchmarking: A Handbook and Toolkit. Project carried out for Hampshire County Council on behalf of ESPACE (European Spatial Planning: Adapting to Climate Events), http://www.espace-project.org/part2/part2_outputs.htm

role in responding to what is a clear risk or opportunity for their business. These changes have been led by the core revenue-creating areas of the companies rather than by a philanthropic desire to be 'sustainable'.

The information here is based on publically available data and therefore it has been difficult to quantify some of the real 'behind-the-scenes' drivers for the change, but we believe there are some common lessons that can be drawn by presenting them here together in this context.

A need for government-business partnerships?

There are a number of major climate-related issues that require joint responses from both the government and business. Here we present two examples of major city-level initiatives that have led to changes in the local community.

Bremen Initiative: business-government partnership for economic regeneration

This case study looks at how a business–government partnership led to the creation of a wind turbine industry in Bremen, using the investment, competitive advantage and collaboration to try to position the region as a world leader.

Local governments around the world have often become sustainable development pioneers as a result of their commitment to Local Agenda 21, the local version of the international Agenda 21 agreement arising from the first Earth Summit in Rio de Janeiro in 1992. The Free Hanseatic City of Bremen, smallest of Germany's federal states, is composed of two cities, Bremen and Bremerhaven, with a combined population of 680,000. Its experiences with Local Agenda 21 prompted Bremen to launch the 'Bremen Initiative' in 1999. Its goal was to promote closer partnerships between municipalities and businesses to achieve a sustainable future for cities. It was the first international campaign to focus on building sustainable development partnerships between city governments and their major stakeholders.

Partnering for regeneration and sustainability

The Bremen government was aware of the growing involvement of local private-sector companies in issues affecting sustainable urban development, but it also knew the difficulties it had encountered in engaging the business sector in the Local Agenda 21. That awareness and experience ensured the Bremen Initiative was focused on creating a platform and a common goal: 'creating better cities: together'.

The Initiative was launched in 1999, and it put Bremen at the centre of a global campaign that served as a platform for exchange of experience in business-municipality partnerships, and a catalyst for more and better partnership results. It created a learning environment where best practices from around the world could be accessed and shared through conferences, publications, a website, and a worldwide network of experts in urban affairs and business-municipality partnerships. The international Bremen Partnership Award recognised city-business partnerships making cities more liveable and sustainable for their citizens.

Bremen itself is an example of the kind of urban areas where such partnerships are most needed. On the one hand, it has a highly skilled workforce employed by the automotive and aerospace industries (Daimler employs 15,000 people, and EADS 5,000). On the other hand, some traditional industries are in decline (e.g. the shipbuilding workforce dropped from 18,000 in the 1970s to 1,600 by 2004). The harbour city of Bremerhaven had been especially hard hit by these changes, characterised by dying and polluting heavy industries and soaring unemployment. However, today it is undergoing something of an economic renaissance, not least because it is striving to be a global leader in renewable energy production, research, and development.

"The local fishing and shipping industries were in decline and we were looking at how to use the workforce's traditional skills in a future based industry," explains Rita Kellner-Stoll, Head of the Department of Environmental Economics, Climate and Resource Protection. "It was a logical connection as it takes a lot of competence to create wind farms in rough seas and we had that expertise in our community."

At the time, offshore wind energy was not high on the environmental or regeneration

Construction of the Bremen Windfarm

agendas in Germany or elsewhere in Europe, and the department recognised the region could leapfrog the competition if the public and private sectors went about it in a very coordinated way.

The first step was to present a political strategy to the Bremen Senate outlining all the elements – economic development, technology research and development, skills training, environmental protection – needed to successfully develop a regional wind industry. This was approved in 2003.

"The second key step was networking," explains Rita Kellner-Stoll. "My department set up a Wind Energy Agency which recruited existing companies and research institutes that could turn their skills to developing a wind industry. With a budget of several million euros – half from the EU and half from the Bremen government – we then identified and funded the research and technology needs to get the industry off the ground. For example, we provided subsidies to offshore companies to solve corrosion and other component problems for the giant windmills they were designing. We also offered prime dockside rental locations in Bremenhaven harbour."

"We got all these players thinking innovatively and working as a community and the result was astonishingly fast progress." By 2008, the agency had 160 members from across north-west Germany, providing hundreds of new jobs. Many are new or reconfigured companies, such as former shipyards now building windmill towers. They include Multibrid and REPower – two of only three companies worldwide that make 5MW windmills for offshore use.

Outcomes

Bremen's vision is that the north-west region of Europe will become the production line for the global offshore wind industry. In 2008, a new generation of 5MW turbines was being trialled onshore in Bremerhaven, with the electricity fed into the national grid. These include structures with innovative tripod and jacket foundations which will reach 40m in depth and operate 50km offshore, compared with a 10km range for existing smaller windmills. When these wind parks are finished they will operate like giant power stations. In addition, two windmills built in Bremen are being piloted off the Scottish coast. By 2015, it is anticipated that 200MW of wind energy will be generated off Bremerhaven.

Sources

- The Prince of Wales's Business & the Environment Programme (BEP) materials, Bremen Initiative: Winds of Change, 2007.
- Lieberum, A., 'The Bremen Initiative', UN Human Settlements Programme Habitat Debate, September 2002, Vol. 8 No. 3. http://ww2.unhabitat.org/hd/hdv8n3/forum6.asp
- Portrait of the Regions. CIRCA (Communication & Information Resource Centre Administrator). http://circa.europa.eu/irc/dsis/regportraits/info/data/en/index.htm

Curitiba: integrated urban transport

Mobility in cities with growing populations plays an important part in reducing carbon emissions, accommodating demographic change, and providing economic opportunities. Curitiba is a famous, early model of how transportation can steer urban development rather than simply react to it. It also highlights the continual effort, experimentation, and investment required to make this kind of system sustainable in the long term.

Curitiba is the capital of the State of Paraná in southern Brazil. It introduced its first public transportation system in 1887, and after a fierce period of competition in the 1940s, eventually replaced its trolley system with buses in the 1950s. During this time, the city started looking into various types of efficient mass transportation systems as part of an urban Master Plan because urban migration was causing the population to grow at over 5% a year. This uncontrolled increase in population demanded effective city planning in areas ranging from social services, housing and sanitation, to the environment and transportation.

In the 1960s, the city committed itself to constructing a consolidated public transportation system to move people easily throughout the metropolitan area and its surrounding municipalities.

Putting mobility at the centre of urban planning

The development of Curitiba's transportation system began in the late 1960s and early 1970s. Unlike other Latin American cities at the time, Curitiba's planners decided to address the process of transportation as an integrative approach that could assist in the development of the city. In Curitiba's case, its planners recognised that transportation systems can serve as the backbone for the development and growth of the city in the future. Instead of succumbing to the demands of the population and addressing transportation as a service that caters to an ever prevalent and pressing demand, they essentially planned their system with the intention of dictating the growth of the city.

Buses were chosen as the primary means of public transport because the population were familiar with them and they were the most cost-effective. The city had a long history of public transport, and buses had been the main form of transport since the 1950s when fares were first regulated by the municipal government. Innovative urban planning was already familiar to Curitiba by the late 1940s when city planner Alfredo Agache had tried to introduce a new standard of urban space design that gave priority to public services such as sanitation, easing traffic congestion, and creating centres that enabled the growth of both social life and commerce. Implementation of the plan was curtailed for economic reasons, but elements such as large avenues, buffer zones for expansion, and an industrial district remain today.

In the 1960s, a new Master Plan for the city changed the city's radial configuration of growth to a linear model of urban expansion. The plan utilised land use and road systems as integrated tools. The city created Brazil's first pedestrian network in its centre in 1971, but the most significant changes in the transportation system were taken in 1974 with the creation of the road hierarchy and land control system. A series of arterial structural roads were built that would form structural growth corridors, and dictate the city's growth pattern. These corridors were composed of a triple road system with the central road having two restricted lanes dedicated to express buses. Parallel to the express bus lanes were two local roads running in opposite directions, allowing local traffic to pass through the city.

The five structural corridors were completed in 1982, along with inter-district and feeder lines. Complementary zoning laws were set in place to structure the growth of the city. The corridors were designed to direct linear growth by attracting residential and commercial density along a mass transportation lane. Large buildings holding a high density of people were permitted to be built along these corridors, but, as one moved away from these central corridors, the admissible densities declined from urban apartment buildings to residential neighbourhoods.

Roads alone are only one of the factors contributing to an efficient public transport system. Passengers need an effective mode of payment to avert delays, and the city has experimented with different types of payment system so as to reduce fare-dodging, and ensure the system is affordable to all. For instance, a distance-related fare system was abandoned because it favoured the rich who lived nearer the city centre, and disadvantaged the poorer who resided on the periphery of the city and had to pay twice to arrive in the centre. Passengers also expect sanitary vehicles and bus stops, which led to the construction of transfer terminals, with telephones and shops that made them safer, aesthetically attractive, and user-friendly. Other experiments and developments over time have included automatic ticketing, modifications to bus design (to allow people to embark and disembark more quickly), and a system of revenue-sharing between bus companies based on the miles covered rather than number of passengers.

Today, the transportation system is made up of three complementary levels of service that include the feeder lines, express lines and inter-district routes. The feeder lines pass through outlying neighbourhoods and make the system easily accessible to lower density areas. Sharing the roads with other vehicles, these feeder lines connect with the express system along the structural corridors. The express system then utilises these dedicated bus lanes and transports large numbers of passengers to various locations along these structural corridors, thus operating much like a surface subway system. The inter-district routes allow passengers to connect to the axis of the express lines without entering the central city area. The Integrated Transportation Network encompasses transfer terminals, express routes, direct routes using boarding tubes, feeder and inter-district routes supplemented by centre city routes, neighbourhood routes, night routes, special education routes, and pro-park routes. Through carefully planned tube or terminal connections, passengers can pay one fare and travel throughout the system.

Outcomes

Today, Curitiba has a mass transportation system that covers eight neighbouring cities, and transports 1.9 million passengers daily with an 89% approval rate. To accommodate the growing population over the past 30 years, the system has grown to utilise varying types of bus services that cater to the needs of passengers within the metropolitan areas and surrounding municipalities. The Integrated Transport Network, now comprising 340 routes and operated by 1,902 buses, allows passengers to travel to a certain destination without paying more than one passage within the metropolitan area. The entire network covers 1,100km of roads with 60km of it dedicated for bus use. There are 25 transfer terminals within the system, and 221 tube stations that all allow for pre-paid boarding.

Source

- Parasram, V., Efficient transportation for successful urban planning in Curitiba, Horizon Solutions, 2003.

Reducing the finance and legal risk?

Here we present two examples from the legal and finance sectors of changes in the way they think about climate change issues and how it potentially impacts their sector. These examples raise questions about whether litigation and finance liability has a role to play in corporate and government responses to climate change.

Kivalina: suing big energy

Lawsuits brought transformation to the tobacco industry, and now a similar strategy is being applied against energy companies. Lawyers have filed a suit against 20 companies on behalf of the small Alaskan island community of Kivalina. They claim it is ultimately these companies that are responsible for the changes in the climate that will force the villagers to relocate.

Kivalina is a village situated at the end of a 12km-long barrier reef island in Alaska. At its highest point it is less than 2.5m above sea level. There are about 380 people, the vast majority of whom are Inupiat Eskimos. Many villagers depend on the sea for their livelihoods, and the community is famous for hunting the bowhead whale. Average family income is about $30,000, and a quarter of the population live below the official poverty line. The village has endured increasingly severe storms in recent years that are ripping apart the shoreline. The US Army Corps of Engineers has concluded that Kivalina will be uninhabitable in ten years' time, and lay the blame on climate change: the sea ice that protected the village in the past is disappearing due to the changing Arctic climate. Now there is serious discussion about having to relocate, but the cost of this is estimated to be as much as $400 million.

Building a case

US lawyers Steve Susman and Steve Berman lined up on opposite sides during the tobacco wars; Susman defending Philip Morris, Berman representing 13 US States to recover smoking-related medical costs.

In February 2008, they joined forces and filed suit in a San Francisco federal court arguing that five oil companies, 14 electric utilities, and America's largest coal company were responsible for Kivalina's plight. The companies, which include BP America, Chevron, ExxonMobil, ConocoPhillips, American Electric Power, Peabody Energy, Duke Energy and Southern, are accused of "creating a public nuisance" through their responsibility for the effects of global warming because they emit millions of tons of greenhouse gases, or, in the case of Peabody, it mines and markets carbon-laden coal that is burned by others. The companies are also accused of conspiracy: "There has been a long campaign by power, coal and oil companies to mislead the public about the science of global warming," the lawsuit says. That campaign contributed "to the public nuisance of global warming by convincing the public at large and the victims of global warming that the process is not man-made when in fact it is."

The second charge of conspiracy is potentially the most damaging because it could eliminate the need for a judge to determine how much of the public nuisance from climate change can be attributed directly to the defendants. "You're not asking the court to evaluate the reasonableness of the conduct," Berman says. "You're asking a court to evaluate if somebody conspired to lie." That would mean that compensation to Kivalina would be based on the damage done by companies preventing the enactment of public measures that might have slowed the warming, rather than on the damage from the defendants' emissions.

This is the kind of allegation that eventually led to Big Tobacco's settlement, and direct links have already been made between the strategies of the two industries. The Union of Concerned Scientists, an environmental advocacy group, has accused ExxonMobil of adopting tobacco's strategy of covertly establishing 'front' groups, promoting writers who exaggerate uncertainties in the science, and improperly cultivating ties within the government. The oil company, it says, has "funnelled approximately $16 million to carefully chosen organisations that promote disinformation on global warming". According to Naomi Oreskes, a Professor of History and Science Studies at the University of California, "The strategy to foster doubt is very effective. If 'nobody knows,'" she says, "then nobody is to blame. If 'nobody knows,' then how can we do anything about it?"

However, the challenge may be greater and is certainly different from the one with the tobacco industry. The fact that global warming is a diffuse worldwide phenomenon makes it difficult to link the defendants' behaviour directly to the harm. Kirsten Engel, a Professor of Law at the University of Arizona, says, "It's very difficult to get a court to jump in here and say that what these companies are doing, and have been doing for years, is unreasonable and creating a public nuisance." Two similar lawsuits against six car manufacturers and a group of utility companies were dismissed by federal judges who said the issues involved were political, and did not belong in the courts. The companies have dismissed the lawsuits, and some media columnists argue that lawyers will be the only beneficiaries. Peabody spokesperson, Vic Svec, says, "Rather than unreasonably suing companies for the weather, we would encourage everyone to join Peabody in supporting aggressive development of carbon capture and storage projects and other technologies that help us provide both energy security and carbon solutions." His counterpart at ExxonMobil, Gantt Walton, dismisses allegations of any disinformation campaign: "The recycling of this type of discredited conspiracy theory only diverts attention from the real challenge at hand – how to provide the energy to improve living standards while also reducing greenhouse gas emissions."

Outcomes

According to the Atlantic Monthly, "Climate change litigation is so new that legal experts have little idea how to handicap it; in unexplored areas of tort law, cases become pivotal only in hindsight. Some legal scholars are skeptical of the merits of the Kivalina case, but many others are looking on with interest. The cultural and political winds are certainly blowing in a favorable direction – and these winds often affect courts and juries. That factor, along with the very deep pockets of Big Oil, is likely to keep the lawsuits coming, testing different theories and different arguments." According to Joseph Wayne Smith, an Australian lawyer and author on climate change litigation, "It's sort of like when infantry used to charge the machine guns: a lot of them would get mowed down, but eventually a wave would get through and take out the pillbox."

However, the first tobacco suits were filed in the 1950s, and did not bring significant results until the late 1980s. If that timeframe plays out with climate change litigation, it may be that the courts are simply too slow a route to bring about change. If the lawsuit succeeds, then similar suits will follow from island nations, ski resorts, drought-stricken communities, and hurricane victims amongst others.

Sources

- Barringer, F., 'On the brink, village fights back; Buffeted, Alaskans sue over warming', International Herald Tribune, February 28th 2008, News p.2
- Beam, A., 'Eskimos, whales, and luaus ... Oh my!', Boston Globe, May 24th 2008, p.C8
- Faris, S., 'Conspiracy theory. Climate-change litigation is heating up. Will the legal strategy that brought down Big Tobacco work against Big Oil?', Atlantic Monthly, June 2008
- 'Suing Big Energy for Global Warming', Broadcast by On Point, NPR Boston, May 13th 2008

Kohlberg Kravis Roberts (KKR): private equity and the environment

Private equity firm Kohlberg Kravis Roberts' record-breaking buy-out of energy utility TXU succeeded because it won the backing of environmental non-governmental organisations (NGOs) by agreeing to cut back the firm's aggressive expansion of coal-fired power stations. The deal agreed in 2007 with Environmental Defense and the Natural Resources Defense Council was heralded as a watershed in getting climate change issues factored into investment decisions, and has led some people to argue that private equity-owned companies are better able to build in environmental considerations than publicly listed ones. However, it is still too early to say if this will become a meaningful trend, and questions remain about the extent of the environmental benefits, and the degree to which the agreement complements the new company's business interests.

Texas is a fast-growing, energy-intensive US state with a population of 23.7 million that is expected to double by 2060. It has a serious pollution problem, with some 694 million tonnes of carbon dioxide (CO_2) emitted each year – nearly double the emissions of California, and more than any other US state. The coal-fired power plants belonging to TXU, a highly profitable Dallas-based utility company, have been highlighted by environmental groups as a major source of that pollution. The conflict between the two sides reached a new level in 2006 when TXU announced plans to build eleven new coal-fired plants to meet the state's growing appetite for electricity.

Kohlberg Kravis Roberts and Texas Pacific Group are two of the world's largest private equity firms, specialising in leveraged buy-outs. They are part of an industry that, despite helping to fund world famous companies, is often depicted as being overly aggressive. This reputation is partly related to the fact that such buy-outs are typically financed by taking on high levels of debt that may lead to the acquired company having to deliver an unduly high return on investment to the exclusion of social and environmental considerations.

Financing change

"Does the record-breaking purchase of TXU signal a new strategy for private equity?" asked *The Economist* on hearing that Texas-based energy company TXU had agreed to be bought out by a group of private-equity firms led by Kohlberg Kravis Roberts (KKR) and Texas Pacific Group in February 2007. What caught their eye was not the then record $45 billion purchase price, but the fact the deal was as much about environmental politics as the kind of financial analysis that is private equity's stock in trade. "In essence, the buyers are betting that the increasingly sensitive question of how to produce energy in an environmentally acceptable way is better handled by a privately owned firm than by one exposed to the public markets."

From a conventional investment perspective the deal made a lot of sense: "The credit story was very compelling – this company had best in class assets and strong cash flow, so it all hung together," says Andrew Safran of Citigroup. But away from the bottom-line, TXU was a troubled company. After seven and a half years of unpopular price rises, the company had positioned itself firmly in the crosshairs of environmental groups by announcing in 2006 that it would build eleven new 'dirty tech' coal-fired power stations to meet Texas's growing energy needs. Focused on the politically prominent issue of national energy security, TXU underestimated the sensitivity of coal-related greenhouse gases, and found itself locked in a battle with Environmental Defense that became a political issue when a coalition of Texas city mayors opposed the plants, and the Texas governor was strongly criticised for trying to rush through permit approval before eventually being blocked by a state judge.

According to Marc Lipschultz, a KKR partner, "This was a company that had a terrific set of assets and operated those assets very well, but at the same time it was a company that had lost contact with some of its key stakeholders." For anyone familiar with KKR's history, talk of stakeholders might seem surprising. KKR had become infamous for its 1989 acquisition of tobacco company RJR Nabisco, chronicled in the book *Barbarians at the Gate*. Now its approach seemed very different, perhaps because in recent years it had seen bids for energy utilities wrecked by environmentalist and consumer opposition.

In a meeting convened by WWF chairman emeritus William Reilly, KKR executives met representatives of Environmental Defense in the start of what would become a process of consultation and collaboration every bit as important as the number crunching and financial alchemy. KKR and Texas Pacific Group (TPG) recognised that there were others who would be just as important to the deal's success as TXU's investors, and they set about appeasing the diverse interests of environmentalists, consumers, trade unions, politicians, and regulatory agencies. "It demonstrated a heightened level of execution sophistication for the sponsors to work with local and national politicians and environmentalists to reposition TXU as an advocate for constructive local and national energy policy in an effort to gain regulatory support for the sale," says Gavin Wolfe, a Credit Suisse managing director. An Environmental Defense representative put it more succinctly, calling the resultant strategy a "watershed moment in America's fight against global warming."

So, what did the deal involve? Environmental Defense and the Natural Resources Defense Council agreed to stop their concerted lobbying of politicians in Texas and Washington, and of investment bankers on Wall Street. In return, the buy-out consortium agreed as part of the acquisition terms to scrap plans for eight of the eleven coal-fired plants, a saving of 56 million tonnes in carbon emissions (although some claim there is a loophole in the deal that could allow the company to build more coal plants in future).

In addition, the consortium worked with the TXU management team to develop further conservation measures including a commitment to spend $200 million on conservation efforts over the next five years. The company, now called Energy Future Holdings, has also committed to reducing mercury, sulphur dioxide, and nitrogen oxide emissions by 20% from 2005 levels, and reduce carbon emissions at its existing plants by 2%. It also plans to bolster its purchase of wind energy-driven power and promote solar power projects, while keeping "an open mind" about nuclear power. Furthermore, KKR has agreed to support legislation for national caps on CO_2.

KKR and TPG argue that private equity makes this kind of strategy possible. They claim that the environmental threats to energy firms are hard for a public company to handle. "The company before was focused on one constituency, public shareholders. That meant it had to concentrate on short-term growth," says Michael MacDougall, a TPG partner. "This deal adds two more constituents, the consumers of the state of Texas and environmentalists. By balancing these three constituencies, we will get the best long-term result for the firm." This view is endorsed by said Jim Marston, Texas regional director for Environmental Defense: "Ironically I believe, these private equity firms that are thought of being very short-term oriented – and they are in some ways – are more long-term than some of our publicly traded organisations, who are thinking of next quarter's profits rather than what the company will be worth in five years."

Outcomes

The deal between the buy-out consortium and the two environmental NGOs had at its core an agreement to withdraw permits for eight coal-fired plants that would have used cheaper but more polluting technology. This is estimated to save 56 million tonnes in carbon emissions. Moreover, the partnership appears to have had wider impacts, and KKR, one of the lead companies in the consortium, will devise a system of measuring the environmental impact of all of its investments. It is now working with Environmental Defense to create metrics to analyse the cost to both the company and the environment of water use, greenhouse gas emissions, toxic substances, and similar dimensions to its investments' operations. KKR will identify a few of its companies to participate in a pilot test of the system from a portfolio that includes Toys R Us, Sealy Corp, Nielsen Ratings, and Alliance Boots, as well as Energy Future Holdings.

But the actual and potential outcomes do not just concern environmental benefits. Cancelling eight plants reduced the company's debt burden, and could leave Texas short of power, thereby allowing the new firm to raise prices. Wood Mackenzie, a research firm, forecasts that most of the US, including Texas, will need more generating capacity in the next few years. But an uncertain regulatory outlook means the safest option for many utilities may be to build fewer plants, allowing them to cash in on higher energy prices.

Energy Future Holdings insists that the three new plants plus greater efficiency will buy it and its stakeholders enough time to address this issue, despite the state's rapid growth in population, which is expected to double by 2060. But irrespective of the motive, cutting back on new coal plants was probably a wise business decision because of the rising cost of building coal-fired plants in recent years. In 2006, Duke Energy, another utility that has highlighted green issues, raised the projected cost of two coal-fired plants from $2 billion to $3 billion. Moreover, new regulations could change the economics of coal-fired power by putting a price on carbon emissions.

Sources

- Holman, K., 'A landmark deal: TXU buy was big, complex and clean', Investment Dealers Digest, January 21st 2008.
- Souder, E., 'TXU buyer KKR to work on improving its environmental impact', The Dallas Morning News, May 1st 2008.
- 'Eco-warriors at the gate', The Economist (US edition), March 3rd 2007.
- Zill de Granados, O., 'The TXU takeover: a dissection of a deal', 2007, PBS Frontline, April 24th 2007.

New opportunities, risks and responses by business?

The following cases highlight examples of business looking at the new opportunities and risks that climate change brings.

Merrill Lynch: carbon credits from forest conservation

Merrill Lynch, the investment bank, is paying $9 million to buy carbon credits derived from the conservation of a large swathe of natural forest in Aceh, Indonesia. The money will be used to protect the forest and improve the

livelihoods of local people. The credits will be sold on voluntary carbon trading markets such as the Chicago Climate Exchange. Merrill is betting that the market for credits from forest conservation will expand, while the Acehnese government and its partners hope this marks the start of a new era where conservation is more profitable than exploitation.

Rainforests play a key role in maintaining the world's environmental balance, their trees and plants soaking up CO_2 through photosynthesis. According to the World Bank, roughly 9 million hectares of rainforest are lost each year when they are cleared by fire for alternate use. Such fires account for about 20% of the world's CO_2. These fires make Indonesia – the world's 22nd largest economy – the third-largest emitter of CO_2 after the USA and China.

In February 2008, Merrill Lynch announced it had reached an agreement with the government of Aceh, a province of Indonesia, that would see $9 million invested over a four-year period to help protect the 750,000 hectare Ulu Masen forest. The agreement marked Merrill's first entrance into the market for carbon credits derived from 'avoided deforestation'. If the people of Aceh reduce logging of the forest to a verifiably sustainable level, then Merrill will buy $2 million worth of credits a year (with an option to buy $1 million more). The money will be made available for community development projects so that people are no longer dependent on illegal logging and converting forests into farmland. In return, investors will receive credits based on how much CO_2 would have been emitted if the forests had been burned.

How it works – the Acehnese perspective

Ulu Masen is the latest example of a REDD project (Reducing Emissions from Deforestation and Degradation). Prior to the Kyoto Protocol, the nascent system recognised carbon credits derived from forest conservation, but under the Protocol the regulated emissions trading schemes only recognised credits associated with afforestation. Other forest-derived credits could only be traded on voluntary carbon markets where prices have been significantly lower. However, this is likely to change with any successor to Kyoto, and companies such as Merrill Lynch and Rio Tinto have been exploring how to invest in REDD projects.

To be credible, REDD projects are independently verified in the same way as afforestation ones are. In the case of Ulu Masen, the project meets land management standards set by the Climate, Community and Biodiversity Alliance (CCB), whose members include the environmental groups Conservation International, The Nature Conservancy and the Rainforest Alliance, and companies such as BP, Intel and SC Johnson. To be accredited by CCB, a project has to simultaneously address climate change, support local communities and conserve biodiversity, while mitigating risks to investors and increasing funding opportunities for the project developers.

The project was put forward for certification by the environmental group Flora and Fauna International (FFI), and subsequently certified by the Rainforest Alliance. According to FFI, the project will reduce deforestation in Ulu Masen by 85% through a combination of forest guards, community conservation, and social development projects. As well as the revenue from the voluntary carbon market, income will be generated through the development and marketing of specially labelled 'Aceh Green' forest products such as sustainable palm oil, coffee, and cacao.

FFI began the project in partnership with Carbon Conservation, an Australian-based company specialising in brokering deals between REDD projects and international investors. Prior to the investment by Merrill Lynch, Carbon Conservation had pitched the project to the likes of financier George Soros and Starbucks founder, Howard Schultz, and it is working with provincial governors elsewhere in Indonesia and in Brazil to develop similar projects. The company's CEO, Dorjee Sun, is a former internet entrepreneur who sees avoided deforestation as a major business opportunity. "The more hectares we manage, the more land we 'farm' carbon on, the more money we make," he says. "Our goal is to be the amazon.com of the Amazon."

FFI and Carbon Conservation met Irwandi Yusuf, who had become Aceh's governor in 2006 after years as a guerrilla with the Free Aceh Movement. The governor was looking for ways to bring new money and opportunities into the province, much of which had been devastated by the 2004 tsunami, while preserving its natural heritage. Yusuf imposed a moratorium on all logging in March 2007, and has personally committed his government to maintaining the integrity of Ulu Masen. The success of the project will ultimately depend on the ability of the government and its partners to use the money from selling credits to provide viable alternative livelihoods for those who are dependent on the forest.

How it works – the investor's perspective

Each credit represents a tonne of CO_2 that is prevented from entering the atmosphere. Merrill Lynch has agreed to buy credits at the fixed price of $4 each, and is betting that the price in the voluntary market – which has ranged $2 and $20 – will increase. For Merrill Lynch, success depends equally on growth in demand for credits from REDD projects, and the credibility/quality of the credits it has to offer.

Merrill is also aware that financial mechanisms for curbing deforestation are currently the subject of intense debate at the UN where one of the topics being discussed as member countries seek a successor to the Kyoto Protocol is the inclusion of avoided deforestation credits in carbon trading schemes. Abyd Karmali, Global Head of Carbon Emissions at Merrill Lynch, says that the value of credits from the Ulu Masen project would increase significantly if such proposals are included as part of a post-Kyoto agreement. However, he insists the project can "stand on its own two feet" even if it has to continue to issue voluntary credits.

Regarding the quality and credibility of the credits, critics of avoided deforestation schemes have argued that it is extremely difficult to accurately verify that carbon emissions reductions have been achieved. Karmali counters that the criteria governing the Ulu Masen project are extremely robust. "Carbon Conservation and FFI have been working in the region for a long time, so there is substantial baseline data on which to base carbon calculations," he says. "The calculations are also in line with the Climate Community and Biodiversity Alliance, which takes an extremely conservative view on how many carbon credits can be issued."

Even if the market prospects turn out to be good, we should not underestimate the challenge of establishing a credible system of community-backed forest conservation. Many Acehnese people regard the forests as their ancestral right, and after years of heavy-handed interference from the Indonesian military, may not be happy to see their own government preventing them from using the forests for their own ends. Disturbingly, the project has been portrayed in part of the Australian media as an opportunity for armed ex-guerrilla fighters to earn a living by keeping people out of the forest. Ultimately, much will depend on how effectively the proceeds from the sale of credits are utilised and distributed: something that should not be gainsaid given

Indonesia's notoriously corrupt political system.

Outcomes

It is too early to talk about outcomes from such a recent initiative. Success is by no means guaranteed, and there are a variety of factors that will ultimately influence the project. Some negotiators at the UN, most notably from the US, have argued that avoided deforestation schemes should not be granted official UN approval on the grounds that it would mean people are effectively being paid not to do something that is already illegal. Merrill Lynch's Karmali is one of those who counters that this ignores the reality of illegal logging, and the importance of finding ways that allow countries to realise the financial value of their forestry assets without recourse to felling.

While much attention will be paid to how much or little Merrill Lynch and others make from deals such as Ulu Masen, such projects could generate enormous sums for tropical forest conservation according to Johannes Ebeling, a senior consultant with emissions-credit developer EcoSecurities Group. He estimates that reducing the loss of forests by as little as 10% could generate as much as $13.5 billion a year for conservation. However, that is unlikely to happen until investors have some sort of a reliable framework to start investing, and while support for avoided deforestation is growing, the future is still uncertain.

Despite these uncertainties, the project has attracted considerable attention, and is part of a growing trend to win private sector investment. In another Indonesian province, Papua, Carbon Conservation has been talking to the governor about a similar project, although he is still under pressure from central government to turn forest land over to oil palm plantations to supply the booming market in biofuels. Marriott International, the world's largest hotel company, has agreed to spend $2 million to help preserve over half a million hectares of rainforest in Brazil through the Amazonas Sustainable Foundation, which will seek to certify the project for tradable carbon credits. Through Plan Vivo, investors get credits for funds invested in conserving forests in Mexico, Mozambique, and Uganda, while Canopy Capital in Guyana is paying towards the protection of the forest, in return for a share of the rights to its ecosystem services should these one day have a marketable economic value.

Sources

- Efstathiou, J., 'Carbon trading can raise billions of dollars to save forests', The Independent (Ireland), April 8th 2008.
- Gunther, M., 'Merrill Lynch's carbon bet: Why a Wall Street firm wants to save a forest in Sumatra', Fortune.com, April 18th 2008.
- Murray, J., 'Merrill Lynch throws weight behind avoided deforestation credits: Investment bank predicts strong demand for credits that it claims will deliver biodiversity benefits alongside carbon reductions', BusinessGreen, April 17th 2008.
- Wright, T., 'Indonesian proposal: Pay us not to chop down our trees', The Wall Street Journal, August 10th 2007, p.A1.
- www.fauna-flora.org/news_ulumasen2.php

Wal-Mart: sustainable supply chains

Wal-Mart's sustainability strategy is being presented as a model of radical change that positions the retail industry as a vital broker of sustainable development. It is founded on the belief that commercial success and sustainability are mutually dependent, and that Wal-Mart has a unique opportunity to influence the behaviour of producers and consumers.

Wal-Mart opened its first store in 1962, providing low-priced products to what it saw as the underserved markets of middle America. Today it is the world's largest retailer, with over 7,000 stores in 14 countries, 1.9 million workforce, and worldwide revenues of $345 billion. By its own estimates, it is the biggest private user of electricity in the US. Until recently, it emitted 19.1 million tonnes of CO_2 a year (equivalent to 2.8 million households). A major part of its commercial success stems from its world-leading supply-chain operations that allow it to keep shelves full but stocks to a minimum. It was one of the first companies to see the possibilities of sourcing from China, and is one of that country's major trading partners.

Its promise of "Always Low Prices, Always" has over the years won it praise and opprobrium.

By offering relatively poor consumers food, clothing, domestic products, electrical, and sporting goods at relatively low prices, it has been commended for raising living standards, and creating shareholder value. But the same business model has also been linked to issues as diverse as low wages, abusive labour practices, urban degeneration, and high environmental costs. Wal-Mart is proud of the flexibility its short-term contracting arrangements with suppliers provides, but critics say the company has too much power, even over multinationals such as Unilever, Nestlé, and Procter & Gamble that are under constant pressure to drive down costs. By some measures, Wal-Mart is the most popular retailer on the planet; by other measures it is amongst the most reviled.

"The revolution is called sustainability"

In 2005, Wal-Mart President and CEO, Lee Scott, announced a business sustainability strategy that would at once dramatically reduce the company's environmental impact, and make it "the most competitive and innovative company in the world."

From the outset, limits were put on what Wal-Mart meant by sustainability. Wal-Mart chose to focus on three main areas based on an assessment of where the company had the greatest environmental impact: energy, waste, and products. Subsequently, ethical sourcing (i.e. labour conditions in its supply chains) has been mentioned as part of the Wal-Mart sustainability story, but arguably, the three elements identified from the original impact assessment are the most coherent and integrated components of the sustainability strategy.

To identify specific environmental improvements related to energy, waste, and products, the company set up 14 sustainable value networks, each with an executive-level sponsor, and a 'network captain' chosen from senior level management. For example, under energy, there are sustainable value networks working on alternative fuels, global logistics, and a greenhouse gas strategy; under waste, there are networks on packaging, and procurement; and products includes networks on jewellery, textiles, electronics, and food and agriculture. The networks are cross-functional teams.

Another feature of the networks is that they invite strategic level input from external organisations – from consultants to environmental groups, customers and academics. Suppliers, too, have become part of the networks. From the beginning, the company has looked at impact throughout its supply chain, recognising that up to 90% of the company's environmental impact is indirect. Therefore, it made no sense for Wal-Mart to talk about an inclusive approach to designing and implementing their sustainability model if suppliers were not part of that equation.

The sustainable value networks require a change in Wal-Mart's relationships with, or attitude towards, certain parties. Wal-Mart's success over the years was in large part due to supply chain management, and while many companies had prospered from this relationship, some of Wal-Mart's practices were controversial. For example, short-term contracts for one batch or one season are common in some parts of the business such as foodstuffs, and there is frequent switching of suppliers. As with its competitors, Wal-Mart is strongly focused on supplier efficiency to keep prices as low as possible, and at times this has led to allegations of unwarranted interference in suppliers' operations. Justified or not, Wal-Mart's attempts to engage suppliers in the new networks could not be divorced from the broader historical context of the company's relationship with its supply chains, and the attitudes and expectations this had engendered.

There is also evidence that the business sustainability strategy has forced Wal-Mart to gain a better understanding of its supply chain. In textiles, for instance, the company did not look further than the category manager with a particular product range. But when it could not obtain organic cotton garments from suppliers, it went straight to the farmers to find out why there was insufficient raw material to increase the volume of organic textiles. It found the costs of organic certification, reduced yields, and the need to diversify crops all represented threats to the farmer. Therefore, to increase and secure its supply of organic cotton, Wal-Mart entered into five-year contracts with farmers to justify the increased costs of organic cotton production.

Emissions reporting	• 58% of responding suppliers report their Scope 1 and 2 emissions (supplier's own fossil fuels burnt and electricity purchased). The majority of these suppliers are large- or medium-sized. • 12% of suppliers report that they track Scope 3 emissions (indirect emissions that are a consequence of their company's activities, but which arise from sources that are owned or controlled by others). • Many suppliers indicated difficulty in accessing Scope 3 emissions data.
Risk and opportunities	• 96% of suppliers identified greenhouse gas regulation as a potential risk. • Taxation and emissions limits are the most commonly reported risks. • Suppliers foresee extreme weather conditions adversely affecting operations and slowing productivity. • 58% identified reduction in energy consumption as the best means of managing climate change related risks. • Only 26% have established greenhouse gas reduction targets so far.

Supply Chain Leadership Collaboration (SCLC), Carbon Disclosure Project, findings from 144 suppliers of the 12 members of the SCLC, April 2008. The table shows responses from suppliers across different sectors on Management's views on the risks and opportunities that climate change presents to the business, and greenhouse gas emissions accounting.

Measuring sustainability

From the outset, Wal-Mart has emphasised the bottom-line significance of its business sustainability strategy. At the launch, Lee Scott said, "Being a good steward of the environment and being profitable are not mutually exclusive. They are one and the same." Many of the areas that were chosen as quick wins were ones where poor environmental performance was a measurable inefficiency.

Sustainability 360, the company-wide plan for taking sustainability beyond the company's direct environmental footprint to engaging Wal-Mart's associates, suppliers, communities and customers in sustainability was announced in 2007. It reiterated the company's commitment to tackling three main aspects of sustainability – energy, waste, and products. It also underlined specific targets.

However, tracking performance is not especially easy. A complete set of the company's key sustainability performance indicators is available on its website. These go far beyond the three aspects of sustainability, and include other areas of company activity such as charitable giving, employment, ethical sourcing, worker health care, and wages. Some of these, such as the Acres for America Program whereby the company permanently preserves an acre of natural habitat for every acre occupied by a store, have relevance to sustainability. The link is less obvious in areas such as charitable giving, and in other areas the data provided tell us little about the company's impact. For example, data on ethical sourcing say something about the quantity of supplier auditing, but little about the conditions of workers. Similarly, stating the average full-time hourly wage of store workers would be more informative with additional data on average pay in comparative employment in each local area.

The link between performance and sustainability goals is clearer once the focus is on energy, waste, and products. There is a wide range of initiatives where targets have been set and performance is being monitored. In some cases, Wal-Mart has set its own targets and standards, in others it is using external standards. For example, for fish, Wal-Mart is sourcing Marine Stewardship Council-certified seafood, and Aquaculture Certification Council shrimp; ASDA's hardwood garden furniture uses

Sustainability Area: Energy Sample initiative and targets	
Existing building efficiency Target: 20% increase in efficiency by 2012	**High-efficiency stores** Target: experimenting with prototype stores expected to be 20% more energy efficient than conventional ones
New building efficiency Target: store prototype opened by 2009 with 25-35% greater efficiency	**Truck fleet efficiency** Targets: 25% reduction in energy use identified by 2008; fleet efficiency doubled by 2015
Sustainability Area: Waste Sample initiative and targets	
Solid-waste reductions in stores Target: 25% reduction in weight by 2008	**Supplier packaging** Target: 5% reduction in overall packaging by 2013
Sustainability Area: Products Sample initiative and targets	
Seafood Target: 100% seafood Marine Stewardship Council-certified by 2010	**Electronics** Targets: all electronics sold compliant with European Restriction on Hazardous Substances standards by 2007; recycling of electronic waste through regular recycling events
Compact fluorescent lightbulbs Target: 100 million CFLs (compact fluorescent lightbulbs) sold by 2008 with resultant savings in energy use and emissions reduction	**Organic cotton** Target: 20% increase in organic cotton sales in 2007, with resultant savings in chemical usage in farming and manufacturing
Alternative fibres Target: 15.5% increase in alternative fibre sales in 2007	**Sustainably harvested wood products** Target: 100% of ASDA's hardwood garden furniture is Forest Stewardship Council certified

Sustainability area targets in Wal-Mart's sustainability strategy

Forest Stewardship Council-certified wood; and the majority of computers sold worldwide now comply with European Restriction on Hazardous Substances (RoHS) standards. The company is also playing a role in the development of new standards. For example, Wal-Mart is a supporter of the CIES (International Committee of Food Retail Chains) Global Social Compliance Programme that aims to harmonise third-party auditing of social and environmental performance.

Outcomes

A major element of Wal-Mart's sustainability strategy is increasing the energy efficiency of its stores and other facilities. It is experimenting with lower-energy prototypes, and exploring ways of increasing the efficiency of its current stock. In the experimental stores, it has sought to reduce the amounts of energy and natural resources required to operate and maintain the stores during the first three years, reduce the amount of raw materials needed to construct the facility, and to increase the use of renewable materials in constructing and maintaining the facility. This has led to the use of technologies such as solar panels and wind turbines; heating supplied by recycled cooking and motor oil; and pervious paving which duplicates natural water filtration.

In conventional facilities, the company is replacing incandescent bulbs with compact fluorescent lightbulbs (CFLs), experimenting with hydrogen-powered forklifts, and introducing refrigerators lit by LEDs (light-emitting diodes). CFLs could save the company $7 million annually, while replacing fluorescent lighting with LED lighting halves the lighting load.

By 2015, the company intends to double the efficiency of its lorry fleet, thereby reducing greenhouse gases, generating savings of $300 million a year, and potentially providing a catalyst for redesign throughout the haulage industry. At present it is introducing improved aerodynamic designs, more efficient tyres, and the use of auxiliary power units to warm or cool the cab when the lorry is stationary. The latter initiative was one of the early 'quick wins', and resulted in savings of $25.5 million per year, and what Wal-Mart estimates to be the elimination of 100,000 tonnes of CO_2 emissions, and 10 million gallons of diesel fuel.

Sources

- Denend, L. and Plambeck, E., Wal-Mart's sustainability strategy, Stanford Graduate School of Business, 2007.
- Fletcher, R., 'Could ASDA be Kicked out of Wal-Mart?', Daily Telegraph, 9th March 2008.
- Forum for the Future Retail futures: scenarios for the future of UK retail and sustainable development, London, 2007.
- Schweiger, A.L., Wal-Mart sustainability and climate change, Fuqua School of Business, 2007.
- Wal-Mart, Sustainability Progress to Date 2007–2008: We're making sustainability our business, Bentonville: Wal-Mart, 2007. http://walmartfacts.com/reports/2006/sustainability/companyPerformance.html.
- Wal-Mart, 2006 Report on Ethical Sourcing. Bentonville: Wal-Mart, 2007.
- www.walmartstores.com
- walmartwatch.com

Holcim: why companies care about natural disasters

Natural disasters such as Hurricane Katrina and the Asian tsunami have seen companies play a significant role in providing humanitarian relief. While the Asian tsunami was not a climate-related natural disaster, the case study offers lessons about what companies can do in such situations, and how they can use their resources most effectively. Holcim, Sri Lanka's largest cement supplier, mobilised an employee-backed response that began with reconstructing local communities, and went on to rebuild the people's livelihoods.

Swiss-owned Holcim manufactures, distributes and markets building materials. The company operates in over 70 countries and employs over 90,000 people. Three-quarters of its operational capacity is based in emerging markets. Holcim Lanka is the leading cement supplier in Sri Lanka with 600 employees.

The Asian tsunami, which hit countries around the Bay of Bengal on 26th December 2004, had a devastating effect on coastal communities such as those in Bangladesh, Sri Lanka, Aceh (Indonesia), and Thailand: all important Holcim markets. It was caused by the second-largest earthquake ever measured, and resulted in the loss of over 250,000 lives, and nearly 1.7 million displaced persons.

From rebuilding houses to reconstructing lives

When coastal communities across Southeast and South Asia were devastated by a giant tsunami on 26th December 2004, the world responded with a significant outpouring of philanthropic aid. Multinationals such as Home Depot, GE and GSK sent money, equipment and expertise to help the devastated communities. Among the many rehabilitation projects launched, the Holcim Fund for Reconstruction in Sri Lanka came to be recognised by governments and non-governmental organisations (NGOs) as a model of best practice, combining a speedy response, innovative community engagement, and professional execution.

The tsunami killed more than 35,000 Sri Lankan citizens, and struck close to home for Holcim Lanka's 600 workers, disabling the company's cement works in Galle on the island's south coast. Each staff member donated a week's wages to help the nation's 516,000 refugees, creating a fund which grew within weeks to US$1.2 million as

contributions poured in from across the Holcim Group. To ensure transparency and accountability, the fund was set up as an independent entity from the company with a Board of Custodians to oversee and approve spending and a project team to administer relief.

The company concentrated first on what it knew best, providing building materials for new homes. Working through well-established and trusted national and local NGOs, and with the active involvement of community religious, business, and local government leaders, the fund built 227 houses in seven stricken villages and donated cement to build 443 more. The first permanent houses were ready within three months, at a time when temporary shelters for victims were still under construction elsewhere.

But Holcim recognised it needed to go beyond its core expertise if it was to be a bigger contributor to rebuilding the devastated communities. So the fund also set up a livelihoods programme to help fisherfolk, small business owners, and former masons who had lost everything to restart their enterprises or learn new skills. Within 14 months of the disaster, 460 families had received small loans to generate new income.

"This was a new, 'philanthropy-plus' approach for us, one which was critical to rebuilding viable communities," says Rathika de Silva, head of sustainable development at Holcim Lanka. "Most of the victims we helped were fisherfolk, traumatised at going back in the sea, and neighbourhood traders and retailers whose shops were washed away. They saw no hope of restarting their lives. For masons, whose role in rebuilding the country was critical, we also provided motivational 'positive thinking' sessions and the new equipment they needed to get back to work."

In another example of added value, the project trained villagers in cement block manufacturing and masonry skills so they could build their own new homes (with technical supervision), and receive wages and new livelihood options into the bargain. Wherever possible, community craftsmen such as carpenters were also employed, keeping reconstruction money circulating in the local economy.

The entire fund was invested in the communities within 14 months, an impressive achievement founded on successful partnerships, according to Rathika de Silva. "Partnerships helped us save costs, respond faster and access expertise we didn't have. For example, in the livelihoods programme we partnered with SEEDS (Sarvodaya Economic Enterprise Development Services) which had the infrastructure to provide micro-financing to villagers and the administration to provide the training required. This way Holcim Lanka didn't have to reinvent these processes and was able to facilitate more funding for livelihood support."

Outcomes

The most tangible outcomes were the completion of 650 houses, seven schools, and several livelihood projects. But in addition to the contribution made to local communities described above, the Holcim Lanka case study provides lessons about the type of intervention companies can make when tackling natural disasters, an aspect of sustainable development that seems likely to grab more attention as the impacts of climate change are increasingly felt.

One of the lessons is how difficult it can be to get reconstruction projects underway. According to Peter Spirig, CEO of Holcim Lanka, it is especially difficult where authority is unclear: "Much communication and persuasion was necessary before any foundation stone could be placed. But persistence paid off." Rathika de Silva, the company's Head of Sustainable Development, stressed that "There is no 'one plan that fits all' concept that can be used, especially in developing countries. Government administration differs, cultural situations play an important role in multi-ethnic communities, and different social levels have to be taken into consideration." But for all this, he suggests, there are lessons that can probably be applied elsewhere:

- Focus clearly on your project's exact role in the rebuilding process;
- Partner with organisations offering complementary expertise and capabilities; and
- Build company-wide, shop floor to management ownership of the initiative, with a transparent and independent oversight body that ensures all donations find their way to their intended purpose.

Sources

- Holcim, Building Foundations for Society's Future
- www.holcim.com

Conclusions

2008 saw the twentieth anniversary of the setting up of the Intergovernmental Panel on Climate Change (IPCC) and the testimony of Dr James Hansen (of NASA Goddard Institute for Space Studies) to the United States Congress. While some progress has been made in the intervening time, a lack of momentum on the issue of climate change has allowed society to create scepticism around the science, and allowed government and business leaders to stall action on the transformational change that is required.

The UK Government's Stern Review of 2006 pushed the standard economic analysis from cost/benefit to cost/benefit and risk. Responding to this risk requires a major push by government, business and society. When countries and companies believe that we are really going to tackle this problem and that the momentum of change is underway and unstoppable, then the market will take over and create the opportunities that will deliver large scale innovation and change. However, with competing interests this has to be a consciously led decision otherwise we risk making the problem a lot worse with economic, political and security interests driving us towards increased use of oil sands, oil shale and coal.

If the worst predictions of climate change are borne out (for example, Dr James Hansen's recent 'bet' on a sea-level rise of over 5m during this century and the increasing evidence that climate change is accelerating) the cost to a future society of just one of the projected impacts is unprecedented. London, Hamburg, Venice, New York, Miami, New Orleans, Buenos Aires, Lagos, Mumbai, Bangkok, Singapore and Shanghai are all in coastal flood plains. While one country can absorb the near total devastation of one of these cities (as was seen during Hurricane Katrina's impact on New Orleans) it is difficult to see how the world could cope with major impacts on all of those cities at the same time. The expected climate impacts could cause such a catastrophic change in societal structures that we should in fact be using negative social discount rates (valuing future generations more highly than the current one as they will be less wealthy and less able to cope than we are), rather than a zero discount rate as used in the Stern Review (valuing future generations equally).

It is clear from the work that has gone into this transformational change model (TCM) that with the right policy framework in place, the costs of this change can be kept to a minimum, and that these costs should be viewed as an investment in our future. With the wrong policy framework in place, or a lack of policy framework, the costs of both incorrect action and inaction are incredibly high.

Tackling climate change must be seen as a long-term economic strategy.

The recent events in the global financial markets have shown that we are not good at measuring and understanding systemic risk to the economy. We have an incredibly complex financial system, but this does not mean that the 'credit crunch' was wholly unpredictable. We cannot be allowed to make the similar mistakes over different risks and we must look towards preventing the 'climate crunch'.

As has been discussed in this TCM and identified in our preferred scenario, 'Task Manager', all nations must take an active part in tackling climate change. We must agree, at the United Nations, a global vision for emissions reductions between now and 2050. Developed countries must take on strong targets and develop markets and regulations that will support achieving these targets. Emerging markets should build frameworks for partnerships to deliver technology transfer and by 2020 have taken on targets under the global framework. Developing countries must be supported in building capacity to create markets for new technologies that will allow them to leapfrog developed countries in achieving a renewables-based economy.

By 2020, global energy demand should

have been reduced through efficiency measures delivered by carbon markets and government standards. By 2050, global energy intensity (the amount of carbon emitted per unit of energy) should have been reduced through the increased use of renewables, carbon capture and storage technology and a moderate interim increase in nuclear in developed countries. By 2100, the global economy should be based on a fully electrified, hydrogen and renewable system. In addition, new markets to preserve carbon sinks should be set up and fully functioning as soon as possible – this should cover reducing deforestation by 2020 and all stored carbon (standing forests and carbon in soils) by 2050.

To enable these changes, governments must institute a mechanism for information-sharing and education amongst the public so that they can fully support a vision of transformational change. Governments must also use regulations and standards across the board to help deliver the necessary technology and behaviour changes, and should work closely with business to ensure that the changes can be delivered rapidly.

To support technology discovery, demonstration and deployment, governments must use cap-and-trade markets to establish a carbon price, forward procurement, rising standards, subsidy reform, funding support for discovery and demonstration and funding support for technology transfer (possibly through revenue generated by auctioning of carbon allowances on cap-and-trade markets).

To reduce the risk of climate impacts, governments must develop strong adaptation strategies and work closely with the insurance sector to ensure that the risks are brought down to a manageable level. Adaptation strategies, in particular around water, food and health, should be shared between governments.

Mechanisms to encourage integration and 'good' design for infrastructure and mobility, manufacturing and consumption, agriculture, land economy and carbon sink management should be implemented. The available technologies and behaviour changes make this transformational change wholly possible and wholly affordable.

There is no one 'silver bullet' technology and there is no one 'silver marksman' in either country, government or business – we all need to do this together if we are to have a chance in achieving a low climate risk economy. We require the biggest public-private partnership ever seen.

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- Climate Leadership Programme

Other organisations

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- Oxfam
- New Economics Foundation
- World Economic Forum
- ClimateStrategies
- Green Ventures

Glossary

AC	alternating current
AOGCM	Atmosphere-Ocean General Circulation Model
AR4	Intergovernmental Panel on Climate Change Fourth Assessment Report
AR4 WG II	Intergovernmental Panel on Climate Change Fourth Assessment Report, Working Group 2
BEP	The Prince of Wales's Business & the Environment Programme
BWEA	British Wind Energy Association
CAES	compressed-air energy storage
C2C	Cradle to Cradle principles
CCB	Climate, Community and Biodiversity Alliance
CCS	carbon capture and storage
CDM	Clean Development Mechanism
CFL	compact fluorescent lightbulb
CH_4	methane
CIES	International Committee of Food Retail Chains
CIRCA	Communication & Information Resource Centre Administrator
CIS	copper indium diselenide (PVs)
CNG	compressed natural gas
CO_2	carbon dioxide
CO_2-eq	carbon dioxide equivalents
CoP	coefficient of performance
COP	United Nations Conference of the Parties
CPSL	Cambridge Programme for Sustainability Leadership (formerly CPI)
CPV	concentrated photovoltaic system
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CSP	concentrated solar power
Defra	Department for Environment, Food and Rural Affairs
DLR	German Aerospace Centre
Dott	Designs of the time
DTI	UK Department for Trade and Industry
EC	European Community
EGS	enhanced/engineered geothermal systems
ESCOs	energy service companies
ESPACE	European Spatial Planning: Adapting to Climate Events
ETS	emissions trading scheme
EU	European Union
EUA	EU emission allowance
EU-ETS	European Union's Emissions Trading Scheme
EUMENA	Europe, the Middle East and North Africa
FAO	UN Food and Agriculture Organization
FCO	Foreign and Commonwealth Office
FFI	Flora and Fauna International
F-gases	fluorinated greenhouse gases
GDP	gross domestic product

GEF	Global Environment Facility
GEN-IV	fourth generation reactor
GFR	gas-cooled fast reactor
GHP	geothermal heat pump/ground source heat pumps
GMOs	genetically modified/engineered organisms
GNEP	Global Nuclear Energy Partnership
$GtCO_2$-eq	gigatonnes of CO_2 equivalents
GtC	gigatonnes of CO_2
GW	gigawatts
HDR	hot dry rock geothermal energy
HFCs	hydroflurocarbons
HPS	hybrid power system
HVDC	high voltage direct current
IAEA	International Atomic Energy Agency
IEA	International Energy Agency
IGCC	Intergrated Gasification Combined Cycle
IIED	International Institute for Environment and Development
IMO	International Marine Organisation
IPCC	Intergovernmental Panel on Climate Change
IPIECA	International Petroleum Industry Environmental Conservation Association
ISCCS	integrated solar combined cycle systems
IUCN	International Union for Conservation of Nature
JI	Joint Implementation
kW	kilowatts
LCA	life-cycle assessment
LED	light-emitting diode
LFR	lead-cooled fast reactor
LHP	large-scale hydropower
Limpet	Land Installed Marine Powered Energy Transformer
LNG	liquefied natural gas
LPG	liquefied petroleum gas
LULUCF	Land Use, Land-Use Change and Forestry, a section of the Kyoto Protocol
LWR	light water reactor
MENA	Middle East and North Africa
MOX	mixed-oxide (fuel)
MSW	municipal solid waste
MSR	molten-salt reactor
Mtoe	million tonnes of oil equivalent
MW	megawatts
NAPAs	National Adaptation Programmes of Action
NGO	non-governmental organisation
N_2O	nitrous oxide
NPT	Treaty on the Nonproliferation of Nuclear Weapons
OCC	Office of Climate Change
OECD	Organisation for Economic Co-operation and Development
OTEC	ocean thermal energy conversion
OWC	oscillating water column

PFCs	perfluorocarbons
PV	photovoltaic
RCT	river current turbine
REDD	Reducing Emissions from Deforestation and Degradation (see also UN-REDD)
SCLC	Supply Chain Leadership Collaboration
SCWR	supercritical water reactor
SDC	Sustainable Development Commission
SEEDS	Sarvodaya Economic Enterprise Development Services
SF_6	sulphurhexafluoride
SFCCD	World Bank, Strategic Framework on Climate Change and Development
SFR	sodium-cooled fast reactor
SHP	small-scale hydropower
SRES	The IPCC's Special Report on Emissions Scenarios
SSSI	Site of Special Scientific Interest
TAR	Intergovernmental Panel on Climate Change Third Assessment Report
TCM	transformational change model
TFPVs	thin-film PVs
TIME	Transport Information Monitoring Environments
TREC	Trans-Mediterranean Renewable Energy Cooperation
TW	terawatts
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
USGS	US Geological Survey
UNHCR	United Nations High Commission on Refugees
UN-OCHA	United Nations Office for the Coordination of Humanitarian Affairs
UN-REDD	United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (see also REDD)
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
USGS	US Geological Survey
VAT	VAT
VHTR	very high-temperature helium reactor
WBCSD	World Business Council for Sustainable Development
WEC	wave energy conversion
WHO	World Health Organization
WMO	World Meteorological Organization

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